ГЛАСНИК Српског географског друштва 106(1) 403-424
BULLETIN OF THE SERBIAN GEOGRAPHICAL SOCIETY 2026

Original scientific paper
UDC 556:616-036.21(282)(594)
https://doi.org/10.2298/GSGD2601403P

Received: August 04, 2025
Corrected: October 23, 2025
Accepted: March 12, 2026

Suhadi Purwantara*, Arif Ashari[1]*, Mukminan Mukminan*

**Department of Geography Education, Universitas Negeri Yogyakarta, Yogyakarta, Indonesia*

SPATIO-TEMPORAL VARIABILITY OF RIVER WATER QUALITY OF COVID-19: A CASE STUDY OF OPAK AND PROGO WATERSHEDS (INDONESIA)

Abstract: The imposition of community activities due to the COVID-19 outbreak positively impacted the environmental quality in various countries, including improving river water quality. This paper examines the spatio-temporal variation of water quality of the Opak and Progo Watersheds after the second wave of COVID-19. This study utilized primary and secondary data obtained from observation, literature study, and data documented by several agencies. Data were analyzed statistically employing an independent sample t-test and simple linear regression, matching, pollution index calculation, and Geographic Information System (GIS) analysis using Average Nearest Neighbor (ANN). The results show that restrictions on community activities that have been repeatedly implemented during the pandemic have improved water quality. However, quality improvement is only found in a few parameters. Heavy metals from transportation, Pb and Cd, tend to be low and decline during pandemics. Pb decreased from 0.2 ppm in 2020 to 0.1 ppm in 2021, while Cd decreased from 0.0033 ppm in 2020 to 0.0008 ppm in 2021. TDS and TSS were smaller during the pandemic due to reduced erosion of farmland. The downward trend in TDS and TSS also impacted the decline in BOD. After the pandemic, most water quality parameters met the national quality standards. Good water quality parameters are dispersed in the study area. This condition indicates the spatial homogeneity of water quality in both watersheds, without pollution zones, even in the megacity of Yogyakarta. In summary, this study presents new insights into understanding the impact of the COVID-19 pandemic on river water quality in watersheds characterized by the dominance of population activities in rural areas.

Keywords: COVID-19 pandemic, spatio-temporal variability, Opak and Progo, watershed, Indonesia

Introduction

Rivers are one of the vital water resources for human life. The number of river water resources is relatively small compared to other freshwater sources (Arbogast, 2011), but they

---

1 arif.ashari@uny.ac.id (corresponding author)
Suhadi Purwantara (https://orcid.org/0000-0001-9953-2215)
Arif Ashari (https://orcid.org/0000-0003-2028-6125)
Mukminan Mukminan (https://orcid.org/0000-0003-1140-7423)

offer ease of accessibility. A significant problem related to the utilization of river water resources deals with water quality, which is not always good. Pollutants entering and spreading in-stream discharges from natural and anthropogenic sources require much attention (Davie, 2008). River pollution causes low water quality. Recent studies conducted by various countries, including China (Li et al., 2021), India (Pandey & Singh, 2017; Shah & Parveen, 2021), and Bangladesh (Uddin & Jeong, 2021), shows that river pollution occurs a lot in urban and agricultural areas. This pollution has lowered the environment and public health quality. Also, polluted river water limits the utilization options. In Indonesia, river water utilization must consider the river water quality criteria as regulated in the Government Regulation of the Republic of Indonesia Number 22 of 2021 (locally known as PPRI No. 22 of 2021). In this regulation, the best-level-water resources will possibly be used for many purposes. The lower class of water quality encourage limited utilization options.

The COVID-19 outbreak, since the WHO declared it as a pandemic on March 11, 2020, has offered a profound impact on many aspects of life, including the environment (Chaudhry et al., 2020; Giuliani et al., 2020; Islam et al., 2021; Parry & Gordon, 2021). This epidemic rapidly spread to various countries, starting from the mainland of China from January 16 to February 6, 2020, (Kang et al., 2020), following its first appearance in Wuhan in December 2019 (Kim & Castro, 2020; Santos, 2020). The COVID-19 pandemic, which had a terrible impact on health, economy, education, social, and culture, also positively impacted the quality of the environment. The implementation of lockdown during a pandemic has decreased air, water, soil, and noise pollution (Loh et al., 2021), energy consumption (Mousazadeh et al., 2021), aerosols and an increase in ozone concentration (Khan et al., 2021; Srivastava, 2021). Rivers are part of the environment that positively impacted, including water quality improvements during this pandemic. Various recent studies conducted in China (Liu et al., 2022; Qiao et al., 2021; Xu et al., 2021) and India (Muduli et al., 2021) proved water quality increased and river sediment decreased.

Globally, implementing the lockdown policy has impacted river water quality improvement. During the pandemic, there was a widespread improvement in river water quality worldwide, but this was temporary during the lockdown period. Various studies from China and India (Asia), Italy and the United Kingdom (Europe), and several locations in the United States show a decrease in TSS and BOD/COD and an increase in DO. This shows a consistent pattern of improvement during restrictions on human activity. Asia and Europe generally recorded more pronounced and rapid enhancements, strongly linked to industrial shutdowns and reduced tourism and transportation activities. Meanwhile, Africa and parts of Latin America showed mixed results, with local improvements in some rivers and problems caused by poor sanitation and domestic runoff (Farrokhi et al., 2023; Manoiu et al., 2022). The changes in community activities during the lockdown, in general, positively impact river water quality. However, the deterioration of river water quality occurred during the lockdown period, and the risk of virus spread increased due to improved household waste dumped directly into rivers, as found in Ecuador (Guerrero-Latorre et al., 2020). Therefore, studies on water quality concerning population activities during a pandemic are essential.

Opak and Progo River watershed is a large watershed on the southern side of central Java. The catchment area of these two watersheds has very complex geological and geomorphological conditions. The upper river is located in volcanic environments and structural-denudational mountains of old volcanic rocks that flow into vast alluvial plains. Also, land use is complex, with dryland agriculture dominating the upstream areas and paddy fields in the lowlands. Both of these watersheds are across urban areas. These cities are in the upstream and downstream regions. The Opak watershed crosses the major cities of Yogyakarta and some of the smaller districts, while the Progo watershed crosses smaller towns from upstream to downstream. With complex landform and land use characteristics, spatial variation of water quality in these two watershed regions is interesting to investigate. Experience in India shows that cities in upstream and downstream influence river water quality (Muduli et al., 2021).

To decrease the impact and spread of the COVID-19 pandemic, the Indonesian Government has imposed several restrictions on community activities from 2020 to 2021. In April 2020, Large-Scale Social Restrictions (locally known as PSBB) were imposed with the provincial scope, refers to Government Regulation of the Republic of Indonesia Number 21 of 2020. Furthermore, PSBB transition with the provincial scope was imposed from October 12, 2020. Enforcement of Community Activities Restrictions (locally known as PPKM) in the seven provinces of Java and Bali was implemented from January 11, 2021, refers to Instruction of the Minister of Home Affairs of the Republic of Indonesia Number 1 of 2021. Micro-level-PPKM with the scope of villages, sub-districts, neighbourhood/community association was carried out from February 22, 2021. Emergency PPKM was implemented starting July 3, 2021, with the scope of Java and Bali and 15 districts/cities with epidemiological status of levels 3 and 4, refers to Instruction of the Minister of Home Affairs of the Republic of Indonesia Number 15 of 2021. The latest restrictions are levels 3 and 4 PPKM starting July 21, 2021, which was extended until the end of August 2021, refers to Instruction of the Minister of Home Affairs of the Republic of Indonesia Number 1 of 2021. Community Restrictions significantly impact densely populated urban areas and many mobility's. As studies have been conducted in various countries, the positive impact of these mobility restrictions on the river water quality of the Opak and Progo watersheds that cross urban areas in both upstream and downstream areas is interesting to investigate. Moreover, the impact in rural areas with agricultural activities also needs to be examined.

This paper describes the water quality spatial variation of Opak and Progo Watershed Rivers during the PPKM period in Java and Bali in response to the second wave of COVID-19 in Indonesia. This study seeks to analyze the impact of the PPKM implementation on river water quality in all catchment areas. This paper aims to examine: (1) water quality variation in various river orders in rural and urban areas, (2) spatial distribution patterns of water quality. This study intends to explain the positive impact of the COVID-19 pandemic on environmental conditions, especially river water quality, which is strongly influenced by community behaviour. This paper provides alternative information on the impact of pandemics on environmental improvement so that it is helpful for the environmental management of watershed areas, as investigated in previous studies.

Methods

The Study Area

This research was conducted in Opak and Progo watershed, in the central part of Java Island. Based on data published in the Decree of the Minister of Public Works of the Republic of Indonesia Number 590 of 2010, Opak watershed is administratively located in Yogyakarta Special Region (89.88%) and a little part lies in Central Java Province (10.12%). This river system flows from the Merapi Volcano in the north to the Indian Ocean in the south with a 65 km main river stretch. The total area of the Opak watershed is 737.68 km^2. The average discharge of the main river in the downstream area reaches 12.35 m^3/s. Meanwhile, the Progo watershed is located next to the Opak watershed. The Progo watershed also empties into the Indian Ocean but flows from a more remote area with a 138 km stretch of the main river. The upstream areas of the Progo watershed are the slopes of the Merapi, Merbabu, Sumbing, and Sindoro Volcanoes (Mukminan et al., 2024). Administratively, the Progo watershed is mostly in Central Java Province (70.54%) and a small part is in Yogyakarta Special Region (29.46%). The total area of the Progo watershed is 2,421 km^2. The average discharge of the main river in the downstream area is 58.50 m3/s. Figure 1 presents the study area. Based on the river valley area that has been selected, a grid that represents an area of 40 km^2 was created. In each grid area, one spot was taken as the sample location. 35 measurement sample locations were obtained (Figure 1).

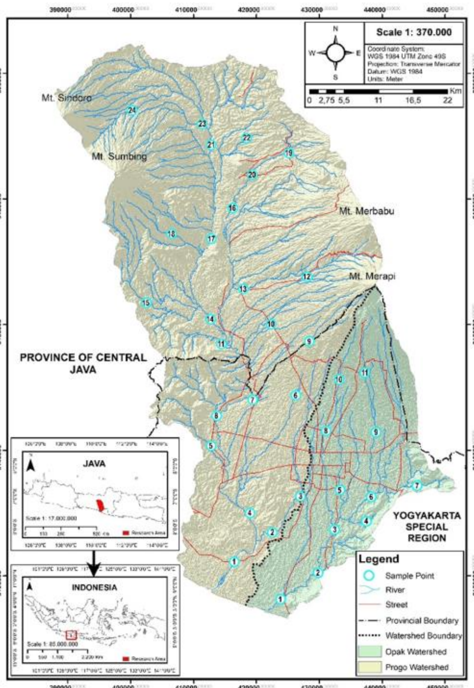


Fig. 1. Study area

Geomorphologically, the Opak and Progo watersheds are dominated by volcanic landforms of stratovolcanoes, older and more denuded volcanic morphology (Ashari & Purwantara, 2022). The volcanism dominance over the geomorphology of this region is also indicated by the large number of volcanic products that spread to low-lying areas and form fluvial-volcanic plains. In addition to volcanic land, structural block mountains exist in the southeast to the south of the Opak watershed and denudational mountains in the border area between the upstream and downstream of the Progo watershed (see Figure 1). Opak and Progo watersheds have varied geological conditions but are dominated by volcanic activity results both past and present. Based on the Geological Map of Yogyakarta and Magelang-Semarang sheet (Raharjo et al., 1995; Thanden et al., 1996), most of the Opak watershed is dominated by young Merapi materials. In the upstream, little Old Merapi material exist. Meanwhile, ancient volcanic materials of agglomerates, lava, tuff, limestone pumice, and tuff breccias are found in the structural mountains. The geological conditions in the Progo watershed are more complex. The results of young Merapi volcanic activity dominate the downstream area. Meanwhile, the upstream region is dominated by material from the large stratovolcanic activity of Merbabu, Sumbing, and Sindoro, and other volcanic products with limited coverage, all of which are quarters old. There are tertiary volcanic rocks, limestone, and marly limestone in the denudational mountain region (Figure 2).

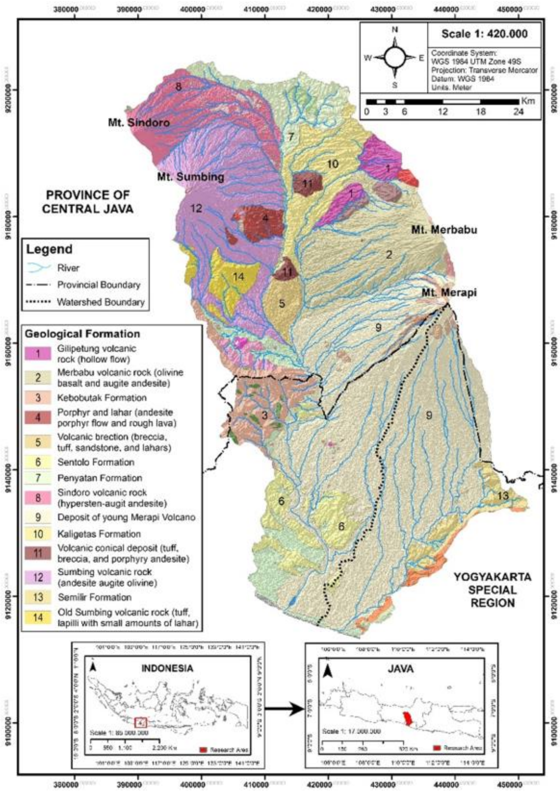


Fig. 2. Geological Formation of Java

The Opak and Progo watersheds climate is a tropical monsoon climate characterized by a rainy season for six months starting from the beginning of the year and a dry season for six months starting from the middle of the year. Data from the Central Statistics Agency shows the maximum rainfall in 2020 upstream of the Opak watershed reaching 680 mm occurred in March. Meanwhile, the maximum rainfall in 2020 upstream of the Progo watershed occurred in January at 487 mm. The Opak and Progo watershed areas are mostly rural and a small part of urban land. In the central part of the Opak watershed, there is a megacity of Yogyakarta and the Town of Bantul in the downstream area. Meanwhile, some towns in the Progo watershed include Temanggung, Magelang, and Sleman. The land in these two watersheds is widely used for agricultural activities, with dryland agriculture in the upstream regions and rice fields in the downstream area.

Data collection and analysis

This research is exploratory research with a spatial approach. The data collected in this study included primary and secondary data. Primary data were collected through field observations, namely by performing in situ measurements using prepared instruments and taking samples to be tested in the laboratory. The determination of sample location in field observation utilized systematic sampling. River valleys with third-order or higher were selected from all Opak and Progo watersheds research areas.

The secondary data collected in this study include land use data, geological conditions, population data, and previous water quality data. Land use data were obtained from the Indonesian Topographical Map, accessed through the website of the Government of the Republic of Indonesia (2025). Geological condition data were obtained from Geological Map (Raharjo et al., 1995; Thanden et al., 1996). Population data were obtained from the publication of the Statistical Agency of Indonesia, district of Temanggung (Central Statistics Agency of Temanggung Regency, 2020), Magelang (Central Statistics Agency of Magelang Regency, 2020), Sleman (Central Statistics Agency of Sleman Regency, 2020), Bantul (Central Statistics Agency of Bantul Regency, 2020), Kulon Progo (Central Statistics Agency of Kulon Progo Regency, 2020), Yogyakarta City (Central Statistics Agency of Yogyakarta City, 2020), and Magelang City (Central Statistics Agency of Magelang City, 2020). Previous water quality data were obtained from the Government of Yogyakarta Special Region (2022) and Yogyakarta City Environment Agency (2022). In addition to documentation, secondary data were also obtained through literature studies from previous research conducted by Sutikno et al. (2007).

Data analysis used in this study includes matching analysis Geographic Information System (GIS) analysis, and statistical analysis. Matching analysis was performed by contrasting field measurement data and laboratory analysis with water quality criteria based on its class according to PPRI No. 22 of 2021 (Table 1). This analysis was supported by calculating the pollution index to determine the pollution level, with quality standards in the class of limiting factors and quality standards in class 1 according to PPRI No. 22 of 2021. Matching analysis is also supported by statistical analysis of independent sample t-test to determine the differences in water quality between upstream and downstream areas as well as between urban and rural in Opak and Progo watershed. Comparative test analysis using an independent sample t-test was also performed to determine the differences of various water quality parameters before and during the pandemic. The pre-pandemic period is represented by 2018 and 2019 data, while the pandemic period is represented by 2020 and 2021 data.

Table 1. Several river water quality parameters based on Indonesian national quality standards according to PPRI No. 22 of 2021

No	Parameter	Unit	Class 1	Class 2	Class 3	Class 4	Additional explanation
1	Temperature	°C	Dev 3	Dev 3	Dev 3	Dev 3	Difference with air temperature above the water surface
2	TDS	mg/L	1.000	1.000	1.000	2.000	Not applicable to estuaries
3	TSS	mg/L	40	50	100	400	-
5	DO	mg/L	6	4	3	1	Minimum limit
6	BOD	mg/L	2	3	6	12	-
7	COD	mg/L	10	25	40	80	-
8	pH	-	6-9	6-9	6-9	6-9	Not applicable to peat water (based on its natural condition)
9	NH3-N	mg/L	0,1	0,2	0,5	-	-
10	Pb	mg/L	0,03	0,03	0,03	0,5	-

GIS analysis employing the ANN analysis technique aims to determine the distribution pattern of water quality. ANN is an analysis technique in GIS that is specifically used to analyze the spatial distribution patterns of an object. Each class of water was analyzed for its distribution pattern, whether clustered, scattered, or random. Referring to Nirwansyah et al. (2015) z-score and p-value were used as indicators to determine the distribution pattern. If the calculation results show a negative z-score, the pattern will Clustered; if the z-score is positive, the pattern will dispersed, and if the z-score is zero, the pattern will be random. Thus, the distribution pattern of good and bad water quality can be revealed. This analysis is further supported by examining the association between water quality distribution patterns and restrictions on community activities during the COVID-19 pandemic (Figure 3).

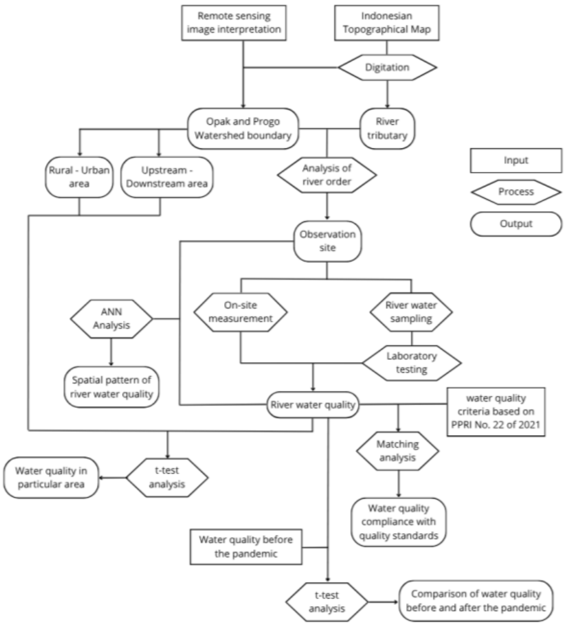


Fig. 3. The association between water quality distribution patterns and restrictions on community activities during the COVID-19 pandemic

Referring to Aziz et al. (2012), the formula in the ANN is as follows:

$$R = \frac{r_{obs}}{r_{exp}} \quad (1)$$

$$r_{obs} = \sum_{i=1}^{N} \frac{\min(d_{ij})}{N} \quad (2)$$

$$r_{exp} = \sqrt{\frac{A}{N}} \quad (3)$$

In this formula, R is the ANN Index; r_{obs} is observed average distance between nearest neighbour; r_{exp} is the expected average distance the nearest neighbour determined by the theoretical pattern tested; min (d_{ij}) is the distance between each point and the nearest neighbour; A is the area; and N is the number of points in the distribution (Ashari et al., 2021). The advantage of using ANN is that it can determine distribution patterns based on statistical calculations, while the disadvantage of ANN is that it should be more accurate when applied to points that are chosen based on random sampling.

Results

Water Quality Difference of Opak and Progo watersheds during the COVID-19 pandemic

River water quality varies spatially because it is influenced by natural processes and human activities that vary between places and the self-purification ability of the river itself. Davie (2008) explains that spatial variation of water quality is influenced by many environmental factors such as climate, geology, weathering processes, vegetation cover, and anthropogenic. This study conducts water quality measurements and testing in the Opak and Progo watershed of Central Java. Measurements in the Opak watershed include 11 sample locations, while the Progo watershed covers 24 sites (Figure 1). All measurement activities were conducted in October 2021. This period is the beginning of the rainy season in the Opak and Progo watersheds located in the monsoon area of Central Java. This period is still included in the PPKM due to the COVID-19 pandemic. There are 11 water quality parameters measured in this study, namely water temperature, total dissolved solids (TDS), total suspended solids (TSS), water pH, electrical conductivity (EC), dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), ammonia nitrogen (NH3-N), lead (Pb), and cadmium (Cd). Five parameters were measured in situ, namely water temperature, TDS, DO, EC, and pH, while the other six parameters were tested in the laboratory.

The measurement results show that the water temperature in Opak ranges 27.01-32,06°C while in Progo 22.77-31,64°C. The elevation is quite influential on the variability of water temperature. Sample locations with high elevations tend to have cooler water temperatures. The effects of elevation on water temperature is more significant in Progo (R^2 = 0.64) than in Opak (R^2 = 0.46). In the Opak watershed, there is a megacity of Yogyakarta, where the measurement results from several sample locations in the city's suburban areas show higher water temperatures than rural areas in downstream areas with lower elevations. The order of the river does not significantly influence the water temperature in Opak (R^2 = 0.42) and Progo (R^2 = 0.03). Opak watershed upstream from Merapi Volcano is very active with a low level of denudation. This condition causes small-order Rivers to elongate and spread radially from the upper slope to the volcanic foot, to form a larger order in the lower areas. In contrast to Opak, the upstream of Progo is the Merbabu, Sumbing, and Sindoro stratovolcanoes which are less active and are influenced by exogenous processes at a later stage. As a result, many valleys notches formed on the volcano slopes, which soon joined to form a larger order in the high elevation region. The stadium of stratovolcano landform development has influenced the development of different river orders between Opak and Progo. High elevation areas with low water temperatures in Opak generally have a small order, while the order is larger in Progo.

The Total Dissolved Solids (TDS) measurement results show that the conditions vary spatially, especially in Progo. TDS in Opak ranges 94-177 ppm while in Progo 53-288 ppm. Of the 11 measurement locations in Opak, one place shows a TDS below 100 ppm (location 10). Another sample with a relatively small result was location 11, with a TDS result of 112 ppm. Both sample locations are in the upstream area physiographically located at the Merapi volcanic foot. In addition to these two samples, the variation of TDS between sites does not show significant results (Figure 4). Meanwhile, the TDS in Progo is much more varied. TDS anomalies are also found in Progo at location 4 (Figure 4). This location is a river flowing in a limestone area with a very small flow discharge at the time of measurement. Comparison between upstream and downstream regions and rural and urban areas in Opak and Progo show no difference in average TDS. In relation to river order, the increase in river order does not affect the increase in TDS in Opak (R^2 = 0.30) and Progo (R^2 = 0.02).

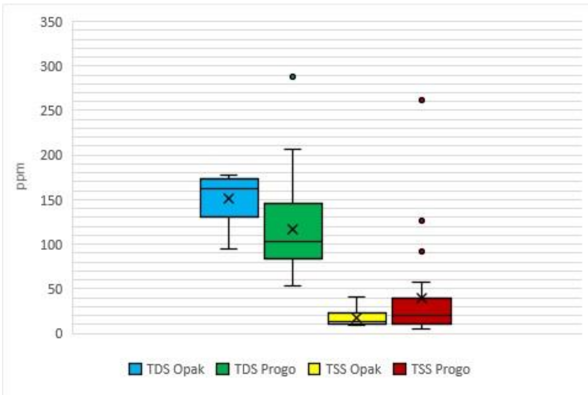
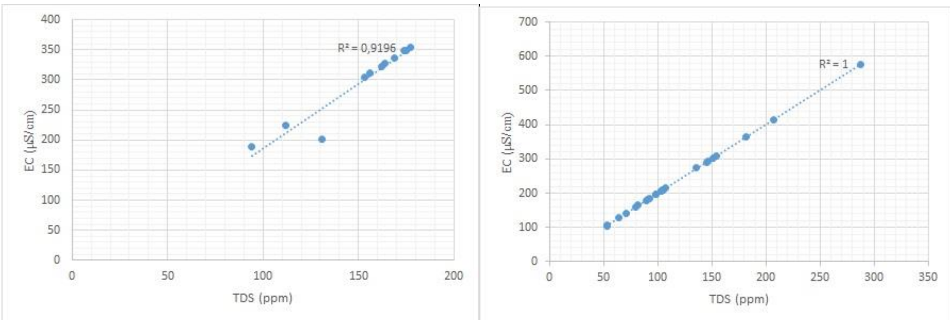


Fig. 4. TDS in Opak and Progo

Total Suspended Solids (TSS) measurements show simpler results than TDS in Opak and Progo. The spatial variation of TSS in 11 Opak samples is relatively small (Figure 4), with only two sample locations whose results differed significantly, namely sites 4 (41 ppm) and 7 (36 ppm). Both locations are tributaries upstream from structural mountain landforms with tertiary old volcanic rock cores. These old structural mountains have undergone further rock weathering and pedogenesis, forming clay-textured soils that will be transported in flow discharges as suspended loads when eroded. In contrast to the structural mountains, there are many eruptive materials in the active Merapi Volcano area, including coarse sand, gravel, and rocks that have not undergone much weathering. Instead of suspended load, the river upstream in the Merapi Volcano carries more bed load.

The measurement results in Progo also show the same condition as Opak, namely a few spatial variations with only three significantly different locations: 4, 5 and 7 (Figure 4). Location 4 (127 ppm) is a limestone area with a very small discharge. Location 7 (262 ppm) is an intake from the river in the Merapi Volcano area, which has a lot of sand mining activities. Meanwhile, location 5 (92 ppm) is an old denudational mountain that has undergone further weathering to form clay-textured soil. This soil is much eroded and transported as a suspended load. TSS results in the Progo denudational mountains (92 ppm) are even more significant than in the Opak structural mountains (41 ppm). The comparison between upstream and downstream areas and rural and urban areas in Opak and Progo shows no difference in the average TSS. Also, the increase in river order does not affect TSS in Opak and Progo.

Electrical Conductivity (EC) varies significantly in Progo, with a range of 105-576 μS/cm. Location 4 (very small discharge in limestone areas) shows an extreme anomaly condition. The EC Progo distribution outside the anomaly is 105-414 µS/cm. Meanwhile, EC in Opak is relatively homogeneous with 188–354 µS/cm range. EC values do not differ between upstream and downstream, and between rural and urban, both in Opak and Progo. Among the various parameters that affect EC, EC values are strongly influenced by TDS, slightly affected by water temperature, and less affected by TSS. TDS had a significant effect on EC, as shown in Opak and Progo (Figure 5). In contrast to EC measurements, Dissolved Oxygen (DO) measurement results are more likely to show spatial variation in Opak and Progo. However, DO values in Opak and Progo are not affected by water temperature variations, as presented by Davie (2008). TDS and TSS levels do not affect DO in Opak and Progo. In addition, there is no difference in DO between upstream and downstream, and between rural and urban, in both Opak and Progo.



(a) *(b)*

Fig. 5. The effect of TDS on EC

Biochemical Oxygen Demand (BOD) measurements show good results in Opak and Progo. Among the 11 measurement locations in Opak, two locations show BODs above 2 ppm, and the others are lower than 1.05 ppm. Three sites are below 0.86 ppm. The BOD condition in Progo is much better because almost all measurement locations have minimal values below 0.86 ppm, with only three areas above that value. The BOD values at the three sites are 1.87 (location 2), 1.86 (location 4), and 3.01 (location 20). Meanwhile, Chemical Oxygen Demand (COD) measurements show more varied conditions. The maximum value of COD in Opak is 28.79 ppm which is only found in location 4. The rest are below 17.88 ppm. There are four locations with values below 10 ppm. Also, the COD and BOD measurement results in Progo are better than that of Opak. COD at 22 Progo locations is below 20 ppm (with 15 areas below 10 ppm), and one place shows extreme anomalies with values of 41.30 ppm. TSS factor is very influential on COD in Opak (R2 = 0.63) but not in Progo. Overall, there is no difference between COD in rural and urban and between upstream and downstream in Opak and Progo.

The pH value of river water spatially varies very little in the range of 7.1-8.4 in both watersheds. No anomalies and extreme conditions were found, but the pH value generally decreased in the larger river order, although not significant (R^2 = 0.21 in both watersheds). Findings in Progo show interesting results that there is a difference in the average pH of river water between rural and urban areas and between upstream and downstream areas. Rural areas dominated by volcanic landforms and farmland use are thought to affect smaller pH values due to agricultural activities and the lithological influence of volcanic rocks. Downstream areas also have a smaller average pH which may be influenced by the accumulation of various factors that affect water quality from upstream to downstream regions. The findings at Progo were not found in Opak, possibly influenced by the smaller watershed area and more homogeneous topographic conditions.

Other water quality parameters tested in this study were heavy metal content, namely dissolved Cd, Pb, and NH3-N. These heavy metal contents are pollutants from transportation activities entering river water. The measurement results show that the Cd content in all water samples from 35 locations in Opak and Progo watershed is very low, which is less than 0.0008 ppm. This condition applies to all river orders, rural and urban areas and upstream and downstream areas. Measurements of Pb show slightly larger results than Cd. In addition, there is a variation of Pb between locations but very small. The measurement results of NH3-N show conditions that are relatively similar to Pb with minimal values and variations. Overall, the slight spatial variation of Pb and NH3-N does not show any difference between the urban area and the rural area and between the upstream and downstream areas. Table 2 shows the results of heavy metal measurements and other water quality parameters discussed in the previous section.

Table 2. The results of the water quality parameters measurement in Opak and Progo Watersheds

Parameter		Opak	Progo	Parameter		Opak	Progo
Temperature	n	11	24	BOD	n	11	24
	Median	28,7	27,33		Median	1,05	0,86
	Mean	29,06	26,99		Mean	1,26	1,03
	Max	32,06	31,64		Max	2,39	3,01
	Min	27,01	22,77		Min	0,86	0,86
	SD	1,5	2,13		SD	0,56	0,51
TDS	n	11	24	COD	n	11	24
	Median	162	103		Median	13,3	8,72
	Mean	151,5	116,7		Mean	13,48	10,81
	Max	177	288		Max	28,79	41,3
	Min	94	53		Min	6,79	2,56
	SD	27,55	53,35		SD	6,33	8,08
TSS	n	11	24	pH	n	11	24
	Median	12,5	20		Median	7,5	8
	Mean	17,95	39,21		Mean	7,6	8,01
	Max	41	262		Max	8,1	8,4
	Min	9	5		Min	7,2	7,2
	SD	11	2,131		SD	0,3	0,24
EC	N	11	24	NH3-N	n	11	24
	Median	323	205,5		Median	0,044	0,0455
	Mean	297,5	233,5		Mean	0,048	0,0506
	Max	354	576		Max	0,09	0,098
	Min	188	105		Min	0,023	0,0139
	SD	61,86	106,8		SD	0,021	0,0272
DO	N	11	24	Pb	n	11	24
	Median	0,97	1,13		Median	0,0119	0,0124
	Mean	1,01	1,08		Mean	0,0121	0,0119
	Max	1,6	1,93		Max	0,0134	0,0175
	Min	0,52	0,23		Min	0,0102	0,0085
	SD	0,3	0,54		SD	0,001	0,0021

The measurement results of various water quality parameters show that during the COVID-19 pandemic at the end of 2020, most of the water quality parameters of the Opak and Progo watersheds are in good condition. As a potential source of water for various purposes, Rivers have good quality in many parameters. In general, among the multiple variations of river order, variations of river location according to upstream-downstream areas and rural-urban areas, many parameters are in good condition. The parameters that become the limiting factors are DO and COD. Anthropogenic pollution of the urban regions does have much effect on water quality during this period. This is indicated by the low content of heavy metals in all Opak and Progo locations. Also, no heavy metals affect DO and COD, which becomes limiting factors. However, the impact of erosion due to rural agriculture on water quality needs to be considered, especially in Opak. This is indicated by the significant influence of TSS on COD, where the source of high TSS is structural mountainous areas and not in the active Merapi Volcano. Anthropogenic activities in agriculture affect water quality due to a large amount of suspended load that enters the river due to erosion. This evidence needs to be strengthened by examining the distribution pattern discussed in the next section.

Water Quality Distribution Patterns in Opak and Progo Watersheds during the COVID-19 pandemic

Based on the results of matching analysis between field data and water quality criteria, the quality of river water in the Opak and Progo watershed is generally in good condition. This is indicated by most of the parameters included in class 1. In Opak, various water quality parameters, including water temperature, TDS, TSS, and pH, are included in class 1. The heavy metal parameters used in this study are also included in class 1 in the Opak region, where the megacity of Yogyakarta is located. On the BOD parameter, except for sample 1, which is included in class 2, all samples are included in class 1. Meanwhile, on the COD parameter, 63% of the samples are included in class 2, and 36% are included in class 1. The only water quality parameter in Opak which is not good is DO, where some of the samples are included in class 3 and others are included in class 4. Due to the low water quality in the DO parameter, the overall Opak water quality is categorized in classes 3 and 4.

Findings in Progo are not much different from Opak. Various water quality parameters in Progo, such as water temperature, TDS, pH, BOD, and various heavy metals, are included in class 1. COD parameters show a slight variation, namely 15 locations, including 8 locations of class 1 and 1 site of class 2. Slightly different from Opak in that all TSS parameters are included in class 1. TSS in Progo is more varied, with three locations included in class 2, one site included in class 3, two locations included in class 4 and the rest are included in class 1. Meanwhile, for DO, conditions like in Opak is also found in Progo. This DO condition is a limiting factor that causes water quality in Progo, generally categorized into class 3 and class 4. According to PPRI No. 22 of 2021, class 3 water quality can be used for fisheries, livestock, and irrigation, while class 4 is limited only to irrigation. Given that the parameters of pH, TDS, and heavy metals are in good condition, the river water in most areas of Opak and Progo is quite potential for domestic water sources. However, it is necessary to consider the pollution level analyzed based on the following pollution index analysis.

In this study, the pollution index was assessed twice. The first assessment was performed with grade 3 and 4 criteria based on the limiting factors at each sample location. The assessment results show that all sample locations in Opak and Progo still met the water quality standards in the class of limiting factors. This is because among the ten parameters tested match with PPRI No. 22 of 2021, mostly included in class one with only two or three lower parameters. In other words, there are many parameters that are of good quality but are constrained by limiting factors so that they are categorized in the water quality class according to these limiting factors. Furthermore, a pollution index assessment was done with class 1 water quality criteria. The assessment results with class 1 criteria still show that most of the sample locations still met water quality standards. Among the 11 areas in Opak, three locations (1, 4, and 10) are included in the lightly polluted category. Meanwhile, in Progo, three (4, 7, and 20) locations belong to the lightly polluted category among the 24 locations.

The pollution index assessment results of class 1 criteria were then further analyzed to determine the distribution pattern of river water quality in Opak and Progo. The analysis results show that the river water quality that still meets the quality standards of class 1 is dispersed in the Opak region (z-score = 4,52) and Progo (z-score = 3,54). Similarly, the distribution pattern of water quality is included in the category of lightly polluted. Also, the distribution is dispersed in both Opak (z-score = 8,72) and Progo (z-score = 65,55). The number of sample locations that fall into the lightly contaminated category is relatively small. With a dispersed distribution pattern, it can be concluded that there are no pollution zones in the Opak and Progo watersheds. In addition, not all areas of the Opak and Progo watersheds are polluted. Furthermore, the distribution pattern analysis of DO and COD classes was performed by considering that DO and COD parameters are two limiting factors of water quality. The distribution pattern of DO class 3 and 4 (z-score = 2,59) was dispersed, both in Opak (z-score = 5,14 and 2,59), and in Progo (z-score = 3,15 and 2,73). The distribution pattern of class 2 COD as a limiting factor is also dispersed in Opak (z-score = 4,20) and Progo (z-score = 3,88).

The distribution pattern of the pollution index and some of the water quality limiting parameters above reinforce the assumption that the anthropogenic effects of pollution in urban areas are not significant in the COVID-19 pandemic period. This is possibly caused by the restrictions on community activities repeatedly imposed during 2020. This condition is typically found in Progo where there are only small towns as district capitals. While the anthropogenic influence in urban areas is limited. Agricultural activities in rural areas are likely to impact water quality during this period. In the previous section, it has been stated that agricultural activities need to be considered as a factor that lowers water quality. Data at Opak 4 and Progo 5 which are structural-denudational mountainous areas with agricultural areas show high TSS, low DO, and high COD. Similarly, Progo 7 receives intake from rivers in volcanic areas with sand mining activities. In general, high COD areas are spread in clusters in the downstream areas of Opak and Progo. This is the accumulation of all processes that occur throughout the watershed.

The impacts of community activity restrictions during the pandemic on river water quality in Opak and Progo watersheds

In this section, various Opak and Progo water quality parameters before the pandemic namely 2016 to 2019 and during the pandemic period from 2020 to 2021 are compared. Data from previous measurements by government agencies used in this study generally focus on urban and downstream areas. Therefore, comparisons in this study cannot be made across all sample locations, but are limited to a few selected locations. There were eight locations in Opak and Progo selected in this level of analysis.

Water temperature in Opak in 2016-2021 is not varied. The average temperature during that period differs from less than 20°C. Moreover, there was no difference between the average water temperature before the pandemic (2018 and 2019) and during the pandemic period (2020 and 2021). TDS in Opak showed interesting variation during 2016-2021. The TDS value in 2017 decreased compared to 2016. Then, it gradually increased from 2017 to 2019 with a relatively similar range. The maximum increase occurred in 2020, indicated by the highest average and range of TDS compared to the previous year. In 2021, there was a decrease in the average and range of TDS compared to last years (Figure 6a). This happened due to community activity restrictions repeatedly imposed since 2020. Community activity restrictions have reduced TDS, shown by the lowest average of TDS 2021 in the last six years. The TDS 2021 range is also the smallest, indicating that the TDS in the eight river samples tends to be low during this period.

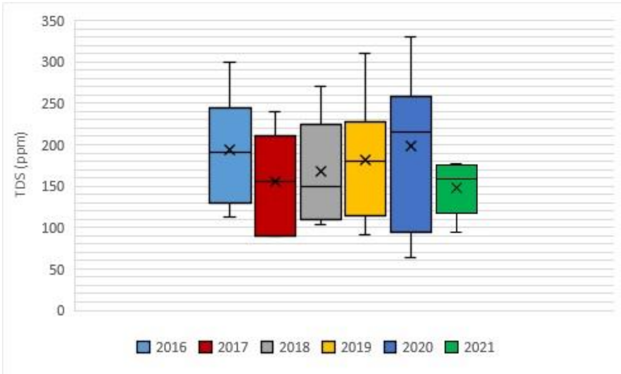


Fig. 6a. The value of TDS in 2016-2021 in Opak

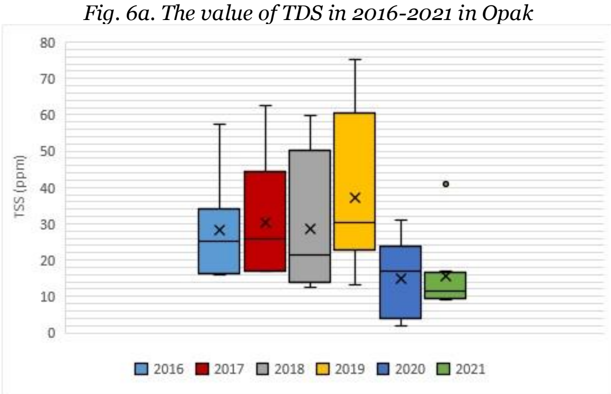


Fig. 6b. The value of TDS in 2016-2021 in Opak

TSS in Opak shows the same conditions as TDS, namely the average and range during the pandemic period in the last two years are lower than in the previous four years. From 2016 to 2019, the range of TDS increased. Meanwhile, the average and maximum value of TDS fluctuate with insignificant increases and decreases from year to year. After an upward trend that lasted until 2019, it declined during the pandemic of the last two years. Even in 2021, the smallest range showed slight variation between rivers in Opak (Figure 6b). The location of the Opak 4 sample from the structural mountains showed that TDS and TSS were still high during the pandemic, making it an anomaly compared to other areas. A significant decrease followed the declining trend of TDS and TSS during this pandemic period in the mean and range of BOD in the last two years (Figure 6c). In general, the average of BOD differs before and after the pandemic. There is an average difference between 2020 and 2021, which shows a continuing downward trend. Meanwhile, COD showed different conditions (Figure 6d). Differences in average COD values before and after the pandemic were not found.

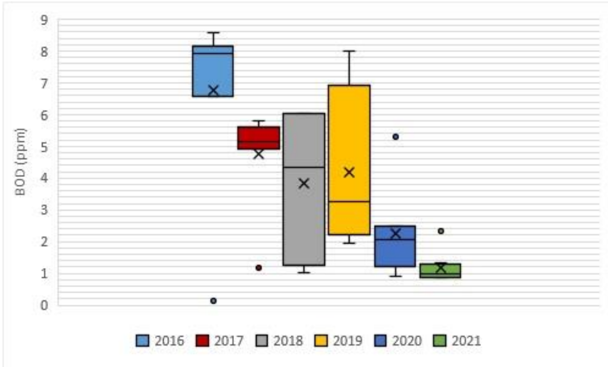


Fig. 6c. The value of BOD in 2016-2021 in Opak

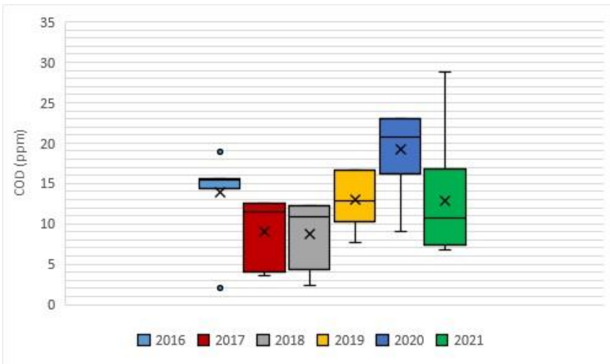


Fig. 6d. The value of COD in 2016-2021 in Opak

Among the three heavy metal parameters tested in this study, Pb and Cd parameters show the average difference before and during the pandemic, especially in 2021. These two parameters deal with transportation pollution. The average Pb of the 8 sample locations was 0.3 in 2016, increased to 0.4 in 2017, decreased to 0.2 during 2018-2020, and declined to 0.1 in 2021. The value of Pb 0.03 is the first-class criterion according to PPRI No. 22 of 2021. This condition shows that the Pb level of the river in Opak is generally relatively low and is declining due to the restrictions on community activities. The value of Cd fluctuated with an average of 0.030 in 2016, increased to 0.0115 in 2017, decreased to 0.0033 in 2018, increased to 0.0049 in 2019, declined to 0.0033 in 2020, and decreased to 0, 0008 in 2021. Pb and Cd figures show that restrictions on community activities carried out repeatedly during 2020 and 2021 have reduced heavy metals as pollutants from transportation. Meanwhile, the parameters that indicate relatively stable conditions are NH3-N and pH.

The conditions in Progo are slightly different from Opak. The water temperature shows constant during the 2016-2021 period and shows no difference before and after the pandemic. TDS in Progo also decreased from 2016 to 2017, as in Opak, then increased from 2017 to 2020, and dropped in 2021 (Figure 7a). The average TDS in 2021 is the lowest since 2016. Statistically, the average TDS in 2021 differed from the pre-pandemic period and even with the TDS in 2020. Meanwhile, the TDS in 2020 does not differ from the pre-pandemic period. TSS in the last six years shows fluctuating conditions but tended to decline over the previous three years (Figure 7b). Similar to TDS, statistically, the average TSS 2021 differs from TSS before the pandemic and TSS 2020. Meanwhile, TSS 2020 does not differ from TSS before the pandemic. Thus, TDS and TSS in the Progo experienced a decline in 2021, indicated by a smaller average and range than in previous years.

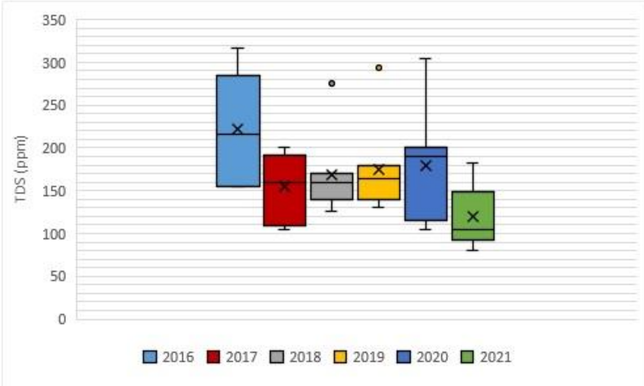


Fig. 7a. The value of TDS in 2016-2021 in Progo

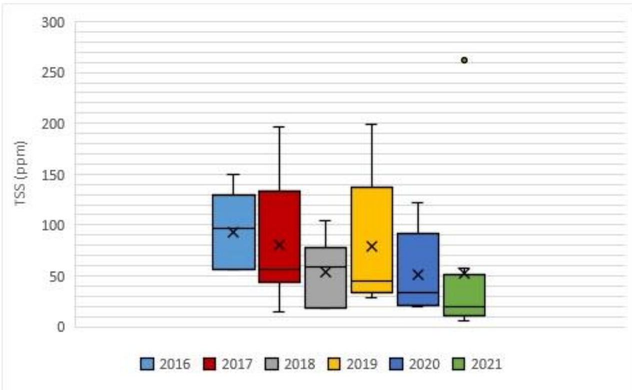


Fig. 7b. The value of TSS in 2016-2021 in Progo

The declining trend of TDS and TSS in Progo has decreased BOD (Figure 7c), similar to Opak. In the last three years, the BOD in Progo has continued to decline. Interestingly, the average BOD of 2020 and 2021 has differed from the average BOD in the period before the pandemic. COD 2021 shows a decrease compared to 2020 after experiencing an increase in several years (Figure 7d). The average BOD in Progo in 2020 and 2021 also differs from the BOD before the pandemic. The relatively constant parameters are pH and DO. Heavy metal parameters show exciting symptoms. The average ammonia nitrogen in 2021 is 0.05 ppm lower than 2017-2019 but higher than 2020 by 0.04 ppm. The average Pb 2021 of 0.01 ppm is the same as in 2020 and lower than 2016-2020. Meanwhile, the average Cd 2021 is 0.0008 lower than Cd 2016-2020.

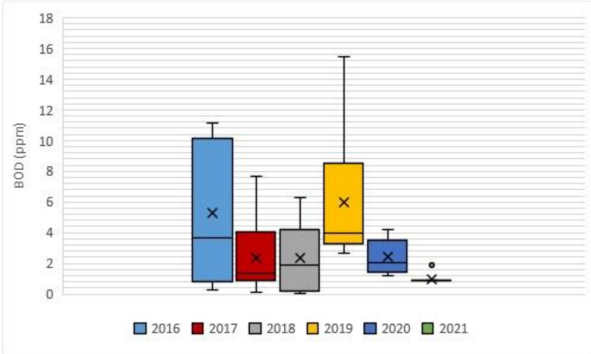


Fig. 7c. The value of BOD in 2016-2021 in Progo

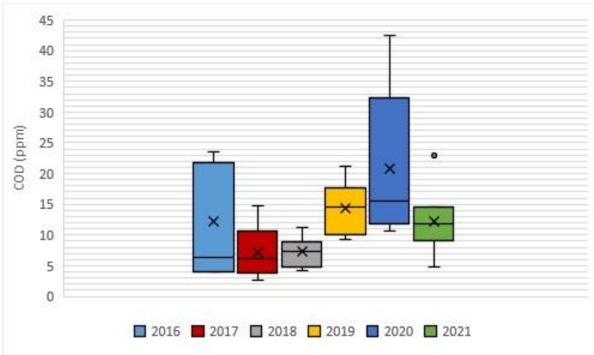


Fig. 7d. The value of COD in 2016-2021 in Progo

Discussion

The findings of this study reveal the influence of restricting community activities during the COVID-19 pandemic on river water quality in two watersheds located in the central part of Java, namely Opak and Progo. The primary findings indicate that in watersheds dominated by rural areas such as Opak and Progo, agricultural activities have a more significant impact on river water quality than urban pollutants. This is indicated by the high TDS and TSS of farming areas in structural and denudational mountains. Meanwhile, heavy metals related to transportation pollutants are relatively small, even in megacities. Restrictions on community activities repeatedly for almost two years have impacted the reduction of heavy metal pollutants, causing small concentrations to become smaller. Meanwhile, the agricultural activities of rural communities that are not too affected by the restrictions of community activities are still a source of pollution. This is proven by the high content of TDS and TSS from structural-denudational mountain areas, making an anomaly of the relatively low average value in the watershed.

The findings of this study indicate that restriction of community activities during the COVID-19 pandemic has reduced water pollution in watersheds, as stated by previous authors (Khan et al., 2021; Singh & Mishra, 2021). However, the positive impact found is limited in a few parameters, so it is not significant compared to the explanation of Loh et al

(2021). In general, many water quality parameters improved compared to the previous period during the pandemic. In other words, more parameters increase than remain the same in quality or even decrease. The water quality improvement through community activities restriction does not always occur in all parameters. This condition is similar to that found by Muduli et al. (2021).

Viewed from the nature of spatial distribution, the improvement in water quality found by Muduli et al. (2021) only occurred in certain areas, for example, at the Haridwar site, where turbidity decreases up to 55%, which was associated with the cessation of pilgrimage activities. In contrast to Muduli's research results, the finding of this study shows that water quality improvements tend to be evenly distributed across regions, leaving one or two locations anomalous. Rural areas dominate the Opak and Progo watersheds; there is only one megacity in Yogyakarta, there is no metropolitan city as a business or industrial area. This condition causes less varied community activities, and the positive impact of water quality improvement is evenly spread in various regions. This research does not find a difference between upstream and downstream areas and rural and urban areas.

The absence of metropolitan cities, densely populated agglomeration, industrial areas, and business areas in the Opak and Progo watersheds leads to no drastic water quality improvement. In general, even before the pandemic, some water quality parameters of Opak and Progo were in good condition. Before the pandemic, Cd and Pb pollutants from transportation waste had been at low levels and still meet class 1 quality standards based on PPRI No. 22 of 2021. Restrictions on community activities during this pandemic has lowered concentrations. The findings in Opak and Progo are different from the findings of Qiao et al. (2021) in large cities upstream of the Yangtze River. The study found that 66% of the 93 locations did not meet national standard III based on the measurement of 23 water quality parameters. There was generally an improvement in water quality during the COVID-19 lockdown period.

Findings from previous research indicate that not only chemical pollutants can be reduced through restricting community activities, but also dissolved charges in river water (Xu et al., 2021). His study has found an improvement in water quality on the parameters of TDS and TSS. Improvements in these two parameters decrease BOD in Opak and Progo. Concerning TSS, based on a study conducted by Xu et al. (2021), downstream of the Min River, China, decreased in TSS during the COVID-19 period. Considering the spatiotemporal changes, the study concluded that the decrease in TSS during the lockdown period was mostly due to a substantial reduction in discharges from industrial areas, densely populated urban centres, and river deliveries. The research findings in Opak and Progo also showed a decrease in TSS during the pandemic period. However, the reduction in TSS in Opak and Progo spatially and temporally was not due to industry and densely populated areas but due to reduced erosion of agricultural zones. This is possibly related to changes in population activity during the pandemic period. Another study conducted by Mousazadeh et al. (2021) in the Ganges River, India, showed an increase in DO of 80% during the pandemic. In contrast to the findings of this study, an increase in DO in Opak and Progo is not found.

Compared to findings from studies conducted in various parts of the world, the findings of this study show that the lockdown imposed in the Opak and Progo Watersheds significantly improved water quality in the short term. These findings are similar to studies conducted in Asia, namely China and India, where DO increased while TDS and TSS decreased. These findings confirm the same pattern for Asia: rapid improvement in water quality concerning human activity restrictions. The findings of this study also show the same conditions as those in Europe. Meanwhile, compared to findings in Latin America, which show mixed results as described by Manoiu et al. (2022) and Farrokhi et al. 2023), this study shows different results because the study area, which is dominated by rural areas and agricultural land, does not have much plastic and medical waste disposal.

Conclusion

Restrictions on community activities repeatedly carried out during the COVID-19 pandemic have improved water quality in the Opak and Progo watersheds. As the watershed is dominated by landform and lithology due to volcanism, having a monsoon climate dominated by rural community activities, the water quality in the Progo watershed is homogeneous. During the second wave of COVID-19, many water quality parameters meet the quality standards of class 1. Spatially, good water quality is evenly distributed in the second region of the watershed, with some inhibiting factors and parameters. Many water quality parameters are in good condition before the pandemic and become better during the pandemic. Heavy metals from transportation pollution continued to decline during the two-year pandemic. Meanwhile, the erosion from agricultural areas in the structural-denudational mountains is still the same as in the pre-pandemic period. This study proves that restrictions on community activities significantly and rapidly impact river water quality.

As an evaluation, this study is still limited to 11 water quality parameters. Therefore, further studies in the future are highly recommended to discuss other parameters. Another limitation of this study is that it has not analyzed comparisons on a shorter temporal scale, such as seasonal or monthly. It is crucial to see how long the impact of restrictions on community activities will last to improve river water quality. Thus, it is highly recommended that the temporal variation of water quality between seasons and between months be analyzed, covering the period from pre-pandemic to pandemic periods. Overall, this study provides alternative information regarding spatio-temporal variations in water quality of Opak and Progo watersheds in relation to the influence of community activity restrictions during the COVID-19 pandemic.

Acknowledgment: The author would like to thank Universitas Negeri Yogyakarta for funding this study through the 2021 Professor Acceleration Research Grant. Also, the author thanks the head and all staff of the Physical Geography Laboratory, Universitas Negeri Yogyakarta, for providing facility support in data collection and analysis and for preparing this article.

Conflict of Interest: The authors declare no conflict of interest.

Publisher's Note: Serbian Geographical Society stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

References

Arbogast, A. F. (2011). *Discovering Physical Geography* (2nd ed.). John Wiley and Sons.

Ashari, A., & Purwantara, S. (2022). *Bentanglahan Vulkanik Indonesia: Aspek Fisikal dan Kultural* (M. Nursa'ban, Ed.). UNY Press.

Ashari, A., Purwantara, S., Arif, N., & Widodo, E. (2021). Spatial Evolution of the River Valleys under the Influence of Active Volcano: A Case of Merapi Volcanic Plain. *Quaestiones Geographicae*, *40*(3), 45–64. https://DOI: 10.2478/quageo-2021-0023

Aziz, S., Ngui, R., Lim, Y. A., Sholehah, I., Farhana, J. N., Azizan, A. S., & Yusoff, W. S. W. (2012). Spatial pattern of 2009 dengue distribution in Kuala Lumpur using GIS application. *Tropical Biomedicine*, *29*(1), 113–120.

Central Statistics Agency of Bantul Regency. (2020). *Kabupaten Bantul dalam Angka 2020 (Bantul Regency in Figures 2020)*. Central Statistics Agency of Bantul Regency.

Central Statistics Agency of Kulon Progo Regency. (2020). *Kabupaten Kulon Progo dalam Angka 2020 (Kulon Progo Regency in Figures 2020)*. Central Statistics Agency of Kulon Progo Regency.

Central Statistics Agency of Magelang City. (2020). *Kota Magelang dalam Angka 2020 (Magelang City in Figures 2020)*. Central Statistics Agency of Magelang City.

Central Statistics Agency of Magelang Regency. (2020). *Kabupaten Magelang dalam angka 2020 (Magelang Regency in figures 2020)*. Central Statistics Agency of Magelang Regency.

Central Statistics Agency of Sleman Regency. (2020). *Kabupaten Sleman dalam Angka 2020 (Sleman Regency in Figures 2020)*. Central Statistics Agency of Sleman Regency.

Central Statistics Agency of Temanggung Regency. (2020). *Kabupaten Temanggung Dalam Angka 2020 (Temanggung Regency in Figures 2020)*. Central Statistics Agency of Temanggung Regency.

Central Statistics Agency of Yogyakarta City. (2020). *Kota Yogyakarta dalam Angka 2020 (Yogyakarta City in Figures 2020)*. Central Statistics Agency of Yogyakarta City.

Chaudhry, R., Dranitsaris, G., Mubashir, T., Bartoszko, J., & Riazi, S. (2020). A country level analysis measuring the impact of government actions, country preparedness and socioeconomic factors on COVID-19 mortality and related health outcomes. *EClinicalMedicine*, *25*, Article 100464. https://doi.org/10.1016/j.eclinm.2020.100464

Davie, T. (2008). *Fundamentals of Hydrology* (Second Edi). Routledge.

Environmental Agency of Yogyakarta City. (2022). *Basis Data Lingkungan Hidup (Environment Database)*. https://lingkunganhidup.jogjakota.go.id/page/index/basis-data-lingkungan-hidup

Farrokhi, M., Khankeh, H., Saatchi, M., Hadinejad, Z., Ahmadi-Mazhin, S., Mohsenzadeh, Y., Mehraein Nazdik, Z., Shojafard, J., Pourvakhshoori, N., & Ahmadi, S. (2023). The Effect of the COVID-19 Pandemic on Environmental Health (Two Sides of the Same Coin): A Systematic Review. *Disaster Medicine and Public Health Preparedness*, *17*, Article e499. https://doi.org/10.1017/dmp.2023.139

Giuliani, D., Dickson, M. M., Espa, G., & Santi, F. (2020). Modelling and predicting the spatio-temporal spread of COVID-19 in Italy. *BMC Infectious Disease*, *20,* Article 700. https://doi.org/https://doi.org/10.1186/s12879-020-05415-7

Guerrero-Latorre, L., Ballesteros, I., Villacrés-Granda, I., Granda, M. G., Freire-Paspuel, B., & Ríos-Touma, B. (2020). SARS-CoV-2 in river water: Implications in low sanitation

countries. *Science of the Total Environment*, *743*, Article 140832. https://doi.org/10.1016/j.scitotenv.2020.140832
Islam, A., Sayed, Md. A., Rahman, Md. K., Ferdous, J., Shano, S., Choudhury, S. D., & Hassan, M. M. (2021). Spatiotemporal patterns and trends of community transmission of the pandemic COVID-19 in South Asia: Bangladesh as a case study. *Biosafety and Health*, *3*(1), 39–49. https://doi.org/10.1016/j.bsheal.2020.09.006
Kang, D., Choi, H., Kim, J.-H., & Choi, J. (2020). Spatial epidemic dynamics of the COVID-19 outbreak in China. *International Journal of Infectious Diseases*, *94*, 96–102. https://doi.org/10.1016/j.ijid.2020.03.076
Khan, I., Shah, D., & Shah, S. S. (2021). COVID-19 pandemic and its positive impacts on environment: an updated review. *International Journal of Environmental Science and Technology*, *18*(2), 521–530. https://doi.org/10.1007/s13762-020-03021-3
Kim, S., & Castro, M. C. (2020). Spatiotemporal pattern of COVID-19 and government response in South Korea (as of May 31, 2020). *International Journal of Infectious Diseases*, *98*, 328–333. https://doi.org/10.1016/j.ijid.2020.07.004
Li, A., Yuan, Q., Strokal, M., Kroeze, C., Ma, L., & Liu, Y. (2021). Equality in river pollution control in China. *Science of the Total Environment*, *777*, Article 146105. https://doi.org/10.1016/j.scitotenv.2021.146105
Liu, D., Yang, H., Thompson, J. R., Li, J., Loiselle, S., & Duan, H. (2022). COVID-19 lockdown improved river water quality in China. *Science of the Total Environment*, *802*, Article 149585. https://doi.org/10.1016/j.scitotenv.2021.149585
Loh, H. C., Looi, I., Ch'ng, A. S. H., Goh, K. W., Ming, L. C., & Ang, K. H. (2021). Positive global environmental impacts of the COVID-19 pandemic lockdown: a review. *GeoJournal,* 87, 4425–4437. https://doi.org/10.1007/s10708-021-10475-6
Manoiu, V.-M., Kubiak-Wójcicka, K., Craciun, A.-I., Akman, Ç., & Akman, E. (2022). Water Quality and Water Pollution in Time of COVID-19: Positive and Negative Repercussions. *Water*, *14*(7), 1124. https://doi.org/10.3390/w14071124
Mousazadeh, M., Paital, B., Naghdali, Z., Mortezania, Z., Hashemi, M., Niaragh, E. K., Aghababaei, M., Ghorbankhani, M., Lichtfouse, E., Sillanpaa, M., Hashim, K. S., & Emamjomeh, M. M. (2021). Positive environmental effects of the coronavirus 2020 episode: a review. *Environment, Development and Sustainability*, *23*(9), 12738–12760. https://doi.org/10.1007/s10668-021-01240-3
Muduli, P. R., Kumar, A., Kanuri, V. V., Mishra, D. R., Acharya, P., Saha, R., Biswas, M. K., Vidyarthi, A. K., & Sudhakar, A. (2021). Water quality assessment of the Ganges River during COVID-19 lockdown. *International Journal of Environmental Science and Technology*, *18*(6), 1645–1652. https://doi.org/10.1007/s13762-021-03245-x
Mukminan, M., Ashari, A., Purwantara, S., & Sumunar, D. R. S. (2024). Opak-Progo watershed's potential for geography experiential learning. *Jurnal Pendidikan Geografi: Kajian, Teori, Dan Praktek Dalam Bidang Pendidikan Dan Ilmu Geografi*, *29*(1), Article 6. https://doi.org/10.17977/um017v29i12024p78-94
Nirwansyah, A. W., Utami, M., Suwarno, S., & Hidayatullah, T. (2015). Analisis pola kejadian sebaran longsorlahan di Kecamatan Somagede dengan Sistem Informasi Geografis (Analysis of the distribution pattern of landslide events in Somagede Sub-District with Geographic Information Systems). *Geoplanning*, *2*(1), 1–9.
Pandey, J., & Singh, R. (2017). Heavy metals in sediments of Ganga River: up- and downstream urban influences. *Applied Water Science*, *7*(4), 1669–1678. https://doi.org/10.1007/s13201-015-0334-7
Parry, B. R., & Gordon, E. (2021). The shadow pandemic: Inequitable gendered impacts of

COVID-19 in South Africa. *Gender, Work and Organization*, *28*(2), 795–806. https://doi.org/10.1111/gwao.12565

Peraturan Pemerintah Republik Indonesia Nomor 22 Tahun 2021. (2021). Government Regulation of the Republic of Indonesia Number 22 of 2021, Pub. L. No. 21.

Qiao, X., Schmidt, A. H., Xu, Y., Zhang, H., Chen, X., Xiang, R., Tang, Y., & Wang, W. (2021). Surface water quality in the upstream-most megacity of the Yangtze River Basin (Chengdu): 2000–2019 trends, the COVID-19 lockdown effects, and water governance implications. *Environmental and Sustainability Indicators*, *10*, Article 100118. https://doi.org/10.1016/j.indic.2021.100118

Raharjo, W., Sukandarrumidi, & Rosidi, H. M. D. (1995). *Peta Geologi Lembar Yogyakarta, Jawa*.

Republic Indonesia. (2025). *Satu Data Indonesia, Akses Informasi Geospasial Terintegrasi*. https://tanahair.indonesia.go.id/portal-web/

Santos, R. M. dos. (2020). Health Isolation, social stress, low socioeconomic status and its relationship to immune response in Covid-19 pandemic context. *Brain, Behavior, & Immunity - Health*, *7*, Article 100103. https://doi.org/10.1016/j.bbih.2020.100103

Shah, Z. U., & Parveen, S. (2021). Pesticides pollution and risk assessment of river Ganga: A review. *Heliyon*, *7*, Article e07726. https://doi.org/10.1016/j.heliyon.2021.e07726

Singh, V., & Mishra, V. (2021). Environmental impacts of coronavirus disease 2019 (COVID-19). *Bioresource Technology Reports*, *15*, Article 100744. https://doi.org/10.1016/j.biteb.2021.100744

Srivastava, A. (2021). COVID-19 and air pollution and meteorology - an intricate relationship: A review. *Chemosphere*, *263*, Article 128297. https://doi.org/10.1016/j.chemosphere.2020.128297

Sutikno, Santosa, L. W., Widiyanto, Kurniawan, A., & Purwanto, T. H. (2007). *"The Merapi Kingdom": Natural resources and carrying capacity ("Kerajaan Merapi": Sumberdaya alam dan daya dukungnya)*. BPFG UGM.

Thanden, R. E., Sumadirdja, H., Richards, P. W., Sutisna, K., & Amin, T. C. (1996). *Peta Geologi Lembar Magelang dan Semarang, Jawa*.

Uddin, Md. J., & Jeong, Y. (2021). Urban river pollution in Bangladesh during last 40 years: potential public health and ecological risk, present policy, and future prospects toward smart water management. *Heliyon*, *7*, Article e06107. https://doi.org/10.1016/j.heliyon.2021.e06107

Xu, H., Xu, G., Wen, X., Hu, X., & Wang, Y. (2021). Lockdown effects on total suspended solids concentrations in the Lower Min River (China) during COVID-19 using time-series remote sensing images. *International Journal of Applied Earth Observations and Geoinformation*, *98*, Article 102301. https://doi.org/10.1016/j.jag.2021.102301

Yogyakarta Special Region. (2022). *Pemantauan Kualitas Air Sungai (Monitoring of River Water Quality)*. Lingkungan Hidup (Environment). https://bapperida.jogjaprov.go.id/dataku/data_dasar/index/185-pemantauan-kualitas-air-sungai