Assessment of Groundwater Vulnerability Using GOD Method

Bantar Tyas Sukmawati Rukmana¹, Waterman Sulistyana Bargawa², and Tedy Agung Cahyadi³

¹,²,³ UPN “Veteran” Yogyakarta, Jl. SWK 104, Condongcatur, Depok, Sleman, DIY
E-mail: bantartyas_rukmana18@yahoo.com

Abstract. Mining activities can affect the availability of groundwater both in quantity and quality. Example of mining activities that can cause pollution are overburden stockpiling, construction of haul road facilities and infrastructure, coal processing and stockpiling activities, workshops, and domestic waste disposal. One effort to maintain groundwater is to analyze the groundwater vulnerability. This research was conducted to analyze the vulnerability of groundwater to pollution of PT. X in Balangan, South Kalimantan. The method used to assess groundwater vulnerability in this study is the GOD method (groundwater occurrence or aquifer type, overall lithology of aquifer, and depth of groundwater). Determining the groundwater vulnerability class with this method will be based on three parameters, namely type of aquifer, lithology or rock type, and depth of groundwater table. The GOD method divides each parameter into several classes in consonance to the weight of each parameter corresponding to the effect on groundwater vulnerability. Based on the results of the analysis, it is indicated that the area of PT. X is included in the category of negligible and moderate vulnerability. The results of the analysis can be used for recommendations for groundwater management in the study area. The GOD method can also be used to determine groundwater vulnerability in urban areas that have different land uses. Keywords: GOD, groundwater vulnerability, mining

1. Introduction

Water is one of the most important components for humans. Increasing population in an area has resulted in increasing human needs for water. Water is used for the needs of the global to local scale, secondary and primary, and various fields in life [1]. Water can be taken from surface water sources or subsurface water (groundwater) stored in the aquifer layer [2]. Groundwater is water that moves in the soil contained in the space between soil grains that seep in the soil, containing the space in between soil grains to seep into the soil and combine to form a layer of soil called an aquifer [3]. Surface water has worse water quality than groundwater because it is easily polluted, while contaminated groundwater will be difficult to recover [4]. The presence of pollutants in groundwater and the physical condition of the area can affect the quality of groundwater. This is because groundwater is located in layers of rock or soil beneath the surface of the ground so that it affects the level of danger of groundwater against pollution [5].

Mining is an activity that can cause changes in land use, morphology, geology, and hydrogeology. This change has an impact on topographic changes, subsurface rock layers, and aquifers [6]. Various types of mining activities that can cause pollution include the construction of haul road facilities and infrastructure, overburden stockpiling, workshops, coal processing and stockpiling activities as well as domestic waste disposal from employees [4].
Study of groundwater vulnerability to pollution needs to be done in preserving the potential and quality of groundwater [7]. The vulnerability of groundwater is the ability of groundwater to survive against contaminants or pollution on the soil surface to reach the aquifer layer or groundwater level [8]. There are several methods for evaluating groundwater vulnerability. The more commonly used method is based on the overlay and index techniques, where different data parameters are assessed and stacked or overlaid with each other to produce a vulnerability map [9]. Criteria for choosing a particular method generally include (a) data availability due to the scarcity of data and (b) geological conditions of the study area, because there are rock formations that require special attention due to their high solubility in water [10].

1.1 Description of Studied Area
The study area is located in Balangan, South Kalimantan. This area has a strategic function as the center of the mining, education, agriculture, trade, fisheries, livestock, plantation, and government. The strategic function causes very high pressure on water resources, especially groundwater. The population in Balangan Regency increased with a population of 92,930 people in 2002 and reached 100,956 in 2007. The rainy season in the study area occurred from November to June while summer was only from July to September. Rain still falls with an intensity of 34-270 mm/month even though dry season is in the period July-September. The highest rainfall usually occurs from December to March with an intensity reaching >600 mm/year with rainy days ranging from 16-27 days. Morphology in this area is low hills with elevations ranging from 75 and 105 meters.

1.2 Geology of Studied Area
The study area is located on the eastern edge of the Barito Sub Basin at the foot of the Meratus Mountains. The Barito Sub Basin is the southern part of the Kutai Basin in the Tertiary Period in the form of a broad sedimentary basin and includes South Kalimantan and East Kalimantan. The boundary of the Barito Sub Basin in the eastern part is the Meratus Mountains, in the western part is the Sunda Expanse, while the northern part is the Kutai Basin, in the southern direction tertiary sedimentary rocks of the Barito Basin dip into the Java Sea. The oldest basic rocks from the Barito Sub Basin are Pre-Tertiary, from the Triassic Period to the Cretaceous. This rock is quite extensive and is a source of sedimentary rock that fills the Barito basin. This research area includes the Middle Miocene Warukin Formation. Stratigraphy of Warukin Formation in the form of intersection between fine sandstone, siltstone, and claystone with coal inserts. This formation experiences folding and forms an asymmetrical anticline. The tilt of the western anticline is around 50° steeper than the eastern which has a slope of around 15°. There are two aquifer systems in the study area, namely confined aquifers and unconfined aquifers. The unconfined aquifer is formed by weathering rocks from all existing formations and exposed rocks. This aquifer is estimated to have a maximum thickness of 25 meters. Confined aquifers are formed by quartz sandstones and coal.

2. Purpose
The purpose of this study was to determine the groundwater vulnerability to pollution due to mining activities using the GOD method. The results of this study are expected to be one of the technical guidelines in an effort to preserve the potential of groundwater in the study location so that it can be used sustainably as a groundwater source.

3. Methods
3.1 Hydrogeological Study
The hydrogeological study includes evaluating data on topography, local, and regional geology, climate and hydrology, lithology, mining systems, and geological structures. The hydrogeological study is also used to determine the hydrogeological basin geometry, configuration, and characteristics of aquifers, types of groundwater flow, and water balance [11]. Grouping of aquifers based on the
attitude of rocks to water is divided into four, namely: aquifers, aquitards, aquicludes, and aquifug [3]. The grouping of aquifers based on the position of the groundwater is divided into three, namely: unconfined aquifer, confined aquifer, and semi-confined aquifer [12]. In this study, a hydrogeological study was conducted to identify each parameter needed in analyzing groundwater vulnerability including the type of lithology aquifers, aquifer type, and groundwater depth.

3.2 Vulnerability of Groundwater

Groundwater is a valuable resource in the mining and urban areas. It is the vital local water source for industry, agriculture, as well as wildlife. Groundwater is also the main source of drinking water in mining and urban area, and hence its vulnerability assessment in delineate areas that are more susceptible to contamination is very important [13]. The groundwater dynamics reflects the response of the groundwater system to external factors such as climate condition, water storage, groundwater consumption, and other human activities [14]. Infiltration of industrial and urban wastewater can recharge groundwater, but can also pollute aquifers used for potable supply [15]. Groundwater is vulnerable to contamination by anthropological activities. The nitrate pollution of groundwater caused by agricultural activity and a substantial increase in fertilizer utilization are also becoming an increasing problem. Groundwater vulnerability mapping is an important key to improving planning and decision-making processes in order to prevent groundwater contamination [16].

The vulnerability of groundwater is the ability of groundwater resistance to contaminants or pollution originating from the subsurface or surface. The vulnerability of groundwater is high if only a small amount of protection is provided by natural factors as groundwater shielding against contaminants at ground level. The vulnerability of groundwater is low if there is relatively good protection provided by natural factors as groundwater shielding against contaminants [12]. The vulnerability of groundwater is divided into two, namely the vulnerability of specific and intrinsic vulnerability. The natural (intrinsic) vulnerability is a function of hydrogeological factors such as the type of soil that is above the aquifer, the characteristics of the aquifer, and the type of geological material. Specific vulnerability is the potential of groundwater sources in the dimensions of space and time affected by human activities [17].

Groundwater vulnerability is an assessment in terms of numerical quality from several parameters used to determine the level of vulnerability of groundwater. An aquifer has different hydrogeological conditions. Therefore, the level of vulnerability of a region will certainly be different from other regions. The hydrogeological conditions used as parameters are usually physical properties but there are also chemical properties used as parameters [18].

3.3 GOD Method

There are many methods that have been used to estimate the level of vulnerability of groundwater. The method for determining groundwater vulnerability is basically divided into three general categories, namely process method based on simulation, statistical method, and overlapping method. The overlapping method is a method that is very easy to implement, especially using geographic information systems (GIS) [4]. Determining of groundwater vulnerability to pollution can be done using the GOD method [15]. GOD stands for the following parameters: \( G = \) groundwater assurance, \( O = \) overall lithology of aquifer or aquitard, and \( D = \) depth to groundwater table. The vulnerability of groundwater can be done quickly with this method [19]. The GOD method considers two basic factors for determining the vulnerability of aquifer pollution: (a) the level of accessibility of the aquifer saturated zone and (b) the weakening capacity of strata contaminants lining saturated aquifers. However, in many cases, these factors cannot be thoroughly evaluated due to data limitations. Thus, simplification is needed and the parameters that need to be considered are (a) hydraulic configuration of groundwater, (b) overlay strata (vadose zone), and (c) depth of groundwater [20].

In this method, three parameters of vulnerability index weighting are carried out: the presence of groundwater depicted in the type of aquifer, the type of lithology aquifer, and the depth of groundwater [18]. Each parameter has a specific weight. Evaluation and mapping of groundwater
vulnerability are carried out with the GOD index, the calculation of the GOD index is carried out using the following equation.

\[
\text{GOD index} = Ca \times Cl \times Cd
\]  

[1]

Where :
Ca = type of aquifer,
Cl = type of lithology aquifer,
Cd = depth of aquifer

After the GOD value in each drill hole is obtained, then interpolated by using the IDW method to obtain delineation between points, so that the zone in the study area is known. The contribution of each GOD parameter to the level of vulnerability of groundwater in the study area varies [4].

4. Results dan Discussions

The level of vulnerability of groundwater in Balangan, South Kalimantan can be determined by analysis using the GOD method. The parameters used include the type of aquifer, type of lithology aquifer, and depth of groundwater. Parameters of aquifer type and aquifer lithology type were obtained from the results of the drill log and the depth parameters of groundwater obtained from the results of hydrogeological mapping.

4.1 Types of Aquifers

The type of aquifer is one of the parameters used in the analysis of the level of vulnerability of groundwater. The type of aquifer can be determined based on the subsurface conditions obtained from the results of the drill log. The type of aquifer in Balangan, South Kalimantan consists of unconfined aquifers and confined aquifers. Determining the value of the type of aquifer can be adjusted by referring to GOD classification which can be seen in Figure 1. Unconfined aquifer in the GOD classification has a value of 1, while the confined aquifer has a value of 0.2 (Table 1).
Determining the values for unconfined aquifers is based on the characteristics of unconfined aquifers which have a tendency to be closer to the surface and do not have aquitards. Determining the confined aquifers based on the characteristics of confined aquifers, namely the upper layer and the lower layer are limited by the aquiclude.

4.2 Type of Aquifer Lithology
Aquifer lithology is one of the parameters which can be used to analyze the level of vulnerability of groundwater. Lithology types can be known based on subsurface conditions which are obtained from the results of the drill log. The research area has aquifer lithology types consisting of topsoil and mudstone. Determining the value of aquifer lithology type is adjusted by referring to the GOD classification which can be seen in Figure 1. Based on the classification value of GOD soil has a lower value of 0.4. Mudstone has a greater value than mudstone which is 0.5 (Table 2).

| Type of Aquifer Lithology | Value |
|---------------------------|-------|
| Residual Soil             | 0.4   |
| Mudstone                  | 0.5   |

4.3 Depth of Groundwater
The depth of groundwater is one of the parameters used to analyze the level of vulnerability of groundwater. The data of groundwater depth is obtained from the measurement of the dug wells in Balangan, South Kalimantan. The final result of this parameter is a groundwater depth map. Table 3 shows that the more shallow groundwater level, the greater the value of vulnerability to pollution. Determining the groundwater depth value is adjusted by referring to the GOD classification which can be seen in Figure 1.

| Depth of Groundwater | Value |
|----------------------|-------|
| <5 m                 | 0.9   |
| 5-20 m               | 0.8   |
| 20-50 m              | 0.7   |
| >50 m                | 0.6   |

4.4 Groundwater Vulnerability Analysis
The vulnerability of groundwater to contamination of groundwater in unconfined aquifers is greater when compared to confined aquifers. The decline in the quality and quantity of groundwater is a problem in the research area. Therefore, it is very important to determine the level of contamination susceptibility based on hydrogeological factors. Based on the results of the Balangan Index GOD method, South Kalimantan is included in the level of negligible vulnerability to the level of moderate vulnerability. The division is based on the results of combining the three GOD parameters (Table 4). Based on groundwater vulnerability maps (Figure 2) it can be a general description of areas vulnerable to pollution. This method only sees in terms of lithology and hydrogeology, so that it cannot show substances that contaminate shallow groundwater.
Table 4. Groundwater vulnerability level

| Value    | Vulnerability Level | Characters                                                                 |
|----------|---------------------|-----------------------------------------------------------------------------|
| 0,06 - 0,08 | Negligible       | Limited to places without significant vertical groundwater (leakage).       |
| 0,32-0,36  | Moderate           | Can be polluted by some pollutants which are disposed of continuously.      |

The GOD model can be a useful tool for identifying areas that are susceptible to pollution, although they cannot show the characteristics of each pollutant. The vulnerability map can help to show potentially high pollution areas as a first step in planning future groundwater protection and economic development. The GOD technique can provide important data for conservation and management of water resources in developing environmental policies in Balangan, South Kalimantan. The GOD method can also be used to determine groundwater vulnerability in urban areas that have different land uses. The use of agricultural land, industry, settlements, and plantations will provide different levels of groundwater vulnerability. Industrial land use is likely to result in higher groundwater vulnerability compared to agricultural and settlements land use.

Figure 2. Groundwater vulnerability map using GOD method
5. Conclusion
The results of the assessment of groundwater vulnerability to contaminants using the GOD method of PT.X in Balangan, South Kalimantan showed that the vulnerability scores were 0.06 - 0.08 and 0.45. Based on this value then it can be considered that the level of vulnerability of groundwater to contaminants at the study site is at the level of negligible vulnerability and moderate vulnerability. The three parameters compiling the level of vulnerability are the type of aquifer, the type of lithology aquifer and the depth of groundwater affect the value of vulnerability at the study site. The distribution of the vulnerability groundwater level is being found in the central area, while the level of negligible vulnerability is widely spread in the study area. Based on the results of the zoning level of vulnerability, it can be concluded that the priority scale for groundwater management needs to be made so that it can minimize the impact of coal mining on groundwater in the study area.

6. Reference
[1] Vias, J.M., Andreo, B., Peries, M.J., and Carrasco, F. 2005. A Comparative Study of Four Schemes For Groundwater Vulnerability Mapping in a Diffuse Flow Carbonate Aquifer Under Mediterranean Climatic Conditions. *Enviro Geol.* 47, 586-595.

[2] Putranto, T.T. and Kuswoyo, B. 2008. Zona Kerentanan Air Tanah terhadap Kontaminan dengan Metode DRASTIC, TEKNIK, 29 (2), 110-120.

[3] Todd, D.K. and Mays, L.W. 2005. Groundwater Hydrology. New York: John Willey and Sons, Inc.

[4] Haq, Shofa Rijalul., Dwinagara, Barlian., Triana, Karlina., and Cahyadi, T. A. 2013. Analisis Tingkat Kerentanan Air Tanah Pada Rencana Pertambangan Batubara di Barito Timur, Kalimantan Tengah. *Prosiding IPT XXII PERHAPI*.

[5] Ghazavi, R., and Ebrahimi, Z. 2015. Assessing Groundwater Vulnerability to Contamination in An Arid Environment Using DRASTIC and GOD Models. *International Journal Enviro Science Technology*. 12, 2909-2918.

[6] Devy, Shalaho D., Hendrayana, Heru., and Putra, Dony P.E. 2014. Pemodelan Air Tanah Daerah Penambangan Batubara Pit Terbuka di Muara Lawa, Kabupaten Kutai Barat, Kalimantan Timur. *Prosiding Seminar Nasional Kebumian Ke-7*. Jurusan Teknik Geologi Universitas Gajah Mada.

[7] Stigter, T.Y., Ribeiro, L., and Dill, A.M.M.C. 2005. Evaluation of an Intrinsic and a Specific Vulnerability Assessment Method in Comparison with Groundwater Salinisation and Nitrate Contamination Levels in Two Agricultural Regions in the South of Portugal. *Hydrogeology Journal*, 14, 79-99.

[8] Kusuma, K.I. 2009. Studi Kerentanan Air Tanah Menggunakan Metode DRASTIC di Urban Area Kota Semarang. Universitas Diponegoro.

[9] Gogu, Radu C., and Dassargues, Alain. 2000. Current Trends and Future Challenges in Groundwater Vulnerability Assessment Using Overlay and Index Methods. *Environmental Geology*. 39,6.

[10] Mendoza, J. A., and Barmen, G. 2006. Assessment of Groundwater Vulnerability in the Rion Artiguanas Basin, Nicaragua. *Enviro Geology*, 50, 569-580.

[11] Sucayahyo, Agus P. A., and Bargawa, Waterman S. 2018. Utilization Plan of Underground River in Dry Area. *Journal of Environmental Science and Engineering B*. 7, 11-17.

[12] Harter, Thomas. 2001. Assessing Vulnerability of Groundwater, California. *Department of Land and Water Resources, University of California at Davis*.

[13] Ighbal J, Gorai A.K., Katpatal YB., and Pathak G. 2014. Development of GIS-Based Fuzzy Pattern Recognition Model (Modified DRASTIC Model) For Groundwater Vulnerability to Pollution Assessment. *Int J Environ Sci Technology*.
[14] Minville, M., Krau, S., Brissette, F., and Leconte, R. 2010. Behaviour and Performance of a Water Resource System in Quebec (Canada) Under Adapted Operating Policies in a Climate Change Context. *Water Resour Manag*, 24, 1333–1352.

[15] Oiste A.M. 2014. Groundwater Quality Assessment in Urban Environment. *Int J Environ Sci Technol*, 11(7), 2095–2102.

[16] Farjad, B., Shafri, H.Z., Mohamed, T.A., Pirasteh, S., and Wijesekara, N. 2012. Groundwater Intrinsic Vulnerability and Risk Mapping. *Water Manag*, 165, 441–450.

[17] Kruseman, G.P., and de Ridder., N.A. 2000. Analysis and Evaluation of Pumping Test Data, Second Edition. *International Institute for Land Reclamation and Improvement*, The Netherlands.

[18] Widyastuti, M., Notosiswoyo, S., and Anggayana, K. 2006. Pengembangan Metode DRASTIC Untuk Prediksi Kerentanan Air Tanah Terhadap Pencemaran di Sleman. *Majalah Geografi Indonesia*, 20 (1), 33 – 51.

[19] Foster, S., Hirata, R., Gomes, D., D’Elia, M., and Paris, M. 2007. Groundwater Quality Protection, 2nd printing. Washington, D.C.: *The World Bank*. ISBN 0-8213-4951-1.

[20] Abdelmadjid, B. and Omar, S. 2013. Assessment of Groundwater Pollution by Nitrates Using Intrinsic Vulnerability Methods: A Case Study of The Nil Valley Groundwater (Jijel, North-East Algeria). *African Journal of Environmental Science and Technology*, 7(10), 949-960.