

Water Quality Status of the Sanga-Sanga River, East Kalimantan, determined with the Pollution Index Method under high- and low-tide conditions

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ARTICLE INFO

Research Article

Article history:

Received June 10, 2025

Received in revised form September 2, 2026

Accepted January 25, 2026

DOI: <https://doi.org/10.30872/tjt1nj72>

Keywords: pollution control, lotic system, tropical, environmental monitoring



ABSTRACT

The Sanga-Sanga River in the Mahakam Delta region of East Kalimantan supplies raw water and supports bathing, washing, transport and fishing for nearby communities, yet it also receives inputs from riverbank settlements and from mining-related industry. This study assessed the river's water quality status with the Pollution Index (PI) method of State Minister of Environment Decree No. 115 of 2003, using the Class I–IV standards of Government Regulation No. 22 of 2021 as references. Water was sampled in four replicates at high tide and at low tide at three stations (upstream, middle and downstream) between November 2024 and January 2025. Chemical oxygen demand (COD), lead (Pb) and copper (Cu) exceeded the standards: COD ranged from 12.7 to 35.1 mg/L, mean Pb from 0.22 to 0.35 mg/L, and mean Cu reached 0.10 mg/L at low tide. At high tide, PI values were 2.89, 1.66, 1.28 and 0.93 for Classes I to IV, so the river was lightly polluted for Classes I–III and met the Class IV standard. At low tide, PI values were 3.02, 1.76, 1.72 and 1.71, and the river was lightly polluted for all four classes. Low-tide PI exceeded high-tide PI for every class, and the difference grew from about 4% for Class I to about 84% for Class IV. The Sanga-Sanga River therefore does not meet the Class I standard for raw drinking water, and its status depends on the tidal phase at the time of sampling. Tidal dilution is the most plausible explanation for the better high-tide condition, but this remains to be tested with salinity and discharge data. Source control of domestic and industrial effluents and monitoring at both tidal phases are recommended.

INTRODUCTION

Rivers are drainage networks that carry water from its source to the sea and are bounded along their length by riparian margins (Sari and Khadiyanto, 2014). Waste discharged into a river can alter its physical, chemical and biological conditions (Hamdhani et al., 2020), and such changes can deplete essential constituents of the water and impair the aquatic environment (Sanita, 2000). Under Government Regulation No. 22 of 2021, water pollution is the entry of living organisms, substances, energy or other components into water through human activity so that the water exceeds its established quality standard. Pollutants reach water bodies through the atmosphere, soil, agricultural runoff, and domestic, urban and industrial wastes (Effendi, 2003).

Sanga-Sanga is a sub-district of Kutai Kartanegara Regency in the Mahakam Delta, covering 233.4 km² (BPS Kutai Kartanegara, 2022). The Sanga-Sanga River is a principal source of raw water and drinking

water for the sub-district and is used daily for washing, bathing, transport and fishing. Its water quality has declined because of human behaviour such as the discharge of domestic and non-domestic waste (Halder and Islam, 2015). Dense riverbank settlements and nearby mining-related industry make the river a plausible recipient of both organic and metal contamination.

The Pollution Index (PI) is a method that the Government of Indonesia recommends for determining the level of river pollution. It expresses water quality relative to the quality standard of a chosen designation, and it can be applied to a whole water body or to part of a river, so that managers can judge whether the water suits a given use and decide on corrective action when quality deteriorates (KLH, 2003; Afif, 2021). The method has been applied to several Indonesian rivers: to determine the water quality status of the lower Angke River (Chandra, 2023), to judge whether the Wubudu River is suitable as a raw water and irrigation source (Mahmud, 2022), and to evaluate pollution from upstream to downstream in the Siwaluh River (Winandar et al., 2016).

Tidal rivers pose an additional difficulty for such assessments. Because the direction and volume of flow change with the tide, water composition at a fixed point can differ markedly within hours, and a status derived from one tidal phase may misrepresent the river. The objectives of this study were therefore (1) to evaluate the physical and chemical water quality of the Sanga-Sanga River against the Class I–IV standards of Government Regulation No. 22 of 2021, (2) to compare water quality at high and low tide, and (3) to determine the river's pollution status with the PI method.

METHODOLOGY

Study area and sampling stations

The study was conducted from November 2024 to January 2025 in the Sanga-Sanga River, Kutai Kartanegara Regency, East Kalimantan. Three stations were established along the river (Figure 1). Station 1 (upstream) lies beneath the Sanga-Sanga Bridge, where no direct residential activity was recorded at the site. Stations 2 (middle) and 3 (downstream) are adjacent to fairly dense riverbank settlements and close to mining-related industry.



Figure 1. Location of the three sampling stations on the Sanga-Sanga River, Kutai Kartanegara Regency, East Kalimantan.

Sampling and laboratory analysis

At each station, water samples and field measurements were taken in four replicates at high tide and at low tide. Samples were collected with a water sampler into sterilised Winkler bottles, sample bottles and 5 L jerrycans. Dissolved oxygen (DO) in the Winkler bottles was fixed and titrated, and the remaining samples were transported to the Water Quality Laboratory, Faculty of Fisheries and Marine Science, Universitas Mulawarman, for analysis. Parameters were thus measured partly in situ and partly ex situ (laboratory), and included DO, COD, Pb and Cu together with the other physical and chemical parameters listed in Annex VI of Government Regulation No. 22 of 2021.

Pollution Index calculation and classification

Water quality status was determined with the Pollution Index in Annex II of State Minister of Environment Decree No. 115 of 2003. Measured concentrations were compared separately with the Class I, II, III and IV river water quality standards in Annex VI of Government Regulation No. 22 of 2021. The index for designation j is calculated as:

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

where PI_j is the pollution index for designation j ; C_i is the measured concentration of water quality parameter i ; L_{ij} is the concentration of parameter i given in the quality standard for designation j ; and the subscripts M and R denote the maximum and the mean (average) of the C_i/L_{ij} ratios, respectively. Values were calculated for all stations combined for each tidal condition. PI values were classified as follows: $0 \leq PI \leq 1.0$, meets the quality standard (good); $1.0 < PI \leq 5.0$, lightly polluted; $5.0 < PI \leq 10$, moderately polluted; and $PI > 10$, heavily polluted.

RESULT AND DISCUSSION

Results

Parameters exceeding the quality standards

COD, Pb and Cu were the parameters that exceeded the quality standards. COD was highest at Station 1 at high tide (35.1 mg/L) and lowest at Station 2 at low tide (12.7 mg/L). Every value was above the Class I standard (10 mg/L), and the highest value was also above the Class II standard (25 mg/L). Mean Pb concentrations ranged from 0.22 to 0.35 mg/L and exceeded the quality standard. Mean Cu concentration was highest at low tide, at 0.10 mg/L, and also exceeded the quality standard.

Pollution Index at high and low tide

Table 1 and Figure 2 give the PI values for the four standard classes. At high tide, PI was 2.89 for Class I, 1.66 for Class II and 1.28 for Class III, all in the lightly polluted range ($1.0 < PI \leq 5.0$), and 0.93 for Class IV, which meets the standard. At low tide, PI was 3.02, 1.76, 1.72 and 1.71 for Classes I to IV, respectively, so the river was lightly polluted against all four classes. No value reached the moderately polluted range ($PI > 5.0$).

Table 1. Pollution Index of the Sanga-Sanga River (all stations combined) at high and low tide, calculated against the Class I–IV river water quality standards of Government Regulation No. 22 of 2021.

Tide	Class	(C_i/L_{ij}) maximum	(C_i/L_{ij}) mean	PI	Status
High tide	I	3.97	0.98	2.89	Lightly polluted
	II	2.29	0.55	1.66	Lightly polluted

Tide	Class	(Ci/Lij) maximum	(Ci/Lij) mean	PI	Status
Low tide	III	1.77	0.41	1.28	Lightly polluted
	IV	1.27	0.35	0.93	Meets standard
	I	4.07	1.29	3.02	Lightly polluted
	II	2.36	0.79	1.76	Lightly polluted
	III	2.36	0.58	1.72	Lightly polluted
	IV	2.36	0.51	1.71	Lightly polluted

Low-tide PI exceeded high-tide PI for every class (Figure 2). The difference was small for the strictest classes, at 0.13 (about 4%) for Class I and 0.10 (about 6%) for Class II, and larger for the less strict classes, at 0.44 (about 34%) for Class III and 0.78 (about 84%) for Class IV. The maximum ratio was the same, 2.36, for Classes II, III and IV at low tide, indicating that a single parameter with the same limit in those classes determined the maximum.

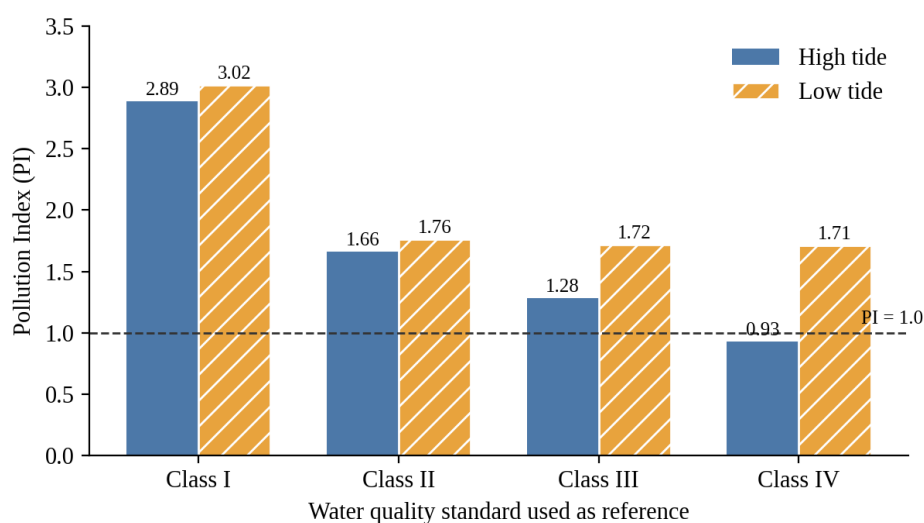


Figure 2. Pollution Index (PI) of the Sanga-Sanga River at high and low tide for the Class I–IV standards. The dashed line marks PI = 1.0, the upper limit for meeting the quality standard.

Discussion

Water quality status relative to designated uses

The river fails the Class I standard, the designation for raw drinking water, in both tidal conditions. Class I carries the strictest limits, so the PI is highest there (2.89 and 3.02). Because the river is a principal source of raw water and drinking water for the sub-district, this result means that water taken from it should be treated before domestic use. Overall, the river is in the lightly polluted category, with a single exception: against the Class IV standard at high tide, the river meets the quality standard.

That exception needs careful reading. At high tide the Class IV maximum ratio was 1.27, so at least one measurement exceeded the Class IV limit; the PI of 0.93 stayed below 1.0 only because the low mean ratio (0.35) offset the maximum in Equation 1. A PI of 0.93 therefore describes the water as a whole and does not mean that every parameter complied. The Class IV result is also close to the threshold, and it was lost at low tide, when PI rose to 1.71.

Influence of the tide

Water quality was better at high tide than at low tide, especially for the less strict classes. The most plausible explanation is dilution and flushing: at high tide a larger volume of water, with more diluted pollutant concentrations, fills the channel, whereas at low tide the water is dominated by the river's own load and by inputs from the banks. This reading is consistent with the higher mean ratios at low tide (for Class I, 1.29 versus 0.98) and with the highest Cu concentration being recorded at low tide. It is, however, an inference. Salinity, tidal range and discharge were not used in the analysis, so it cannot be confirmed here that tidal water was the diluting source.

The spatial pattern shows that the tide is not the only influence. COD was highest at Station 1 at high tide (35.1 mg/L), even though that station has no direct residential activity at the site. If dilution were the only process, the highest COD would be expected at low tide. A flood tide may instead carry organic matter upstream, or local inputs near the bridge and the settlements around it may matter, and the data available cannot separate these. Station-level PI values and tide-specific salinity measurements would resolve the question. Whatever the mechanism, a single sampling at one tidal phase could place the river in a different category: at Class IV, high-tide sampling would classify it as meeting the standard and low-tide sampling as lightly polluted.

Likely sources of COD, Pb and Cu

COD reflects the load of organic and other oxidisable matter, which is consistent with domestic waste from the riverbank settlements. The Pb and Cu concentrations are more likely to come from industrial activity, as the river flows close to mining-related industry; heavy-metal contamination of river and estuarine water has previously been linked to industrial activity (Rochyatun et al., 2010). The sources were not measured directly, so these attributions remain hypotheses. Even so, the combination of organic and metal contamination suggests that both domestic and industrial inputs contribute to the lightly polluted status, in line with the effects of waste discharge on rivers described by Halder and Islam (2015).

Management implications and limitations

Three recommendations follow. First, domestic wastewater from riverbank settlements and effluent from industrial activity should be managed at source. Second, water quality monitoring should cover both tidal phases, and low-tide results, which were the more unfavourable, are the more cautious basis for judging compliance. Third, Pb and Cu should be monitored in water and sediment, given that both exceeded the standards.

The study has limitations. Sampling covered one three-month period, so seasonal variation could not be assessed. PI values are reported for all stations combined, so differences among stations cannot be identified. The PI is also based only on the parameters measured, and it is sensitive to the maximum ratio, which can be governed by a single parameter. Future work should report station-level indices, include salinity and discharge, and extend sampling across seasons.

CONCLUSION

The Sanga-Sanga River did not meet the Class I water quality standard under Government Regulation of the Republic of Indonesia No. 22 of 2021. The parameters identified as exceeding the applicable standards included COD, lead (Pb), and copper (Cu). These parameters contributed substantially to the observed Pollution Index values and indicate that anthropogenic inputs are affecting the river's water quality.

Water quality differed between tidal conditions. The Pollution Index values during high tide were lower than those during low tide for all water quality classes assessed. During high tide, the river met the Class IV standard, with a Pollution Index of 0.93, whereas during low tide the Class IV Pollution Index

was 1.71 and was therefore classified as lightly polluted. This pattern indicates that tidal dynamics, including dilution, mixing, and pollutant redistribution, should be considered when evaluating the water quality of the Sanga-Sanga River.

Overall, the Sanga-Sanga River was classified as lightly polluted based on the Pollution Index, with pollution potentially associated with human activities in riverside settlements and nearby industrial areas. Continued monitoring of COD and heavy metals, particularly Pb and Cu, is recommended, together with improved management of domestic and industrial wastewater. Monitoring under both high-tide and low-tide conditions and over longer periods would provide a stronger basis for evaluating temporal variation and supporting effective water quality management.

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