Groundwater Vulnerability to Pollution in Kediri City, East Java Province, Indonesia

T Widodo 1,4,*, W Wilopo 2,3,*, A Setianto 2,3

1Magister 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
4Ministry of Public Works and Housing, Indonesia

*Corresponding Author: trisnowidodo@mail.ugm.ac.id, wilopo_w@ugm.ac.id

Abstract. Groundwater is a water resource that is still a mainstay for humans. The need for groundwater increases with the growth of population and the development of the industrial and agricultural sectors. The residents of Kediri City still use wells from shallow aquifers to fulfill their water needs. Shallow aquifers are prone to pollution due to the influence of shallow groundwater depths and human activities. The purpose of this study is to determine the vulnerability of groundwater pollution in Kediri City. Groundwater vulnerability was conducted by the GOD method (Groundwater Occurrence, Overlaying Lithology, and Depth of Groundwater) that consists of 3 parameters, namely the groundwater confinement, the type of overlying strata, and the depth of the groundwater level. The analysis results show that the level of groundwater vulnerability according to the GOD method in Kediri City consists of moderate and high classes. The western and the eastern part of Kediri City is classified as a high level of vulnerability. In contrast, in the middle of Kediri City, it tends to experience a moderate level of vulnerability.

Keywords: GOD method, groundwater, shallow aquifers, vulnerability

1. Introduction

Groundwater is a water resource that is still a mainstay for humans. The need for groundwater increases with the growth of population and the development of the industrial and agricultural sectors. The utilization of groundwater is still a significant mainstay for regions globally because it is a cheap and always available water resource without being influenced by the amount of rainfall compared to surface water [1][2]. Kediri City experienced population growth from 2018 to 2019 of 0.74 percent [3]. The residents of Kediri City still use wells from shallow aquifers to fulfill their water needs. Shallow aquifers are prone to pollution due to the influence of shallow groundwater depths and human activities.

In using groundwater activities, it is better to pay attention to aquifer vulnerability. There are two kinds of groundwater vulnerability to pollution: intrinsic vulnerability, a natural vulnerability due to
hydrogeological factors such as aquifer characteristics, rock types, and geological materials, and specific vulnerability, which is groundwater vulnerability due to human activities. The groundwater vulnerability of an area is more easily communicated to the public through the media of groundwater vulnerability maps [4]. The basic concept of groundwater vulnerability is whether the rock above the aquifer can prevent groundwater contamination in a place because the rock affects reducing the concentration of pollutants into the aquifer. In the unsaturated zone, retardation and elimination processes occur. The retardation process is the process of contaminants experiencing a decrease in speed due to the absorption of contaminants by the material being passed, and there is an ion replacement process in the rock material. Moreover, the elimination process reduces the concentration of contaminants due to filtration, contaminant deposition, contaminant reaction with water, evaporation, and reduction of organic compounds [5]. The benefits of groundwater vulnerability studies are an indicator of groundwater sensitivity to the surrounding environment, which is helpful for planning and decision making in groundwater resource management [6][7]. Aquifer vulnerability studies should be carried out in land use planning and groundwater resource development. Aquifer vulnerability maps help policymakers select suitable sites for future reclamation [8].

The purpose of this study is to determine the vulnerability of groundwater pollution in Kediri City. Groundwater vulnerability is conducted by the GOD method (Groundwater Occurrence, Overlaying Lithology, and Depth of Groundwater) [9] that consists of 3 parameters, namely the groundwater confinement, the type of overlying strata, and the depth of the groundwater level. A map of the groundwater vulnerability zone to pollution in Kediri City is obtained from those parameters.

Figure 1. Location of the study area
2. Material and Methods

The study site is located in Kediri City, East Java Province, Indonesia. Kediri City is astronomically located at coordinates 7°45'00" South Latitude to 7°55'00" South Latitude, 111°05'00" East Longitude to 112°03'00" East Longitude, as shown in Figure 1.

Kediri City is composed of surficial deposits and volcanic rocks. Surficial deposits consist of alluvium (Qa), including pebble, gravel, sand, clay, mud. Volcanic rocks consist of Qjk (klothok morphonit), including volcanic breccia, tuff, and pyroxene andesite lava; Qp (pawonsewu morphocet) consist of volcanic breccia with pyroxene andesite fragments, tuff, agglomerate, and lava pyroxene andesite lava; and Qvlh (laharic deposits) consist of volcanic pebble-sand, tuff, clay, and plant remains and archeological artefacts [10][11].

Kediri City had four aquifers systems [12], includes:

1. Aquifers in which flow is through fissures and interstices, extensive moderately productive aquifers, aquifers of vastly varying transmissivity.
2. Aquifers in which flow is intergranular, locally, moderately productive aquifers, mostly incoherent aquifers of low thickness and transmissivity.
3. Aquifers in which flow is intergranular, low to moderate transmissivity.
4. Aquifers in which flow is intergranular, moderate transmissivity.

This research uses the GOD method introduced by Foster in 1987 [9] to identify the vulnerability of groundwater to pollution. The parameters used in the GOD method include: Groundwater Confinement (aquifer type), the aquifer type parameter has an index value range of 0.0 to 1.0; Overlying Strata (lithology of the top layer of the aquifer) has a range of index values from 0.4 to 1.0; Depth to groundwater table has an index value of 0.6 to 1.0, as shown in Figure 2. The data for the groundwater confinement, the overlying strata, and groundwater depth were obtained from the field survey results at 55 stop sites, as shown in Figure 1. The GOD index (GI) is given according to the following formula:

\[ GI = C_g \times C_o \times C_d \] (1)

Cg is the aquifer type dimension; Co is the lithology dimension of the aquifer's top layer, and Cd is the depth dimension to the groundwater table. Figure 2 describes the value of the GOD index based on each parameter. All of the parameters were overlay using Geographic Information System (GIS) software. The base map carried out in the analysis uses a digital topographic map obtained from the Indonesian Geospatial Agency. The final classification of aquifer pollution vulnerability was determined from the multiplication of the GOD index based on equation (1). Each level of groundwater vulnerability from the analysis with the GOD method means how much the aquifer is vulnerable to pollution. The level of aquifer pollution vulnerability consists of 5 levels [13], namely:

1. Extreme level means the aquifer is vulnerable to most of the pollutants with immediate impact.
2. The high level indicates that the aquifer is vulnerable to many pollutants.
3. Moderate level indicates that the aquifer is vulnerable to pollutants, but these pollutants are discharged continuously.
4. A Low level indicates that the aquifer is vulnerable to conservative pollutants (which do not change in concentration with time) in the long term, widely and continuously discharged.
5. Negligible level means confining beds without significant vertical groundwater flow.

3. Results and Discussion

Based on geological observations, Kediri City consists of four lithological units: andesite lava, andesite breccia, gravelly sand, and clayey sand. Geological observations were carried out at 55 stop sites, namely by observing the lithological character and composition found in the field. Figure 3 shows the distribution zone of four lithologies units in Kediri City.
Figure 2. The assessment GOD index value for aquifer pollution vulnerability [13].

Figure 3. The distribution zone of lithological units in Kediri City.
Kediri City consists of four lithological units and has one type of aquifer. Lithologies of the aquifer consist of andesite lava, andesite breccia, gravelly sand, and clayey sand. The type of aquifer in Kediri City is an unconfined aquifer. The GOD index value of the groundwater confinement parameter with the unconfined aquifer type is 1.0. Determination of GOD index value for the groundwater confinement parameter (aquifer type) is presented in Table 1. Figure 4 shows the GOD index value distribution zone based on the groundwater confinement parameter in Kediri City.

| Lithology          | Type of Aquifer | GOD Index Value |
|--------------------|----------------|-----------------|
| Andesite lava      | Unconfined aquifer | 1.0            |
| Andesite breccia   | Unconfined aquifer | 1.0            |
| Gravelly sand      | Unconfined aquifer | 1.0            |
| Clayey sand        | Unconfined aquifer | 1.0            |

Determination of GOD index value for the overlying strata (lithology of the top layer of the aquifer) is presented in Table 2. The GOD index value for the overlying strata parameter is 0.5 for clayey sand, 0.6 for andesite lava, 0.7 for breccia andesite and gravelly sand. Figure 5 shows the GOD index value distribution zone based on the overlying strata parameter in Kediri City. The areas of Kediri City with a GOD index value of 0.5 are the eastern part of the Mojoroto Sub-district, the western part of the Kota Sub-district, and the part of the west Pesantren Sub-district. The area of Kediri City with a GOD index value of 0.6 is near Mount Klothok, the western part of the Mojoroto Sub-district. The areas of Kediri City with a GOD index value of 0.7 are located in the west part of the Mojoroto Sub-district, the east part of the Kota Sub-district, most Pesantren's area Sub-district.

![Figure 4. The distribution zone of the GOD index value of the groundwater confinement parameter in Kediri City.](image-url)
Table 2. The GOD index value based on the overlying strata parameter

| The lithology of the top layer of the aquifer | GOD Index Value |
|---------------------------------------------|-----------------|
| Andesite lava                               | 0.6             |
| Andesite breccia                            | 0.7             |
| Gravelly sand                               | 0.7             |
| Clayey sand                                 | 0.5             |

The depth of groundwater table in the Kediri City based on measurements at 55 wells of residents ranges from 0 to 20 meters. The area with a depth to groundwater table of 5 meters to 20 meters is located around Mount Klothok, the west part of Kediri City. In comparison, areas with a groundwater table depth of 0 to 5 meters are almost all areas of Kediri City. The determination of GOD index value for the depth to groundwater table is presented in Table 3. GOD index value for the depth to groundwater table 0 to 5 meters is 0.9, and 5 meters to 20 meters is 0.8, as shown in Figure 6.

Table 3. The GOD index value based on the depth to the groundwater table parameter

| Depth to Groundwater Table | GOD Index Value |
|----------------------------|-----------------|
| 0 m – 5 m                  | 0.9             |
| 5 m – 20 m                 | 0.8             |

Analysis of groundwater vulnerability was carried out by multiplying the GOD value index of each parameter based on equation (1) with GIS software. The result of the groundwater vulnerability analysis is shown in Table 4 and Figure 7. The area of Kediri City can be divided into moderate and high vulnerabilities based on the GOD index value. The moderate vulnerability has the GOD index value range from 0.3 to 0.5, located in the middle of the city extending from the north to the south. The high vulnerability is located in the west and east of Kediri City, mostly belonging to Mojoroto and Pesantren Sub-districts. Aquifers in these areas are prone to pollution because the materials consist of porous media of gravelly sand.
Table 4. The assessment GOD index value for aquifer pollution

| Total GOD Index Value | The level of the aquifer pollution vulnerability | Distribution Area |
|-----------------------|-------------------------------------------------|-------------------|
| 0.3 – 0.5             | Moderate                                        | In the eastern part of Mojoroto Sub-district, almost all areas of the Kota Sub-district |
| 0.5 – 0.7             | High                                            | The western part of Mojoroto Sub-district, a small area in the eastern part of the Kota Sub-district, almost all area of the Pesantren Sub-district |

Figure 6. The distribution zone of the GOD index value of the depth to groundwater table parameter in Kediri City.

Figure 7. The groundwater vulnerability map to pollution based on the GOD method in Kediri City.
4. Conclusion
The results of parameter analysis show that the level of groundwater vulnerability according to the GOD method in Kediri City consists of a moderate class with a total GOD index value of 0.3 - 0.5 and a high class with a total GOD index value of 0.5 - 0.7. The western and the eastern part of Kediri City is classified as a high level of vulnerability. In contrast, in the middle of Kediri City tends to experience a moderate level of vulnerability. Therefore, the result of the study can be used as guidance for land use planning and sanitation system to protect groundwater quality, especially in the high vulnerability area.

Acknowledgments
This research was supported by the Department of Geological Engineering, Universitas Gadjah Mada. This article is part of the author’s research funded through the Ministry of Public Works and Housing scholarship.

References
[1] Sophocleous MA 2003 Environmental implications of intensive groundwater use with special regard to streams and wetlands In *Intensive Use of Groundwater: Challenges and Opportunities* by Llamas MR, Custodio E (eds) (Lisse, The Netherlands: Balkema Publishers) pp 93-112
[2] Meng X, Deng B, Shao J, Yin M, Liu D and Hu Q 2015 Confined aquifer vulnerability induced by a pumping well in a leakage area Remote Sensing and GIS for Hydrology and Water Resources IAHS Publ. 368 pp 442-447
[3] Badan Pusat Statistik Kota Kediri 2020 *Kota Kediri Dalam Angka* (Kediri: Badan Pusat Statistik)
[4] Vrba J and Zaporozec A 1994 Guidebook on Mapping Groundwater Vulnerability (Hannover: International Contributions to Hydrogeologists).
[5] Morris B, Adam B, Calow R, Chilton J, Klinck B, Lawrence A and Robin N 2003 *Groundwater and Its susceptibility to Degradation: A Global Assessment of the Problem and Option for Management.* (Nairobi, Kenya: United Nations Environment Program)
[6] Rahman A 2008 A GIS based DRASTIC model for assessing groundwater vulnerability in shallow aquifer in Aligarh, India *Appl. Geogr.* 28 (1) pp 32-53
[7] Lindstrom R and Scharp C 1995 *Approaches to Groundwater Vulnerability Assessments: A State of the Art Report* (Stockholm, Div. of Land and Water Resources, Royal Institute of Technology) p 77
[8] Abu-Bakr HA 2020 Groundwater vulnerability assessment in different types of aquifers *Agricultural Water Management* 240 (2020) 106275
[9] Foster SSD 1987 Fundamental concepts in aquifer vulnerability, pollution risk and protection strategy *Proceedings and information in vulnerability of soil and ground-water to pollutants vol 38* (The Hague: TNO Committee on Hydrological Research) pp 69-86
[10] Hartono U, Baharuddin and Brata K 1992 *Peta Geologi Lembar Madiun, Jawa* (Bandung: Pusat Penelitian dan Pengembangan Geologi)
[11] Santosa S and Atmawinata S 1992 *Peta Geologi Lembar Kediri, Jawa* (Bandung: Pusat Penelitian dan Pengembangan Geologi)
[12] Poepowardooyo and Soekardi R 1984 *Peta Hidrogeologi Indonesia Lembar X* (Kediri, Jawa) (Bandung: Direktorat Geologi Tata Lingkungan)
[13] Foster S, Hirata R, Gomes D, D’Elia M and Paris M 2007 *Groundwater quality protection - a guide for water utilities, municipal authorities and environment agencies* (Washington DC: The International Bank for Reconstruction and Development / The World Bank)