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Water Quality and Pollution Potential Studies: Impacts on Public Health and Ecosystems

Ivnaini Andesgur[1]*, Hartono[2], Prabang Setyono[3], Evi Gravitiani[4]
[1] Doctoral Program of Environmental Science, Universitas Sebelas Maret, Indonesia
[2]Faculty Medical, Universitas Sebelas Maret, Indonesia
[3] Faculty of Mathematics and Natural Sciences, Universitas Sebelas Maret, Indonesia
[4] Faculty of Economics and Business, Universitas Sebelas Maret, Indonesia
Email: ivnaini.andesgur@lecturer.unri.ac.id

Abstract
This research aims to analyze water quality and potential pollution loads and their impact on health. The research focuses on the pollution index, using a regression analysis to determine the relationships between potential pollutant loads and river water quality, as well as analyzing the impact of Pusur River pollution on the ecosystem and human health. The results show that pollutants in the Pusur River exceed the quality standard for the nitrate parameter in samples taken at Sudimoro and Cokro Villages, and for the fecal coliform parameter at all sample points. The potential pollutant load in the Pusur River from fecal coliform parameters is 1.514E+13 MPN/day from domestic sources and 9.958E+08 MPN/day from livestock sources, with an Rsquare value of 63.3. The presence of Cd and Cu in Pusur River water is safe for the ecosystem and the environment. The level of health risk based on the concentration value of the fecal coliform pathogen in Pusur River water is deemed unsafe for consumption, while the statistical limit value (410 MPN / 100 mL) according to the Indonesian Ministry of Health only the water quality at the sample points in Cokro Village (188 < 410 MPN / 100 mL) and Taji (214 < 410 MPN / mL) is safe for swimming. The results of this research can be used to improve decision-making strategies to improve water quality, especially in the Pusur River, which is used for recreational activities.
Keywords: *health risk, pollution load, pollution index, Pusur River, regression analysis.*

1. Introduction

Water pollution in medium and small river basins has increased in recent years. (Ye et al., 2023). Currently, water quality is being discussed throughout the world, so water quality patterns are important for controlling water pollution. Surface water is widely used for drinking water, agriculture, and recreational activities, so surface water quality is very important. (Azhari et al., 2022); (Cheng et al., 2022) River water that is polluted beyond its purification capacity will decline in quality, and the aquatic ecosystem will be under threat. The causes of river water pollution are natural factors such as soil erosion and rainfall, as well as human activities such as industry, agriculture, urban/domestic activities, increased exploitation of water resources. (Darko et al., 2022)And waste disposal into rivers. Pollution of rivers, lakes, and oceans can hurt the environment and human health, resulting in a loss of biodiversity and the spread of waterborne diseases. (Waskitho & Wibowo, 2024); (Fajar et al., 2023). River water quality assessment is an ongoing process that must be carried out regularly to ensure that aquatic ecosystems remain healthy and safe for humans and the environment. River water quality assessments can be used to formulate appropriate management policies and actions. (Colín Carreño et al., 2023). Water quality can be viewed from its impact on health, which can be seen from the parameter of fecal coliform. Fecal coliform is most commonly used to determine the bacteriological characteristics of natural waters (Tchobanoglous & Schroeder, 1985). Fecal coliform is a group of bacteria found in the intestines of warm-blooded animals and humans. The presence of these bacteria in the environment indicates fecal contamination. Escherichia coli (E. coli) is a fecal coliform species that is often used as the main indicator in assessing water quality. (Xu et al., 2022). Existing research related to river management in Indonesia analyzes river water quality and its impact on the environment, as in the study by, which evaluates water quality status and pollution load capacity of the Way Umpu River based on land use. Sara et al. (2018)

look at the relationship between river water quality and human health in Banjar Regency, which is rich in natural resources and important rivers, using the concentration of dissolved organic components as an indicator. (Wulansari & Karnaningroem, 2019) analyze the amount of fecal coliform bacteria in the Kuin River and look at ways to overcome the decline in Kuin River water quality due to the presence of fecal coliform bacteria. Sari and Wijaya (2019) determine water quality status and strategies for controlling Ogan River water pollution in Ogan Komering Ulu Regency. The method used in this research is purposive sampling using pollution index calculations. (Yohannes et al., 2019) analyze water quality and determine efforts to control water pollution in the Krukut River. Sugiester et al. (2021) use a literature review approach to determine the relationship between river pollution and health problems in Indonesia, based on the results of previous research summarized in environmental health-based research, but there has been no research that specifically discusses the quality of safe rivers as recreation areas.The Pusur River is a river located in the Pusur River Basin area, which covers an area of around 5,781.87 ha. The Pusur sub-watershed consists of three sections, namely the upstream, middle, and downstream sections, from which the water flows into the Bengawan Solo River. The Pusur River has become a new tourism destination that offers activities such as tubing, and is visited by many people from various regions of Indonesia. (Wijayanti et al., 2016). However, to date there has been no research regarding the suitability of the Pusur River water for tourism activities, so research is needed to determine the quality of the water and the impact of river pollution on the environment, especially human health, and to discover the potential pollutant loads in the river area, so that the water quality of the Pusur River can be properly managed to ensure that it is safe for tourism activities.The novelty of this research lies in the focus of the study of energy sector companies listed on the Indonesia Stock Exchange (IDX) during the 2019–2023 period, which is still rarely studied in the context of the relationship between the Value Added Intellectual Capital (VAIC) component and the company's financial performance. In addition, this study adds a new dimension by integrating Sustainable Growth Rate (SGR) as a moderation variable to test the extent to which company growth strengthens or weakens the influence of VACA, VAHU, and STVA on Return on Assets (ROA). Using the moderated regression analysis (MRA) approach, this study provides a new perspective on the dynamics of intellectual capital management in the energy sector which is strategic and is greatly influenced by external fluctuations and internal capabilities of companies.This study aims to analyze the effect of Value Added Capital Employed Coefficient (VACA), Value Added Human Capital Coefficient (VAHU), and Structural Capital Value Added (STVA) on the company's financial performance as measured through Return on Assets (ROA) in energy sector companies listed on the Indonesia Stock Exchange (IDX) for the 2019–2023 period. In addition, this study also aims to examine the role of Sustainable Growth Rate (SGR) as a moderation variable in strengthening or weakening the relationship between the intellectual capital component and the company's financial performance.

2. MATERIALS AND METHODS

The research area is located on the Pusur River which is part of the Pusur Sub-watershed, in the West Bengawan Solo Watershed. The Pusur River is located in Klaten Regency.

Data Collection

The collection of water samples was carried out along the Pusur River, in 6 villages (Sudimoro, Cokro, Wangen, Sabrang, Juwiring and Taji Villages). The geographic locations of the sample points can be seen in Table 1. An analysis of the water samples was carried out in the Laboratory of Physical and Chemical Environmental Risk Factors at the Yogyakarta Center for Environmental Health Engineering and Disease Control, to determine the water quality of the Pusur River. The types of parameters analyzed and the analysis methods can be seen in Table 1.

Table 1. Geographical Location of Research Locations

Research location	Geographic location		
	Regency/City	Longitude-East	Latitude-South

Sudimoro Village		7°35'25,080"	110°35'48,120"
Cokro Village		7°36'2,160"	110°38'13,920"
Wangen Village	Klaten	7°36'23,760"	110°39'25,920"
Sabrang Village		7°37'21,720"	110°42'0,000"
Juwiring Village		7°38'24,360"	110°43'1,200"
Taji Village		7°39'52,920"	110°46'36,120"

Table 2. Physical, Chemical, and Biological Parameters of Pusur River Water and Analysis Methods

Parameter	Method	Unit	Analysis
Turbidity	SNI 06-6989.25-2005	Cm	*Ex situ*
Temperature	SNI 06-6989.23-2005	°C	*In situ*
TSS	In House Method	mg/L	*Ex situ*
pH DO	SNI 06-6989.11-2019 APHA 2017, section 4500-OG	- Mg O_2/L	*In situ* *Ex situ*
COD	SNI 6989.2-2019	mg/L	*Ex situ*
Nitrate (NO_3)	APHA 2017, section 4500-NO_3B	mg/L	*Ex situ*
Heavy metal Cd Heavy metal Cu	SNI 06.6989.38-2005 SNI 6989.84-2019	mg/L mg/L	*Ex situ* *Ex situ*
Fecal Coliform	APHA, 2017 section 9221-E	MPN/100 ml	*Ex situ*

Data analysis

The results of the data analysis of Pusur River water samples from the laboratory were analyzed descriptively, and the results were compared with Republic of Indonesia Government Regulation Number 22 of 2021 concerning Protection and Management of Water Quality (Government of the Republic of Indonesia 2021). The potential pollutant loads calculated were from non-point pollutant sources. The potential pollutant load calculations used the effluent factor and were calculated based on the parameters of fecal coliform, COD, and nitrate, (depending on whether or not the emission factor was present for each of these parameters at the pollutant source). The potential pollutant load analysis was assisted by maps, such as topographic maps or Earth Shapes, land use maps, and administrative maps. The potential sources of pollution to be calculated were from domestic activities, agriculture, livestock, and waste.

The calculation of the potential pollution load of domestic waste used Equation 1.

$$PBP = \alpha \, x \, Total\ Population \, x \, Effluent\ Factor \, x \, rek \quad (1)$$

Note: PBP = potential pollution load of domestic waste. Alpha (α) = coefficient which states the level of ease with which waste reaches the river, with a value ranging from 0.3 to 0.1. The easier it is for waste to reach the river, the greater the α value (KLH, 2013).

In the study of the calculation of pollution load in the Pusur river, the α value is divided into 3 classes, as follows: (1) α value = 1 is used for locations that are between 0 and 100 meters from the river, (2) α value = 0.85 is used for locations that are 100 - 500 meters from the river and (3) α value = 0.3 is used for locations that are more than 500 meters from the river. rek = city equivalent ratio which states

the difference in domestic waste load produced between urban, suburban and inland areas. According to (Iskandar, 2021) The values of these ratios are as follows: a value of 1 for urban areas, 0.8125 for suburban areas, and 0.6250 for inland areas. The effluent factor values from domestic waste are as follows: COD 0.055 kg/person/day.
The estimated pollution load of fecal coliform was calculated using Equation 2:

$$BP_{fc} = P\ x\ Production\ _{fc}\ x\ Koef.transmission\ x\ 0{,}85 \quad (2)$$

Note: BPfc = Fecal coliform pollution load (MPN/day), P = Population (people) Productionfc = 2000 x 106 MPN/person/day (Tchobanoglous, 1991; Chapra, 1997), Transmission coefficient = 0.5 (Nippon, 2001)

The pollution load from livestock was calculated using the effluent factor. The data required for this calculation are the types and numbers of livestock. Meanwhile, the effluent factor can be seen in Table 3.
The potential pollution load of waste from the livestock sector was calculated using Equation 3:

$$PBP = Number\ of\ Livestock\ x\ Emission\ Factor\ x\ Coefficient \quad (3)$$

Information: PBTN = Potential Livestock Load, Emission Factor (Table 3), Coefficient = 20%

Table 3. Livestock Emission Factors

Type of Livestock	Potential Causes of Pollution from Livestock		
	Fecal Coliform (number/head/hour)	COD (gr/head/hour)	NO3 (gr/head/hour)
Cow	$3.70E^{+06}$	716	0.1742
Goat	$2.10E^{+05}$	136.23	0.0333
Duck	$1.00E^{+05}$	2.22	0.0005
Chicken	$4.30E^{+04}$	5.59	0.0011

Source: Iskandar (2007) with modifications

3. RESULTS AND DISCUSSION

Pusur River Water Quality

Water quality is a description of the quality characteristics that are required in the process of utilizing or managing water resources. Rivers are a source of surface water that provides various benefits for human life, and for this reason, they are important to study. In this research, the water quality of the Pusur River was measured based on Government Regulation Number 82 of 2001 concerning Water Quality Management and Water Pollution Control. In accordance with its designation, Class II Water Quality Standard Criteria apply, from which the quality of river water can be known. The water quality of the Pusur River can be seen in Figure 1. In this study, the water quality of the Pusur River was viewed from the values of turbidity, TSS, pH, DO, COD, nitrate, Cd, Cu, and temperature.

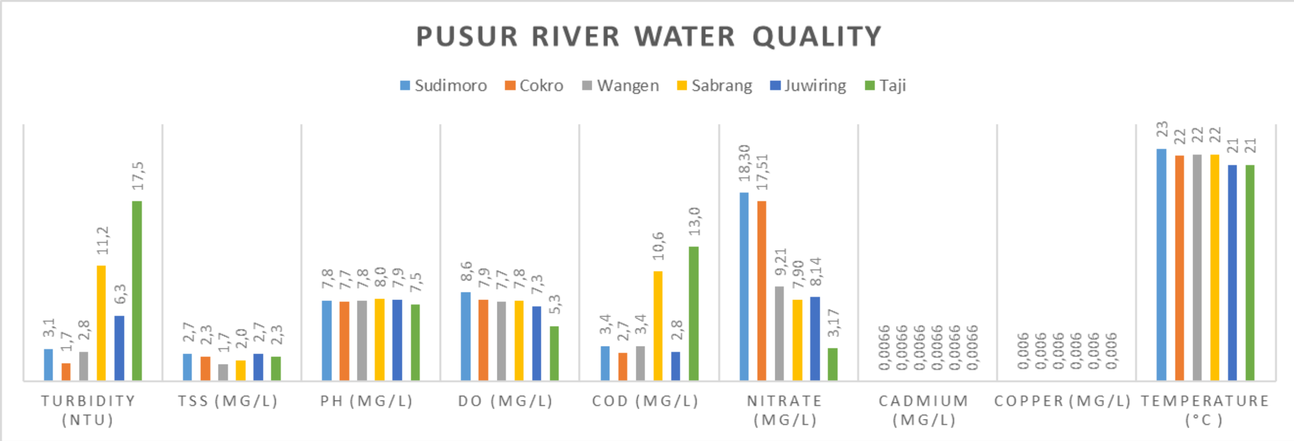

Figure 1. Pusur River Water Quality based on Turbidity, TSS, pH, DO, COD, Nitrate, Cd, Cu, and Temperature.

The results of the calculations of the pollution concentrations for each water quality parameter in Figure 1 above, when compared with class 2 river water quality standards, it can be seen that the turbidity parameter at all sampling points was below the quality standard of 25 NTU. The TSS parameter at all sampling points was also below the quality standard of 50 mg/L. The quality of the Pusur River water, when viewed in terms of pH value, had a value of 7.5-8.0, which meets the quality standard of Government Regulation Number 82 of 2001, namely pH 6 - 9, so the Pusur River water can still be used for recreational facilities, freshwater fish cultivation, animal husbandry and agriculture. Dissolved oxygen (DO) is an important parameter that is required for the survival and maintenance of aquatic systems. The level of pollution of a water body can be explained by DO, where the higher the DO value, the lower the extent of pollution and vice versa. DO input sources are aeration and photosynthesis, respiration, decomposition of organic matter by microorganisms, and evaporation at higher temperatures (Kumar et al., 2021). Figure 2 shows that the DO levels at all sample points were within the quality standard, namely a minimum of 4 mg/L and a saturation point of 9 mg/L, seen from the average river water temperature at the time of sampling of 22 °C, with a range of 5.3 to 8.6 mg/L. The highest DO levels were found in Sudimoro Village, while the lowest levels were found in Taji Village. The DO levels at all locations indicate that the river water has good aeration. The DO value for a healthy aquatic environment is 6 mg/L (Kumar et al., 2021); (Vadde et al., 2018).In this research, water quality was also viewed in terms of COD (chemical oxygen demand), which is a measure of the oxygen needed to oxidize dissolved organic pollutants and particulates in wastewater. High COD levels indicate that the amount of organic material that can be oxidized in the water is higher, which causes a decrease in dissolved oxygen (DO) levels (Ayana 2019). Based on the standard criteria for class 2 river water quality for the COD parameter, which is 25 mg/L, the results of the measurements at all sample points show that the COD concentration was below the quality standard, namely in the range of 2.7 - 13.0 mg/L.Based on Figure 1, it can be seen that a nitrate concentration value exceeding the standard threshold (10 mg/L) was found in the samples from Sudimoro and Cokro Villages, at 18.30 mg/L and 17.51 mg/L, while at the other sample points the nitrate concentration was below the quality standard, with an average of around 3.17 – 9.21 mg/L. The difference in nitrate concentration at each sample location is due to the land use in each village. The nitrate concentration in surface water comes from inorganic fertilizers, manure, and liquid waste discharged from septic tanks. (Zhang et al., 2021). The Pusur River water quality for the Cd and Cu parameters (Figure 1) was below the class 2 river water quality standard (0.02 mg/L), namely Cd of 0.0066 mg/L and Cu of 0.006 mg/L at all sample points. This shows that the Pusur River is safe to use as a facility for water recreation, freshwater fish cultivation, animal husbandry, and other uses that require the same water quality. According to Islami et al. (2024) the concentration of metal elements was found to be higher in mining and agricultural areas, but did not exceed the permissible levels.

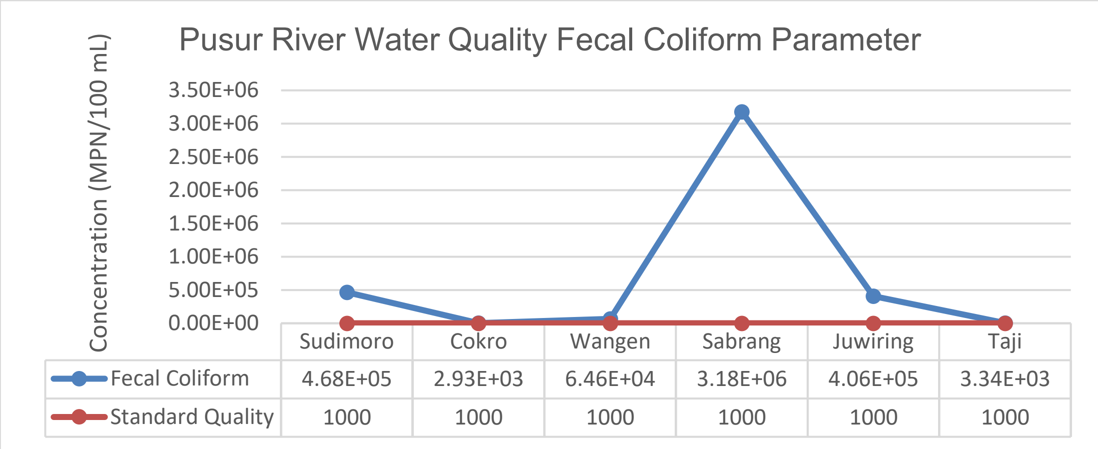

Figure 2. Pusur River water quality based on the amount of fecal coliform

The concentration of fecal coliform parameters at all sample points exceeded the quality standard (1000 MPN/100 mL) of 2,933 MPN/100 mL – 3,180,133 MPN/100 mL. The high concentration of fecal coliform in the Pusur River is due to surface runoff, which carries various pollutants, including fecal coliform, from contaminated areas to water bodies such as rivers, thereby increasing the concentration of fecal coliform in the water (Abia et al. 2016; Edokpayi et al. 2018).

Sources of Pusur River Pollution

Rivers are open bodies of water that flow and receive input from all kinds of waste that originates from human activities in residential, agricultural, and industrial areas in the surrounding region. The input of waste into rivers changes the physical, chemical, and biological factors in the water. Sources of water pollution based on the characteristics of the waste produced can be divided into domestic waste sources and non-domestic waste sources. In general, sources of domestic waste are residential areas, while sources of non-domestic waste come from activities such as agriculture and animal husbandry, or activities that do not originate from residential areas. Sources of Pusur River pollution can be seen in Table 4.

Table 4. Data on Population, Agricultural Land Area, and Types and Numbers of Livestock at the Research Location

Village	Number of residents (people)	Agricultural land area (ha)		Number of livestock (head)				
		Ricefield	Garden	Cow	Sheep	Goat	Duck	Chicken
Sudimoro	4,234	154.19	14.57	457	104	177	-	3,770
Cokro	2,035	60.9	3.73	89	49	171	-	2,548
Wangen	3,038	127.88	0	105	180	91	350	3,436
Sabrang	3,684	60.49	4.54	122	160	218	-	-
Juwiring	2,052	86.2	0.34	12	40	124	1,033	11,517
Taji	2,772	141	0.6	40	239	315	811	9,307
Total	17,815	630.66	23.78	825	772	1,096	2,194	30,578

Source: BPS Klaten Regency 2022.

From Table 4, it can be seen that the largest population is in Sudimoro Village, 24% > Sabrang 21% > Wangen 17% > Taji 15% > Juwiring 12% > Cokro 11%. The total area of agricultural land in Sudimoro Village is 168.76 ha > Wangen Village 127.88 ha > Taji Village 141.6 ha > Juwiring Village 86.54 ha > Sabrang Village 65.03 ha > and Cokro Village 64.63 ha. The largest number of cattle is 450, in Sudimoro Village, the largest number of sheep and goats is in Taji Village, with 239 sheep and 315 goats. The largest number of ducks and chickens is in Juwiring Village, with 1,033 ducks and 11,517 chickens.

Table 5. Potential Pollution Load in the Pusur River Area

Sample Point	Potential pollution load in the Pusur River area						
	Fecal coliform (MPN/day)		NO_3 (Kg/day)	COD (Kg/day)			
	Domestic	Livestock	Livestock	Domestic	Agriculture	Livestock	Rubbish
Sudimoro	3.599E+12	3.824E+08	0.019	189	43	77	7
Cokro	1.730E+12	9.701E+07	0.005	112	17	22	3
Wangen	2.582E+12	1.256E+08	0.006	167	35	26	5
Sabrang	3.131E+12	1.062E+08	0.007	203	17	28	6
Juwiring	1.744E+12	1.355E+08	0.004	113	24	20	4
Taji	2.356E+12	1.491E+08	0.007	152	39	32	5
Total	1.514E+13	9.958E+08	0.048	936	175	205	30

In this study, the main sources of the pollutant load for the fecal coliform parameter were domestic and livestock waste. It can be seen from Table 8 that the largest source of pollution at all sample points was domestic waste. The largest source of fecal coliform pollution was from Sudimoro Village at 3,599E+12 MPN/day. This is because the largest population is also found in this village, as reinforced by the opinion of Hsu et al (2023), who state that anthropogenic sources are the main threat to the quality of water microbes in river basins. This condition is also reinforced by statements from other researchers who found that the largest sources of fecal coliform pollution parameters were domestic waste and livestock manure (Tong et al. 2016; Niyoyitungiye et al. 2020; (Xu et al., 2022). The source of the pollutant load for the nitrate parameter was only calculated from the livestock sector, because the emission factor consisted only of cattle, sheep/goats, ducks, and chickens. The highest potential pollutant load for this parameter was in Sudimoro Village, namely 0.019 kg/day. This is because the largest number of cattle is found in this village compared to other areas (Table 5). The largest source of the total pollution load for the COD parameter was domestic waste, namely 936 kg/day > livestock 205 kg/day > agriculture 175 kg/day > waste 30 kg/day. The largest source of potential COD pollution from domestic sources was at the sample point in Sabrang Village, at 203 kg/day. This is due to the number of residents in the village. Meanwhile, the largest source of COD from other sectors was in Sudimoro Village, where the amount of COD from agriculture was found to be 43 kg/day, livestock 77 kg/day, and waste 7 kg/day. This is influenced by population size, agricultural land area, and the number of livestock.

1.1. Pusur River Water Quality Status

The determination of water quality status using the pollution index method is regulated by Decree Number 115 of 2003 from the Minister of Environment concerning Guidelines for Determining Water Quality Status (Decree of the State Minister for the Environment 2003). In general, water quality status is determined using the pollution index method by dividing the concentration value of the pollutant parameter by the standard value of the pollutant quality. Water quality status is divided into several categories based on the pollution index value (Table 5). The results of the calculations of the pollution index values at each sampling location can be seen in Table 6.

Table 6. Pollution Index Value and Pusur River Water Quality Status

Sample Point	Pollution Index Value	Water Quality Status
Sudimoro	10	Moderate Pollution
Cokro	2	Light Pollution
Wangen	7	Moderate Pollution

Sabrang	13	Heavy Pollution
Juwiring	10	Moderate Pollution
Taji	3	Light Pollution
Average	7.5	Moderate Pollution

The average water quality status of the Pusur River is moderately polluted with a value of 7.5 (5 < Pij > 10). The water quality status of the Pusur River at the sample points in Cokro and Taji Villages is classified as lightly polluted (1 < Pij ≤ 5) (Table 6). The pollution index value is 2 in Cokro Village and 3 in Taji Village. The water quality at the sample points in Sudimoro, Wangen, and Juwiring Villages is classified as moderately polluted (5 < Pij ≤ 10), namely 10 in Sudimoro and Juwiring Villages and 7 at the sample point in Wangen Village. At the sample point in Sabrang Village, the water quality is classified as heavily polluted, with a value of 13 (Pij > 10). The high pollution index value at the sample point in Sabrang Village is influenced by the high fecal coliform value (Figure 2).

Relationship between potential pollutant load and Pusur River water quality

The analysis of the relationships between the potential pollutant loads of the fecal coliform, nitrate, and COD parameters at the research location and the water quality of the Pusur River used a regression test with SPSS. The independent variables for the fecal coliform parameter are X_1 = domestic, X_2 = livestock. The independent variable for the nitrate parameter is X = livestock, while the independent variables for the COD parameter are $X1$ = domestic, X_2 = agriculture, X_3 = livestock, and X_4 = rubbish. The dependent variable is Y = water quality of the Pusur River in the samples at Sudimoro, Cokro, Wangen, Sabrang, Juwiring, and Taji Villages. The results of the interpretation of the regression test with SPSS based on the coefficient of determination value (Rsquare) for the parameter fecal coliform shows that the influence of domestic and livestock source variables on the water quality of the Pusur River is 62.3%, while the remaining 37.7% is influenced by other variables that were not included in this model. According to Rojas-Peña et al (2024) and Gbekley et al (2023), fecal coliform can have a negative impact on river water quality. Fecal coliform comes from industrial waste as well as livestock and human waste (Rojas-Peña et al. 2024; Gbekley et al. 2023; Jabbar and Grote 2019).Based on the coefficient of determination (Rsquare) value for the nitrate parameter, the influence of the livestock source variable on Pusur River water quality is 9.9%, while the remaining 90.1% is influenced by other variables not included in this model. According to (Zhang et al., 2021), the concentration of nitrate in surface water comes from inorganic fertilizers, manure, and liquid waste discharged from septic tanks. Based on the coefficient of determination (Rsquare) value for the COD parameter, the influence of domestic, agricultural, livestock and waste source variables on the Pusur River water quality is 37.4%, while the remaining 62.6% is influenced by other variables not included in this model. According to (Arkhypova et al., 2021), the highest COD concentration in river water comes from unprocessed industrial waste.

The impact of Pusur River pollution on the ecosystem and human health.

The ecological risk index (RI) is calculated to assess the potential risk of heavy metals from the river water. This method takes into account the toxicity and combined effects of heavy metals on aquatic ecosystems. In this research, the parameters used were Cd and Cu. The results of the calculations can be seen in Table 7.

Table 7. Ecological risk index value for Pusur River water

Sample Point	Pusur River Water Quality		CF		Er		RI	Explanation
	Cadmium	Copper	Cadmium	Copper	Cadmium	Copper		
Sidimoro	0.0066	0.006	0.66	0.3	19.8	1.5	21.3	Low risk
Cokro	0.0066	0.006	0.66	0.3	19.8	1.5	21.3	Low risk
Wangen	0.0066	0.006	0.66	0.3	19.8	1.5	21.3	Low risk

Sabrang	0.0066	0.006	0.66	0.3	19.8	1.5	21.3	Low risk
Juwiring	0.0066	0.006	0.66	0.3	19.8	1.5	21.3	Low risk
Taji	0.0066	0.006	0.66	0.3	19.8	1.5	21.3	Low risk

The potential ecological risk factor (Er) evaluates the ecological risk of each element, and the results show that Cd and Cu in Pusur River water at all the sample points have a low potential ecological risk to the environment, with a Cd value of 0.3 and Cu 19.8 <40. The potential ecological risk index (RI) considers all the elements analyzed, and shows a low ecological risk for Pusur River water, where the RI value is 21.3 <150, so it can be concluded that the presence of Cd and Cu metals in Pusur River water is safe for the ecosystem and the environment (it does not affect water quality, organism health, or ecological balance). However, it is also necessary to control it so that in the future the parameters of heavy metal pollution do not exceed the Pusur River water quality standards. In this research, control efforts can be carried out structurally and non-structurally. Structurally, this can be done by building wastewater treatment plants to reduce heavy metal loads and carrying out environmentally friendly land management. Meanwhile, non-structurally, namely increasing public awareness of the dangers of the impact of Pusur river water pollution on the environment. To measure the non-carcinogenic human health risks for the fecal coliform parameter, the exposure routes used were absorption through the skin (dermal) and consumption (swallowing/ingestion). The results of the calculations can be seen in Table 8.

Table 8 Human Health Risk Data from Fecal Coliform Pollutant Parameters

Sample Point	Fecal Coliform Concentration (C0)	Fecal Coliform Pathogen Concentration (C)	Risk Level	Exposure Dose (MPN/mL)	
	(MPN/100 ml)	(MPN/100 ml)		Consumption	Skin Contact
Sudimoro	467,583	37,407	High risk	748	29,925
Cokro	2,933	235	High risk	5	188
Wangen	64,633	5,171	High risk	103	4,137
Sabrang	3,180,133	254,411	High risk	5.088	203,529
Juwiring	406,333	32,507	High risk	650	26,005
Taji	3,343	267	High risk	5	214

The limits of exposure doses for fecal coliform in drinking water and in skin contact are set by various health and safety agencies worldwide. In general, fecal coliform exposure is considered primarily in the context of drinking water quality, since these bacteria often indicate fecal contamination that could potentially transmit disease. Drinking water must not contain any fecal coliform. This means that the threshold for fecal coliform in drinking water is 0 MPN/100 mL (Most Probable Number per 100 milliliters). The EPA also stipulates that for drinking water, the fecal coliform limit is 0 MPN/100 mL to meet the required quality standard of safe drinking water, whereas for skin contact there are no limits specifically regulated for fecal coliform (EPA 2012). According to Regulation of the Minister of Health to the Republic of Indonesia Number 2 of 2023, the maximum level allowed for coliform bacteria is 0 MPN/100mL, and in water for public bathing (fresh water/rivers), the maximum geometric average level is 126 MPN/100 mL, while the statistical limit value is 410 MPN/100 mL (Ministry of Health 2023).The lowest exposure dose to fecal coliform is 5 MPN/mL (consumption), found at the sample points in Cokro and Taji Villages, and 188 MPN/mL (skin contact) in Cokro Village, while the highest is 5,088 MPN/ml (consumption) and 203,529 MPN/mL (skin contact), both in Sabrang Village. The level of health risk is based on the concentration value of the fecal coliform pathogen in Pusur River water at all high-risk points, namely with a value of more than 101-1000 MPN/100 mL (Table 8.Pusur River water is not safe for consumption. The Pusur River is said to be unsafe for swimming when compared with the geometric average maximum level (126 MPN/100 mL) stipulated by Regulation Number 2 of 2023 by Minister of Health to the Republic of Indonesia. If we compare the results with the statistical limit (410 MPN/100 mL), only the water quality at the sample points in Cokro Village (188 <410 MPN/100 mL) and Taji Village (214<410 MPN/mL) are determined to be safe for swimming, while all the other sample points of Pusur River water are unsafe for swimming.Water contamination by fecal coliform bacteria can cause death and morbidity such as typhoid fever, cholera, diarrhea, and hepatitis (Colín Carreño et al., 2023). To avoid negative impacts, Pusur River water must be treated before being used as a source of drinking water and as a recreation area. One way to process Pusur River water is by creating a wetland ecosystem that can neutralize pollutants through natural processes (de Campos and Soto, 2024).The amount of fecal coliform pollutant load that enters the Pusur River comes from domestic waste and livestock waste, therefore, efforts need to be made to maximize the use of fecal waste processing plants (IPLT) and provide wastewater treatment plants (IPAL) to reduce domestic waste. Then, provide infrastructure for processing livestock waste into biogas, compost, and goat urine into POC fertilizer, to reduce livestock waste. As well as increasing public awareness of the dangers of the impact of Pusur River water pollution on human health.

5. CONCLUSIONS

The concentration of the pollutant parameter in the Pusur River that exceeds the quality standard is the nitrate parameter in the samples in Sudimoro and Cokro Villages, which exceed the quality standard (10 mg/L) with measurements of 18.30 mg/L and 17.51 mg/L. The largest potential source of pollution load for COD parameters is domestic waste, which is 936 kg/day> livestock 205 kg/day> agriculture 175 kg/day> waste 30 kg/day and the main source of pollution load for fecal coliform parameters is domestic waste. Of the six sample points, the largest source of fecal coliform, COD and nitrate pollution is in Sudimoro Village, this is influenced by the population, agricultural land area, and number of livestock. The influence of domestic and livestock source variables on the water quality of fecal coliform parameters is 62.3%. The influence of livestock source variables on the water quality of nitrate parameters is 9.9%, and the influence of domestic, agricultural, livestock and waste source variables on the water quality of COD parameters is 37.4%. The average water quality status of the Pusur River is moderately polluted with a value of 7.5 ($5 < Pij > 10$). Based on the concentration value of the fecal coliform pathogen in the Pusur River, the risk is found to be high, with a value of more than 101-1000 MPN/100 mL, so it is not safe for consumption. The Pusur River is not safe for swimming, according to the regulation of the Indonesian Ministry of Health, which states that the maximum geometric mean level for fecal coliform must not exceed 126 MPN/100 mL, whereas according to the statistical limit (410 MPN/100 mL) only the water quality at the sample points in Cokro Village (188 < 410 MPN/100 mL) and Taji Village (214 < 410 MPN/mL) are safe for swimming, while the water at all other sample points is declared to be unsafe for swimming. The results of this research can be used to improve decision-making strategies to improve water quality, especially in the Pusur River and rivers in Indonesia that are used for recreational activities.

Ethical considerations

Not applicable

Conflict of Interest

The authors declare no conflicts of interest.

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