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Assessment of Groundwater Vulnerability and Total Organic Carbon in the Shallow Groundwater of Wonosari City, Gunung Kidul, Yogyakarta, Indonesia

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ABSTRACT. Wonosari city is the capital of Gunung Kidul regency of Yogyakarta Special Province. The city is located on the karst plateau overlaying a succession of limestone lithologies. The groundwater in this city is shallow, and people use this groundwater as their daily water supply. This study aims to determine the intrinsic groundwater vulnerability, identify the TOC level in groundwater, and investigate the relationship between groundwater vulnerability and TOC levels in the groundwater. Field observation was conducted on 40 groundwater occurrences (dug wells, bore wells, and springs) to investigate the aquifer types, overlying lithology, and depth to groundwater. At the same time, 16 groundwater samples were taken from the dug wells and analyzed for the TOC content. Secondary data was also collected from previous research, especially sub-surface lithology information. Groundwater vulnerability was evaluated using the GOD method. The correlation between groundwater vulnerability and TOC in groundwater was analyzed spatially and statistically using map pverlaying, linear regression, and Spearman's rho test. The results showed that the groundwater vulnerability in the city is dominated by extreme and high vulnerability, covering about 84 % of the study area. The TOC level in the groundwater ranges between 4.532 mg/L to 6.849 mg/L, showing a pollution loading process may occur. Linear regression and Spearman's rho value show that the TOC levels and groundwater vulnerability have a moderate positive correlation with an r^2 value of about 0.324 for linear regression. Despite the moderate correlation, the research proved that the groundwater vulnerability map in this study is good enough to represent the ability of the natural process to protect the groundwater quality.

Keywords: Groundwater vulnerability · GOD · TOC · Wonosari.

1 INTRODUCTION

Wonosari City is located on a karst plateau and is composed of limestone supported by relatively shallow groundwater (MacDonald & Partners, 1984). Currently, the development of Wonosari City is very rapid. It is supported by many tourist areas that attract people outside the community to visit business land and build residential places. Seeing the rapid population growth and development in Wonosari, Gunungkidul Regency, generally using on-site sanitation facilities can increase the potential for groundwater contamination (ARGOSS, 2001).

The actual groundwater pollution in an area is an interaction between the amount of pollutant load (pollutant source) and groundwater vulnerability (Putra, 2007). Groundwater vulnerability measures how easy or difficult it is

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for a pollutant or contaminant on the groundwater to reach an aquifer, also known as the "degree of protection" provided by natural and artificial factors (Harter and Walker, 2001). The groundwater vulnerability is high if nature offers low protection to protect the groundwater from activities on the ground surface contaminating groundwater. Vice versa, groundwater vulnerability is low if natural factors can provide good protection for groundwater.

Vrba and Zaporozec (1994) mentioned two types of groundwater vulnerability which are; (1) intrinsic groundwater vulnerability and (2) specific groundwater vulnerability. Intrinsic groundwater vulnerability is determined based on the natural geology and hydrogeology factors, such as the characteristics of the aquifer and the soil and rocks above it. On the other side, specific groundwater vulnerability is determined based on geology and hydrogeology factors and other factors such as the type of pollutant or pollutant source. One of the simplest intrinsic groundwater vulnerability methods is the GOD method. The method used three main factors to determine groundwater vulnerability: Groundwater confinement, Overlying strata, and Depth to groundwater, introduced by Foster *et al.* (2002). In order to verify the result of groundwater vulnerability maps, validation is needed. Verification can be done in several ways. One of the most common ways is by comparing the vulnerability maps with the actual presence of contaminants in groundwater. Pavlis and Cummins (2014) showed that Total organic carbon (TOC) has a significant relationship with the groundwater vulnerability in the Karst area. In addition, Mudarra *et al.* (2014) proved that TOC could show the Karst area's infiltration process and hydrogeological function. Moreover, organic content is also one of the parameters of clean water standards in Indonesia (Permenkes RI No. 32, 2017).

Related to groundwater vulnerability, previous research showed that the class of regional groundwater vulnerability to pollution in the Gunung Kidul Regency area varied from high to very high (Khodira, 2019), while research from Widiastuti and Widyastuti (2012) and Sanusi (2017) showed that in this region groundwater vulnerability is categorized as low – medium vulnerability. Based on the above facts, this study aims to determine the vulnerability of groundwater in Wonosari City and validate the vulnerability map with the TOC levels in groundwater. It is hoped that the map of groundwater vulnerability in this area can reveal the exact groundwater vulnerability in this area and may be adopted for the regional planning of the city, as the increasing rapid urbanization in this area protects the groundwater resources.

2 STUDY AREA

The study area of Wonosari city, Gunung Kidul Regency, Special Province of Yogyakarta, Indonesia, is shown in Figure 1. The study area covered approximately 75.51 km^2 and was bounded by the Playen sub-district on the west side, the Karangmojo sub-district on the east, and the Tanjungsari sub-district on the south.

The study area is included in the Surakarta geological maps (Surono *et al.*, 1992). The geological maps show that the study area belongs to the Wonosari Formation (Tmwl), which is generally composed of reef limestone, calcarenite, and tuffaceous calcarenite). This formation is well exposed in the Wonosari area, and its surroundings and calcarenite rocks dominate the central part of the Wonosari Formation (Hartono and Bronto, 2007). The thickness of this formation is more than 800 m (Surono *et al.*, 1992). According to the Hydrogeological Map of Yogyakarta (Djaeni, 1982), the Wonosari city area is located in the productive groundwater zone in which groundwater flows through fissures and inter-grain spaces, and the groundwater table is relatively shallow.

3 RESEARCH METHOD

In order to answer the objectives of the research, the study was conducted as described below. Field observation was conducted to collect primary data in the field. About 40 observation points have been surveyed to measure groundwater depth, overlying lithology mapping, and Physico-chemical measurement of groundwater using the Hanna water test kit to measure pH, temperature, Total Dissolved Solid (TDS), and Electric Conductivity (EC) of water. About 16 water samples were taken from shallow dug wells (15) and springs (1) for TOC analysis in the GetIn-Cicero laboratory of the Geologi-

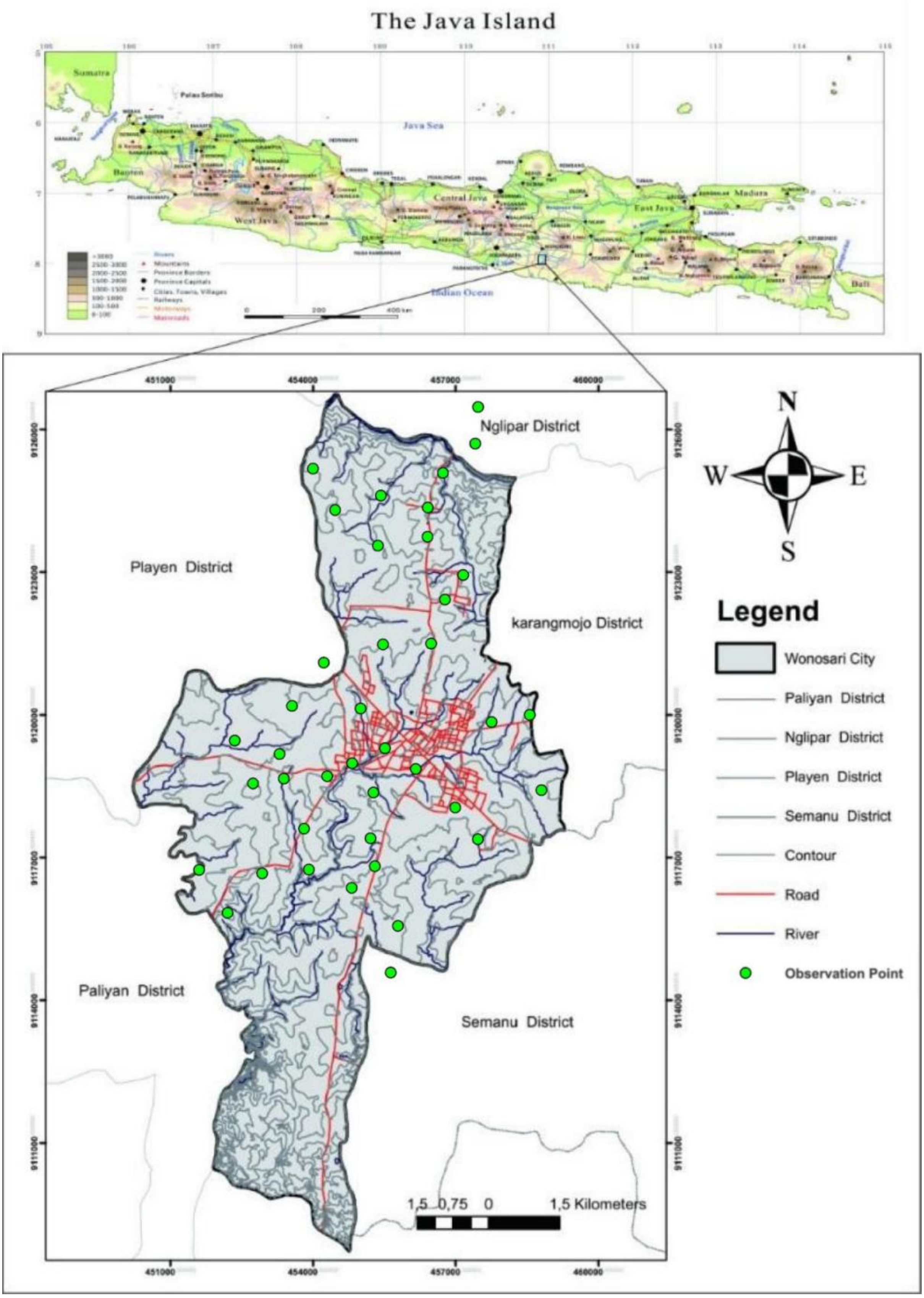

FIGURE 1. Location of the study area and the groundwater observation points (source of Java Island Map and Research Area Basemap: Badan Informasi Geospasial, 2017).

TABLE 1. The GOD index interval value and class (Foster *et al.*, 2002).

No.	Groundwater vulnerability	Index value
1	Very low	0 – 0.1
2	Low vulnerability	0.1 – 0.3
3	Moderate vulnerability	0.3 – 0.5
4	High vulnerability	0.5 – 0.7
5	Extreme vulnerability	0.7 – 1

cal Engineering Department, Universitas Gadjah Mada. All the samples were taken in a similar settlement area of land use conditions. The methodology of TOC sampling was based on the method described by Kaemfpner (2019), with addition. After groundwater samples are taken and collected using dark glass bottles, they are stored in an icebox to keep the samples below room temperatures. In addition, to understand the shallow aquifer system, about 16 sub-surface secondary data of bore-log data are collected from Setiawan and Asgaf (2016) and Sanusi (2017).

As mentioned in the background, the GOD method is used to map the groundwater vulnerability in this study. According to Foster *et al.* (2002), to calculate the GOD index, the calculation can easily be performed by multiplication of score from each parameter of GOD (groundwater confinement/aquifer types, overlying material, and depth to groundwater table) as shown in Figure 2. From Figure 2, it can be seen that the degree of confinement (G), whose value range from 0 to 1, can be classified into six classes. The lithological or overlying material (O) can range from 0.4 to 1. Finally, values between 0.6 and 1 can be assigned to the parameter D for depth to groundwater <5 m; 5–20 m; 20–50 m; >50 m and all depths. The vulnerability degree with GOD index value ranges between 0 to 1 and is divided into five vulnerability classes which can be seen in Table 1. GIS software is used to develop a map of parameters and overlay them to reveal the final groundwater vulnerability map.

The tool used to analyze the TOC content of the groundwater sample in this study was the Vario TOC Analyzer. This tool provides measurement results in TOC content in mg/l unit. The method of measurement was conducted according to Kampfner (2019). In order to validate the groundwater vulnerability map with the TOC value, spatial evaluation and parametric to non-parametric regression analysis are performed by using JASP open statistical software. Linear regression and a non-parametric method of Spearman's rho test were used to verify the relationship between TOC levels and GOD index values. This correlation assumes that land use condition in the sampling area was relatively similar.

4 RESULTS AND DISCUSSION

4.1 GOD Vulnerability Assessment

Groundwater Confinement (G)

The first parameter of GOD is the groundwater confinement or aquifer types. In order to determine the aquifer types, the cross-sectional sub-surface lithological condition was overlaid by the water table level, as shown in Figure 3. The cross-section of the stratigraphic sub-surface was developed based on data from Setiawan and Asgaf (2016) and Sanusi (2017). Figure 3 shows that the aquifer system in this area is developed by calcarenite's limestone aquifer. Based on this cross-section, the aquifer type in the study area can also be determined into three types; (1) semi-confined aquifer located in the center of Wonosari city as thick clay-limestone overlying the aquifer, (2) unconfined aquifer as the major aquifer system and (3) covered unconfined aquifer as a thin layer of gravely limestone and sandy limestone covering the aquifer. The map of the groundwater confinement parameter score is shown in Figure 4.

Overlying Lithology (O)

The second parameter of GOD is the overlying lithology or lithology above the water table. This parameter can be determined according to the lithology map in Figure 3. The overlying lithology found in the study area is clayey limestone, sandy limestone, gravelly limestone, calcarenite, and karst limestone. Based on Figure 2, the score of the parameter of overlying lithology is defined into two categories; (1) calcarenite limestone group and karst limestone group, as shown in Figure 4.

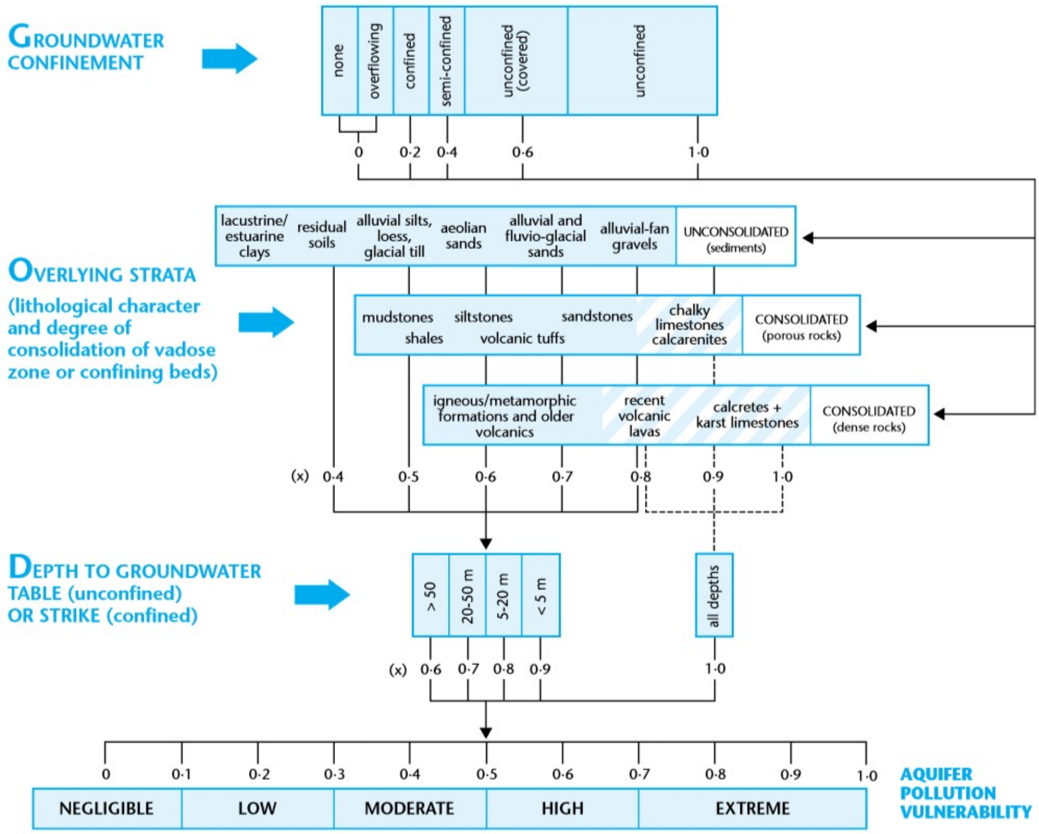

FIGURE 2. GOD method (Foster *et al.*, 2002).

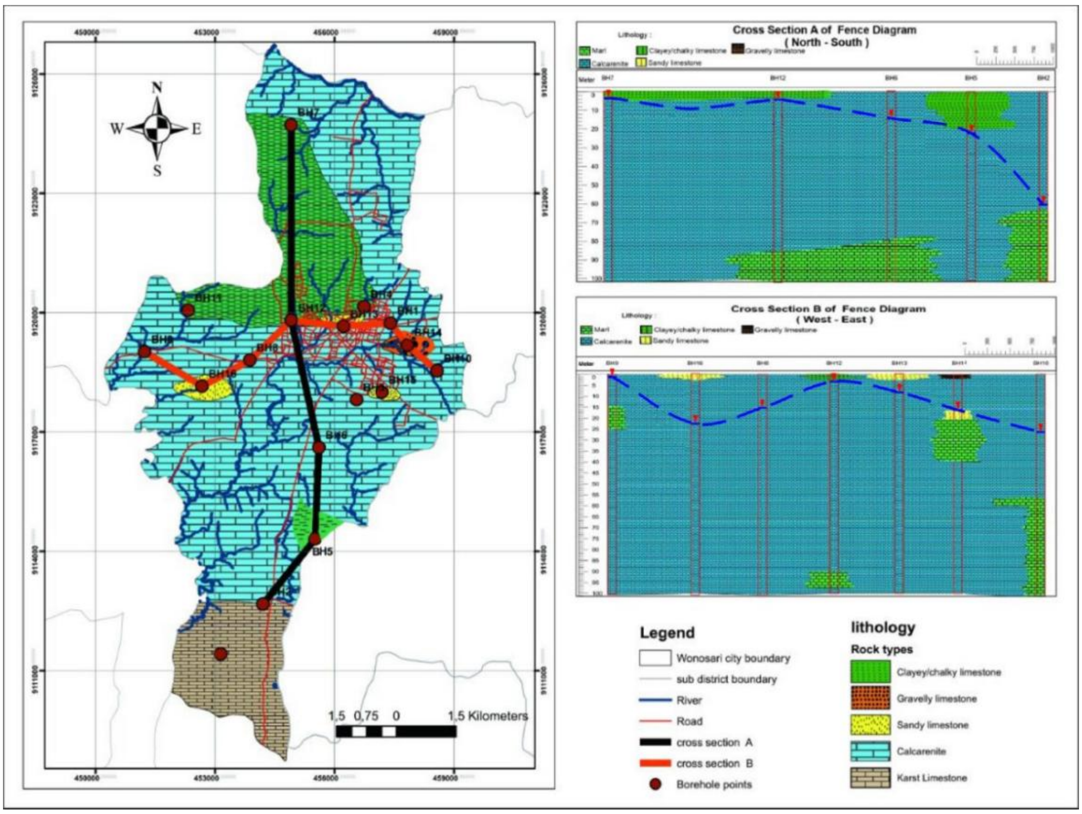

FIGURE 3. Surface and sub-surface lithology in the study area.

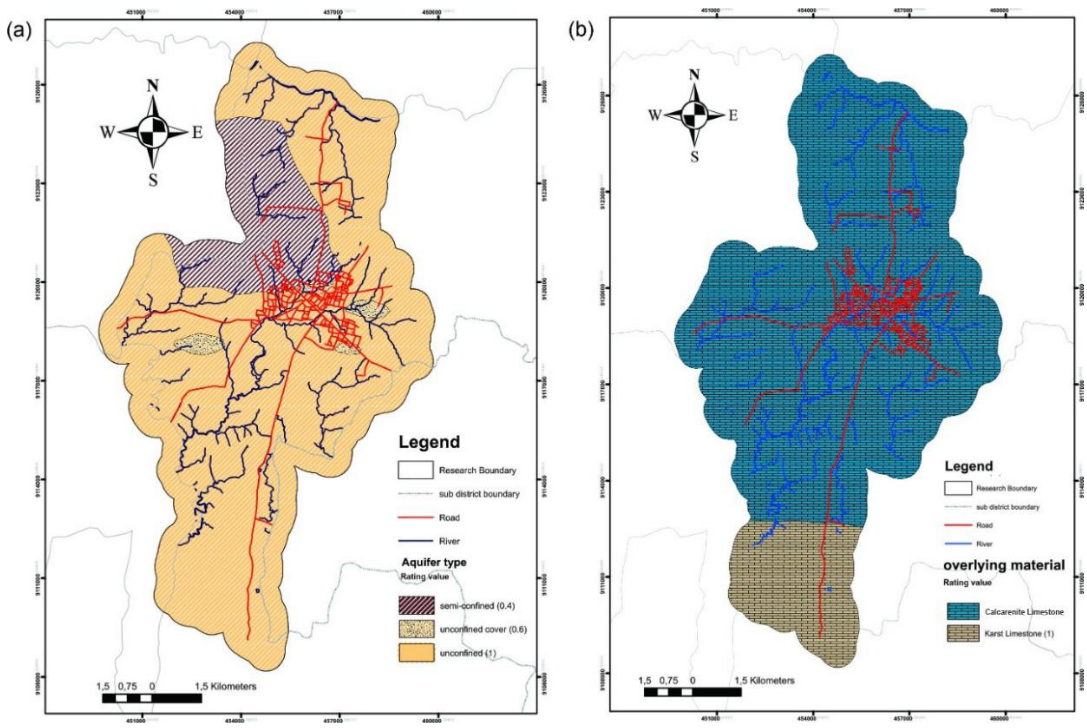

FIGURE 4. GOD score for (a) groundwater confinement and (b) overlying lithology in the study area.

Depth to Groundwater (D)

The third parameter of the GOD method is the groundwater depth. Based on the field observation result, the groundwater depth in the study area ranges from 0.3 to 26 m below the ground surface. The result of the depth to groundwater map, which was made according to the GOD classification, is shown in Figure 5. From Figure 5, the deepest water table was found in the southern region of the study area. In this southern area, dug wells are uncommon and local people use borewells to sub stract groundwater. Moving to the north from the southern-part area, the water table gradually changes to be more shallow. In the central study area, which is Wonosari city, the groundwater depth ranges from less than 5 to 20 m below the ground surface. According to the GOD method, the scores for depth to groundwater can be seen in Figure 5(a).

By overlaying the three maps of GOD parameters, the groundwater vulnerability map of the study area was built and shown in Figure 5(b). According to Figure 5(b), about 61 % of the study area classified as extreme vulnerability class, more or less 23 % fell into high vulnerability class, about 7 % moderate vulnerability, and only 9 % classified as low vulnerability area. The result of the groundwater vulnerability map is matched with the regional map of Khodira (2019) but is quite different from Widiastuti and Widyastuti (2012) and Sanusi (2017).

4.2 Total Organic Carbon in the Groundwater

TOC analysis on 16 groundwater samples showed that the TOC content ranged from 4.532 mg/L to 6.849 mg/L, with an average value of 5.526 mg/L. Compared to the Indonesian national standard of clean water (Permenkes RI No.32, 2017), the concentration is still below the maximum allowable concentration for clean water (<10 mg/L). However, this value is high compared to the normal reported concentration of TOC in the groundwater, which is only 0.7 mg/L (Eby, 2004) and Bradl (2005). When the presence of substance indicates that the groundwater exceeds the normal limit, it can be said that groundwater has been contaminated. As the surface and aquifer lithology are limestones rich in anorganic carbon, anthropogenic activities may become the source. Morris *et al.* (2003) has listed individual on-site sanitation system as one possible source of organic content in the groundwater.

The value and distribution of TOC content and GOD score on the sampling site are shown

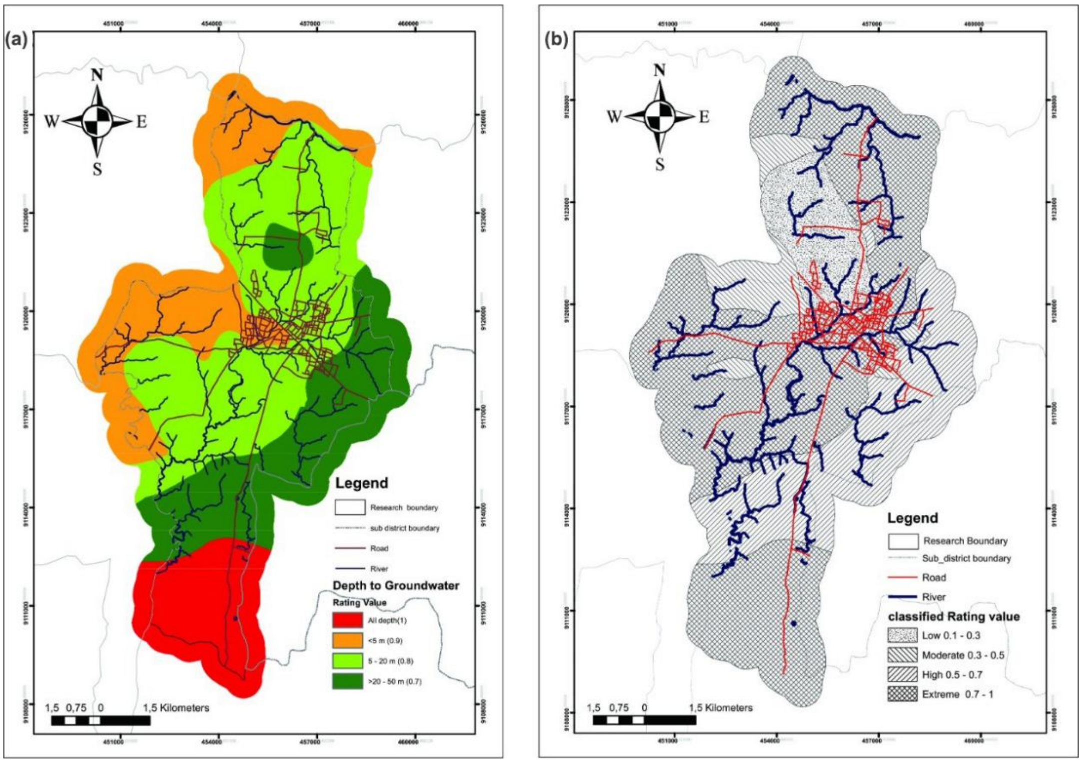

FIGURE 5. (a) GOD score of depth to groundwater parameter and (b) Groundwater vulnerability map based on GOD method in the study area.

in Table 2. Based on Table 2, a frequency histogram of the TOC value is made, and the diagram shows a normal data distribution (see Figure 6). Kolmogorov-Smirnov test to TOC and GOD data reveal p-value 0.826 and 0.105, respectively. This p-value shows that both data are normally distributed, although it is clear that TOC data have a strongly normal distribution compared to GOD data.

4.3 Validation of Groundwater Vulnerability Map

As mentioned in the background, it is necessary to conduct verification of the groundwater vulnerability map. The verification aims to prove whether the vulnerability map can show the degree of protection from the pollution events based on some indicator parameters. In this study, verification is conducted by spatially overlaying TOC value to the groundwater vulnerability map (see Figure 7) and findings the correlation statistically by using simple linear regression and Spearman's rho test. From Figure 7, we can see that most of the high TOC content is located in the extreme and high groundwater vulnerability areas. However, some high value of TOC is also found in the low-moderate vulnerability area and vice versa. Therefore, it is difficult to conclude if there is any relationship between those factors by only using overlaying spatial evaluation.

TABLE 2. The GOD index interval value and class (Foster *et al.*, 2002).

No.	Sample Code	TOC value	GOD value
1	SP#1	5.903	0.72
2	SW2	4.990	0.63
3	SW3	5.354	0.63
4	SW6	5.193	0.72
5	SW18	6.849	0.81
6	SW19	6.022	0.72
7	SW20	6.179	0.81
8	SW22	5.670	0.72
9	SW23	5.690	0.81
10	SW25	5.069	0.70
11	SW27	5.475	0.72
12	SW28	5.037	0.72
13	SW29	4.532	0.72
14	SW36	5.054	0.63
15	SW37	6.479	0.72
16	SW38	4.927	0.72

According to the Kolmogorov-Smirnov test, it was found that the data of TOC and GOD are

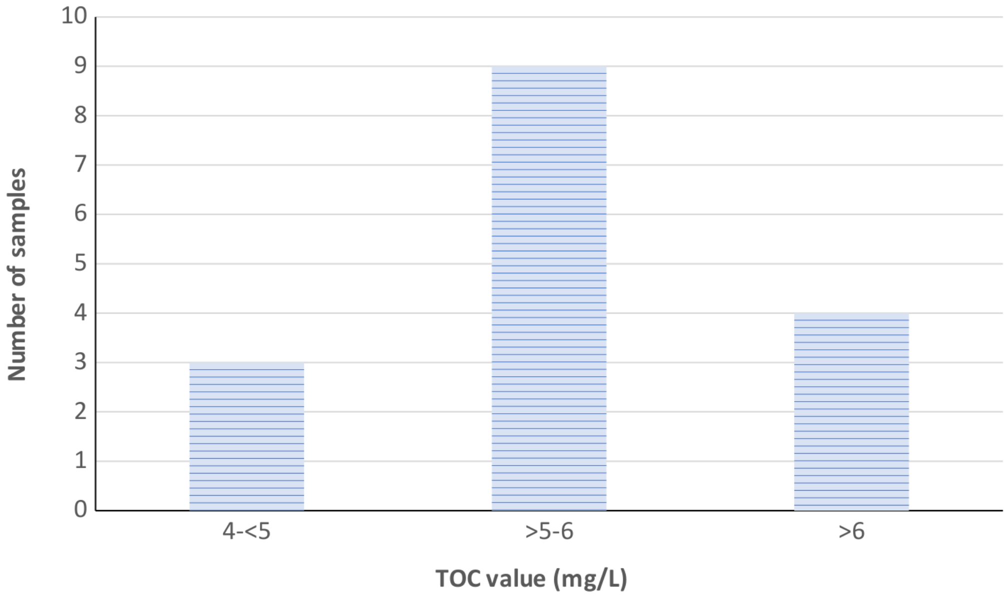

FIGURE 6. TOC value of groundwater in the study area.

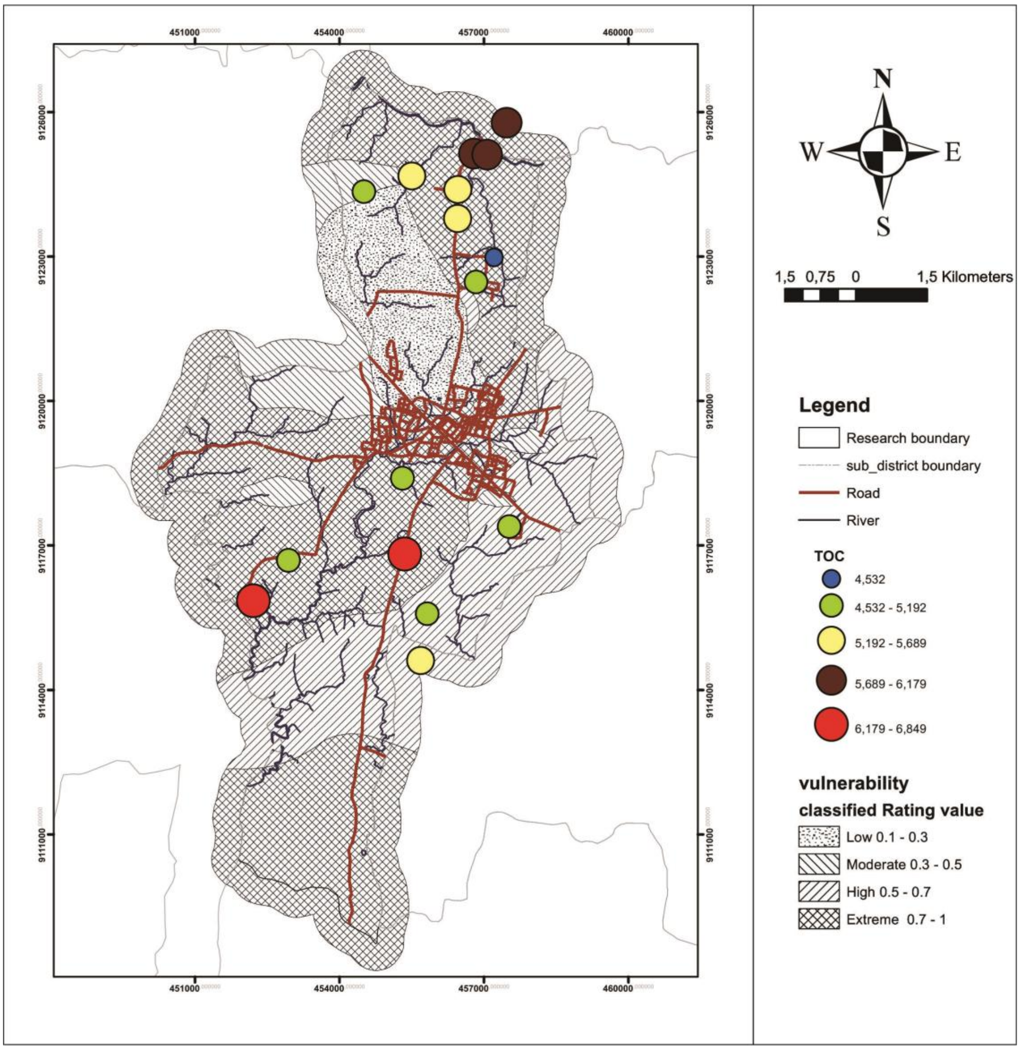

FIGURE 7. TOC value in groundwater versus GOD vulnerability class in the study area.

classified as standard distribution data. Therefore, a simple linear regression analysis can be done. Figure 8 shows the linear regression relationship between the TOC value and GOD score for the sampling site in this study. The graph shows a positive relationship between TOC value and GOD score. The linear regression has an R^2 value of only 0.324, which means the relationship is not strong but only has a moderate correlation. However, this positive correlation means that the TOC value will also be high when GOD scores high. A non-parametric test, which shows correlation using Spearman's method, also revealed the same result. Based on this method, Spearman's rho value is 0.561 with a p-value of 0.024. Although the relationship between TOC value and GOD score has revealed a moderate correlation, it is already proved that the intrinsic groundwater vulnerability map developed can represent the site's natural processes to protect the groundwater from pollution. However, one should bear in mind that in terms of pollutant or contaminant concentration, two aspects should be taken: groundwater vulnerability and the pollutant/contaminant loading (Morris *et al.*, 2003). This pollutant loading is called a lurking variable in terms of statistics. Therefore, an intrinsic vulnerability map alone can not be used to predict the pollutant/contaminant concentration in the groundwater.

5 Conclusion

Based on the result and discussion above, this research has achieved the stated objectives: to produce a map of groundwater vulnerability to pollution using the GOD method and successfully verify the reliability of the groundwater vulnerability map by using TOC levels in groundwater as a validation tool. The groundwater vulnerability to pollution in the study area is dominantly categorized as high to extreme. This study also indirectly proves that the GOD method is quite good for mapping groundwater vulnerability in areas composed of limestone, especially in plateau karst areas. In the study area, the concentration of TOC in groundwater is generally still below the clean water quality standard. However, the presence of TOC needs to be a concern as it may come from the household sanitation system, which is generally adjacent to the dug wells in this study area. The recent urbanization development in Wonosari will undoubtedly impact by increasing the pollution/contaminant load on groundwater in this region. It is hoped that this groundwater vulnerability map can be used as additional tools for regional planning and development in the capital city of Gunung Kidul district.

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References

ARGOS (2002). Assessing Risk to Groundwater from On-site Sanitation: Scientific Review and Case Studies. British Geological Survey Commissioned Report, England., 97p.

Badan Informasi Geospasial (BIG) (2017). *Informasi Geospasial Dasar*. https://tanahair.indonesia.go.id/

Bradl, H. B. (2005). Heavy Metals in the Environment. Volume 6, London, Elsevier. 282p.

Djaeni, A. (1982). *Peta Hidrogeologi Indonesia Lembar Yogyakarta, skala 1:250.000*. Direktorat Geologi Tata Lingkungan, Bandung

Eby, G. N. (2004). Principles of Environmental Geochemistry (K. Dodson, Ed.). The USA, Thomson Brooks/Cole, 511 p.

Foster, S., Hirata, R., Gomes, D., D'Elia, M., & Paris, M. (2002). Groundwater Quality Protection: A Guide for Water Utilities, Municipal Authorities, and Environment Agencies. The World Bank, Washington, D.C., 103p.

Harter, T., & Walker, L. G. (2001). Assessing Vulnerability of Groundwater. California Department of Health Services, Sacramento, CA, USA., Report 1–11.

Hartono, G., & Bronto, S. (2007). *Asal-usul pembentukan Gunung Batur di daerah Wediombo, Gunungkidul, Yogyakarta*. Jurnal Geologi Indonesia, Vol. 2 No. 3 September 2007, p.143 – 158.

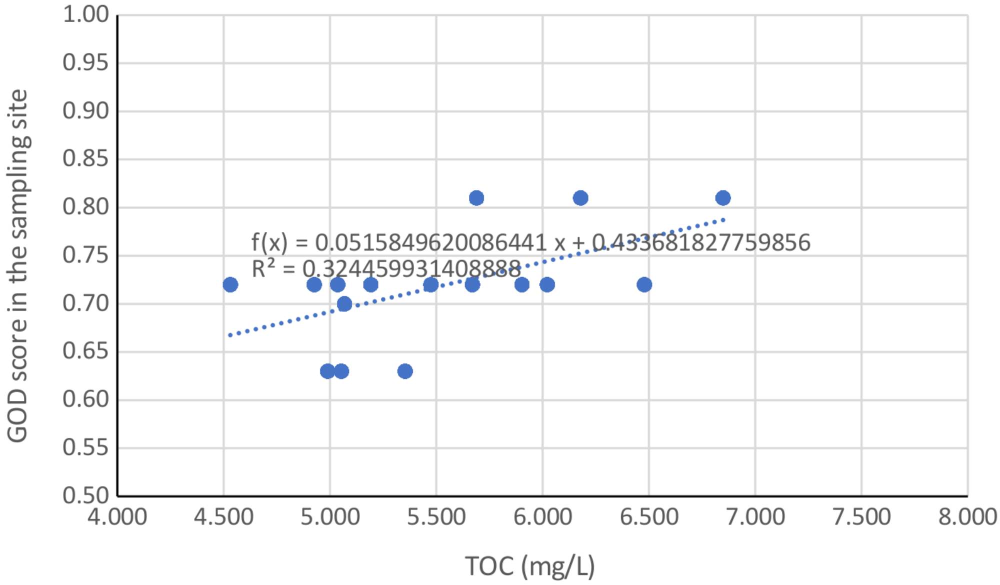

FIGURE 8. Relationship between TOC value in groundwater and GOD score in the sampling site.

Kaempfner, L. (2019). Redox State and Zonation of Groundwater In the City of Yogyakarta (Java, Indonesia), Thesis, Lehr- und Forschungsgebiet Hydrogeologie. Faculty of Georesources and Materials Engineering, RWTH Aachen and Universitas Gadjah Mada (Unpublished).

Khorida, P. A. (2019). *Pemetaan Kerentanan Air Tanah Regional Daerah Istimewa Yogyakarta*. Skripsi, Departemen Teknik Geologi, Fakultas Teknik, Universitas Gadjah Mada, (Unpublished).

MacDonald & Partners (1984). Greater Yogyakarta Groundwater Resources Study. Volume 3: Groundwater, Directorate General of Water Resources Development Project (P2AT), Ministry of Public Works, Government of The Republic of Indonesia, 116 p.

Morris, B. L., Lawrence, A. R., Chilton, P. J. C., Adams, B., Calow, R. C., & Klinck, B. A. (2003). Groundwater and its susceptibility to degradation: A global assessment of the problem and options for management. Early Warning and Assessment Report Series, RS.03-3. United Nations Environment Programme, Nairobi, Kenya.

Mudarra, M., Andreo, B., Barbera, J. A., & Mudry, J. (2014). Hydrochemical dynamics of TOC and NO3- contents as natural tracers of infiltration in karst aquifers. Environmental Earth Science Vol. 71, p. 507-523, Springer.

Permenkes RI No.32 (2017). *Tentang Standar Baku Mutu Kesehatan Lingkungan dan Persyaratan Kesehatan Air Untuk Keperluan Higiene Sanitasi, Kolam Renang, Solus Per Aqua, dan Pemandian Umum*. Kementrian Kesehatan Republik Indonesia.

Putra, D. P. E. (2007). The Impact of Urbanization on Groundwater Quality, A Case Study in Yogyakarta City–Indonesia, Mitteilungen zur Ingenieurgeologie und Hydrogeologie, Heft 96, Okt 2007, Herausgegeben vom Lehrstuhl fuer Ingenieurgeologie und Hydrogeologie, 148 p.

Sanusi, R. F., 2017, *Kerentanan Airtanah Terhadap Pencemaran di Kota Wonosari dan Sekitarnya Kabupaten Gunungkidul, Daerah Istimewa Yogyakarta*. Thesis, Departemen Teknik Geologi, Fakultas Teknik, Universitas Gadjah Mada (Unpublished).

Setiawan, T., & Asgaf, N. M. A. (2016). *Analisis Karakteristik Akuifer dan Zonasi Kuantitas Air Tanah di Dataran Kars Wonosari dan Sekitarnya, Kabupaten Gunungkidul, Provinsi Daerah Istimewa Yogyakarta*. Jurnal Lingkungan dan Bencana Geologi, 7(3), p. 155-167.

Surono, Toha, B., & Sudarno, I. (1992). *Peta Geologi Lembar Surakarta-Giritontro, Jawa*. Bandung, Pusat Penelitian dan Pengembangan Geologi.

Pavlis, M., & Cummins, E. (2014). Using Total Organic Carbon for The Assessment of Groundwater Vulnerability in Karst Regions at Regional Scales. Environmental Earth Science Vol. 72, Springer, p.1993-2007.

Vbra, J., & Zaporosec, A. (1994). Guidebook on Mapping Groundwater Vulnerability. International Association of Hydrogeologists (International Contributions to Hydrogeology 16). Verlag Heinz Heise, Hannover, 131p.