Global Journal of Environmental Science and Management
(GJESM)

Homepage: https://www.gjesm.net/

Podcasts

ORIGINAL RESEARCH PAPER

Environmental assessment of river water quality near oil and gas fields

A.S. Patimah[1], A. Prasetya[2], S.H.M.B. Santosa[3,*]

[1] *Department of Environmental Science, Postgraduate School of Gadjah Mada University, Yogyakarta, Indonesia*

[2] *Department of Chemical Engineering, Faculty of Engineering, Gadjah Mada University, Yogyakarta, Indonesia*

[3] *Department of Geographic Information Science, Faculty of Geography, Gadjah Mada University, Yogyakarta, Indonesia*

ARTICLE INFO

Article History:
Received 24 June 2022
Revised 03 September 2022
Accepted 20 October 2022

Keywords:
Agriculture
Oil and gas industry
Pollution index
River water quality

DOI: 10.22034/gjesm.2023.02.07

ABSTRACT

BACKGROUND AND OBJECTIVES: The research aimed to evaluate the water quality of the Cangkring River in Tuban Regency, East Java Province, Indonesia, at the segment near the oil and gas fields (Mudi Pad A, B, and C).

METHODS: Water samples were collected from January to September 2021 at seven locations along the river segment and tested ex-situ using six parameters, including physical, chemical, and microbiological. The pollution index formula was used to calculate, determine, and analyze the river water quality status. Samples at three locations were further tested with 13 additional chemical parameters due to potential contamination by other substances as they were located the closest to the production site and office area.

FINDINGS: Sample analysis with six parameters showed a pollution index value of 0.558 or within the predefined standard at one location (SW6) and 1.080–2.721 at the other six locations, indicating slight pollution. Another test at three selected locations (i.e., SW1, SW2, and SW7) with 13 additional parameters increased the pollution index to 5.556–6.170 (moderate pollution). This status change was due to the high presence of nitrite and ammonia in the water samples.

CONCLUSION: The oil and gas industry near the Cangkring River has strictly complied with the regulations in treating their produced water. However, it still contains a high amount of nitrite and ammonia, moderately polluting the river water. Therefore, it is necessary to regularly test the river water near oil and gas fields to ensure its quality and safety.

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
38	1	7

*Corresponding Author:
Email: *sigit.heru.m@ugm.ac.id*
Phone: 0000-0002-6821-6364
ORCID: +62811 470 6027

Note: Discussion period for this manuscript open until July 1, 2023 on GJESM website at the “Show Article”.

INTRODUCTION

Environmental pollution is often linked to the growth of economic activities and industrialization (Carvalho *et al.,* 2018; Tran *et al.,* 2019; Nasrollahi *et al.,* 2020). Manufacturing and mining industries are the primary economic sectors in the Asian region that generate different types of pollutants. Industrial activities have been known to contaminate rivers around the business district (Vu *et al.*, 2017; Li *et al.*, 2019; Hoang *et al.*, 2020), including those of the oil and gas sector that potentially diminish the water quality near and downstream of its operational areas. For instance, crude oil extraction brings water to the surface, termed produced water (PW), which constitutes more than 80% of the total wastewater (Bagheri *et al.*, 2018) and contains hydrocarbons and their derivatives. PW is often discharged into the ocean from offshore operations (Jepsen *et al.*, 2018), which can pollute the marine environment, a problem frequently caused by the oil and gas industry that should be handled seriously (Carpenter, 2019). Similarly, on-shore operations often release PW into rivers (McLaughlin *et al.*, 2020). Introducing pollutants into a river can have vast adverse impacts on the ecology and the surrounding communities that depend on its water and many other benefits (Khan and Zhao, 2019). Therefore, PW and other domestic wastes generated by the oil and gas industry should meet a certain standard of quality prior to disposal or reuse (Patimah *et al.*, 2022). According to many previous studies, PW can be utilized to irrigate food crops and other agricultural plants on dry terrains (Echchelh *et al.*, 2018; Sedlacko *et al.*, 2019; McLaughlin *et al.*, 2020). For this purpose, PW is commonly treated using produced water reinjection (PWRI) by adsorption (Costa *et al.*, 2022). However, this method can damage the reservoir formations if it is not conducted carefully and in compliance with the procedures (Liang *et al.*, 2018). It is necessary to be vigilant even when existing processing technologies and processes have been shown to meet the quality criteria, mainly because PW is generated daily in a large volume and can thus endanger the ecosystem around the production area (Ganiyu *et al.*, 2022). PW management requires a structured framework and a risk-based strategy and incorporates various issues, including environmental, technical, and financial (Ghafoori *et al.*, 2022). In some cases, it solely relies on the most cost-efficient alternative (Sabie *et al.*, 2022). Subpar management practices can reduce soil fertility, microbial diversity, agricultural yields (Miller *et al.*, 2020), and lead to river pollution. Therefore, river segments near and downstream of oil and gas fields should be regularly inspected to ensure the water quality standard is met. The water quality index (WQI) is often proposed to estimate and monitor water quality (Aliyu *et al.*, 2019; Lkr *et al.*, 2020). However, because the quality standards vary across countries and purposes, the estimation method should refer to or be adjusted to local government regulations (Costa *et al.*, 2022). For instance, in Indonesia, one of the techniques used to assess river water quality is the pollution index (PI), as outlined in the Decree of the Minister of the Environment No. 115 of 2003 (Hamuna and Tanjung, 2021; Wikurendra *et al.*, 2022). This study primarily aimed to evaluate the river water quality using PI. Samples were collected along the Cangkring River segment near the Mudi Field in 2021. It is one of the locations in Tuban, East Java, Indonesia, where the oil and gas industry operates.

MATERIALS AND METHODS

Bengawan Solo River and one of its tributaries, Cangkring River, run close to the Mudi Field, an oil and gas exploration site in Tuban Regency, East Java Province, Indonesia. The field lies between 7° 04'41" and 7° 08'45"S and between 111° 57'02" and 111° 59'46"E (Fig. 1). It is about 32 km from Tuban Regency and 101 km from Surabaya City, the capital of East Java Province. Tuban has two seasons during which various disasters have been reported: drought and forest fires in dry seasons and floods and landslides in multiple places in rainy seasons (Rustinsyah *et al.*, 2021). It is one of the regencies in the province that relies on agricultural commodities, and the livelihood of its people is mostly in the farming sector (Widiatmaka *et al.*, 2016).

Water sampling

Samples were collected from January to September 2021 at several points along the Cangkring River segment near the oil and gas production site (Mudi Pad B) and the office areas (Mudi Pad A and Mudi Pad C) (Fig.1). The sampling points were selected based on their turbidity level and their position relative to potential sources of pollutants. Different hypotheses were formulated for each point so that the data obtained could describe the entire study area. Table 1 describes the condition and the hypothesis of each sampling location.

Test parameters and quality standards

The water samples collected at seven points were tested ex-situ at the Hydrology Laboratory, Gadjah

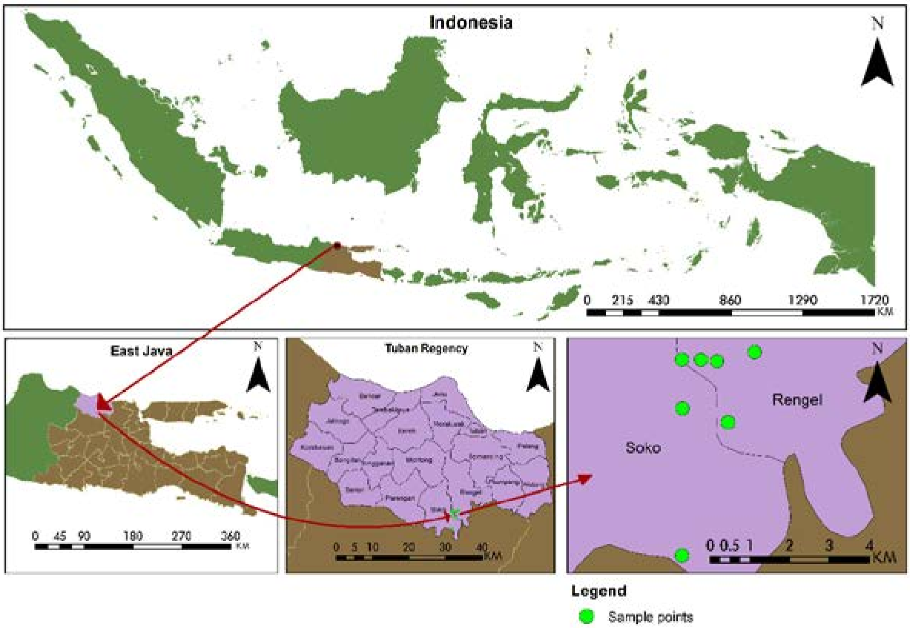

Fig. 1: Geographical location of the Cangkring River, Indonesia, along with the seven sampling points

Mada University, Yogyakarta, Indonesia. The primary characteristics used to gauge the water pollution level were total dissolved solids (TDS), total suspended solids (TSS), biological oxygen demand (BOD_5), chemical oxygen demand (COD), oil and grease, and total coliform, on which the test parameters were based. Three of the seven sampling points, namely SW1, SW2, and SW7, were in direct contact with Mudi Pad B (oil and gas production site) and were assumed to have a higher pollution potential than other points. Thirteen additional organic chemical parameters, including pH, nitrate, nitrite, chloride, sulfate, ammonia, phosphate, detergent, hexavalent chrome, cadmium (Cd), lead (Pb), zinc (Zn), and copper (Cu), were tested at these points. Table 2 summarizes the test parameters, units of measurement, and standards or requirements for the river water quality. These parameters were assessed using specific methods according to applicable laws and regulations (MLHK, 2016). All parameter values were compared against their respective quality standards for class III purposes according to Government Regulation Number 82 of 2001 because the Cangkring River was designated for agricultural activities. Water quality standards measure the highest amount or level of substances, energy, living organisms, or other components a body of water can tolerate without changing its desired condition for specific utilization.

Calculation of the pollution index value

According to the ministerial decree, PI is a method used to assess the river water quality in Indonesia (Hamuna and Tanjung, 2021; Wikurendra *et al*., 2022). It calculates the pollution level of a water body in relation to water quality parameters measured directly in the field or assessed in the laboratory using collected water samples (Martinus *et al*., 2018; Suriadikusumah *et al*., 2021). However, unlike the water quality index, PI is produced to inform about the designated uses of one segment or the entire body of water (Effendi *et al*., 2015). In other words, it decides the water quality status for a specific purpose (Ikhsan *et al*., 2021) and lays the groundwork for improving water quality due to high pollutant content (Rahmatillah *et al*., 2021).

Following the ministerial decree, the pollution index (PI) was used to generate and analyze the water quality parameter values at each sampling point in the Microsoft Excel program. In this study, the PI value was calculated using Eq. 1 (MNLH, 2003).

$$PI_j = \sqrt{\frac{\left(\frac{C_i}{L_{ij}}\right)_M^2 + \left(\frac{C_i}{L_{ij}}\right)_R^2}{2}} \quad (1)$$

Table 1: Water sampling locations and tested hypotheses

Sampling location	Information
Point 1 (SW1)	- Near Mudi Pad B, upstream of the oil and gas production site - The water flows to point 2 (SW2) - Selected to determine the river's water quality before traversing Mudi Pad B, assumed to be the source of pollutants
Point 2 (SW2)	- Near Mudi Pad B, downstream of the oil and gas production site - Water flows from point 1 (SW1) to point 6 (SW6) - Selected to determine the river's water quality after traversing Mudi Pad B. Hypothesis: pollution has occurred at this point
Point 3 (SW3)	- Just upstream of Mudi Pad A (the industry's office area) - Water flows to point 5 (SW5) - Selected to determine the river's water quality before traversing Mudi Pad A, assumed to be the source of pollutants
Point 4 (SW4)	- The outlet of the Cangkring River, before it meets the main river (Bengawan Solo) - Selected to determine the river's water quality before entering Bengawan Solo River, with the assumption that the water is slightly polluted because it is connected to several other water sources
Point 5 (SW5)	- Near Mudi Pad A, just downstream of the oil and gas production site - The water flows from point 3 (SW3) and traverses Mudi Pad A before reaching this point - Selected to determine the river's water quality after flowing through Mudi Pad A. Hypothesis: pollution has occurred at this point
Point 6 (SW6)	- Downstream of Mudi Pad B and upstream of Mudi Pad C, but this point also receives water from other sources. - Water flows from point 2 (SW2) to point 7 (SW7). - Selected to study the conditions around Mudi Pad B (production site) and Mudi Pad C (office area), fed by other water sources assumed to be slightly polluted
Point 7 (SW7)	- Downstream of Mudi Pad C (office area) - Water flows from point 6 (SW6) - Selected to determine the river's water quality after traversing Mudi Pad C. Hypothesis: slight pollution has occurred at this point

Where, L_{ij} is the maximum allowable concentration of water parameter (i) for designated use (j), C_i is the value of the water parameter (i) based on the test results, PI_j is the pollution index for designated use (j), *M* on C_i / L_{ij} is the highest value, and R on C_i / L_{ij} is the average value.

The level of damage or water pollution is difficult to determine if two C_i / L_{ij} values are close to the reference value (1.0), e.g., C_1 / L_{1j} = 0.9 and C_2 / L_{2j} = 1.1, or if they are substantially different, e.g., C_3 / L_{3j} = 5.0 and C_4 / L_{4j} = 10.0. The points below should be considered in solving these problems:

1) If C_i / L_{ij} < 1.0, then the PI is the same as the measurement result

2) Suppose C_i / L_{ij} > 1.0. In that case, $(C_i / L_{ij})_{New}$ is calculated using Eq. 2 (MNLH, 2003). *P* is a constant, and its value can be flexibly chosen depending on the results of environmental observations and the intended criteria for a designated use. The commonly used *P* value is 5.

$$\left(\frac{C_i}{L_{ij}}\right)_{New} = 1.0 + P.log\left(\frac{C_i}{L_{ij}}\right) \quad (2)$$

The derived PI values were then converted into water quality status, which indicates if a body of water is suitable for a particular purpose or polluted at a predefined time (MNLH, 2003). Table 3 classifies the status into four: good condition for PI smaller than 1, slight, moderate, and heavy pollution for PI larger than 1. Each water quality parameter directly correlates to and strongly influences the PI value.

RESULTS AND DISCUSSION

River water quality

Table 4 shows the water quality test results of the Cangkring River between January and September 2021. Seven water samples were collected from different sites along the river segment near the oil and gas production site and office areas and analyzed using six physical, chemical, and microbiological parameters (see Table 2). The two physical parameters, TDS and TSS, were 146–682 mg/L and 12–36 mg/L, or below the upper threshold of 1,000 and 400 mg/L for class III purposes. TDS is influenced by several anthropogenic and natural activities on the surface, while TSS is

Table 2: Test parameters and their maximum allowable presence (MLHK, 2016)

No	Parameter	Abbreviation	Unit	Quality standard for class III**	Sample water (SW)
	Physical				
1	Total dissolved solids	TDS	mg/L	1,000	1–7
2	Total suspended solids	TSS	mg/L	400	1–7
	Chemical				
3	Five-day biological oxygen demand	BOD_5	mg/L	6	1–7
4	Chemical oxygen demand	COD	mg/L	50	1–7
5	Power of hydrogen*	pH	-	6–9	1, 2, 7
6	Nitrate*	NO_3^-	mg/L	20	1, 2, 7
7	Nitrite*	NO_2^-	mg/L	0.06	1, 2, 7
8	Chloride*	Cl	mg/L	600	1, 2, 7
9	Sulfate*	SO_4	mg/L	400	1, 2, 7
10	Ammonia*	NH_3^-N	mg/L	0.5	1, 2, 7
11	Phosphate*	PO_4^{3-}	mg/L	1	1, 2, 7
12	Detergent*		mg/L	0.2	1, 2, 7
13	Chromium hexavalent*	Cr^{6+}	mg/L	0.05	1, 2, 7
14	Cadmium*	Cd	mg/L	0.01	1, 2, 7
15	Leads*	Pb	mg/L	0.03	1, 2, 7
16	Zinc*	Zn	mg/L	0.05	1, 2, 7
17	Copper*	Cu	mg/L	0.02	1, 2, 7
18	Oil and grease		mg/L	1	1–7
	Microbiological				
19	Total coliform		Σ/100 mL	10,000	1–7

*additional organic chemical parameters
**per the Decree of the Indonesia Minister of Environment Number 115 of 223

determined by plant roots and their role in nutrient adsorption, dust distribution from the air, and root decomposition (Suriadikusumah *et al.*, 2021). The chemical parameters tested were BOD_5, COD, and oil and grease contents. BOD_5 values varied widely from 1.70 to 20.60 mg/L. SW1, SW4, SW5, and SW7 had BOD_5 above its maximum allowable presence for class III purposes. Moreover, SW7 had the highest BOD_5 of 20.6 mg/L or three times greater than the upper limit. The cause is impurities from agricultural and domestic waste disposed of into the river. On the contrary, the COD values of all the points were below the upper limit. Nevertheless, there is a linear relationship between COD and BOD_5 (Qi *et al.*, 2021). The next chemical parameter was oil and grease content, which exceeded its maximum allowable presence at SW1, SW2, and SW3. The only microbiological parameter tested in this study was total coliform, and the results showed that it was below the upper threshold of 10,000 per 100 mL at all the sampling points. Based on the physical and microbiological parameter values, the Cangkring River segment near the oil and gas production site and office

Table 3: Water quality status based on pollution index values (MNLH, 2003)

PI_j Score	Water quality status
$0 \le PI_j \le 1.0$	Good condition (the quality standards are met)
$1.0 < PI_j \le 5.0$	Slight pollution
$5.0 < PI_j \le 10.0$	Moderate pollution
$PI_j > 10.0$	Heavy pollution

Table 4: Water quality test results of the seven samples along the Cangkring River segment near the oil and gas production site and office areas in Tuban

No.	Parameters	Unit	Quality standards for class III	Parameter values						
				SW1	SW2	SW3	SW4	SW5	SW6	SW7
1	TDS	mg/L	1,000	146.00	170.00	268.00	506.00	430.00	457.00	682.00
2	TSS	mg/L	400	13.00	13.00	13.00	24.00	20.00	25.50	36.00
3	BOD_5	mg/L	6	6.53	4.60	1.70	9.70	7.40	4.30	20.60
4	COD	mg/L	50	17.38	13.95	12.31	14.20	11.00	7.80	36.70
5	Oil and grease	mg/L	1	1.60	1.60	1.60	0.80	0.40	0.50	0.80
6	Total coliform	/100 mL	10,000	2,400	2,400	1,100	3,600	2,200	850	8,000

areas still meets the water quality standards and is thus suitable for supplying agricultural irrigation water. However, the chemical conditions put a limit to this purpose because the upper thresholds were exceeded at SW1, SW2, and SW7, which were close to Mudi Pad B (production site). Of the seven points, SW6 is the only location whose parameter values were below their respective maximum allowable presence. It is located between Mudi Pad B (production site) and Mudi Pad C (office area) and receives water from other sources.

Additional testing of chemical parameters

Because the BOD_5 and oil and grease content at SW1, SW2, and SW7 exceeded their maximum allowable presence for class III purposes, the three points were further tested using 13 additional organic chemical parameters. Their selection for the additional test was also based on their proximity to the potential sources of pollutants. SW1 and SW2 were in direct contact with the oil and gas production site Mudi Pad B, while SW7 was located between Mudi Pad B and the office area Mudi Pad A. In addition, they had a higher pollution potential than the other four sampling points, and SW7 had a slightly higher value than the rest for some parameters. Of the 13 additional parameters, the nitrite, ammonia, and phosphate concentrations exceeded their respective upper limits for class III purposes, as shown in Table 5.

Pollution index and water quality status

PI values determine the river's water quality at each sampling location based on their physical, chemical, and microbiological parameter values (see Table 4). The PI of each parameter was calculated using Eqs. 1 and 2 to obtain the value of C_i / L_{ij} and $(C_i / L_{ij})_{New}$ for class III purposes, i.e., agricultural irrigation, before being classified into one of the four water quality statuses (see Table 3). Table 6 shows the entire calculation results for the six parameters and the water quality status of each point. Tables 4 and 6 also indicate a linear relationship between the parameter values, PI values, and water quality status. The water quality test results showed that SW6 was the only point that met all the criteria for class III water. Similarly, its PI value, 0.558, categorized the water quality as good condition. On the contrary, the PI values of other points ranged from 1.080 to 1.522, indicating slight pollution. This pollution level is also characterized by the PI value of each tested parameter.

Table 5: Test results of three selected sampling points with additional 13 chemical parameters

No	Parameters	Unit	Quality standards class III	Sample test results		
				SW1	SW2	SW7
1	TDS	mg/L	1,000	146.00	170.00	682.00
2	TSS	mg/L	400	13.00	13.00	36.00
3	Power of hydrogen*	-	9	7.80	7.76	7.61
4	BOD_5	mg/L	6	6.53	4.60	20.60
5	COD	mg/L	50	17.38	13.95	36.70
6	Nitrate*	mg/L	20	2.35	2.29	20.00
7	Nitrite*	mg/L	0.06	2.00	1.55	1.33
8	Chloride*	mg/L	600	28.00	28.40	28.40
9	Sulfate*	mg/L	400	18.00	12.30	11.90
10	Ammonia*	mg/L	0.5	4.25	4.07	6.13
11	Phosphate*	mg/L	1	1.15	1.06	0.99
12	Detergent*	mg/L	0.2	0.0480	0.1200	0.0640
13	Chromium hexavalent*	mg/L	0.05	0.0100	0.0036	0.0036
14	Cadmium*	mg/L	0.01	0.0033	0.0033	0.0033
15	Leads*	mg/L	0.03	0.0130	0.0130	0.0130
16	Zinc*	mg/L	0.05	0.0180	0.0096	0.0140
17	Copper*	mg/L	0.02	0.0860	0.0086	0.0086
18	Oil and grease	mg/L	1	1.60	1.60	0.80
19	Total coliform	/100 mL	10,000	2,400	2,400	8,000

*Additional organic chemical parameters

For instance, BOD_5 and oil and grease content at other locations had a PI value of between 1 to 5, contributing to slight pollution. The sampling points other than SW6 were classified as slightly polluted, with the primary contributing factors being BOD_5 and oil and grease content because only both parameters had the C_i / L_{ij} and $(C_i / L_{ij})_{New}$ of higher than 1.

Table 7 shows the PI calculation for the six parameters measured at the initial stage and the additional 13 chemical parameters at SW1, SW2, and SW7. Compared with the PI values of the six parameters (Table 6), there was a considerable increase in value and water quality status from slight to moderate pollution. The three selected points were previously identified as potentially polluted by the production activities of the oil and gas sector because BOD_5 and oil and grease content had the C_i / L_{ij} and $(C_i / L_{ij})_{New}$ of higher than 1 (see Table 6). Aside from these two chemical parameters, the additional test also revealed that nitrite, ammonia, and phosphate contributed to the high PI values. However, nitrite and ammonia contents (dissolved nitrogen) were found to be substantially above their upper limits for class III water. The total nitrogen calculated using Total Kjeldahl Nitrogen (TKN) includes ammonia and all organic nitrogen molecules that can cause the formation of a hypoxic zone, resulting in oxygen deprivation (Al-Ghouti *et al.*, 2019). The high nitrite contents indicated that the organic matter breakdown along the Cangkring River segment consumed oxygen, thereby decreasing the oxygen content in the water. Meanwhile, an increase in nitrogen levels, specifically nitrite, is caused by the influx of waste from agricultural activities (John *et al.*, 2020).

The average and maximum C_i / L_{ij} and/or $(C_i / L_{ij})_{New}$ values of all the parameters are components of PI calculation formula. PI values determine the water quality status; thus, if one parameter value increases to very high, it will also increase the PI value and worsens the status. The maximum C_i / L_{ij} and/or $(C_i / L_{ij})_{New}$ values of nitrite and ammonia were higher than 5, indicating moderate pollution. Both parameters caused the water quality status at SW1, SW2, and SW7 to change from slightly to moderately polluted. Nitrite and ammonia, which include nitrogen, are not always produced by the oil and gas industry but can also result from agricultural

Table 6: Pollution Index values and water quality status at seven points along the Cangkring River segment near the oil and gas production site and office areas in Tuban

No.	Parameters	SW1		SW2		SW3	
		C_1/L_{1j}	$(C_1/L_{1j})_{New}$	C_2/L_{2j}	$(C_2/L_{2j})_{New}$	C_3/L_{3j}	$(C_3/L_{3j})_{New}$
1	TDS	0.146	0.146	0.170	0.170	0.268	0.268
2	TSS	0.033	0.033	0.033	0.033	0.033	0.033
3	BOD_5	1.088*	1.184	0.767	0.767	0.283	0.283
4	COD	0.348	0.348	0.279	0.279	0.246	0.246
5	Oil and Grease	1.600*	2.021	1.600*	2.021	1.600*	2.021
6	Total Coliform	0.240	0.240	0.240	0.240	0.110	0.110
Average		$(C_1/L_{1j})_R$	0.662	$(C_2/L_{2j})_R$	0.585	$(C_3/L_{3j})_R$	0.493
Maximum		$(C_1/L_{1j})_M$	2.021	$(C_2/L_{2j})_M$	2.021	$(C_3/L_{3j})_M$	2.021
Pollutant Index		PI_{1j}	1.503	PI_{2j}	1.487	PI_{3j}	1.471
Quality status		Slightly polluted		Slightly polluted		Slightly polluted	

No.	Parameters	SW4		SW5		SW6	
		C_4/L_{4j}	$(C_4/L_{4j})_{New}$	C_5/L_{5j}	$(C_5/L_{5j})_{New}$	C_6/L_{6j}	$(C_6/L_{6j})_{New}$
1	TDS	0.506	0.506	0.430	0.430	0.457	0.457
2	TSS	0.060	0.060	0.050	0.050	0.064	0.064
3	BOD_5	1.617*	2.043	1.233*	1.455	0.717	0.717
4	COD	0.284	0.284	0.220	0.220	0.156	0.156
5	Oil and Grease	0.800	0.800	0.400	0.400	0.500	0.500
6	Total Coliform	0.360	0.360	0.220	0.220	0.085	0.085
Average		$(C_4/L_{4j})_R$	0.676	$(C_5/L_{5j})_R$	0.463	$(C_6/L_{6j})_R$	0.330
Maximum		$(C_4/L_{4j})_M$	2.043	$(C_5/L_{5j})_M$	1.455	$(C_6/L_{6j})_M$	0.717
Pollutant Index		PI_{4j}	1.522	PI_{5j}	1.080	PI_{6j}	0.558
Quality status		Slightly polluted		Slightly polluted		Good condition (Quality standards are met)	

No.	Parameters	SW7	
		C_{i7}/L_{ij}	$(C_{i7}/L_{ij})_{New}$
1	TDS	0.682	0.682
2	TSS	0.090	0.090
3	BOD_5	3.433*	3.679
4	COD	0.734	0.734
5	Oil and Grease	0.800	0.800
6	Total Coliform	0.800	0.800
Average		$(C_7/L_{7j})_R$	1.131
Maximum		$(C_7/L_{7j})_M$	3.679
Pollutant Index		PI_{7j}	2.721
Quality status			Slightly polluted

*C_i/L_j >1, indicating the need for a new C_i/L_j calculation, $(C_i/L_j)_{New}$.

practices that apply nitrogen-based fertilizers. Even though nitrite and ammonia are non-carcinogenic, their high presence in moderately contaminated water is still harmful to human health (Adimalla and Qian, 2019). Nevertheless, Cangkring River water can still be used for agricultural irrigation, provided that a further investigation into the effect of high nitrate and ammonia content on plant growth be conducted.

Table 7: Pollution Index values and water quality status at three selected points near the oil and gas production site and office areas in Tuban with 13 additional chemical parameters

No	Parameters	SW1		SW2		SW7	
		C_1/L_{1j}	$(C_1/L_{1j})_{New}$	C_2/L_{2j}	$(C_2/L_{2j})_{New}$	C_7/L_{7j}	$(C_7/L_{7j})_{New}$
1	TDS	0.146	0.146	0.170	0.170	0.682	0.682
2	TSS	0.033	0.033	0.033	0.033	0.090	0.090
3	pH	0.867	0.867	0.862	0.862	0.846	0.846
4	BOD_5	1.088*	1.184	0.767	0.767	3.433*	3.679
5	COD	0.348	0.348	0.279	0.279	0.734	0.734
6	Nitrate	0.118	0.118	0.115	0.115	1.000	1,000
7	Nitrite	33.333*	8.614	25.833*	8.061	22.167*	7,729
8	Chloride	0.047	0.047	0.047	0.047	0.047	0.047
9	Sulfate	0.045	0.045	0.031	0.031	0.030	0.030
10	Ammonia	8.500*	5.647	8.140*	5.553	12.260*	6.442
11	Phosphate	1.150*	1.303	1.060*	1.127	0.990	0.990
12	Detergent	0.240	0.240	0.600	0.600	0.320	0.320
13	Chromium hexavalent	0.200	0.200	0.072	0.072	0.072	0.072
14	Cadmium	0.330	0.330	0.330	0.330	0.330	0.330
15	Leads	0.433	0.433	0.433	0.433	0.433	0.433
16	Zinc	0.360	0.360	0.192	0.192	0.280	0.280
17	Copper	4.300*	4.167	0.430	0.430	0.430	0.430
18	Oil and grease	1.600*	2.021	1.600*	2.021	0.800	0.800
19	Total coliform	0.240	0.240	0.240	0.240	0.800	0.800
Average		$(C_1/L_{1j})_R$	1.386	$(C_2/L_{2j})_R$	1.124	$(C_7/L_{7j})_R$	1.420
Maximum		$(C_1/L_{1j})_M$	8.614	$(C_2/L_{2j})_M$	8.061	$(C_7/L_{7j})_M$	7.729
Pollutant index		PI_{1j}	6.170	PI_{2j}	5.755	PI_{7j}	5.556
Quality status		Moderately polluted		Moderately polluted		Moderately polluted	

*C_i/L_j >1, indicating the need for a new C_i/L_j calculation, $(C_i/L_j)_{New}$.

CONCLUSION

The water quality of the Cangkring River segment near the oil and gas fields has been determined at seven sampling points using six main physical, chemical, and microbiological parameters, i.e., TDS, TSS, BOD_5, COD, oil and grease, and total coliform. Furthermore, points SW1, SW2, and SW7 have been selected for further analysis using 13 more chemical parameters because of their high BOD_5 and oil and grease levels and proximity to the production site and office areas. Based on the additional analysis, the river's nitrite, ammonia, and phosphate concentrations are above their maximum allowable presence in water for class III purposes. For these reasons, their water quality status is moderately polluted. The nitrite and ammonia contents are substantially above their upper limits, presumably caused by an increase in nitrogen. Nitrite and ammonia are not always associated with the oil and gas industry but also agricultural activities. Nevertheless, the Cangkring River water can still be used to irrigate farmlands despite its low to moderate contamination levels. The research has found that even with the strict regulations currently enforced in treating the produced water (PW) from the oil and gas fields, the discharged PW still contains a significant amount of nitrite and ammonia, resulting in moderately polluted river water. Also, conducting an additional test with 13 chemical parameters at three locations closest to the fields has provided a good comparison for the six-parameter water quality test results and confirmed this finding. Therefore, to address the high nitrite and ammonia contents, it is also necessary to regularly assess the river water quality near the fields to ensure that it is safe for the agricultural sector and the environment and to investigate the effect of moderately contaminated water on crop health.

AUTHOR CONTRIBUTIONS

A.S. Patimah conducted the literature review, designed the research, performed data collection, data analysis and interpretation, and prepared the article. A. Prasetya performed the literature review for chemical parameters and analyzed and interpreted the data, especially on the water test results. S.H.M.B. Santosa conducted the literature review for site selection for the research, sampling, and data collection and analyzed and interpreted the data, especially those related to location and mapping.

ACKNOWLEDGMENT

The authors would like to express their gratitude to the Doctoral Program in Environmental Sciences at Gadjah Mada University in Yogyakarta, Indonesia, for funding this research through the dissertation research grant program (PDD) in 2022 [Grant Number 1873/UN1/DITLIT/Dit-Lit/PT.01.03/2022]. Gratitude is also extended to the Hydrology Laboratory of Gadjah Mada University and Pertamina LLC in Tuban for their support in acquiring field data and test results.

CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy, have been completely witnessed by the authors.

ABBREVIATIONS

BOD_5	Five-day biological oxygen demand
Cd	Cadmium
C_i	Parameter value at point (i) based on the test results
Cl	Chloride
COD	Chemical oxygen demand
Cr^{6+}	Chromium hexavalent
Cu	Copper
Eq.	Equation
et al.	*et alia* (others)
Fig.	Figure
L_{ij}	Water quality standards for purpose (j) at point (i)
mg/L	Milligrams per liter
MLHK	*Menteri Lingkungan Hidup dan Kehutanan* (Minister of Environment and Forestry of the Republic of Indonesia)
MNLH	*Menteri Negara Lingkungan Hidup* (Secretary of State for Environment of the Republic of Indonesia)
NH_3^-N	Ammonia
NO_2^-	Nitrite
NO_3^-	Nitrate
P	Constants (usually filled with the number 5)
Pb	Lead
pH	Power of hydrogen
PI	Pollution Index
PI_j	Pollution index value for purpose (j)
PO_4^{3-}	Phosphate
PP	*Peraturan Pemerintah* (Government Regulation of the Republic of Indonesia)
PT	*Perseroan Terbatas* (limited liability company)
PW	Produced Water
PWRI	Produced water reinjection
SO_4	Sulfate
SW	Water sample
TDS	Total dissolved solid
TKN	Total Kjeldahl Nitrogen

TSS	Total suspended solid
WQI	Water Quality Index
Zn	Zinc
Σ/100 mL	A certain amount in every 100 milliliters
$\left(\frac{C_i}{L_{ij}}\right)$	Pollution index of each parameter
$\left(\frac{C_i}{L_{ij}}\right)_M$	The maximum value of the pollution index of all parameters
$\left(\frac{C_i}{L_{ij}}\right)_{New}$	Pollution index of each new parameter (if the value of the previously calculated pollution index is higher than 1)
$\left(\frac{C_i}{L_{ij}}\right)_R$	The average value of the pollution index of all parameters

REFERENCES

Adimalla, N.; Qian, H., (2019). Groundwater quality evaluation using water quality index (WQI) for drinking purposes and human health risk (HHR) assessment in an agricultural region of Nanganur, South India. Ecotoxicol. Environ. Saf., 176: 153-161 **(9 pages)**.

Al-Ghouti, M.A.; Al-Kaabi, M.A.; Ashfaq, M.Y.; Da'na, D.A., (2019). Produced water characteristics, treatment and reuse: A review. J. Water Process Eng., 28: 222-239 **(18 pages)**.

Aliyu, G.A.; Jamil, N.R.B.; Adam, M.B.; Zulkeflee, Z., (2019). Assessment of Guinea Savanna River system to evaluate water quality and water monitoring networks. Global J. Environ. Sci. Manage., 5(3): 345-356 **(12 pages)**.

Bagheri, M.; Roshandel, R.; Shayegan, J., (2018). Optimal selection of an integrated produced water treatment system in the upstream of oil industry. Process Saf. Environ. Protect., 117: 67-81 **(15 pages)**.

Carpenter, A., (2019). Oil pollution in the North Sea: the impact of governance measures on oil pollution over several decades. Hydrobiol., 845: 109-127 **(19 pages)**.

Carvalho, N.; Chaim, O.; Cazarini, E.; Gerolamo, M., (2018). Manufacturing in the fourth industrial revolution: A positive prospect in sustainable manufacturing. Procedia Manuf., 21: 671-678 **(8 pages)**.

Costa, T.C.; Hendges, L.T.; Temochko, B.; Mazur, L.P.; Marinho, B.A.; Weschenfelder, S.E.; Florido, P.L.; da Silva, A.; de Souza, A.A.U.; de Souza, S.M.A.G.U., (2022). Evaluation of the technical and environmental feasibility of adsorption process to remove water soluble organics from produced water: A review. J. Pet. Sci. Eng., 208: 109360 **(15 pages)**.

Echchelh, A.; Hess, T.; Sakrabani, R., (2018). Reusing oil and gas produced water for irrigation of food crops in drylands. Agric. Water Manage., 206: 124-134 **(11 pages)**.

Effendi, H.; Romanto, R.; Wardiatno, Y., (2015). Water Quality Status of Ciambulawung River, Banten Province, Based on Pollution Index and NSF-WQI. Procedia Environ. Sci., 24: 228-237 **(10 pages)**.

Ganiyu, S.O.; Sable, S.; El-Din, M.G., (2022). Advanced oxidation processes for the degradation of dissolved organics in produced water: A review of process performance, degradation kinetics and pathway. Chem. Eng. J., 429: 132492 **(24 pages)**.

Ghafoori, S.; Omar, M.; Koutahzadeh, N.; Zendehboudi, S.; Malhas, R.N.; Mohamed, M.; Al-Zubaidi, S.; Redha, K.; Baraki, F.; Mehrvar, M., (2022). New advancements, challenges, and future needs on treatment of oilfield produced water: A state-of-the-art review. Sep. Purif. Technol., 289: 120652 **(24 pages)**.

Hamuna, B.; Tanjung, R.H.R., (2021). Heavy metal content and spatial distribution to determine the water pollution index in Depapre Waters, Papua, Indonesia. Current Appl. Sci. Technol., 21(1): 1-11 **(11 pages)**.

Hoang, H.G.; Lin, C.; Tran, H.T.; Chiang, C.F.; Bui, X.T.; Cheruiyot, N.K.; Shern, C.C.; Lee, C.W., (2020). Heavy metal contamination trends in surface water and sediments of a river in a highly-industrialized region. Environ. Technol. Innovation, 20: 101043 **(14 pages)**.

Ikhsan, J.; Kurniati, R.; Rozainy, M.R., (2021). Analysis of river water quality in the upstream of the Code River, Indonesia. IOP Conference Series: Earth and Environmental Science, 794: 012044 **(8 pages)**.

Jepsen, K.L.; Bram, M.V.; Pedersen, S.; Yang, Z., (2018). Membrane fouling for produced water treatment: A review study from a process control perspective. Water, 10(7): 847 **(28 pages)**.

John, E.M.; Krishnapriya, K.; Sankar, T.V., (2020). Treatment of ammonia and nitrite in aquaculture wastewater by an assembled bacterial consortium. Aquaculture, 526: 735390 **(6 pages)**.

Khan, I.; Zhao, M., (2019). Water resource management and public preferences for water ecosystem services: A choice experiment approach for inland river basin management. Sci. Total Environ., 646: 821-832 **(11 pages)**.

Liang, Y.; Ning, Y.; Liao, L.; Yuan, B., (2018). Special focus on produced water in oil and gas fields: Origin, management, and reinjection practice. In: Formation Damage During Improved Oil Recovery. Gulf Professional Publishing, 515-586 **(71 pages)**.

Li, Y.; Zhou, Q.; Ren, B.; Luo, J.; Yuan, J.; Ding, X.; Bian, H.; Yao, X., (2019). Trends and health risks of dissolved heavy metal pollution in global river and lake water from 1970 to 2017. Rev. Environ. Contam. Toxicol., 251: 1-24 **(24 pages)**.

Lkr, A.; Singh, M.R.; Puro, N., (2020). Assessment of water quality status of Doyang River, Nagaland, India, using water quality index. Appl. Water Sci., 10: 46 **(13 pages)**.

Martinus, Y.; Astono, W.; Hendrawan, D., (2018). Water quality study of Sunter River in Jakarta, Indonesia. IOP Conference Series: Earth and Environmental Science, 106: 012022 **(6 pages)**.

McLaughlin, M.C.; Borch, T.; McDevitt, B.; Warner, N.R.; Blotevogel, J., (2020). Water quality assessment downstream of oil and gas produced water discharges intended for beneficial reuse in arid regions. Sci. Total Environ., 713: 136607 **(12 pages)**.

Miller, H.; Dias, K.; Hare, H.; Borton, M.A.; Blotevogel, J.; Danforth, C.; Wrighton, K.C.; Ippolito, J.A.; Borch, T., (2020). Reusing oil and gas produced water for agricultural irrigation: Effects on soil health and the soil microbiome. Sci. The Total Environ., 722: 137888 **(9 pages)**.

MLHK, (2016). Peraturan Menteri Lingkungan Hidup dan Kehutanan Republik Indonesia Nomor: P.68/Menlhk/Setjen/Kum.1/8/2016 tentang Baku Mutu Air Limbah Domestik. Jakarta: Kementerian Lingkungan Hidup dan Kehutanan.

MNLH, (2003). Keputusan Menteri Negara Lingkungan Hidup Nomor: 115 Tahun 2003 tentang Pedoman Penentuan Status Mutu Air. Jakarta: Menteri Negara Lingkungan Hidup.

Nasrollahi, Z.; Hashemi, M.S.; Bameri, S.; Taghvaee, V.M., (2020). Environmental pollution, economic growth, population, industrialization, and technology in weak and strong sustainability: using STIRPAT model. Environ. Dev. Sustainability, 22(2): 1105-1122 **(18 pages)**.

Patimah, A.S.; Prasetya, A.; Murti, S.H., (2022). Study of domestic wastewater in oil and gas field: A case study in the Cangkring River, Tuban, East Java. IOP Conference Series: Earth Environmental Science, 963: 012051 **(12 pages)**.

Peraturan Pemerintah, (2001). Peraturan Pemerintah Republik Indonesia Nomor 82 Tahun 2001 tentang Pengelolaan Kualitas Air dan Pengendalian Pencemaran Air. Jakarta: Pemerintah Republik Indonesia.

Qi, M.; Han, Y.; Zhao, Z.; Li, Y., (2021). Integrated determination of chemical oxygen demand and biochemical oxygen demand. Pol. J. Environ. Stud., 30(2): 1785-1794 **(10 pages)**.

Rahmatillah, R.; Meilina, H.; Ramli, I., (2021). Water quality index and the sediment criteria due to anthropogenic activity in West Aceh District, Indonesia. IOP Conference Series: Earth and Environmental Science, 922: 012042 **(9 pages)**.

Rustinsyah, R.; Prasetyo, R.A.; Adib, M., (2021). Social capital for flood disaster management: Case study of flooding in a village of Bengawan Solo Riverbank, Tuban, East Java Province. Int. J. Disaster Risk Reduct., 52: 101963 **(10 pages)**.

Sabie, R.; Langarudi, S.P.; Perez, K.; Thomson, B.; Fernald, A., (2022). Conceptual framework for modeling dynamic complexities in produced water management. Water, 14(15): 2341 **(13 pages)**.

Sedlacko, E.M.; Jahn, C.E.; Heuberger, A.L.; Sindt, N.M.; Miller, H.M.; Borch, T.; Blaine, A.C.; Cath, T.Y.; Higgins, C.P., (2019). Potential for beneficial reuse of oil and gas–derived produced water in agriculture: Physiological and morphological responses in Spring Wheat (Triticum aestivum). Environ. Toxicol. Chem., 38(8): 1756-1769 **(14 pages)**.

Suriadikusumah, A.; Mulyani, O.; Sudirja, R.; Sofyan, E.T.; Maulana, M.H.R.; Mulyono, A., (2021). Analysis of the water quality at Cipeusing river, Indonesia using the pollution index method. Acta Ecol. Sin., 41(3): 177-182 **(6 pages)**.

Tran, H.; Vi, H.; Dang, H.; Narbaitz, R., (2019). Pollutant removal by Canna Generalis in tropical constructed wetlands for domestic wastewater treatment. Global J. Environ. Sci. Manage., 5(3): 331-344 **(14 pages)**.

Vu, C.T.; Lin, C.; Shern, C.C.; Yeh, G.; Le, V.G.; Tran, H.T., (2017). Contamination, ecological risk and source apportionment of heavy metals in sediments and water of a contaminated river in Taiwan. Ecol. Indic., 82: 32-42 **(11 pages)**.

Widiatmaka, W.; Ambarwulan, W.; Setiawan, Y.; Walter, C., (2016). Assessing the Suitability and Availability of Land for Agriculture in Tuban Regency, East Java, Indonesia. Appl. Environ. Soil Sci., 2016: 7302148 **(13 pages)**.

Wikurendra, E.A.; Syafiuddin, A.; Nurika, G.; Elisanti, A.D., (2022). Water quality analysis of pucang river, sidoarjo regency to control water pollution. Environ. Qual. Manage., 1-12 **(12 pages)**.

AUTHOR (S) BIOSKETCHES

Patimah, A.S., Ph.D. Candidate, Department of Environmental Science, School of Postgraduate, Universitas Gadjah Mada, Yogyakarta, Indonesia.

- Email: *fatimah13lee@gmail.com*
- ORCID: 0000-0002-3381-3193
- Web of Science ResearcherID: GSE-6331-2022
- Scopus Author ID: 57440910300
- Homepage: http://www.pasca.ugm.ac.id/v3.0/id/programs.sub-40

Prasetya, A., Ph.D., Associate Professor, Department of Chemical Engineering, Faculty of Engineering, Universitas Gadjah Mada, Yogyakarta, Indonesia.

- Email: *aguspras@ugm.ac.id*
- ORCID: 0000-0001-5126-6253
- Web of Science ResearcherID: GWC-3938-2022
- Scopus Author ID: 36154870700
- Homepage: https://chemeng.ugm.ac.id/web/?page_id=2263

Santosa, S.H.M.B., Ph.D., Associate Professor, Department of Geographic Information Science, Faculty of Geography, Universitas Gadjah Mada, Yogyakarta, Indonesia.

- Email: *sigit.heru.m@ugm.ac.id*
- ORCID: 0000-0002-6821-6364
- Web of Science ResearcherID: G-2594-2017
- Scopus Author ID: 57193140660
- Homepage: https://acadstaff.ugm.ac.id/MTk3MjA5MjQxOTk4MDMxMDAy

HOW TO CITE THIS ARTICLE

Patimah, A.S.; Prasetya, A.; Santosa, S.H.M.B, (2022). Environmental assessment of river water quality around the oil and gas field. Global J. Environ. Sci. Manage., 9(2): 275-286.

DOI: 10.22034/gjesm.2023.02.07

url: https://www.gjesm.net/article_696591.html