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Original Article

The Impact of COVID-19 Lockdown on People's Mobility and Water Quality of Siak River, Indonesia

Saberina Hasibuan [a], Monalisa Hasibuan [b], Alana Jakob [c]

[a] *Environmental Quality Laboratory, Department of Aquaculture, Faculty of Fisheries and Marine Sciences, University of Riau, Pekanbaru, Indonesia*

[b] *Research and Development of Riau Province, Pekanbaru, Indonesia*

[c] *Environmental Research and Statistics, Jakarta Pusat, Daerah Khusus Ibukota Jakarta, Jakarta, Indonesia*

ABSTRACT

Countries around the world have implemented lockdowns to contain the spread of COVID-19 infection. The impact of lockdown on actual people's mobility and the physical, chemical, biological quality of water have never been analyzed simultaneously. This study aimed to address this gap by monitoring water quality on the Siak River, one of the deepest rivers in Indonesia, characterized by the highest dissolved organic carbon recorded globally due to the contributing peat soils. Human mobility before and after the implementation of nationwide lockdown was quantified using social media data. Sampling was carried out on the Siak River in 2018, 2019, and 2020 at sixteen monitoring locations. The samples were analyzed for physical, chemical, heavy metals, biological quality. Nutrients and heavy metals concentrations indicated that Siak River was medium to heavily contaminated. Lockdown presents an immediate reduction in movement, people's mobility on average was reduced by 33%, to improvements in water quality in terms of NH_4^+, NO_3^- concentrations with a 14% reduction compared to the pre COVID-19 values, and a 30% reduction in heavy metals contamination. The reduction was attributed to decrease farming activities and farm supplies. This was because the Siak River was heavily influenced by dissolved organic carbon from peatland.

Keywords: Environmental health; water health; coronavirus; COVID-19; water quality

INTRODUCTION

In many Asian countries − such as Indonesia − water quality is under severe pressure due to industrial pollution, poor waste management, high population growth, and the lack of wastewater treatment systems for households and industry [1]. Siak River is one of the largest and deepest rivers, has a very important role in supporting community and industrial activities in the Riau province in Indonesia [2]. Siak River also has a high dissolved organic carbon, one of the highest globally, due to the contributing peat soils surrounding the river [3].

The recently COVID-19, Coronavirus has managed to conquer the whole world. After the discovery in December 2019 in Wuhan, more than 220 million infections have already been registered at the end of August 2021, and there are more than 4.5 million people died. In response to the COVID-19 pandemic, many lockdown measures are in place worldwide, and these measures have had many relevant positive effects on the environment. Most studies indicated lockdown had caused an immediate improvement of 10–30% of air quality [4]. However, very few studies explore the effect of lockdown on water quality, especially river quality in densely populated cities [5].

The COVID-19 pandemic has profound consequences for the transport and industry sectors. In many cities, public transport use is in the initial phases of the lockdown has decreased by more than 90%. One of the first studies on the influence of lockdown measures on water quality was from Venice, Italy [6]. The study was based on satellite images

Corresponding author: Saberina Hasibuan, E-mail: saberina.hasibuan@lecturer.unri.ac.id
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of water transparency and turbidity. Another study in India [7] also indicated improved water quality in lake Vembanad due to lockdown based on Landsat satellite images. These studies indicated that the reduction of industrial effluent and water transport improved water transparency. The impact of COVID-19 lockdown on the river's physical, chemical, and biological parameters has not been widely investigated. A recent study reported the impact of lockdown on river water quality in China [5]. They found that lockdown caused a reduction in ammonia immediately, while chemical oxygen demand (COD) and dissolved oxygen (DO) also improved a month later. The Water Quality Index increased to 67.4%. Nevertheless, there is a lack of studies that evaluate river water's physical, chemical, and microbiological quality due to COVID-19 lockdown.

The Siak River is an important river in the province of Riau, south of Sumatra. It is about 300 km long, passing through Pekanbaru, the capital of Riau province, with catchment areas of more than 14,000 km^2 [2]. Siak River serves important ecosystem and economic functions to meet various needs, including water transportation, clean water sources, and business activity centers. Along with efforts to improve the community's welfare, the area's development along the river for various needs (residential facilities, trade & industry, transportation, offices, tourism, and others) have increased rapidly. With the change in land use, the river water quality has also decreased.

Floods, droughts, erosion, sedimentation, and river water pollution are responses to land management in the Siak watershed. Various activities around the Siak watershed produce various kinds of organic and inorganic pollutants that directly or indirectly end in river waters and accumulate in river tributaries. The pollution originating from the community and industrial activities causes serious pollution impacts in the waters of the Siak River. This pollution threatens the life and diversity of organisms the aquatic. Efforts to improve the river quality have been trialed by reducing industrial activities and wastewater management. However, the quality of water has not improved. The lockdown due to the COVID-19 pandemic provided an opportunity on the effect of lockdown and movement activities on the health and quality of the Siak River.

The social and environmental consequences of the lockdown due to COVID-19 measures can be large. For example, people in the transport and industry sector lost their jobs, among other things. However, there are positive environmental effects. While there are qualitative measures or anecdotal observations of the impact of lockdown on people's movement, there is a lack of quantitative data. As Indonesia is one of the biggest users of Facebook, using social media data, this study shows the quantity on the effect of lockdown on people movement. Subsequently, this study can show how this reduced movement and activities by people impacted on water quality can be quantified. Therefore, this study aims to quantify the effect of lockdown on the movement of people in Riau and quantify the effect of lockdown on the water quality of Siak.

MATERIALS AND METHODS

Study area and climate

The Siak River is located in the Riau province in Sumatra, Indonesia (see **Fig. S1**). The Siak River is the deepest river in Indonesia, with a depth of about 20–30 meters. With a length of 300 kilometers, the Siak River passes through four district administration areas and one city, namely Rokan Hulu district, Bengkalis district, Siak district, Kampar district and Pekanbaru City. It has a headstream at Tapung Kiri and Tapung Kanan with a tributary at Mandau [2]. The catchment areas range from the coastal plain to highlands, discharging into an estuary and further into the Indian ocean of Malacca Strait. The river passed through peatlands and characterized by high dissolved organic matter [8,9]. The Siak watershed has an area about 14,239 km^2 which comprises Rokan Hulu: 979 km^2, Kampar 3,589 km^2, Bengkalis: 2,813 km^2, Siak: 6,304 km^2, and Pekanbaru: 553 km^2.

The Siak watershed includes critical watersheds, areas prone to floods and landslides, erosion and siltation, as well as various kinds of pollution. Changes in the Siak watershed ecosystem are indicated by the occurrence of flooding in Riau Province due to the overflow of the Siak River and its tributaries. In addition, the Siak River ecosystem is significantly influenced by population and economic developments, which encourage the development of cultivation areas and settlements.

The climate of the Siak River basin is tropical, classified as Af (tropical humid) according to the Köppen-Geiger system. The capital of Riau, Pekanbaru has a mean annual rainfall of 2,510 mm. The mean temperature is 25°C and remains relatively constant throughout the year. The rain season is roughly divided into dry months (February–August) and wet months (September–January). The wettest month is in November, with an average of 301 mm and relative humidity of 90.5%, while the driest month is July with 131 mm. April has the highest number of rainy days (26 days), while June has the lowest number of rainy days (19 days). The warmest

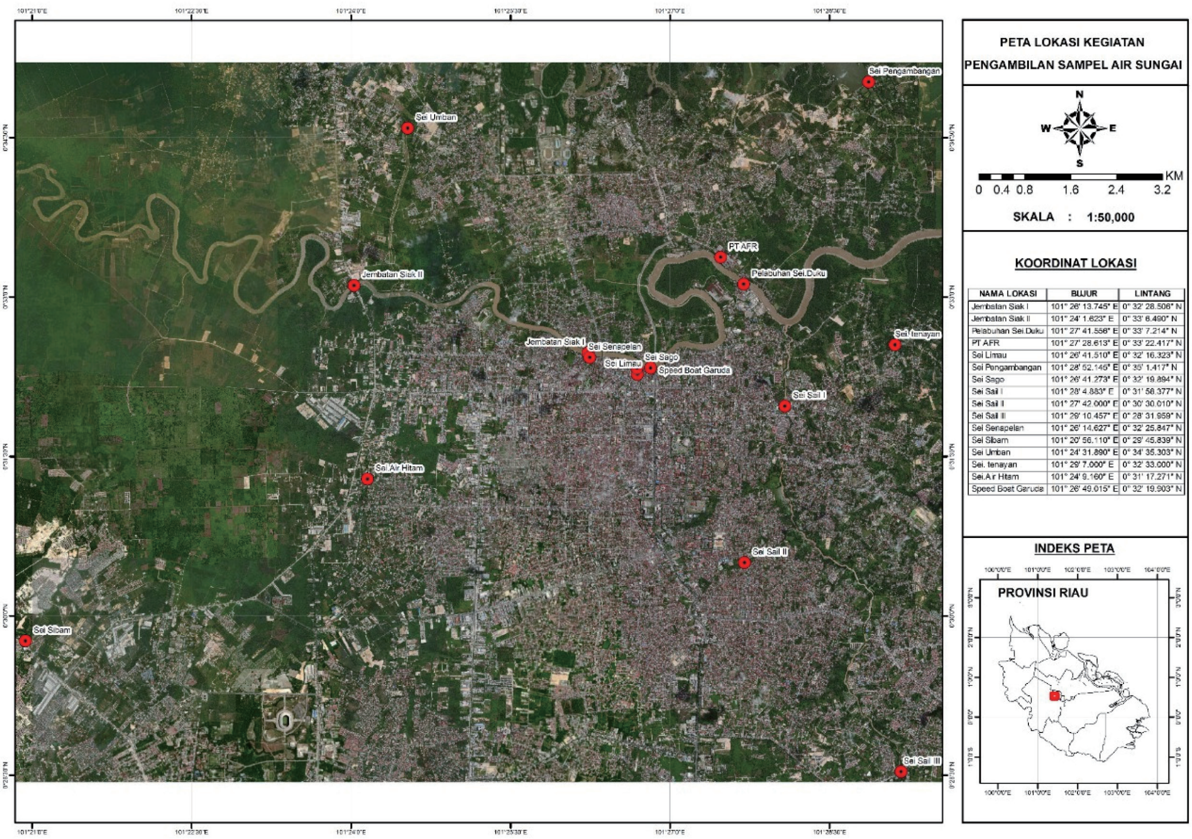

Fig. 1 The location of the sampling points in Siak River.

month occurs in May with an average of 26.5°C.

Mobility of people

Indonesia is one of the highest users of Facebook, with an estimate in January 2020 of 55.4% of its entire population, with the largest users in 18–34 years old (65%). As half of the population uses Facebook, it allows the calculation of the change in movement based on Facebook data collected at the Research Facebook page. The mobility of people was calculated by counting the number of level-16 Bing tiles (about 600 meters by 600 meters) that Facebook registered within a day. The change in Mobility metric was calculated comparing the values pre COVID-19 in February 2020.

Water quality monitoring

Water samples were collected from 12 locations of the Siak River watershed, which passes the city of Pekanbaru (details in **Table S1**). The catchment area of the watershed in Pekanbaru is around 553 km^2 with land use is 59% urban 31% agriculture, 10% forest and shrubs (**Table S2**) [11]. Water sampling was collected twice a year during the wet and dry periods. This study used the same sampling during the April–May period for the years 2018, 2019, and 2020.

A total of 16 location points along the Siak River and its tributaries were monitored, the locations were recorded using a GPS. Five observations points were taken on the main river that passes Pekanbaru: Siak Bridge II, Siak Bridge I waters around PT. Asia Forestama Raya, Pelita Pantai, and Duku river. Samples were taken at 11 tributaries to the Siak River: Siak River I, Siak River II, Saik River III, Sago River, Senapelan River, Air Hitam River, Umban River, Tenayan River, Pengambang River, Limau River, and Sibam River. The location of the sampling points is presented in **Fig. 1**.

The sampling was carried out by taking composite water. The physical and chemical factors of river surface water were measured in situ and ex situ. Observations and measurements of temperature, pH, turbidity and DO were carried out in the field (*in situ*). Water clarity was measured using the Secchi disk, temperature (°C) with a thermometer, pH was measured with a waterproof portable pH meter − HI9124 (Hanna Instruments, Woonsocket, USA), dissolved oxygen (DO, mg L^{-1}) with YSI Pro20 ((Xylem Inc., Rye Brook, USA)). Water samples were collected in a 1 L PET bottle and stored in a

Table 1 Ecological water quality classification (based on Barinova [13]).

Water quality Class	Rank	NH_4^+ mg N L^{-1}	NO_2^- mg N L^{-1}	NO_3^- mg N L^{-1}	PO_4^{3-} mg P L^{-1}	Conductivity, µs cm^{-1}
I-very pure	1	< 0.05	0	< 0.05	< 0.005	< 400
II-pure	2	0.05–0.10	0.001–0.002	0.05–0.20	0.005–0.015	400–700
II-pure	3	0.11–0.20	0.003–0.005	0.21–0.50	0.016–0.030	400–700
III-moderate	4	0.21–0.30	0.006–0.010	0.51–1.00	0.031–0.050	700–1100
III − moderate	5	0.31–0.50	0.011–0.020	1.00–1.50	0.051–0.100	700–1100
IV − polluted	6	0.51–1.00	0.021–0.050	1.51–2.00	0.101–0.200	1100–1300
IV − polluted	7	1.01–2.50	0.051–0.100	2.01–2.50	0.201–0.300	1100–1300
V -very polluted	8	2.51–5.00	0.101–0.300	2.51–4.00	0.301–0.600	1300–1600
V -very polluted	9	> 5.00	> 0.300	> 4.00	> 0.600	> 1600

cool box to transport to the laboratory. For BOD analysis, a glass sample flask was used and sealed airtight and covered with aluminum foil to avoid light penetration. For Coliform analysis, the sample was put into an airtight glass bottle that had been sterilized in an autoclave.

Biochemical water analysis includes total dissolved solids (TDS), total suspended solids (TSS), electrical conductivity (EC), DO, biochemical oxygen demand (BOD), chemical oxygen demand (COD), phosphate, N-nitrate, N-ammonia, N-nitrite, sulfide, detergent, oil and grease. The chemical analyses were analyzed in the laboratory using the method described in [12]. In addition, heavy metals (arsenic, manganese, zinc, chromium, lead, selenium. cadmium, mercury, copper, and iron) were measured using atomic absorption spectrophotometer. The detailed analysis is provided in supplementary material (**Table S3**).

The water quality was ranked according to the ecological classification of [13] based on the NH_4^+, NO_2^-, NO_3^-, PO_4^{3-}, and EC (**Table 1**).

The water quality was also assessed for the degree of pollution of the river in terms of nutrients and metals, the concentrations of nutrients and metals were first normalized by a standard or background value to represent contamination factor (*CF*) [14]:

$$CF = C_{site} / C_{background} \quad (1)$$

where *C* is the concentration of nutrients or metals in water, and it can be used to assess the impact of anthropogenic activities on the river. The background value is difficult to estimate as the river has been polluted, and thus it was estimated based on a regional water study set by Government Regulation no. 82 of 2001 for Class II Water on Water Pollution Control [15]. The background concentration for nutrients and heavy metals is provided in supplementary material.

The pollution related to nutrients (NH_4^+, NO_3^-, NO_2^-, and SO_4^{2-}) were calculated and presented as single pollution indices, the pollution index (*PI*), calculated as:

$$PI = [0.5\ (CF_{average}^{\ 2} + CF_{max}^{\ 2})\ ]^{0.5} \quad (2)$$

where, $CF_{average}$ is the average of measured contaminants *CF* and the CF_{max} is the maximum value among the *CF* values. The same index was calculated for heavy metals (As, Mn, Zn, Cr, Pb, Se, Cd, Hg, Cu, and Fe). The *PI* is classified according to Nemerouw [16]: Unpolluted ($PI < 0.7$), Slightly polluted ($0.7 < PI < 1$), Moderately polluted ($1 < PI < 2$), Heavily polluted ($2 < PI < 3$), and severely polluted ($PI > 3$).

Independent-samples *t*-test was performed to determine the significant difference between pre COVID-19 concentrations and 2020 concentration of water parameters [5]. A significance level of $p < 0.05$ indicated a significant difference. All statistical analyses were conducted using MS Excel and SPPS version 16 (International Business Machines Corporation, Armonk, USA).

RESULTS AND DISCUSSION

COVID-19 lockdown and people mobility

Figure 2 shows the relative change in people mobility from Facebook data with relation to pre-Covid in the Riau province for five districts: Rokan Hulu Regency, Kampar, Bengkalis, Siak, and Pekanbaru. COVID-19 was first discovered in Indonesia in February 2020 and was declared as a pandemic in March 2020. The general policy that requires the public to practice social and physical distancing is apparently challenging to the people who are already accustomed to social gatherings. Lockdown policies are then modified in such a way by various countries and as minimal as possible to affect the economy. The lockdown in Indonesia is called

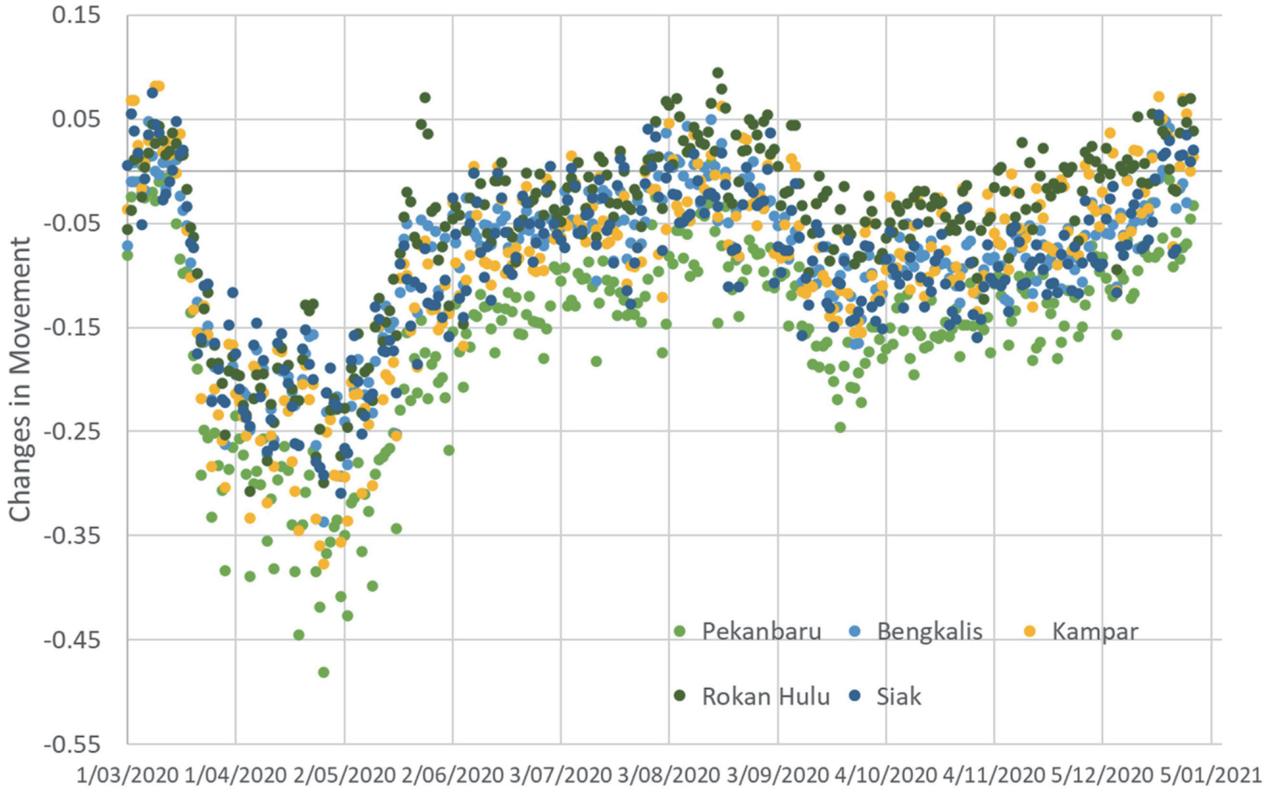

Fig. 2 Changes in movement relative to pre COVID-19 (February 2020) based on social media (Facebook) activities.

Table 2 Change in social mobilities in Pekanbaru dan Siak River regions compared to February 2020.

Month	Pekanbaru		Bengkalis		Kampar		Rokan Hulu		Siak	
	Min	Mean	Min	Mean	Min	Mean	Min	Mean	Min	Mean
Mar-20	-0.384	-0.126	-0.263	-0.077	-0.304	-0.067	-0.253	-0.058	-0.222	-0.056
Apr-20	-0.481	-0.328	-0.337	-0.219	-0.377	-0.255	-0.307	-0.213	-0.292	-0.215
May-20	-0.427	-0.264	-0.293	-0.149	-0.356	-0.184	-0.273	-0.114	-0.309	-0.165
Jun-20	-0.268	-0.149	-0.134	-0.062	-0.168	-0.072	-0.146	-0.039	-0.158	-0.064
Jul-20	-0.183	-0.111	-0.106	-0.041	-0.108	-0.047	-0.063	-0.017	-0.127	-0.039
Aug-20	-0.175	-0.083	-0.083	-0.009	-0.121	-0.022	-0.036	0.034	-0.111	-0.032
Sep-20	-0.246	-0.161	-0.166	-0.094	-0.155	-0.089	-0.097	-0.034	-0.158	-0.092
Oct-20	-0.195	-0.153	-0.137	-0.093	-0.135	-0.084	-0.103	-0.047	-0.159	-0.104
Nov-20	-0.181	-0.135	-0.126	-0.084	-0.131	-0.056	-0.123	-0.024	-0.135	-0.092
Dec-20	-0.157	-0.081	-0.111	-0.034	-0.114	-0.007	-0.095	0.013	-0.116	-0.036

Large-Scale Social Restrictions (PSBB) which is enforced per region, either province or district/city based on the severity of the outbreak determined by the central government through the Ministry of Health. The PSBB implementation rules are regulated through Government Regulation Number 21 of 2020 concerning Large-Scale Social Restrictions. In addition, the rules regarding PSBB are also regulated by the Presidential Decree No. 11 of 2020 concerning the Determination of Public Health Emergency enacted on March 31, 2020. The PSBB officially started on April 15, 2020 and was extended until the end of May 2020. Unlike strict regional quarantine or lockdown, the PSBB still allows economic activity to keep the wheels of the economy running, although there are many restrictions.

Due to this restriction in mobility, many economic activities were reduced. The lockdown caused reduced activities in agriculture, forestry and fisheries sector, industry and manufacturing, trade, transportation. and food hospitality [17]. Farmers faced difficulty in obtaining agricultural inputs, such as seeds, fertilizers, and pesticides. In West Sumatra, it was found that almost half of the farmers have difficulty accessing farm inputs [18]. Because of limited movements, in Java, farmers' income were reduced [19]. The effect of lockdown on disrupting farmers' activities was also reported in India [20] and China [21].

The COVID-19 lockdown caused a disruption in most economic activities in Indonesia. People in the office job were asked to work at home while many workers and laborers cannot work causing a loss of income and reduced purchasing ability. The worst hit was the industry sector which experienced a drastic decline in sales which made many companies to lay off employees, and in many cases went bankrupt [17]. The lockdown also has a negative impact on the social environment of urban people, which caused a decline in social interactions, gatherings, and community meetings [22].

Siak River quality

The water quality collected in 2020 was compared to the mean of water quality collected in 2018 and 2019 as a baseline (pre COVID-19 outbreak) to quantify the effect of lockdown and reduced social movement. In addition, the data were collected at the same period in the year and thus less affected by seasonality. Water quality of Siak River as an average of 16 observations along the river (**Table 3**).

Physical parameters

The Siak River is characterized by a high load of TSS. Suspended solids are organic and mineral particles that are suspended in water leached from the land. The TSS in Siak River was in the range of 12–275 mg L^{-1}(**Table 3**). The TDS in the Siak range from 5 to 21 mg L^{-1}. The TDS and TSS of the Siak River in 2020 were 80.6 and 12.9 mg L^{-1} with an EC of 149.5 µS cm^{-1} and turbidity of 6.2. Although the mean indicated a 12–30% increase in the physical parameters, there was no significant difference in the values of physical parameters (TSS, TDS, EC, and turbidity) between pre COVID-19 (2018 and 2019) and 2020. The physical parameters are due to the environment that is not easy to modify.

Chemical parameters

The pH of the river was 6.4 pre COVID-19 and 6.2 in 2020, with no significant difference (**Table 3**). DO was 5.9 mg L^{-1} in 2020 and not significantly compared to the previous years. BOD and COD are two main river pollution indexes. BOD is the amount of oxygen required to decompose organic matter under aerobic conditions, while COD is the amount of oxygen required to oxidize all organic matter. The threshold of BOD and COD in Indonesia are 3 and 25 mg L^{-1} and the Siak River levels are much higher (39 and 183 mg L^{-1}, respectively). The main reason is that the Siak River passes through surrounding peat soils with high dissolved organic matter (DOM) [23]. These measurements showed that there are clear indications that the river is polluted by an accumulation of organic materials. These locations are also associated with the various discharge points of domestic wastewater and discharges from industry (high BOD and COD levels are measured in the river).

The nutrient contents showed a significant reduction after lockdown compared to previous years. In particular, N-nitrate, N-nitrite, and N-ammonia concentrations in 2018–2019 (1.180, 0.033, and 0.338 mg L^{-1}) were considered moderately polluted. After lockdown, their concentrations were reduced by 19–29%. Especially nitrate and ammonia reductions were statistically significant ($p < 0.01$). According to the ecological water quality [13], the nitrate and ammonia concentrations pre COVID-19 were ranked 5 (1–9 category) and during the lockdown, the quality increased to rank 4 (see **Table 1**). Ammonia and nitrate level was considered high with a contamination factor (*CF*) of 1.18 and 1.69 pre COVID-19. The CF reduced to 0.89 and 1.21, respectively, in 2020, indicating ammonia was still high (**Table 3**).

Nevertheless, the decrease of other nutrients such as phosphate and sulfide was not significant. An overall nutrient concentration was significantly reduced at −14% ($p = 0.02$). Nitrogen and phosphate are essential ingredients in fertilizers that farms use to increase production. Nitrate concentrations in the river are mainly fed from agricultural areas. Nitrate concentrations in the river decreased and the quality of surface water has improved. Lockdown caused some farmers to reduce farming activities. In addition, farmers have difficulty accessing seeds, chemical fertilizers, pesticides, labor, and agricultural tools. The implementation of a lockdown policy disrupted farmers' ability to access farm inputs. A similar condition to farmers in China was also reported [21].

Considering the pollution index (*PI*) for all nutrients, the pre COVID-19 level *PI* was 1.243 (moderately polluted) and in 2020, the *PI* decreased 21% to 0.976 (slightly polluted) ($p < 0.05$) (**Table 3**).

Heavy metals are chemical compounds widely used in industry and leached to the river [23,24]. Manganese, copper, and iron were the highest metal pollutants in the Siak River with a contamination factor (*CF*) of 1.2, 1.4, and 7.4

Table 3 Water quality of Siak River as an average of 16 observations along the river.

Parameters	Units	Mean values 2018 and 2019	Mean values 2020	Mean difference (2020-2018) (%)	p-value
Physical					
TDS	mg L^{-1}	68.9	80.6	16.9	0.630
TSS	mg L^{-1}	11.0	12.9	17.0	0.298
EC	µS cm^{-1}	113.6	149.5	31.6	0.417
Turbidity	NTU	5.5	6.2	12.2	0.580
Biochemical					
pH		6.4	6.2	-2.9	0.093
DO	mg L^{-1}	5.7	5.9	2.7	0.312
BOD	mg L^{-1}	38.8	33.5	-13.6	0.252
COD	mg L^{-1}	183.2	153.1	-16.4	0.192
Nutrients					
Total Phosphate	mg L^{-1}	0.098	0.086	-12.2	0.523
N-Nitrate	mg L^{-1}	1.180	0.895	-24.2	0.007
N-Ammonia	mg L^{-1}	0.338	0.241	-28.7	0.003
N-Nitrite	mg L^{-1}	0.033	0.027	-18.7	0.085
Sulfide	mg L^{-1}	0.016	0.015	-6.0	0.312
Detergent	mg L^{-1}	0.094	0.102	9.2	0.617
Oil and grease	mg L^{-1}	2.036	1.982	-2.7	0.794
Total Nutrients	mg L^{-1}	3.124	2.690	-13.9	0.021
PI nutrients		1.243	0.976	-21.5	0.005
		Moderately polluted	Slightly polluted		
Heavy Metals					
Arsenic	mg L^{-1}	n.d.	n.d.		
Manganese	mg L^{-1}	0.018	0.013	-28.2	0.010
Zinc	mg L^{-1}	0.020	0.015	-23.3	0.000
Chromium	mg L^{-1}	0.007	0.006	-19.5	0.099
Lead	mg L^{-1}	0.007	0.005	-23.9	0.009
Selenium	mg L^{-1}	n.d.	n.d.		
Cadmium	mg L^{-1}	0.005	0.003	-46.4	0.002
Mercury	mg L^{-1}	n.d.	n.d.		
Copper	mg L^{-1}	0.014	0.011	-25.6	0.000
Iron	mg L^{-1}	0.740	0.517	-30.1	0.007
Total metals	mg L^{-1}	0.802	0.563	-29.7	0.004
PI metals		4.215	2.998	-28.9	0.006
		Severely polluted	Heavily polluted		
Microbiologicial					
Coliform	MPN	5859	5781	-1.3	0.467
E. coli	MPN	1112	976	-12.2	0.573

before COVID-19. In 2020, the *CF* of the three metals reduced to 0.88, 1.05, and 5.17. Other metals such as As, Zn, Cr, Pb, Se, Cd, and Hg were low in concentration and did not present a risk. After lockdown, the heavy metals contamination reduced, especially Mn, Zn, Pb, Cd, Cu, and Fe. Overall, the heavy metals were reduced by 29.7% ($p < 0.05$). Pre COVID-19, the pollution index (*PI*) was 4.21 (severely polluted) and in 2020, the *PI* was reduced to 2.99 (heavily polluted). While there was a decrease, the river was still heavily contaminated. This reduction of heavy metals could be attributed to the reduced industry and manufacturing industries along the Siak River, such as pulp and paper, oil palm factories, crumb rubber, and plywood [17].

Microbiological parameters

The Siak River recorded an average of 5,859 for coliform and 1,112 for *E. coli*, which are considered very high and not suitable for drinking. Nevertheless, there was no significant difference in microbiological parameters pre COVID-19 and 2020. The microbiological parameters could be due to household activities do not change during lockdown.

Overall results

The results of this study support the hypothesis that lockdown reduced mobilities and improved the quality of river water. This study presents findings as a first step to investigate the current reference situation of water pollution in Indonesia. There are three key findings of the present research. First, the lockdown imposed by the government had an immediate effect on the reduction of the mobility and activities of people in Pekanbaru. A mean of 33% reduction in mobility was observed a month after the lockdown was announced. Second, compared to the pre COVID-19 monitoring round (2018–2019), there were improvements in water quality in terms of nutrients (NH_4^+ and NO_3^-) with 14% reduction and 30% reduction in heavy metals (Mn, Zn, Pb, Cd, Cu, and Fe). Third, expected changes in the organic pollution regime (e.g., oxygen concentration, BOD, and COD) were not proven. Whereas a study in China [5] found lockdown improved chemical oxygen demand (COD) and dissolved oxygen (DO), the present study did not find such evidence. This is because the Siak River has an inherent high dissolved organic matter due to peat soils [23,24]. A previous study [3] measured 1.942 mmol L^{-1} or 23 mg L^{-1} of DOC or 46 mg L^{-1} of DOM in the Siak River. Thus, the effects of lockdown on nutrient loads are very sensitive to river basin characteristics. In addition, biological changes due to lockdown are minimal [25].

These results represent the first direct demonstration of the influence of lockdown is most prominent for nutrients and heavy metals concentration [26]. Although the present results clearly support the hypotheses, it is appropriate to recognize several potential limitations. Primarily there are temporal water quality variations that cannot be controlled, such as weather and water flows. However, the study compared past monitoring data conducted at a similar period, minimizing this effect. Nutrient concentrations are expected to increase again after lockdown is relaxed. The quality of the Siak River water will also often remain insufficient. Nitrate, other nitrogen compounds, and phosphate cause undesirable environmental effects in the majority of surface waters. The nitrogen and phosphorus concentrations in the water have a major influence on flora and fauna in the river [27–29].

The results imply that the improvements in water quality resulting from measures taken in response to COVID-19 pandemic are limited. The nitrate and ammonia concentrations in the water are related to reduced plantation and agricultural activities, while the heavy metals are related to reduced industrial activities. These data have some potential intervention implications. As the impact of environmental management is still not optimal, water pollution in the Siak River will continue to occur and lead to a more significant river water quality decline. So far, the Siak watershed has been very useful for various purposes such as industry, settlements, agriculture, fisheries, and transportation [30]. River water damage and pollution will eventually make the river function reduced. Current challenges in the upstream include illegal logging; in the midstream is domestic waste, and downstream is industrial waste and housing. Much work remains to be done to continue the monitoring before a complete understanding of the extent of reduced activities on water quality can be established.

CONCLUSIONS

The concentrations of nutrients and heavy metals in Siak River show that it was considered medium to heavily contaminated. Lockdown due to COVID-19 pandemic presents an immediate reduction in mobility, particularly in April in Pekanbaru, movement on average was reduced 33%. This reduction in activities translated to improvements in water quality in NH_4^+ and NO_3^- with a 14% reduction compared to the pre-COVID-19 monitoring round (2018–2019). There was also a 30% reduction in heavy metals (Mn, Zn, Pb, Cd, Cu, and Fe) contamination. The results show a good first indication of the influence of lockdown on water quality. However, this analysis is preliminary, and little changes in water quality related to DO, BOD, and COD as they are inherently difficult to change. The results of the study would be valuable for researchers in environmental quality evaluation, and the methods applied can also be used for pollution assessment in other environments. We hope that the current research will stimulate further investigation of this vital area. Examining the relationship between lockdown and water quality and its consequences for water management context further is recommended.

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SUPPLEMENTARY MATERIALS

Supplementary Materials file for this article is available at the link below.

https://www.jstage.jst.go.jp/article/jwet/20/3/20_21-084/_supplement/_download/20_21-084_1.pdf

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