

RESEARCH ARTICLE

# Application of DRASTIC Method for Groundwater Vulnerability Analysis to Contamination in Pemalang District, Pemalang Regency, Central Java Province, Indonesia

Firginawan Surya Wanda<sup>1</sup>, Doni Prakasa Eka Putra<sup>1\*</sup>, Wahyu Wilopo<sup>1</sup>

<sup>1</sup> Geological Engineering Department, Faculty of Engineering, Universitas Gadjah Mada, Yogyakarta, Indonesia

\* Corresponding author: putra\_dpe@ugm.ac.id  
Tel.: +62 818 0424 7407  
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## Abstract

Pemalang District, Pemalang Regency, Central Java Province, as the district's capital, has experienced rapid economic and population growth. This has resulted in increased exploitation and degradation of groundwater quality, with groundwater extraction increasing from 91,856 m<sup>3</sup> to 133,708 m<sup>3</sup>. There was an average decrease in groundwater levels of 40-70 cm from 2020 to 2023, and an increase in nitrate and chloride levels in groundwater was recorded from 2021 to 2023. To maintain the availability of groundwater that is suitable for use, efforts are needed to prevent groundwater contamination in vulnerable areas. The approach applied to examine groundwater vulnerability to contamination is the DRASTIC method. The research location is a coastal area composed of quaternary deposits with lithology consisting of sand and gravel in the south and clay and silt in the north. It has a shallow groundwater depth and a groundwater flow pattern that flows from south to north. The results of the geospatial analysis revealed two zones of groundwater vulnerability to contamination, based on the DRASTIC Index value, consisting of moderate vulnerability (>106-146) and high vulnerability (>146-186). There were 67.4% of high vulnerability zones in this research area, spread from the central part, which is Wanamulya Village, to the southern part, which is Surajaya Village.

**Keywords:** DRASTIC, Groundwater, Pemalang, Vulnerability

## 1. Introduction

In 2022, the population in Pemalang Regency above 1.5 million population (Central Statistics Agency of Pemalang Regency, 2023) and an average population growth rate of 1.13% per year for the period 2020-2022, has a fairly strategic position because it is on the Java Island economic cross-country route and the Central Java development corridor. Central Statistics Agency of Pemalang Regency (2023) noted that the economic growth rate of Pemalang Regency for the period 2020-2022 continued to increase to reach 5.08%. The increase in the economy and population growth certainly has consequences, including changes in land use shifting from agricultural to non-agricultural uses, as well as urban development. One of the sub-districts in Pemalang Regency that has experienced quite rapid economic growth and population growth is Pemalang District. Apart from being the district capital, Pemalang District is also the center of government and economy, with the largest population, comprising 204,524 people, or approximately 13.63% of the total population of Pemalang Regency (Central Statistics Agency of Pemalang Regency, 2023).

Land-use changes resulting from population growth and economic development also have negative impacts. One of the natural resources affected by land use changes is the increased exploitation of groundwater to meet the raw water needs of various sectors, including both industry and households.

According to data from the Department of Energy and Mineral Resources of Central Java Province (2023),

Pemalang District experienced an increase in groundwater use from 91,856 m<sup>3</sup> to 133,708 m<sup>3</sup> from 2020 to 2023. According to this, Pemalang District experienced a slight decrease in groundwater levels, with an average decrease of 40-70 cm during the same period. The increased groundwater extraction, accompanied by the city's development in Pemalang District, also had an impact, increasing Nitrate (NO<sub>3</sub><sup>-</sup>) and Chloride (Cl<sup>-</sup>) levels in the groundwater. The Department of Energy and Mineral Resources of Central Java Province noted that from 2021 to 2023, Nitrate (NO<sub>3</sub><sup>-</sup>) levels increased by an average of around 0.5 mg/L, and Chloride (Cl<sup>-</sup>) levels increased by an average of around 12 mg/L. However, the values were still below the quality standards set by the government. According to Utomo (2011), Pemalang District has experienced an increase in salinity levels in shallow groundwater at a distance of 1 km from the coastline. Like other coastal areas, groundwater conditions in Semarang City, particularly those near the sea, have become brackish (Listiawan et al., 2024), as have those in Demak Regency (Ondara et al., 2020) and Kendal Regency (Wilopo et al., 2019).

Freshwater availability is a critical issue worldwide, with groundwater serving as a primary resource for drinking water and other essential needs, particularly in Indonesia (Yusti et al., 2025). Groundwater is threatened by degradation, both by contaminants and excessive extraction. Groundwater is also often misused due to inadequate management. The leading threat to groundwater sustainability begins with the continued increase in water demand (resulting from an enlarging

population and per capita use, as well as rising irrigation needs) and from the escalating use and discharge of chemicals to the ground surface (Morris et al., 2003). Hydrogeological conditions also influence the entry of dissolved contaminants into groundwater, including factors such as groundwater depth, aquifer type, recharge, topography, soil texture, hydraulic conductivity, and the type of unsaturated zone (Aller et al., 1985). To maintain the availability of quality groundwater, efforts are needed to prevent groundwater pollution in areas with high levels of pollution vulnerability. Therefore, research related to groundwater vulnerability needs to be conducted, as there has been no research that discusses this topic using various methods in Pemalang District, Pemalang Regency.

The objective of this study is to assess the vulnerability of groundwater to contamination using the DRASTIC method. Groundwater vulnerability maps are a crucial tool for assessing groundwater vulnerability and informing future land use planning (Barbulescu, 2020). This method approach is a development of a parametric evaluation system through multiplicative identification of the weight and class of each parameter to draw the relationship between parameters and their significance for vulnerability analysis.

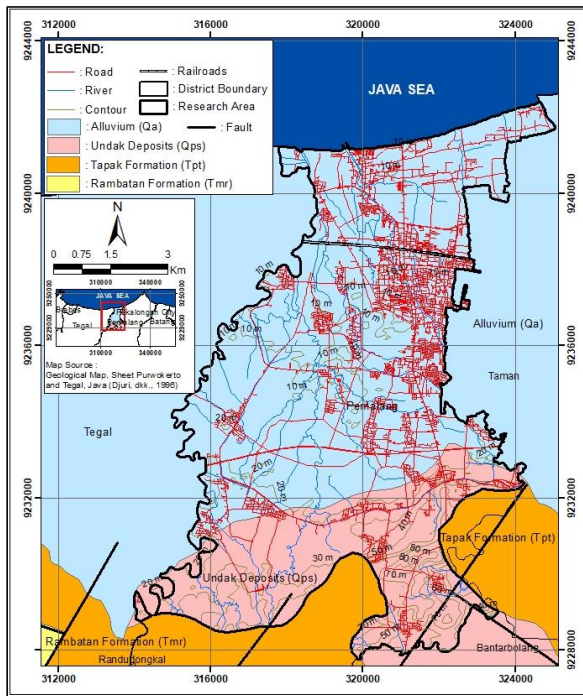


Fig. 1. Regional geological map (Djuri et al., 1996)

## 2. Materials and Methods

This study uses primary and secondary data. Primary data was obtained through hydrogeological mapping, geoelectric measurements, and pumping tests. Secondary data was used in the form of a Regional Geological Map of Tegal and Purwokerto, Java scale of 1:100,000, a Hydrogeological Map of Indonesia Sheet Pekalongan scale of 1:250,000, a Topographic Map of Indonesia, Rainfall Data from the Department of Public Works and Spatial Planning, Pemalang Regency. Groundwater vulnerability zones were analyzed using the DRASTIC method, and geospatial analysis was employed to create a groundwater vulnerability map.

Referring to the Geological Map of Tegal and Purwokerto, Java, scale 1:100,000 (Djuri et al., 1996), it can be seen that the geological conditions in the research area are composed of Quaternary deposits. Lithostratigraphically, the various types of rocks forming the research area can consist of Alluvium (Qa), which is composed of gravel, sand, silt, and clay, followed by terrace deposits (Qps), which are composed of layers of tuffaceous sandstone, sand, tuff, conglomerate, and tuffaceous breccia (Fig. 1).

Based on the Indonesian Hydrogeological Map, Pekalongan Sheet (Effendi, 1985), the research location has hydrogeological conditions that can be distinguished by aquifer productivity, namely areas with productive aquifers, moderately productive aquifers, and areas with small productive aquifers (Fig. 2).

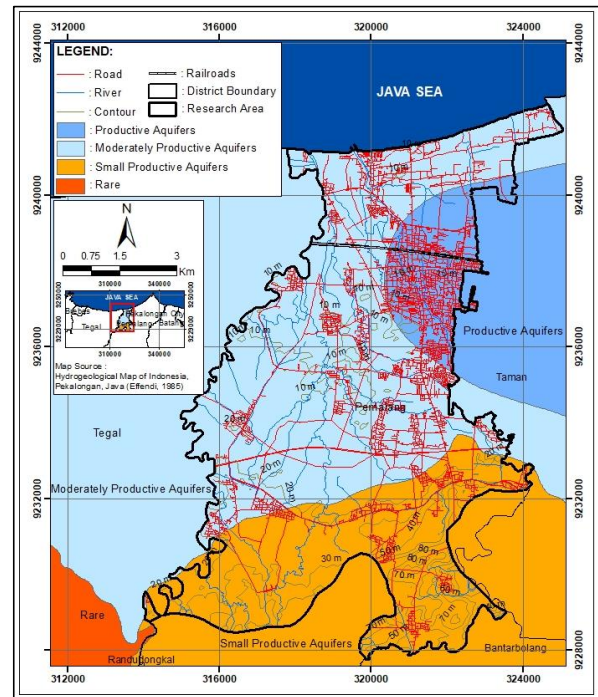


Fig. 2. Hydrogeological map (Effendi, 1985)

### 2.1 Hydrogeological Mapping

Hydrogeological mapping involves groundwater sampling at 36 dug well locations spread across the field of study (Fig. 4) and measuring the depth of the groundwater table at each dug well as one of the DRASTIC parameters. Hydrogeological mapping was carried out in September 2024.

Climate conditions, geographical location, and air current circulation affect rainfall in the field of research. The amount of rainfall varies each year as shown in Table 1.

### 2.2 DRASTIC Method

The DRASTIC method was developed by Aller et al. (1985) from the US Environmental Protection Agency. This method consists of seven parameters: depth to the water table (D), net recharge (R), aquifer media (A), soil media (S), topography (T), impact of the vadose zone (I), and hydraulic conductivity of the aquifer (C). The DRASTIC method was developed for large areas by weighting each parameter. Many researchers have employed the DRASTIC method, including Huan et al. (2012), Saidi et al. (2012), Abdeslam et al. (2017),

Putranto et al. (2019), Aribowo et al. (2021) and others. There are three key components in processing this method's data, namely, range, weight, and score, which determine the level of groundwater vulnerability. This is achieved by adding up the score values of each parameter, as in Equation 1, where R Represents Rating, W Represents Weight, and producing the DRASTIC Index (DI) value. The rating has a value of 1-10, while weight is 1-5. The higher the DI, the more susceptible it is to contamination by contaminants that migrate toward the water-saturated zone saturated zone. The data visualization was processed using ArcGIS version 10.8 to perform interpolation with the Inverse Distance Weighted (IDW) method, which determined the distribution of each parameter.

The DRASTIC method is a method of assessing intrinsic groundwater vulnerability, which is influenced by regional conditions (Vrba and Zapotec, 1994). The DRASTIC method was chosen because it is easy to use, requires minimal data, and effectively explains groundwater vulnerability (Huan et al., 2012).

This intrinsic groundwater vulnerability is entirely related to the natural function of the hydrogeological factors of the research area (Putra, 2007). This method examines it from a hydrogeological and geological perspective, which means it cannot determine the types of substances that contaminate groundwater (Putranto et al., 2016). The equation to determine the DRASTIC Index is as follows (Aller et al., 1985):

$$\text{DRASTIC Index/DI} = D_{RDW} + R_{RRW} + A_{RAW} + S_{RSW} + T_{RTW} + I_{RIW} + C_{RCW} \quad (1)$$

Where,

$D_R$  = Rating value of each parameter range

$D_w$  = Parameter weight value

The level of groundwater vulnerability was determined based on the DRASTIC Index, as shown in Table 2 (Aller et al., . More concisely, the flow of groundwater vulnerability research using the DRASTIC method is illustrated in Fig. 3.

Table 1. Rainfall in the research area 2014-2023 (Department of Public Works and Spatial Planning of Pemalang Regency, 2023)

Observation Station	Coordinate		Rainfall (mm/year)										Average (mm/year)
	X	Y	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	
Rainfall Station 1	320446	9239765	1854	1977	1687	1987	1807	1678	1660	1587	1537	1765	1753.9
Rainfall Station 2	324730	9234350	2262	2547	2049	2060	1292	821	1574	2607	2113	1720	1904.5
Rainfall Station 3	315366	9235542	1746	1841	2242	1712	1071	1797	2313	2636	2132	1387	1887.7
Rainfall Station 4	320465	9234235	1987	2014	2120	1876	1987	1934	2089	2033	1876	2092	2000.8
Rainfall Station 5	323909	9232047	2095	2350	2173	1931	1488	1225	2864	2802	2590	1921	2143.9
Rainfall Station 6	320484	9228706	2203	2328	2012	2321	2432	2377	2465	2210	2265	2342	2295.5

Table 2. DRASTIC method final score (Aller et al., 1985)

DRASTIC Index	Level of Vulnerability
<66	Very Low
>66 - 106	Low
>106 - 146	Moderate
>146 - 186	High
>186	Very High

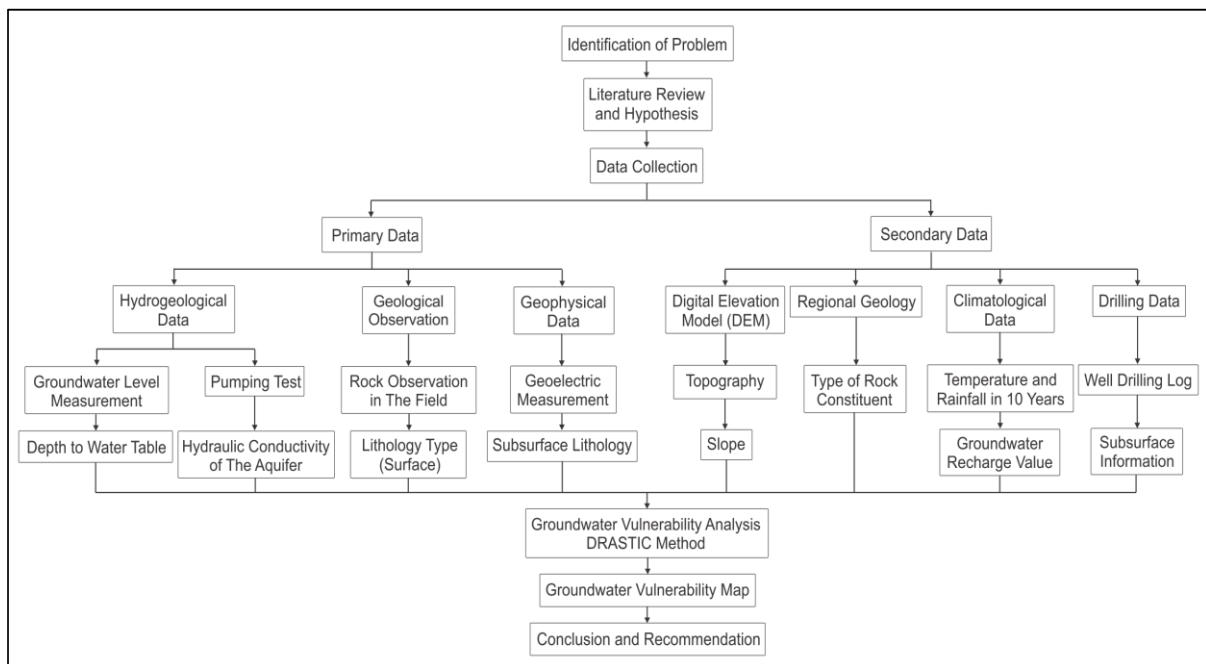


Fig. 3. Research flow diagram

### 3. Results

#### 3.1 Depth and Flow Pattern of Groundwater

The existing dug wells in Pemalang District have had their groundwater depths measured using a roll meter or a measuring tape with a weight wrapped around the bottom, allowing for accurate measurements of the maximum depth of the dug well. According to the measurement results, the depth of the groundwater ranges from 0.8 to 12.1 meters, with groundwater level elevation conditions ranging from 0.8 to 46.6 meters above sea level. The highest elevation is located in the south of the research area, with a groundwater elevation value of 46.6 meters above sea level, which is composed of Terrace Deposits (Qps). Groundwater has a direction from south to north, going to the sea.

#### 3.2 Groundwater Quality

Measurement of groundwater quality observed directly in the field consists of acidity level (pH), electrical conductivity (EC), and total dissolved solids (TDS). Based on the field measurements, the pH value ranges from 6.86 to 8.84, with an average of 7.89.

The electrical conductivity (EC) value ranges from 237 to 2,634  $\mu\text{S}/\text{cm}$ , with an average of 772  $\mu\text{S}/\text{cm}$ . The results of the EC analysis show that the further north you go, the higher the EC value tends to be. The high EC value is due to the location of the water sampling site being directly adjacent to the Java Sea, allowing it to move toward land, indicating seawater intrusion.

The results of the measurement of total dissolved solids (TDS) values at the research location have a range of values from 119 to 1,316 mg/L, with an average of 390 mg/L. High TDS values were also found in the northern region of the research location.

#### 3.3 Groundwater Vulnerability DRASTIC Method

Each parameter in this method is visualized in the form of a map to show the distribution of each parameter. Then, each parameter will be summed based on its weight, where the parameter with the highest weight (weight 5) will have the greatest influence on the final result of the groundwater vulnerability map.

##### 1) Depth to Water Table (D)

The depth of the groundwater table in an unconfined aquifer significantly affects its vulnerability, as the shallower the depth, the easier it is for contaminants from the surface to enter the groundwater. This groundwater table depth weights 5. The condition of the groundwater table depth in the research area is divided into four categories (Table 3) namely, a depth of 0-1.5 m is slightly west and east of the research area, a depth of >1.5-4.6 m is spread in the central to northern parts of the research area while in the southern part, the groundwater table depth ranges from >4.6-9.1 m and >9.1-15.2 m (Fig. 4).

Table 3. Calculation of depth to water table scores

Depth to Water Table (m)	Rating	Weight	Score
0-1,5	10	5	50
>1.5-4.6	9	5	45
>4.6-9.1	7	5	35
>9.1-15.2	5	5	25

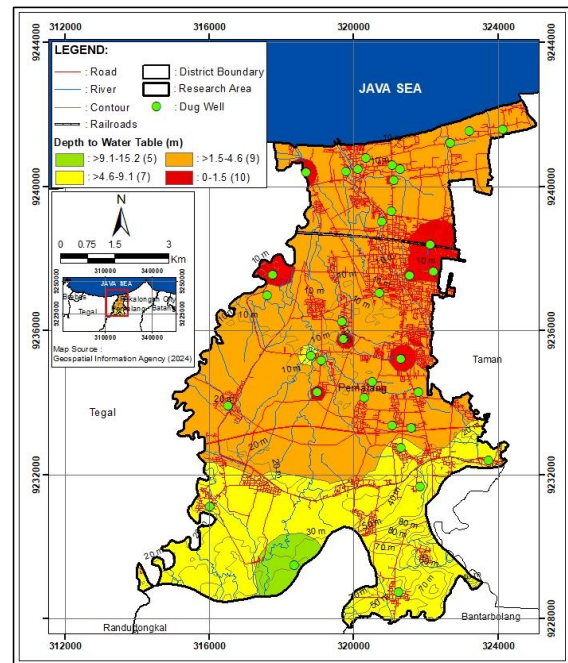


Fig. 4. Deep to water table map

##### 2) Net Recharge (R)

Groundwater recharge describes the amount of water supply that seeps into the ground. Recharge plays a crucial role in facilitating the vertical entry of contaminants into groundwater. The amount of recharge significantly affects vulnerability because the greater the recharge, the higher the risk of contamination. This groundwater recharge weights 4. Based on the recharge calculation, the research area, according to Aller et al. (1985), can be grouped into three categories (Table 4), namely recharge values >102-178 mm/year in the northern part, recharge values >178-254 mm/year in the central part and the southern part recharge values >254 mm/year. The distribution is shown in Fig. 5.

Table 4. Calculation of net recharge scores

Recharge (mm/year)	Rating	Weight	Score
>102-178	6	4	24
>178-254	8	4	32
>254	9	4	36

##### 3) Aquifer Media (A)

Aquifer media significantly affects the movement of contaminants into groundwater because contaminants flow according to the physical properties of the aquifer media, such as porosity, permeability, and cracks. The greater the aquifer's ability to hold contaminants, the longer the contaminant movement and the smaller the potential for contaminants to enter groundwater. This aquifer media weights 3. The type of aquifer media can be grouped into three categories: fine sand, medium sand, and coarse sand, with score calculations shown in Table 5. The aquifer media in the research area are generally sand, but they have a finer grain size towards the north, as shown in Fig. 6.

Table 5. Calculation of aquifer media scores

Aquifer Media	Rating	Weight	Score
Fine Sand	6	3	18
Medium Sand	7	3	21
Coarse Sand	8	3	24

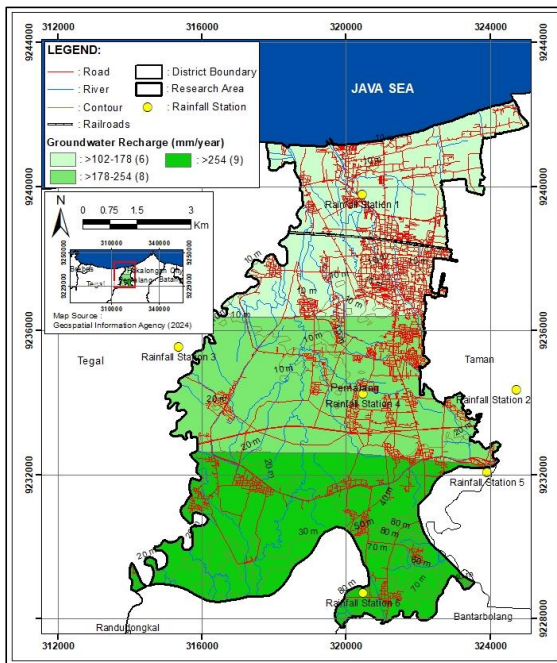


Fig. 5. Groundwater recharge map

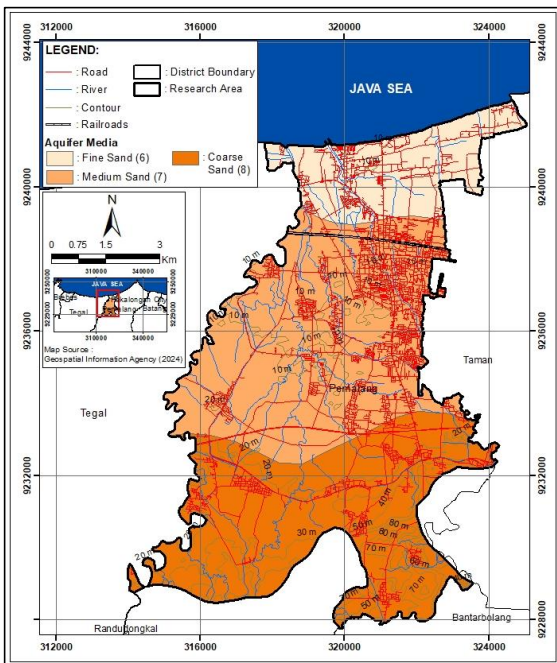


Fig. 6. Aquifer media map

#### 4) Soil Media (S)

Soil media is a part of the soil surface that influences the entry of runoff water into the free aquifer layer through the unsaturated zone. The determination of this soil media is obtained from the results of laboratory tests in the form of sieve analysis of several soil samples in the research area, where the results are categorized as sandy soil types. This soil media weights 2. Soil media consists of two categories, namely sandy loam and sand (Table 6). The soil media and its distribution in the study area are shown in Fig. 7.

Table 6. Calculation of soil media scores

Soil Media	Rating	Weight	Score
Sandy Loam	6	2	12
Sand	9	2	18

#### 5) Topography (T)

Land slope or topography will cause the movement of water speed on the surface to vary so that the amount of water that seeps into the soil in each group of land slopes will be different. This condition will certainly affect the rate at which contaminants enter the saturated zone. The flatter an area is, the faster the rate of contaminants entering the water zone will be. Meanwhile, in areas with steeper topography, the rate of contaminants entering the water-saturated zone will be slower because the slope causes contaminants to tend to be transported to flatter areas. This topography weights 1. According to Aller et al. (1985), the topography in the research area is categorized into five categories (Table 7). The distribution of topography in the research area is presented in Fig. 8.

Table 7. Calculation of topography scores

Topography (%)	Rating	Weight	Score
0-2	10	1	10
>2-6	9	1	9
>6-12	5	1	5
>12-18	3	1	3
>18	1	1	1

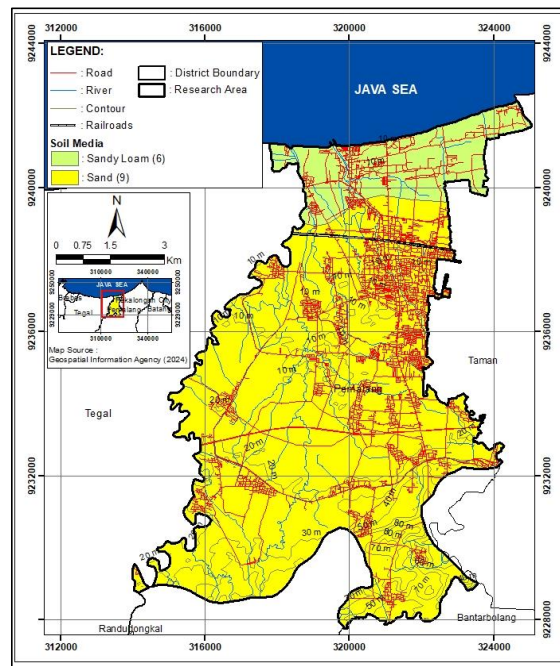


Fig. 7. Soil media map

#### 6) Impact of The Vadose Zone (I)

This zone is above the groundwater level. This zone has a significant impact on the rate at which contaminants enter the groundwater. The smaller the porosity and permeability of the material in this zone, the longer the speed of contaminants to enter the groundwater. This unsaturated zone media weights 5. According to Aller et al. (1985), in the research area, there are four categories of unsaturated zones, consisting of clay, silt, silty sand, and sand and gravel. The calculation of this parameter score is presented in Table 8, and its distribution is illustrated in Fig. 9.

Table 8. Calculation of impact of the vadose zone scores

Impact of The Vadose Zone	Rating	Weight	Score
Clay	1	5	5
Silt	2	5	10
Silty Sand	6	5	30
Sand and Gravel	8	5	40

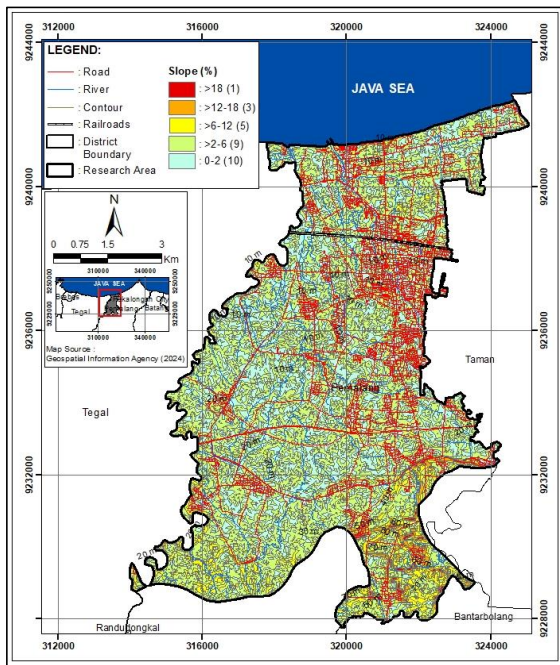


Fig. 8. Topography map

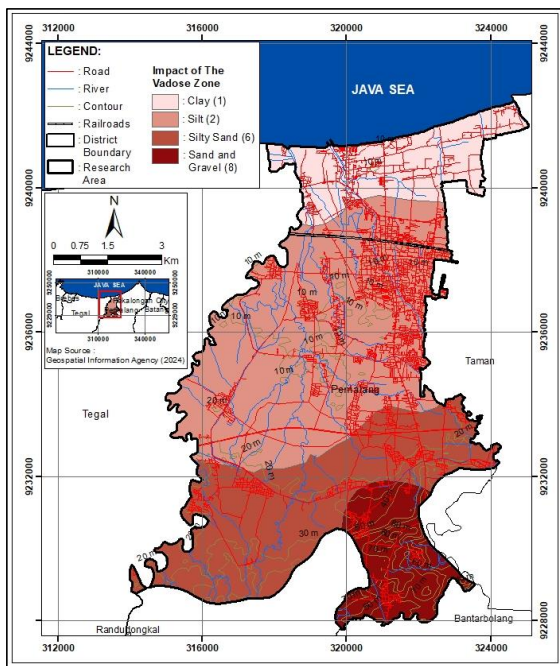


Fig. 9. Impact of the vadose zone map

### 7) Hydraulic Conductivity of The Aquifer (C)

Hydraulic conductivity is the ability of soil or rock to pass a fluid. This relates to the ability of soil or rock to remove a contaminant from the environment. Hydraulic conductivity is influenced by the type of rock, grain size, compactness, grain arrangement, and some types of rock, also by the presence of fracture zones. Determination of the hydraulic conductivity value is obtained from pumping tests using the slug test method on several dug wells in the research area. This hydraulic conductivity weights 3. Based on the classification by Aller et al. (1985), hydraulic conductivity in the research area is divided into three categories, as shown in Table 9. The

hydraulic conductivity value at the research location is shown in Fig. 10.

Table 9. Calculation of hydraulic conductivity scores

Hydraulic Conductivity (m/day)	Rating	Weight	Score
>4.1-12.2	2	3	6
>12.2-28.5	4	3	12
>28.5-40.7	6	3	18

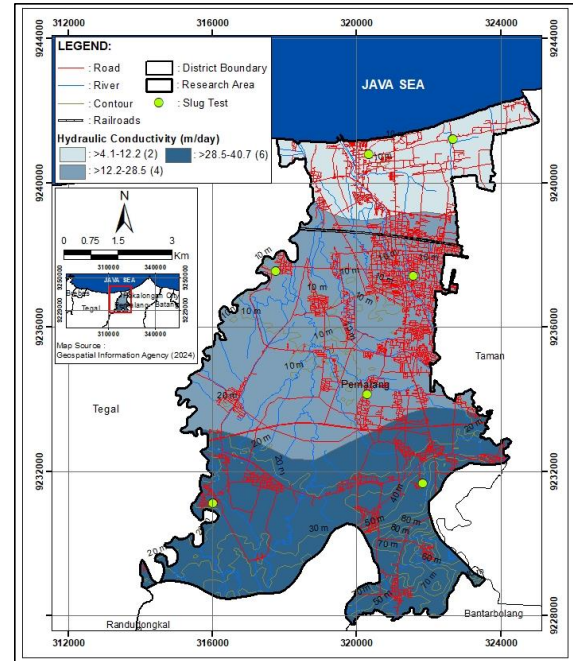


Fig. 10. Hydraulic conductivity map

From the results of the weighting analysis calculated for the DRASTIC parameters and overlaid, Pemalang District is included in the area with a moderate to high level of groundwater vulnerability. The moderate level of groundwater vulnerability has a DRASTIC Index value of >106-146, and the high level of groundwater vulnerability has a DRASTIC Index value of >146-186 (Fig. 11).

The moderate groundwater vulnerability zone has a percentage area of 32.6%, with a shallow groundwater depth ranging from 0 to 4.6 m. The distribution of this zone tends to be concentrated in the northern part, starting from Danasari Village in the north to Bojongnangka Village, which is located further south. It has a groundwater recharge of between 102 and 178 mm/year, which is smaller than that of the southern part of the research area. This causes areas in this zone to have a lower risk of contaminant seepage as the quantity of recharge is smaller. The aquifer media consists of fine to medium sand, and the soil media consists of sandy loam and sand. The land slope in this zone ranges from 0-6%, with unsaturated zone media (vadose) consisting of clay and silt, which causes contaminants to be retained longer in the vadose zone. This is due to the impermeable nature of clay, which has a hydraulic conductivity of between 4.1 and 28.5 m/day.

The high groundwater vulnerability zone has a percentage area of 67.4%, with a shallow to rather deep groundwater depth ranging from 1.5 to 15.2 m. The distribution of this zone tends to be in the southern part, starting from Wanamulya Village in the central part to Surajaya Village in the southern part. It has a groundwater recharge amount of more than 178 mm/year, which is

greater than that of the northern part of the research area. Consequently, areas in this zone have a higher risk of contaminant seepage due to the increased recharge. The aquifer media is in the form of medium to coarse sand, and the soil media is sand. The slope of the land in this zone varies greatly, ranging from 0-18% with unsaturated zone media (vadose) in the form of a little silt, and the majority is silty sand and sand and gravel, which causes contaminants to pass through the vadose zone more quickly, this is due to the nature of sand and gravel which are permeable and have a hydraulic conductivity of between 12.2-40.7 m/day. This relatively high hydraulic conductivity value indicates that contaminants in the aquifer can spread more quickly (Table 10).

Areas with shallow groundwater levels and media types in the unsaturated zone in the form of sand and gravel have the highest level of vulnerability. This occurs due to media or lithology that easily allows water to pass through and is located at a short distance from the shallow groundwater level. In general, the most effective attenuation occurs in the unsaturated zone, especially in the upper part of the soil layer, because the greatest biological activity occurs. In the saturated zone, attenuation continues but with lower intensity because groundwater moves more quickly. In this zone, the dispersion and dilution processes play a role in reducing the concentration of contaminants. The attenuation process decreases with increasing depth (Morris and Foster, 2000; Morris et al., 2003). The results of this study are similar to those of a study that mapped groundwater vulnerability using the DRASTIC method in urban areas composed of quaternary deposits. Locations with shallow groundwater levels and lithology in the unsaturated zone, characterized by sand deposits, resulted in high groundwater vulnerability (Aribowo et al., 2021).

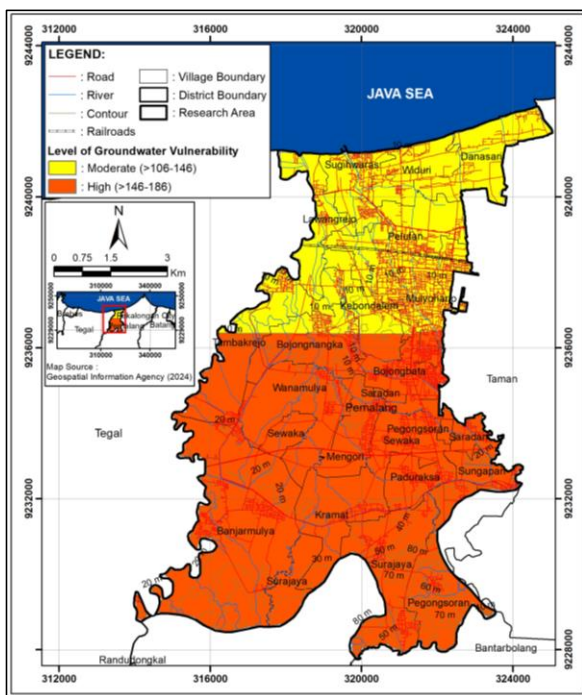


Fig. 11. Groundwater vulnerability map using the DRASTIC method

#### 4. Discussion

The DRASTIC method is a method for mapping groundwater vulnerability using the Point Count System

Model (PCSM). This method is a development of the parametric evaluation system, which utilizes the multiplication of ratings and weights. The DRASTIC method has the advantage of applying to large areas (Lingasari et al., 2019). The wider the area, the more detailed the analysis will be in mapping the vulnerability zone to contamination.

A groundwater vulnerability map generated using the DRASTIC method requires a substantial amount of data for accurate analysis results. The accuracy is better and more effective in determining groundwater vulnerability zones.

This study categorizes the vulnerability zones into two levels: medium and high. From the parameters used in the DRASTIC method analysis, the groundwater depth parameter (parameter "D") and the impact on the unsaturated zone (parameter "I") have the most significant impact on the results of the groundwater vulnerability zone map to contamination. The shallower the groundwater depth and the more permeable the layer in the unsaturated zone, the more vulnerable the area is to contamination by contaminants that enter the aquifer. Although it cannot reveal the characteristics of each pollutant, the results of this vulnerability zone map for contamination can be utilized in regional development activities and the evaluation of industrial and residential development plans.

This method needs to be validated in order to produce a more accurate map. Contaminants that are conservative ions, such as nitrate and chloride, can be used as indicators in validation (Rachman et al., 2022). Parameters with a high weight value are those located in the unsaturated zone, where they have the greatest influence on the assessment of this method. In this zone, the attenuation process occurs most intensively so that if the score on this parameter is high, the groundwater vulnerability map in the area tends to have high vulnerability. This finding aligns with research results in other areas that utilize the DRASTIC method, where the depth of the water table and the impact of vadose zone parameters significantly influence the final results of the groundwater vulnerability map (Aribowo et al., 2021).

Table 10. Level of groundwater vulnerability

DI Value	Level of Vulnerability	Characteristic
>106-146	Moderate	It can be contaminated by some contaminants that are continuously discharged.
>146-186	High	All contaminants can contaminate it, except those that require high absorption and are volatile in various scenarios.

#### 5. Conclusion

The hydrogeological factors that have the most significant influence on the level of groundwater vulnerability in the research area are those related to the unsaturated zone, as this zone is where the most effective attenuation processes occur, reducing the concentration and mobility of contaminants. The factors or parameters in question are the depth of the groundwater table, groundwater recharge, and the type of soil or rock layer in the unsaturated zone. The shallow groundwater table depth, high groundwater recharge value, and soil/rock layers in the unsaturated zone, composed of coarse

material (sand and gravel), will accelerate the transportation of contaminants from the surface to the saturated zone, resulting in a higher level of groundwater vulnerability, and vice versa.

Groundwater vulnerability zoning using the DRASTIC method in Pemalang District yields two categories of groundwater vulnerability levels: medium and high. In the DRASTIC method, moderate groundwater vulnerability zoning (DI >106-146) covers 32.6% of the research area, predominantly located in the northern part, extending from Danasari Village in the north to Bojongnangka Village in the central part. High groundwater vulnerability zoning (DI >146-186) covers 67.4% of the research area, predominantly located in the southern part, extending from Wanamulya Village in the central area to Surajaya Village in the south.

Recommendations that can be made to minimize the vulnerability of groundwater to pollution include conducting regular monitoring of groundwater levels and groundwater quality, conducting socialization of the use of surface water as an alternative water source for daily needs, conducting socialization of household wastewater management in locations close to dug wells, making regional regulations regarding wastewater disposal routes and wastewater drainage construction and the use of drilled wells for industrial activities compared to dug wells.

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