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Research article

Evaluation of river water quality in a tropical South Sumatra wetland during COVID-19 pandemic period

Muhammad Rendana[1,*], Yandriani[1], Muhammad Izzudin[2], Mona Lestari[3], Muhammad Ilham Fattullah[1] and Jimmy Aldian Maulana[1]

[1] Department of Chemical Engineering, Faculty of Engineering, Universitas Sriwijaya, Indralaya 30662 Sumatera Selatan, Indonesia
[2] Department of of Sociology, Faculty of Social and Political Science, Universitas Sriwijaya, Indralaya 30662 Sumatera Selatan, Indonesia
[3] Department of Public Health Sciences, Faculty of Public Health, Universitas Sriwijaya, Indralaya 30662 Sumatera Selatan, Indonesia

* **Correspondence:** Email: muhrendana@ft.unsri.ac.id; Tel: +6281379895949.

Abstract: The COVID-19 outbreak affected the world badly in this 21st century leading to the closure of all types of anthropogenic activities. It is declared that there was an environmental betterment in names of water quality and air quality during the COVID-19 period. In this study, we analyzed the improvement in water quality by evaluating the suspended particulate matter (SPM) using the remote sensing technique in a tropical South Sumatra wetland i.e., Musi River in Southern Sumatra, Indonesia. The SPM values were estimated from Landsat 8 images Level-2 product. A quantitative and spatial analyses of before (20th May 2019), during (22nd May 2020), and after COVID-19 (28th May 2022) periods were also calculated. Results revealed that the mean SPM values during COVID-19 period (4.56 mg/L) were lower than that before COVID-19 period (8.33 mg/L). Surprisingly, SPM showed an increase of 54% in SPM values after COVID-19 period, compared with during COVID-19 period. The role of human activities including industrial and domestic wastes during the restriction period was the main reason for alteration of pollution loads in the river. Outputs of this study can be used to arrange policies for the sustainable management of aquatic environments and water resources.

Keywords: COVID-19; suspended particulate matter; remote sensing; wetland

Abbreviations: COVID-19: 2019 novel coronavirus; LSSR: Large scale social restriction; OLI: Operational land imager; SPM: Suspended particulate matter; LEDAPS: Landsat Ecosystem Disturbance Adaptive Processing System; LaSRC: Land Surface Reflectance Code; NTU: Nephelometric Turbidity unit; RMSE: Root means square error; USGS: United States Geological Survey

1. Introduction

Anthropogenic activities are still the main source liable for deteriorating the water quality, although we have seen many actions to preserve susceptible aquatic and terrestrial ecosystems [1]. In Indonesia, it currently produces around 200,000 tons of waste annually, with only 64% reaching landfills while the remaining goes to the surroundings, including aquatic ecosystems [2]. Downs and Piégay [3] found that combining human activities and climate factors had a negative impact on aquatic ecosystems. In-situ measurements are a common method of assessing water quality, but they are time-consuming and labor-intensive, making it difficult to conduct long-term observations of the aquatic environment [4,5]. Additionally, it calculates only point-to-point information and is not present spatially for the whole water body area [6]. Therefore, the use of remote sensing-based satellite data offers an effective technique for the rapid and simple study of surface water quality. Remote sensing data provides spatial and temporal information about water quality from local to broad scales [7]. Studies of the quality of water bodies using remote sensing methods have been conducted since the Landsat satellites were introduced.

One of the most prominent water quality parameters is suspended particulate matter (SPM) [8]. The SPM is the most ordinary issue in surface water bodies [9]. These suspended particles decrease the effluence of the sun's light for aquatic species. Furthermore, it is a good benchmark for the eutrophication event [10]. The turbidity of a body of water increases as SPM values in water rise [11]. Several factors can affect the turbidity level due to climate shifts, weather changes, and anthropogenic activities [12,13]. Assessment of suspended matter values from satellite images has become a substantial tool for research to predict and observe suspended sediment variation in bodies of water [14–17]. The turbidity in a body of water is evaluated by how SPM values change water characteristics. It is also found that the SPM values or turbidity exhibit a good association with the visible band of the spectrum, while the red and NIR bands are more susceptive to turbidity [18].

The COVID-19 outbreak has become a lethiferous disease worldwide, affecting more than 200 nations [19]. The COVID-19 pandemic deteriorated many countries and severely affected the global economy [20]. The Indonesian government applied a tight restriction policy (known as large-scale social restriction, LSSR) on April 10, 2020, and this policy led to the closure of offices, mobility, educational places, industries, markets, and social activities [21]. This restriction period was extended into several phases till the whole year 2021, which formed a partial restriction period with a tight COVID-19 protocol. Finally, on May 17, 2022, considering a significant reduction of COVID-19 cases in this country, the Indonesian president announced not to wear a mask in outdoor activities.

Numerous studies have found that decreasing water and air pollution improves global environmental quality [22–25]. In Indonesia, some studies reported that air quality improved during the COVID-19 period [26–29]. However, to date, there have been no studies about how the water quality improved in the Indonesian region during the COVID-19 period. Therefore, it will be a novel study to discuss how water quality conditions in Indonesia. In addition, we chose a unique river within a tropical wetland area, which would be different from other existing studies around the world. To identify whether the decrease in human activities during the COVID-19 period resulted in the improved water quality in the Musi River, South Sumatra, Indonesia, the current study employed remote sensing-based satellite data to analyze alterations in the SPM concentration as a water quality benchmark.

2. Materials and methods

2.1. Study area

The river chosen for the present study is a part of the South Sumatra wetland region, in the province of South Sumatra, Indonesia and lies between 2 57'0"N and 3 0'0"N latitudes and 104 42'0"E–104 51'0"E longitudes (Figure 1).

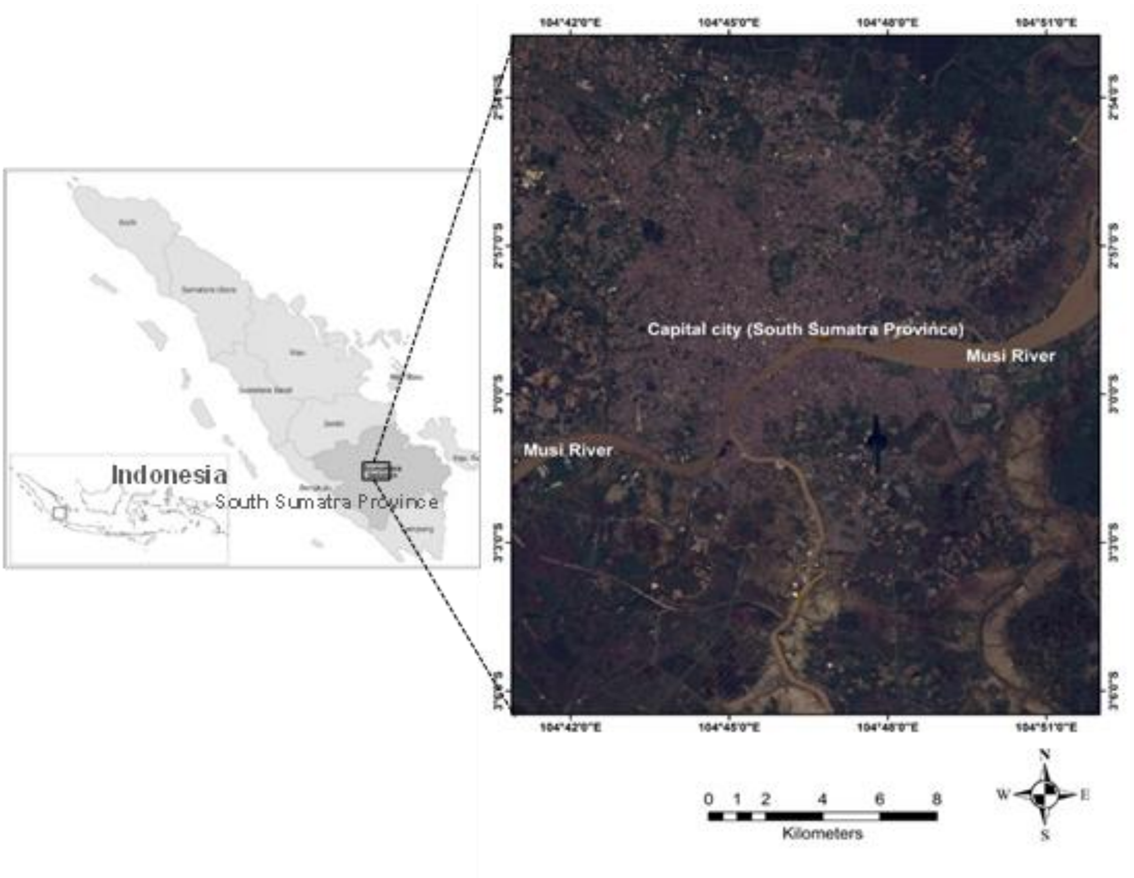


Figure 1. Location of study area.

There are four major kinds of wetlands in South Sumatra, such as tidal swamps, freshwater swamps, lakes, rivers, and peatlands [30]. The Musi River is the primary freshwater contributor to the Musi Estuary. The river flows from southwestern to northeastern, originating from the Barisan Mountains Range that was once a spine of Sumatra Island in Bengkulu Province, to the Bangka Strait and finally flows to the South China Sea. It is approximately 750 km long and becomes the heart of South Sumatra province because it drains most of the South Sumatra region. The water river is used for various needs such as industry, transportation, and households. People used the water for their daily needs, including washing, bathing, and using the restroom directly in the river. Moreover, companies and factories located around the Musi River have contributed to river pollution due to their dumping activities of waste into the river [31]. The annual mean temperature in this region is 24 °C, with the mean annual rainfall of 2,579 mm.

2.2. Data collection and pre-processing stage

In the current study, three Landsat 8 Operational Land Imager (OLI) images of the Musi River area from May 20, 2019 to May 28, 2022 were obtained from the United States Geological Survey (USGS). Table 1 showed the specification of the Landsat 8 satellite images that used in this study. We used the month of May because the COVID-19 restriction policy in the study area was started in that month thus to reduce the bias in selecting the other months, we chose the same month for all periods of study. In this study, all the satellite images downloaded were of level-2 type, meaning that they had a major improvement in the absolute geo-location accuracy of the global ground reference dataset, which enhanced the interoperability of the Landsat archive over time. This level-2 type has also been updated with global digital elevation modeling sources and validation updates. Surface reflectance is used to quantify the proportion of incoming solar radiation that is thrown from the surface of the earth to the Landsat sensor. The Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS) and Land Surface Reflectance Code (LaSRC) surface reflectance algorithms compensate for the spectral, spatial, and temporal effects of atmospheric aerosols, gaseous, and water vapor, which are required to analyze the earth's land surface. Therefore, to obtain surface reflectance values from Landsat 8 level-2 type images, we used a scale factor of 0.0000275 and an additional offset of −0.2 per pixel.

Table 1. Specifications of the Landsat 8 satellite images and the study period.

Product ID	Band used	RMSE	%Cloud	Period
LC08_L2SP_124062_20190520_20200828_02_T1	Band 4 (0.630 to 0.680 μm)	0.087	9.20	2019 (before COVID-19 period)
LC08_L2SP_124062_20200522_20200820_02_T1	Band 4 (0.630 to 0.680 μm)	0.056	8.05	2020 (During COVID-19 period)
LC08_L2SP_124062_20220528_20220603_02_T1	Band 4 (0.630 to 0.680 μm)	0.030	7.56	2022 (After COVID-19 period)

2.3. Suspended particulate matter (SPM) calculation

Based on a prior study, Fachrurrozi [31] measured the turbidity value of the Musi River and reported it varied from 7 to 9 NTU. The NTU is the acronym of Nephelometric Turbidity unit. The specific unit used to gauge the turbidity of water or the suspended matters in water. Furthermore, Trisnaini et al. [32] measured turbidity values in the Musi River around dense areas and found them to be lower than 50 NTU. These studies stated that the turbidity value in the Musi River is below 110 mg/L. Several studies have explained that using a single band for turbidity analysis can obtain a good result if the band is selected in the right way [33,34]. Therefore, the current study applied a SPM algorithm to evaluate the SPM values for water, and it showed good performance when the SPM values were less than 110 mg/L [35]. The SPM is computed by using the red band based on Eq (1) below:

$$\text{SPM} = \frac{A\,\rho w}{(1-\rho w)/B} \tag{1}$$

where A and B are empirical constants: and A = 289.29 and B = 0.1686. ρW is water-leaving reflectance from the red band (655 nm). The empirical constant of A came from the previous study by Nechad et al. [35] that found this value (A = 289.29) gave the best fit to total suspended matter and the subsurface reflectance calculations. While, the empirical constant of B was set to 0.1686 because the satellite sensor and its process would possibly have dissimilar measurement errors from the data calibration. A higher SPM value from the Eq 1 showed more turbid water or dirty water, while the lower SPM value indicated cleaner water. Our study found there was a high association between the SPM and the band ratio of the water-leaving radiances at 655 nm (Figure 2). It could be concluded that the model showed a good performance, with the R-squared of 0.95, the RMSE of 15% and the standard deviation of 2.5 mg/L. The accuracy assessment of this study was carried out using the Pearson's correlation between the satellite-based SPM data and the in-situ SPM measurement. Thus, we have applied the Pearson's correlation coefficient (R^2), mean absolute error (MAE), and root means square error (RMSE) analyses in this study. Our finding obtained the values of R^2 was 0.92, MAE was 0.04, and RMSE was 0.08, indicating a good accuracy.

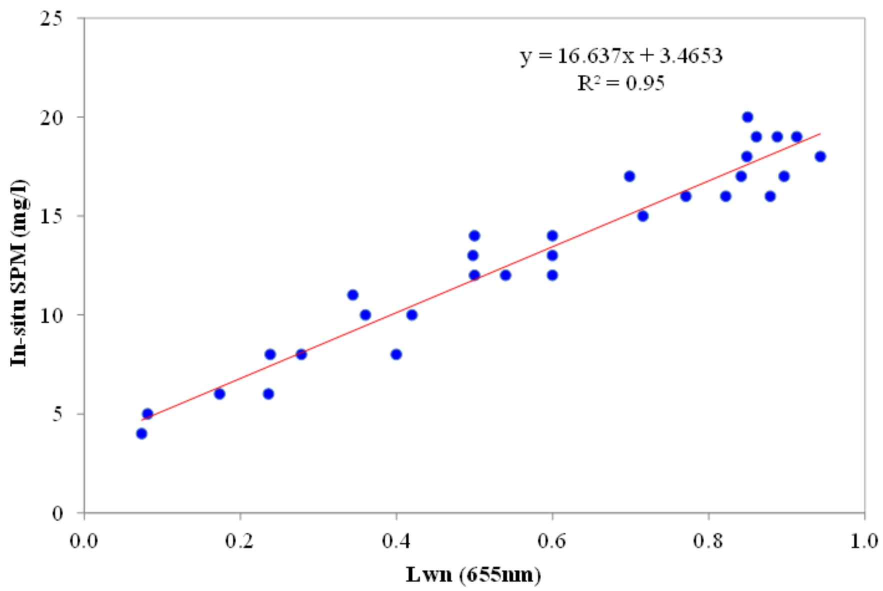
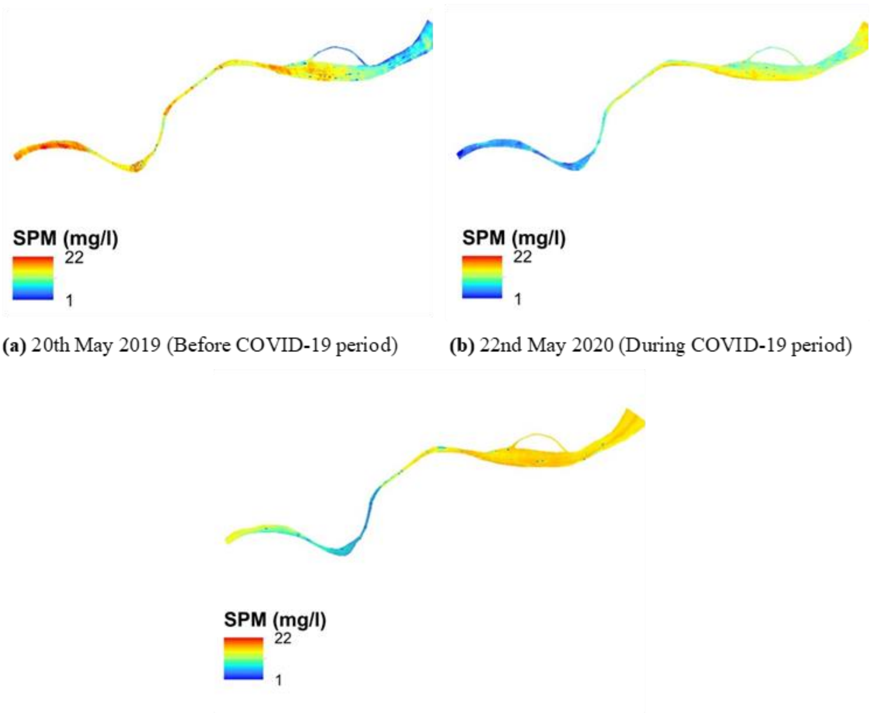


Figure 2. The association between the field-measured SPM concentration and the band ratio of the water-leaving radiance at 655 nm.

3. Results and discussion

The spatial and temporal distribution of SPM values in the Musi River from 2019 to 2022, including before, during, and after COVID-19 periods, was depicted in Figure 3. It could be observed that a reduction in SPM values during the COVID-19 period was found compared to before the COVID-19 period. The dense urban area that mostly located at the middle and downstream areas led to higher number of pollutants entried into the river due to domestic and industrial activities (Figure 3(a)). During the COVID-19 period, the upstream area showed higher SPM values than the downstream area. It might be due to the natural process such as soil erosion at the upstream area. The higher altitude of the upstream area contributed to high risk of soil erosion and especially during the rainfall. In contrast, the downstream area sustained a great reduction due to anthropogenic activities restriction (Figure 3(b)). After the COVID-19 period, the SPM values started to rebound at the same level at before the COVID-19 period, it was shown by the SPM values from the middle to downstream areas gradually increased (Figure 3(c)).

To analyze further the reduction in SPM concentrations of the Musi River, we analyzed the situation of the river around the busy port area before and during the COVID-19 periods using Sentinel-2 data (Figures 4(a),(b)). The result found there was a decrease in vessel traffic along the Musi River. The number of black vessels that carried coal products has been reduced, as have the white vessels that are commonly used as public transport for people. Traffic condition along the Musi River near the main port. Due to the low number of vessels sailed along the Musi River, it would certainly diminish the total discharge of the water pollutants originating from the vessels into the river. This result was consistent with other studies [36].



(a) 20th May 2019 (Before COVID-19 period) **(b)** 22nd May 2020 (During COVID-19 period)

(c) 28th May 2022 (After COVID-19 period)

Figure 3. Changes in SPM values predicted for the Musi River from 20th May 2019 to 28th May 2022. Red color shows higher values of SPM while blue color shows low values.

Effects of inter-monthly and rainfall factors could also contribute to decreases in SPM values, as stated in a study by Moquet et al. [37]. Time series Landsat 8 images from different years but in the same month were chosen, and precipitation data were also evaluated and obtained, no significant difference was found during the study period. This showed that the COVID-19 restriction policy (large-scale social restriction policy) has greatly affected the water quality of the Musi River and significantly reduced the pollution level. Furthermore, the pollution from industrial sources, domestic sources, and other related human activities was less during the COVID-19 restriction policy, and thus it improved the water quality of the river.

(a). Before COVID-19 period (in May 2019).

(b). During COVID-19 period (in May 2020).

Figure 4 Traffic condition along the Musi River near the main port. Black vessels: coal transport, white vessels: public transport.

A comparison of the SPM values in the Musi River in several study periods was tabulated in Table 2. Our results revealed that the highest average SPM values of 8.33 mg/L were observed in May 2019, followed by 2022 (7.06 mg/L) and 2020 (4.56 mg/L). It was recorded that SPM values during the COVID-19 period varied from 1 mg/L to 11 mg/L with an average SPM of 4.56 mg/L, which was lower than before the COVID-19 period. Furthermore, a comparison between the pre-COVID-19 period and the COVID-19 period obtained a reduction of the total average SPM concentration from 8.33 mg/L to 4.56 mg/L (Table 2).

Spatial analysis exhibited that higher SPM values were found in the southwestern area (the most congested areas in the South Sumatra Region). Specifically, this occurred during the year 2019 and then this SPM was decreased during the COVID-19 period in 2020, where this spatial pattern was more concentrated in the northeastern area. We assumed the lower SPM value in the northeastern region during the COVID-19 period, as compared with before the COVID-19 period, might be due to the application of the COVID-19 restriction policy. This might be due to the fact that since it was near to industrial areas, the COVID-19 period resulted in the closure of industrial activities, thus the pollution levels decreased in those areas. A quantitative analysis between mean SPM values of the pre-COVID-19 period and SPM values during the COVID-19 period in the northeastern regions showed a notable reduction in SPM concentrations during the COVID-19 period as compared with the pre-COVID-19 period (Figure 2(a),(b)). In the COVID-19 period, which in this study we took two years interval, we found a substantial increase in SPM concentration of about 54%, as compared with the COVID-19 period (Figure 2(c)). The changes of SPM also associated with other water quality parameters like Cu, As, Fe and Ni metals. It was because the heavy metals were transported together with organic or sediment masses. Suspended sediments brought metals into river flow through runoff event. Surface sediments carried metals from anthropogenic sources into the river. A previous study by Rahutami et al. [38] found there was a linear increase between the SPM with Fe, Cr, and Pb concentrations in the Musi river.

Table 2. SPM values of the Musi River for the study periods.

Date of satellite images	SPM values				Notes
	Min	Max	Average	SD	
20/05/2019	2.67	10.50	7.06	0.71	Before COVID-19 period
22/05/2020	1.03	11.19	4.56	0.67	During COVID-19 period
28/05/2022	3.03	21.83	8.33	1.31	After COVID-19 period

Additionally, heavy metals in water mostly accumulated in the SPM due to direct contact with the water and the precipitation of metal-absorbed [39]. Thus, the SPM is the main process for the deposition of heavy metals in floor sediments. This is a prominent process for the understanding of heavy metals in the water-sediment interface. A study by Helali et al. [40] in the Gulf of Tunis found that heavy metals (Cu, Pb, Fe, and Zn) were primarily caused by commercial and fishing activities. In the Musi river, a previous study by Tjahjono et al. [41] has found that Pb concentration in the water could be associated with the SPM value. The highest SPM value was found in the busy port around the Musi river where the Pb content has exceeded the water quality standard (0.03 mg/L). The concentration of Pb in the water showed that the presence of oil spills due to water activities. Furthermore, the Cd concentration in the Musi river was constant but it still exceeded the quality standard (0.01 mg/L). The high Cd concentration was due to the excessive use of fertilizers around the basin. The correlation analysis based on this study showed a weak correlation between both metals and SPM. But, in another study by Wang et al. [42] which located in the Huanghe River, China, they found a high significant correlation between Pb and SPM ($r = 0.84$, $p<0.01$). It could be assumed that when the SPM was high, dissolved metals were prone to be scavenged via aggregating into compact particles, thus dissolved metals reduced to the sea [43].

Although this study showed lower SPM values than before the COVID-19 period in 2019, there was an increase in the pollution level during that period. This might be due to the fact that the withdrawal of restriction policies in social activities, industrial and commercial sectors has allowed the intrusion of waste into the lake, which changed the pollution loads in the Musi River. Therefore, the restriction of human activities such as commercial and industries has contributed to the reduction of SPM value in the Musi River. Due to the restriction policy and lack of in-situ data, the validation with in-situ data was not carried out in this current work. But our results were comparable with the other studies carried out in Indonesian regions. Because there was a lack of studies in our region discussing the SPM changes during the COVID-19 period, we compared our results with other studies outside the country. For instance, Yunus et al. [44] analyzed the SPM level changes during the lockdown period in Vembanad lake, India and found a 15.9% decrease in SPM compared to before the lockdown period. Another study by Liu et al. [13] also revealed the SPM changes in Min River, China and reported a 48% decrease in SPM. Those above-mentioned results were the same as the outputs of our study. In contrast, Tokatlı and Varol [45] analyzed the water quality changes in the Meriç-Ergene River Basin, Turkey and found no significant differences between before the lockdown and during lockdown periods. This might be due to nonstop agricultural activities and domestic wastewater discharges into the water body during the lockdown period. The agricultural wastes (organic and chemical fertilizers) were the main effluents in the river which located near agricultural areas [46].

Hence, the COVID-19 restriction not only resulted in an increase in water quality but also an improvement in air quality [47]. Several studies revealed air quality parameters such as PM2.5, PM10, SO_2, NO_2, and CO showed major reductions that led to an improvement in the air quality index during lockdown period in Tehran [48], China [49] and Germany [50]. The lower SPM concentrations in the South Sumatera wetland helped to improve the sun light effluence and surely had positive effects on freshwater ecosystems and the environmental condition of the water body. For future studies, the data was extracted from satellite only, and thus it might be hard to obtain accurate data on the physical and chemical properties. Hence, in situ fieldwork was needed to arrange an appropriate management policy to face the COVID-19 pandemic period. Therefore, a study was done to analyze the spatial and temporal data on water quality of the South Sumatera wetland. Despite other human activity factors, the COVID-19 restriction policy in this study area was likely to start a recovery process for the ecosystem. But authorities should give more attention to the alteration of river pollution, which is how this restriction has affected water bodies. Therefore, it was also recommended that this policy could increase the self-recovery of the ecosystems.

4. Conclusions

COVID-19 has become a serious threat to our lives, with more than 150 million people infected and around 3 million deaths announced all over the world in May 2021. Due to the large transmission of COVID-19, many nations implemented a total lockdown with full restrictions on social, economic, industrial, spiritual, schools, and other activities. But on the other hand, this restriction successfully had a good impact on the environment by decreasing air and water pollution. In this recent study, we tried to analyze the impact of the COVID-19 period on the Musi River by using remote sensing and GIS techniques. Even though we could not determine the particular origins of river pollution, the output of this study revealed that water quality (SPM as an indicator) could improve significantly as human activities were diminished. The analysis of the SPM value in Musi River using Landsat 8 images revealed that SPM values during the COVID-19 period (average SPM of 4.56 mg/L) were lower than before the COVID-19 period (8.33 mg/L) and the next two years (average of 7.06 mg/L). Mean reduction of 45% was reported in SPM values during the COVID-19 period compared to before the COVID-19 period. It was also found that after the COVID-19 period with the loosening restriction policy, domestic waste started to enter the Musi River again, which, followed by industrial waste, were the main activities that aggravated the water pollution in the Musi River. As a result, the current study provided important insights into the future management of the Musi River and other wetland and aquatic environments. In addition, the authorities should know about the improved water quality due to the decreased human activities and should arrange an effective action plan for the future Musi River management policy.

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Conflict of interest

Conflict of interest on behalf of all authors. The corresponding author states that there is no conflict of interest.

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