Analysis of free groundwater vulnerability level to pollution using “DRASTIC METHOD” development in Surakarta city

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Abstract. Increasing population density affects clean water reserves in Surakarta City. Free groundwater reserves in 2015 during the transition season in Solo is merely 1.34 billion L, whereas the amount of confined groundwater at the same time is up to 21 billion L. Solo population’s water requirement, however, is 51 million L/day or 18.62 billion L/year; therefore, it is predicted that well water crisis will occur in 2020. Population growth rate and the emergence of other supporting facilities in Surakarta result in a rapid change in agricultural lands into housing and industrial areas. The land utilization conversion becomes one of groundwater pollution sources and contributes to the entry of pollutants into the groundwater. This research aims to find out free groundwater vulnerability level to pollution and distribution of each DRASTIC parameter as well as land utilization for Surakarta City territories. The research is conducted using weighting method and parameter appraisal consists of DRASTIC parameters as main parameters and land utilization as development parameter. According to data obtained, the overall free groundwater in Surakarta territories indicates a high vulnerability level to pollution. Factors that are estimated to influencing the high level of the vulnerability include: soil texture that is dominated by loam, sand, and gravel, and land utilization.

1. Introduction
Groundwater is the most often utilized water source by human to support life necessities for domestic needs (household), industries, services, and agriculture. In meeting the needs would require sufficient groundwater quantity and quality. This should be emphasized as groundwater oftentimes is sufficient in terms of quantity yet its quality does not meet the requirements to fulfill the needs. Various factors play roles in water quality, natural and non-natural [1]. Increased population and facility and infrastructure demand are non-natural factors that play role in the increase in groundwater demand. These activities could bring adverse effects on the decrease of water quality or pollution, the groundwater in particular. The entry process of pollutants into the groundwater influences by hydrogeological factors of an area. It means that the hydrogeological characteristics of an area have a certain protection level to groundwater pollution [2]. There are considerable methods utilized to analyze groundwater vulnerability to pollution. One of the methods is DRASTIC, which is the hybrid of the Point Count System Models (PCSM) technique. This method provides weight and value that will be multiplied with weight of each parameter. The sum of all parameters that have been multiplied will be a final value indicating the groundwater vulnerability level to pollution [3].
2. Materials and Method

2.1. DRASTIC Method

DRASTIC method is the most utilized method to evaluate intrinsic vulnerability for various potential contaminants. It is an overlay and index model designed to produce vulnerability score by combining several thematic maps. The term of DRASTIC is an acronym of the most important factors in hydrogeology that control groundwater pollution. Hydrogeology defines as a composite description of all geological factors and the main hydrogeology that influences groundwater movement into, through, and out of an area [4].

![Figure 1. DRASTIC Method Flow](image)

2.2. DRASTIC Method Calculation

Reduction of the measured gravity value to eliminate or reduce the influence of geological conditions in the study area that can change the reading value on the gravity meter. There are several corrections to reduce the reading value of the device including drift correction, tide correction, latitude correction, free air correction, Bouguer correction, and terrain correction.

Once the seven-parameter technique is identified, the final vulnerability index (DI) could be found. The final vulnerability index is the weighted number of seven factors and it can be calculated using the following equation 1.

\[
DRASTIC \text{ Index} = D \cdot D_w + R \cdot R_w + A \cdot A_w + S \cdot S_w + T \cdot T_w + I \cdot I_w + C \cdot C_w 
\]  

(1)

Where; \( w = \) Parameter weight (1-5), \( r = \) Rate of each Parameter (1-10), \( D = \) Depth of groundwater (m), \( R = \) rainfall (mm/year), \( A = \) aquifer media, \( S = \) soil texture, \( T = \) topography (%), \( I = \) Vadose’s zone impact, \( C = \) hydraulic conductivity (ml/day).

Dynamic free-groundwater vulnerability assessment carried out by summing the results of DRASTIC index (equation 1) with the results of multiplication of weight (\( w \)) and land utilization rate (\( r \)). It could be written as in the following equation 2.

\[
\text{Vulnerability Index} = DI + L \cdot U \cdot U_w 
\]  

(2)

Where; \( w = \) Parameter weight (1-5), \( r = \) rate of each Parameter (1-10), \( DI = \) DRASTIC index, \( LU = \) land utilization.
2.3. Data Processing
Data processing technique and analysis used *ArcGIS*. Each DRASTIC parameter and land utilization were mapped. The map of free groundwater vulnerability to static pollution is the result of all DRASTIC parameters, namely: depth of groundwater, net recharge, aquifer media, soil texture, topography, vadose’s zone impact, and hydraulic conductivity. The map of free groundwater vulnerability to dynamic pollution is the result of combination between free groundwater vulnerability to pollution map and land utilization map. Analysis of estimation results of free groundwater risk to pollution was carried out spatially and descriptively. It aims to describe risk distribution pattern and link between free groundwater risk parameters and pollution [5].

3. Result and Discussion
3.1. Map of Depth of Groundwater, Net Recharge, and Hydraulic Conductivity
The map describes a zoning of groundwater depth, net recharge, and hydraulic conductivity to observe groundwater distribution pattern in Surakarta City. The map is based on data from geoelectric survey in 2019 and BMKG of Semarang for Surakarta City and Sukoharjo Regency areas.

![Map of depth to water](image1)

![Map of Net Recharge](image2)

**Figure 2.** (a) Map of depth to water (b) Map of Net Recharge

Map (Figure 2 a) indicates that the average of groundwater depth in the coastal area of Surakarta was around 50 – 80 meter below the soil surface. In the central area of Surakarta City, the depth was medium, which was between 30 – 50 meters below the soil surface. As regards groundwater vulnerability weighting [6], however, all sub-districts had low weight due to the depth that above 30 meters. In terms of Net Recharge, map (Figure 2 b) indicates that rainfall in 2019 in Banjarsari sub-district and Laweyan sub-district areas had fairly high rainfall intensity, which was 2573 mm/year. On the contrary, Serangan and Pasar Kliwon areas had rainfall of 1752 mm/year. According to the groundwater vulnerability weighting table, the higher the rainfall, the higher is the risk of vertical transport of pollutants to the water surface.
Hydraulic conductivity is used to find out groundwater flow rate in aquifer media. Map (Figure 4a) shows that data obtained from rock types in aquifer media. Area with high flow rate was Pasar Kliwon Sub-district, which was above 9 ml/day, whereas areas with small flow rate included Laweyan sub-district, Banjarsari sub-district, and small parts of Jebres area.

3.2. Map of Soil Structure, Aquifer Media, and Vadose’s Zone
This map illustrates the distribution of rock types according to geoelectric survey in 2019. The map is divided into three groundwater vulnerability parameters, namely: soil structure, aquifer media, and vadose’s zone (unsaturated zone).

Map (Figure 4b) illustrates soil structure distribution in Surakarta City. Data results displayed various types of rock, namely: sand, sandy loam, loam, clay loam, and clay aggregate. Jebres sub-district was dominated by sand and clay aggregate. Banjarsari sub-district was dominated by clay aggregate and sandy loam. Laweyan sub-district was dominated by sandy loam and clay loam. Seregan Sub-district was dominated by sand and Pasar Kliwon sub-district was dominated by sandy loam and clay aggregate. Soil structure is considered as a determinant of the amount of infiltration from soil surface. Map (Figure 5) shows types of surface in aquifer media. The data indicates that sand surface type was dominating in Laweyan and Serengan Sub-district. Banjarsari sub-district was dominated by clay sand. Jebres sub-district was dominated by sandstone, whereas Pasar Kliwon sub-district was dominated by gravel sand. Attenuation of contaminants in aquifer media depends on the number and fineness of...
granules. Larger granule size generally results in high permeability value and attenuation capacity becomes low; as a consequence, an increase in pollution potential [7].

Figure 5. Map of Vadose’s Zone

Unsaturated zone (vadose) is similar to soil structure but this layer is generally located above the aquifer media layer; therefore, vadose’s zone is considered as important since it serves as a filter of contaminants before reaching the saturated zone (aquifer) [8]. The data result displayed on map (Figure 6) indicates that there were four types of rock in Surakarta city area, namely: shale that dominated Pasarkliwon sub-district, Laweyan sub-district, and Serengan sub-district, sandstone was in some parts of Banjarsari sub-district and Jebres sub-district, clay that dominated Jebres and Laweyan sub-district, and sand was majority in the border of Banjarsari and Karanganyar sub-district.

3.3. Slope

Figure 6. Map of Slope

Slope obtained from Digital Elevation Model (DEM) data of Surakarta City. Slope was represented in the form of percent based on elevation differences in each region. Map (Figure 7a) indicated that slope percent level in Surakarta City had a varied elevation differences. In Jebres sub-district it was 2% in the southern part and 10% in the northern part. The eastern part of Banjarsari sub-district had a slope of 2% up to 8%. Other sub-districts, such as Laweyan sub-district, Serengan sub-district, and Pasar Kliwon sub-district had a slope of 0-2%. Small slope could produce a little runoff and more water retention; thus, more infiltration. It could have a potential of high contamination [9].
3.4. Results of Groundwater Vulnerability to Static and Dynamic Pollutions

Results of 7 parameters analyzed were then weighted in accordance with the effect of each parameter on soil vulnerability and summed using equation (1).

\[ \text{Vulnerability} = \sum \text{Weighted Parameters} \]

\[ (1) \]

Figure 7. (a) Map of Groundwater Vulnerability using Hydrogeological Parameters (b) Map of Groundwater Vulnerability by adding Land Utilization Parameter

Map (Figure 7b) illustrates normal groundwater vulnerability using hydrogeological parameters. The results only indicated vulnerability due to the nature regardless of human activities on the surface. It can be seen that some areas indicated sufficient vulnerability, namely in Jebres Sub-district in Untoroloyo region, Laweyan sub-district in Yosodipuro region, and Pasar Kliwon sub-district in Sampangan region. Based on the data analysis results it can be inferred that parameters that influenced vulnerability in sufficient vulnerability areas consisted of soil structure, aquifer media, and vadose’s zone. Map (Figure 7b) is the result of DRASTIC method development, which is by adding land utilization parameter as a dynamic parameter that affects groundwater pollution, infiltration, and the existence of plough pan as a barrier for the entry of water into the water table. The parameter is dynamic as it is a representation of human activities [10]. Equation (2) was used to obtain the data, which is by adding a final score of static DRASTIC with the result of multiplication of weight and land utilization level in each sub-district. Based on the map, a significant change could be observed with the addition of land utilization parameter. There was one area that indicated a high vulnerability level, which was Yosodipuro region of Laweyan Sub-district. It was due to moderate population along with industrial allocation in the region. Other areas experienced an increase from low to sufficient vulnerability. There were two areas, however, that still in the low vulnerability, namely: Margoyudan region of Jebres sub-district and Mutihan region of Laweyan Sub-district. It was related to small groundwater flow rate and vadose’s zone of clay.

4. Conclusion

Groundwater vulnerability to pollution based on hydrogeological data indicated that most areas in Surakarta City had low vulnerability to pollution. There were several areas, however, that had sufficient vulnerability level. Those areas included Untoroloyo region of Jebres sub-district, Yosodipuro region of Laweyan sub-district, and Sampangan region of Pasar Kliwon sub-district. Regarding groundwater vulnerability to pollution with the addition of land utilization parameter, most areas in Surakarta City indicated sufficient vulnerability. Yosodipuro region of Laweyan sub-district, however, indicated high vulnerability due to moderate population along with industrial allocation in the region. Margoyudan region of Jebres sub-district and Mutihan region of Laweyan sub-district had low vulnerability level. It was due to small groundwater flow rate and vadose’s zone of clay.
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