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Characteristics of Nitrate Pollution in Shallow Groundwater on the South Slope of Mount Merapi, Yogyakarta, Indonesia

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ABSTRACT

Groundwater is the primary clean water source for most Indonesian society. The increasing use of groundwater is inevitable due to the rapid development in Indonesia, particularly in Yogyakarta. Shallow aquifers are vulnerable to contamination due to anthropogenic influences. Therefore, this research aims to determine shallow groundwater's physicochemical and chemical characteristics on the southern slope of Mount Merapi, specifically focusing on nitrate and chloride concentrations in groundwater. This research collected monthly data from eighteen dug wells or springs and rainfall data in the study area during the rainy and dry seasons from August 2022 to January 2023. The analyzing sample used argentometry to determine chloride concentration and ultraviolet spectrophotometric to determine nitrate concentration in Yogyakarta Environmental Health and Disease Control Technical Center (BBTKLPP) laboratory. The physicochemical parameters were tested directly in the field using Hanna instruments. The results indicate that a significant portion of shallow groundwater has high nitrate concentrations, corresponding to the growing settlements in the research area. Furthermore, according to the comparison graph between nitrate and chloride, the nitrate source was indicated as anthropogenic. Fecal matter from sanitation practices using septic tanks will likely influence the nitrate increase.

Keywords: Mount Merapi, shallow groundwater, nitrate pollution, anthropogenic.

INTRODUCTION

Mount Merapi is located in Central Java Province (covering the Regencies of Magelang, Boyolali, and Klaten) and the Special Region of Yogyakarta (Sleman Regency). Rapid development and population growth have been occurring in the areas surrounding the southern slope of Mount Merapi. According to data from the Central Bureau of Statistics (BPS) in 2021 [1], several districts have relatively high population densities. For example, Depok District has a population density of 3691.76 people per square kilometer, Mlati District has a density of 3531.10 people per square kilometer, and Ngaglik District has a density of 2756.31 people per square kilometer. Rapid urbanization in Yogyakarta began in the early 1970s, accompanied by significant infrastructure and settlement development [2]–[4].

Groundwater on the southern slopes of Mount Merapi is prone to pollution. Based on the GOD method, the contamination occurs because of natural factors such as the type of aquifer, the constituent material of the aeration zone, the depth of groundwater level, and anthropogenic factors such as population density. These factors can facilitate interaction between natural and anthropogenic pollutant sources with the unconfined groundwater [5].

Due to the rapid development in Yogyakarta, there has been a substantial increase in groundwater usage in the Yogyakarta-Sleman groundwater basin. Based on Sustainable Development Goal (SDG) number 6, water availability and quality are crucial for human life and environmental sustainability [6]. Therefore, studies on the physical and chemical characteristics of groundwater are critical.

Location

The research was conducted on the southern slope of Mount Merapi, bounded by the Boyong River on the west side and the Kuning River on the east side, covering an area of approximately 77 km^2 and located in five districts of Sleman Regency (Figure 1).

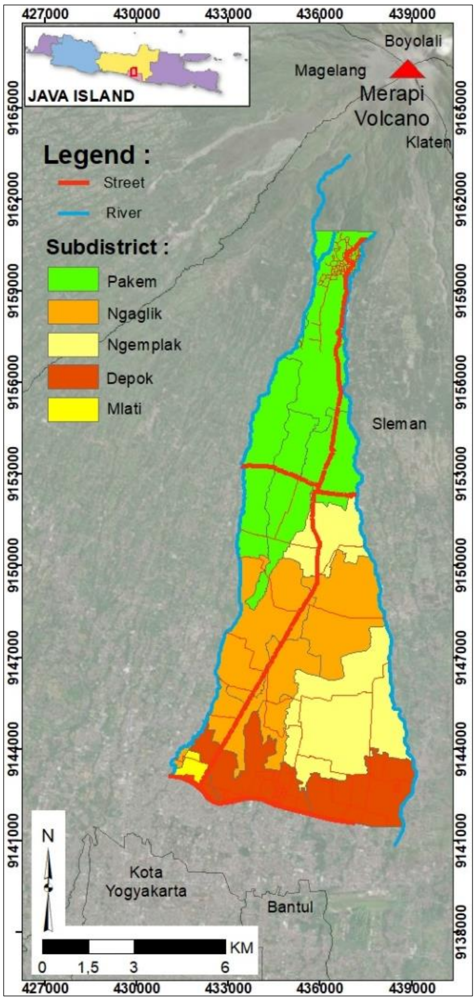

Figure 1. Research Location Map.

Geological Background

The study area has a relatively high topographic contour due to its location in the volcanic landscape of Mount Merapi. Based on the Digital Elevation Model (DEM) data (Figure 2), the topographic elevation in the research area ranges from 135 to 1,085 meters above sea level, with the highest elevation located in the northern part of the research area near the summit of Mount Merapi.

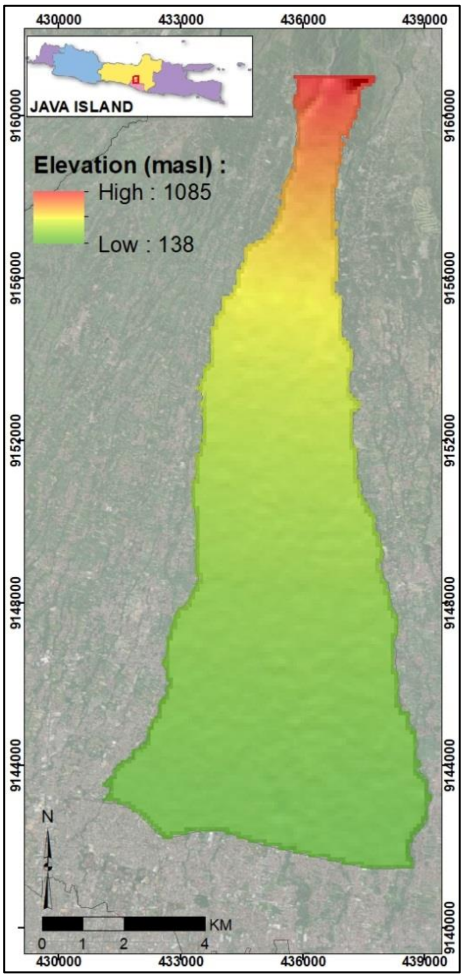

Figure 2. Topographic Map of the Research Location.

The underlying rocks in the research area belong to Old and Young Merapi volcanoes that consist of surficial deposits with young pyroclastic flow and avalanche deposits from young Merapi deposits, which are widely distributed in the southern part of the study area, in the northern part consist of old pyroclastic flow and lahar deposits with

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pyroxene andesite lava flows [7] (Figure 3). The rocks at the research location were formed through sedimentation processes and composed of fluvial-volcaniclastic products [8].

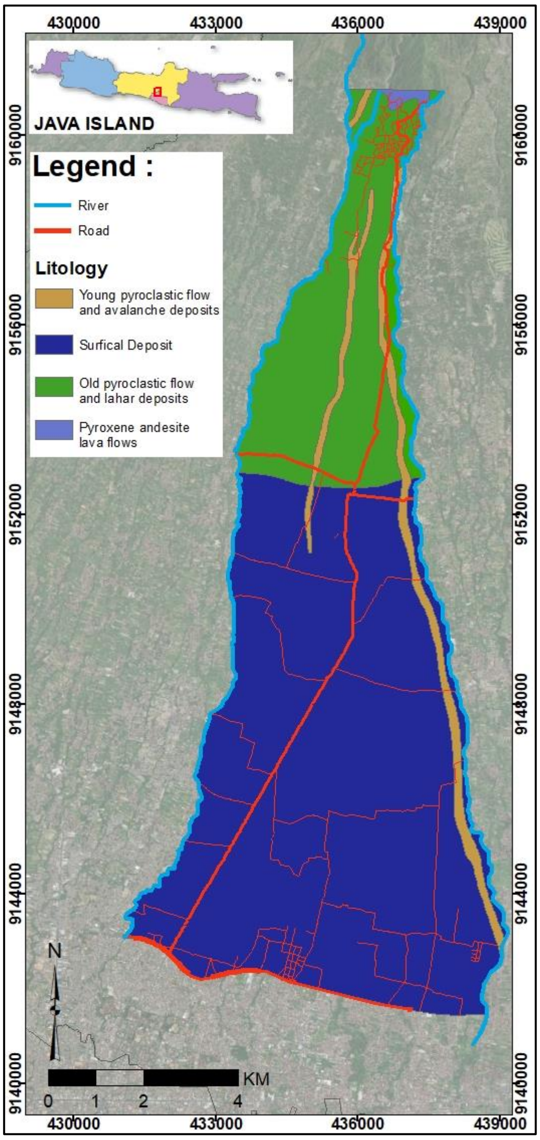

Figure 3. Geological map of the research location [7].

METHODOLOGY

The research was conducted by field observation and collecting eighteen groundwater data from dug wells or springs. Secondary data from nine rainfall stations were collected from Yogyakarta Meteorological Climatology Station (BMKG) to know the influence of rainfall on groundwater (Figure 4). The groundwater and rainfall data were observed from August 2022 until January 2023 to represent data from the rainy and dry seasons. After that, physicochemical parameters of groundwater, such as pH, total dissolved solids (TDS), and electrical conductivity (EC), were tested directly in the field using Hanna instruments. The laboratory analysis of this research uses argentometry to determine chloride concentration and ultraviolet spectrophotometric to determine nitrate concentration in Yogyakarta Environmental Health and Disease Control Technical Center (BBTKLPP) laboratory.

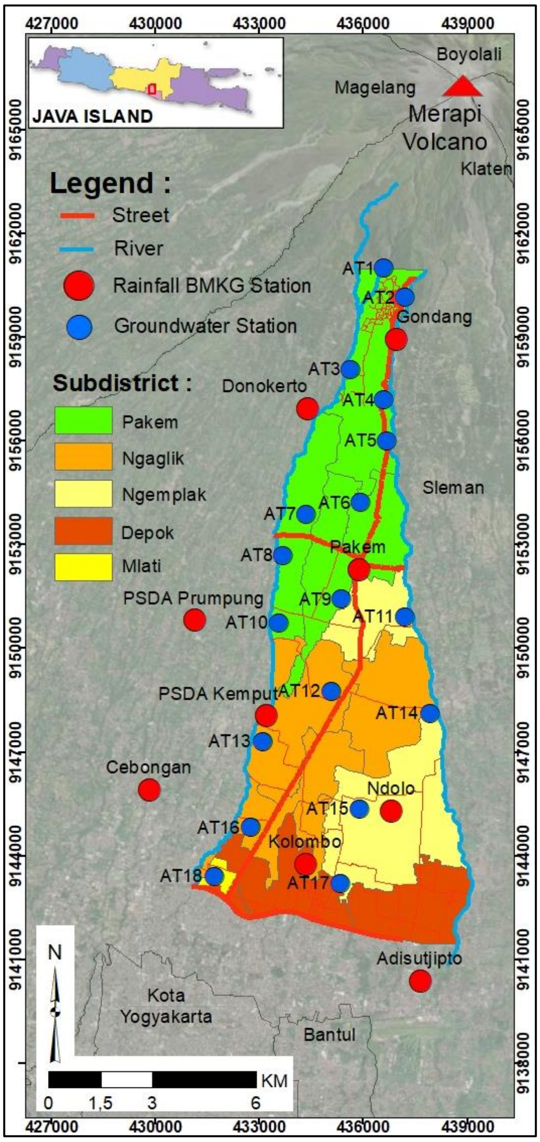

Figure 4. Groundwater and rainfall stations of the research location.

RESULTS AND DISCUSSION

The rainfall data were based on the monthly average rainfall data from the Yogyakarta BMKG observation stations. The highest value was recorded in October 2022, with a rainfall of 543.77 mm/month, while the lowest was in August 2022, with a rainfall of 89.57 mm/month. In general, the rainfall in August and September 2022 was relatively low, below 100 mm/month, whereas from October 2022 to January 2023, the rainfall was relatively high, above 250 mm/month (Figure 5).

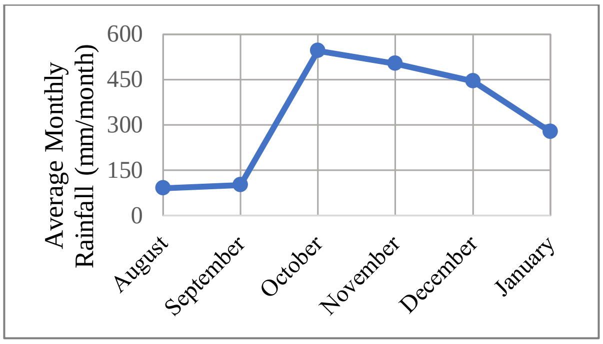

Figure 5.Graph of monthly average rainfall.

Furthermore, the pH values of groundwater showed an average value of 6.67, with the highest value recorded in August 2022 at 6.72, while the lowest value was in November 2022 at 6.64 (Figure 6). Regarding the total dissolved solids (TDS) parameter at the research site, the average value was found to be 117.19 mg/L, with the highest value occurring in December 2022 at 122.78 mg/L, while the lowest value was in August 2022 at 114.38 mg/L (Figure 7). Moving on to the electrical conductivity (EC) parameter, the average value was 237.56 µS/cm, with the highest value observed in December 2022 at 245 µS/cm, while the lowest value was in August 2022 at 233.75 µS/cm (Figure 8).

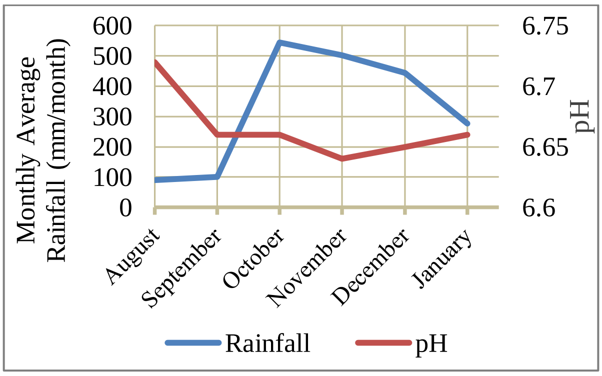

Figure 6.Graph of average pH vs. monthly rainfall.

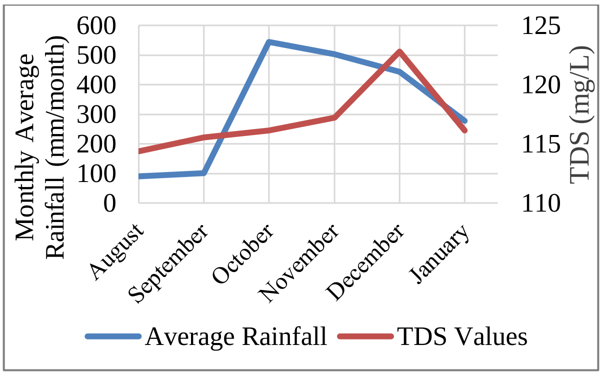

Figure 7. Graph of average TDS vs. monthly rainfall.

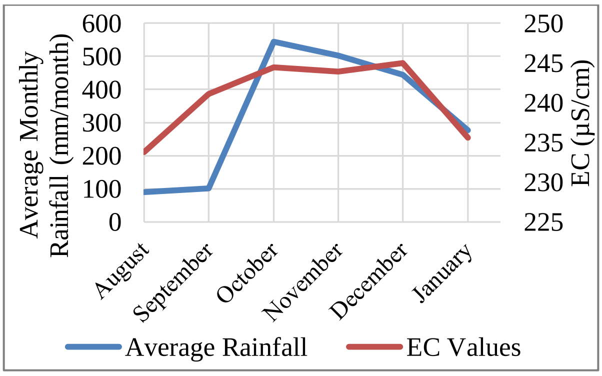

Figure 8. Graph of average EC vs. monthly rainfall.

The average value of nitrate ion measurements in the groundwater was 21.8 mg/L, with the highest average recorded in November 2022 at 24.64 mg/L, while the lowest value was in August 2022 at 15.35 mg/L (Figure 9). Regarding the chloride parameter at the research site, the average concentration of chloride ions was found to be 8.015 mg/L, with the highest average value occurring in December 2022 at 8.75 mg/L, while the lowest value was in August

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at 7.06 mg/L (Figure 10). A pattern of increasing chloride and nitrate ion values corresponds to increased rainfall at the research site. In August, with the lowest rainfall, chloride and nitrate values were the lowest compared to other months. Generally, areas with higher elevations tend to have lower chloride and nitrate values than those with lower elevations.

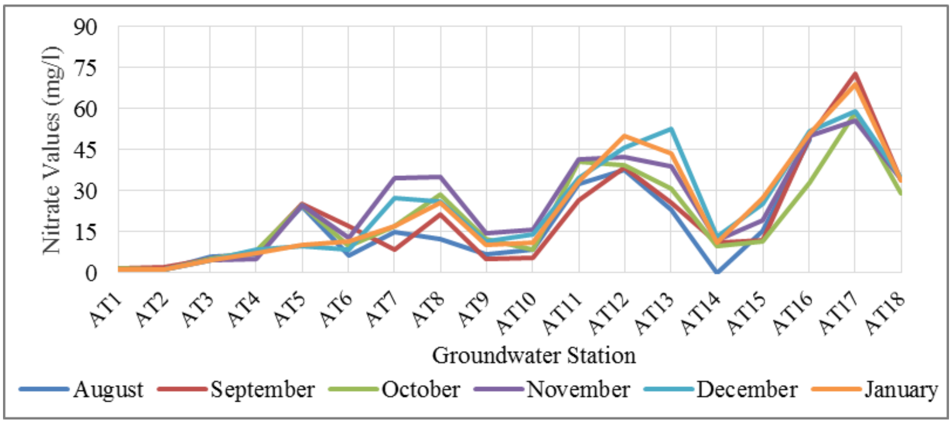

Figure 9. Graph of variations in nitrate values in the study area.

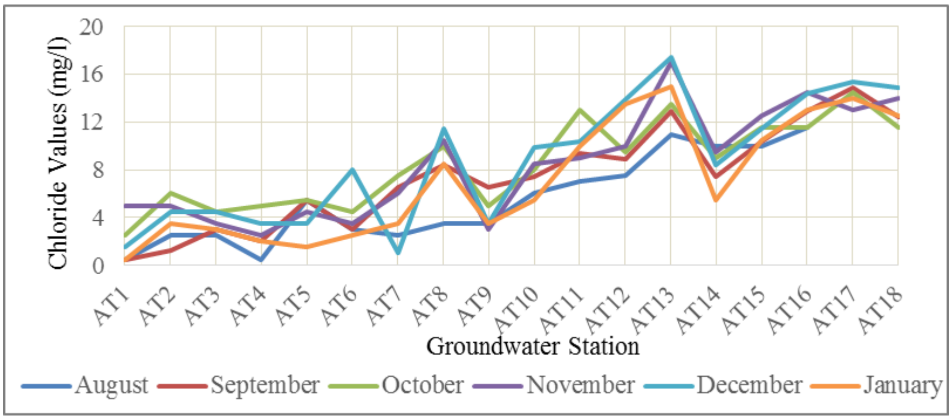

Figure 10. Graph of variations in chloride values in the study area.

Characteristics of Groundwater Chemical Physical Properties

In the characteristics of the physical and chemical properties of groundwater at the research site, there is a general correlation with the level of rainfall. Regarding the pH parameter, values change with increasing rainfall, where higher rainfall decreases the pH value. The decrease in pH value due to increased rainfall is likely caused by the occurrence of acid rain at the research site. Acid rain is caused by pollutants such as Nitrogen Oxides (NOx) and Sulfur Dioxide (SO_2) present in the atmosphere, which interact with moisture in the air to form acid rain [9]. The acidic content of the rainwater is then carried into the groundwater, resulting in a decrease in pH value at the research site (Figure 4).

Then, the value of TDS and EC in the study area indicated an influence on the rainfall. The existence of high rainfall causes more ions to dissolve in groundwater from the soil or aquifers. The TDS and EC values accumulated in December 2022 when dissolved ions increased. So the relationship between rainfall and TDS/EC values is positive.

Characteristics of Groundwater Chemical Properties

The characteristics of groundwater chemistry at the research site are generally related to the presence of chloride and nitrate ions and their correlation with rainfall. In the case of chloride ions, there is an increase in concentration with the increase in rainfall until November 2022, followed by the decrease of chloride ions in December 2022 and January 2023 as the rainfall decreases. Based on the analysis, the increase in chloride and nitrate ion concentrations is likely due to the leaching of these ions during the rainy season. The large volume of rainfall leads to the leaching of chloride and nitrate ions into the shallow aquifer layer, increasing their concentrations in the groundwater.

In general, the characteristics of shallow groundwater on the southern slopes of Mount Merapi are young groundwater because it is dominated by bicarbonate ions [9], and the groundwater facies are dominated by Ca^{2+}-Na^{+}-HCO_3-type [10]. These facies are related to the shallow aquifer system of the Merapi Aquifer System that is affected by local rainwater [11], so the influence of rainwater is relatively high on the chemistry of groundwater in the study area.

The Ratio of Nitrate Ions to Chloride Ions

The nitrate and chloride ratio graph can be used to determine the origin of nitrate in groundwater. According to [12],[13], if the nitrate-to-chloride ratio ranges from 1:1 to 8:1, it may indicate that the nitrate source is from feces or manure [12]. The nitrate and chloride ratio graph can be seen in Figure 11. In the groundwater samples in the research area, there were three samples with a nitrate-to-chloride ratio of 1:20 to 1:1, three samples with a ratio of 1:1 to 2:1, six samples with a ratio of 2:1 to 3:1, two samples with a ratio of 3:1 to 4:1, and four samples with a ratio of 4:1 to 5:1. In the Yogyakarta-Sleman area, groundwater with a ratio above 1:20 already indicates that the nitrate content originates from feces or manure [14]. The increasing nitrate values are likely due to the rising source of nitrate from anthropogenic activities and characteristics of nitrate ions that can move quickly and not easily undergo retardation and degradation processes.

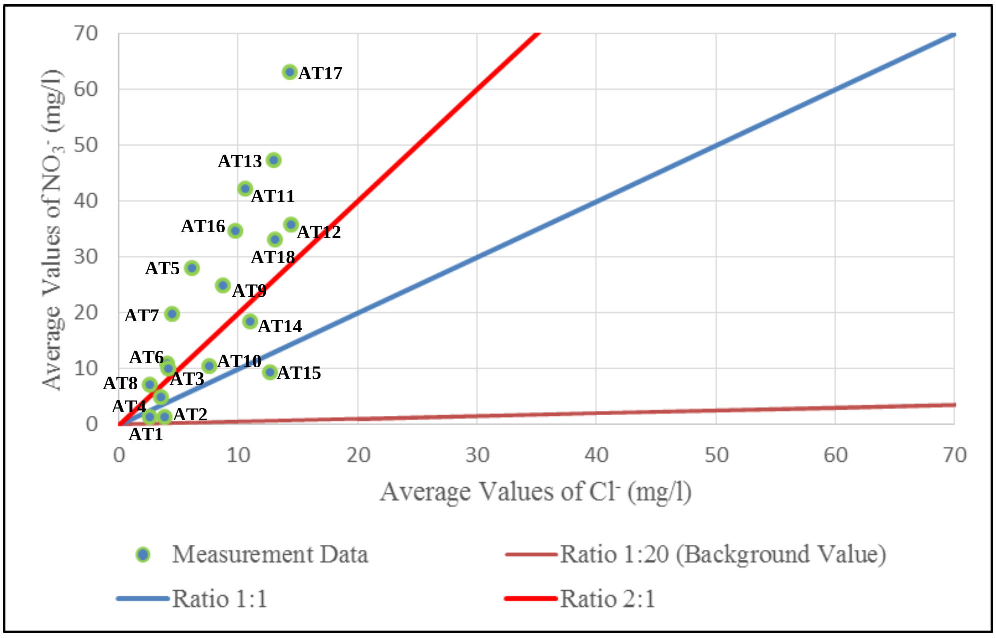

Figure 11. Graph of the ratio between nitrate and chloride in the study area.

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Distribution of Nitrate Pollution

Interpolation of nitrate values was conducted to determine the distribution of nitrate pollution in the research area using the inverse distance squared method (Figure 12). The nitrate interpolation map shows that the area around the North Ringroad has the highest nitrate levels, especially in sample AT17, which has an average nitrate value of 63.026 mg/L. Similarly, the area around Kaliurang Road exhibits significant pollution levels, as seen in samples AT12, AT16, and AT18. Locations with high nitrate ion content also correlate with relatively low rainfall compared to surrounding areas, resulting in the accumulation and concentration of nitrate ions in those areas. Otherwise, the northern part of the research site tends to have lower nitrate values. Variation in nitrate values is strongly influenced by nitrate input from feces or manure, with nitrate levels increasing as the population and settlements increase, accumulating contaminated nitrate content in the groundwater [13],[15].

The World Health Organization (WHO) has set a maximum limit for nitrate in drinking water at 50 mg/L [16]. In addition, the regulation in Indonesia sets the maximum permissible nitrate level at 50 mg/L [17]. Based on the chemical parameters, if the water from a dug well-containing nitrate levels above the threshold limits of 50 mg/L consumed by people around the well, then it is risky to interfere with the digestive system, causing diarrhea mixed with blood, convulsions, to the risk of death if not soon get help, chronic poisoning due to consuming water containing nitrates high ones lead to general depression, pain headaches and mental disorders [18]. Clean water needs according to provisions for household needs and drinking water is necessary.

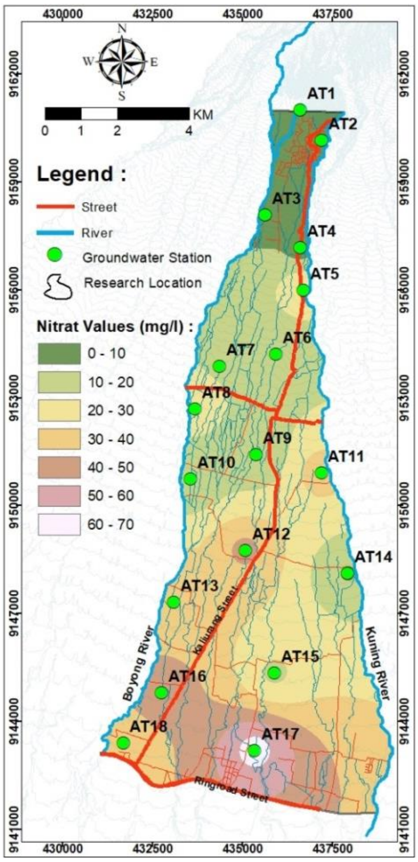

Figure 12. Interpolation map of nitrate values in the study area.

CONCLUSION

Water availability and quality need special attention to meet the aspects of sustainable development according to the Sustainable Development Goals (SDGs). The TDS and EC values have an increasing trend with increasing rainfall but are negatively correlated with the pH value in the study area. The increase in rainfall is also positively correlated with the rise in chloride and nitrate concentration. Nitrate pollution occurs in areas along the northern Ringroad Road and southern Kaliurang Road with concentrations above 50 mg/L. The ratio of nitrate to chloride indicates that the source of nitrate contamination comes from anthropogenic such as septic tanks due to the increased population and inappropriate sanitation systems. Therefore, wastewater management in the community needs to improve.

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