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Pollution load carrying capacity and water pollution index in the upstream and downstream sections of the Tondano River

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Abstract
The Tondano River is an important water resource in North Sulawesi, Indonesia, supporting ecological functions and community livelihoods. Human activities within its watershed may increase pollutant inputs and alter water quality. This study assessed water quality, calculated the Pollution Index (PI), and evaluated pollution load carrying capacity (PLCC) at upstream and downstream sites. A quantitative descriptive approach was applied using purposive water sampling at two locations and laboratory analysis of water quality parameters. The PI was calculated for nitrate, total dissolved solids (TDS), total suspended solids (TSS), chemical oxygen demand (COD), and biochemical oxygen demand (BOD), using Class IV standards in Appendix VI of Indonesian Government Regulation No. 22 of 2021. PLCC was estimated from the difference between allowable and existing pollutant loads. Reported PI values were 0.0775 upstream and 0.1881 downstream, indicating compliance for the parameters included in the index. Nitrate increased from 2 to 5 mg/L, TSS from 2.2 to 37 mg/L, and BOD from 0.1 to 0.3 mg/L downstream, whereas TDS decreased from 116 to 72 mg/L. All five evaluated parameters had positive reported PLCC values. These results indicate remaining calculated loading capacity under the selected Class IV criteria, with higher downstream concentrations of several pollution indicators. Continued monitoring and source control are recommended. Interpretation is limited by the two-site design and incomplete documentation of discharge measurements and load calculations.

Keywords: Tondano River, water quality, pollution index, pollution load carrying capacity, class iv water quality standards

Introduction

Rivers provide water for domestic use, agriculture, fisheries, industry, and other economic activities. Their water quality reflects processes within the surrounding watershed, including land use changes and human activities. Domestic wastewater, agricultural runoff, industrial discharges, and other inputs can alter the physical, chemical, and biological characteristics of river water. Organic matter, nutrients, suspended solids, and indicator microorganisms are therefore relevant components of water quality assessment.

The Tondano River is a major river in North Sulawesi Province, Indonesia. It supports surrounding communities through water supply, agricultural activities, fisheries, and other uses. Expanding settlements and increasing economic activities within the watershed may add pollutant loads to the river. Persistent inputs can increase pressure on aquatic ecosystems and reduce the effectiveness of natural recovery processes.

Water quality assessment requires both concentration measurements and an evaluation of pollutant loads. The Pollution Index (PI) compares measured concentrations with standards for a specified water use, providing a numerical indicator of compliance. Pollution load carrying capacity (PLCC) estimates the remaining difference between an allowable pollutant load and the load associated with existing concentrations and river discharge. These measures offer complementary information for water management.

Upstream and downstream sections of the Tondano River differ in surrounding land use and human activity. Downstream water may receive additional inputs from settlements, agriculture, and other activities along the river. Comparing these sections can identify spatial differences in water quality, although measurements at two sites alone cannot establish the sources or mechanisms responsible for those differences.

This study analyzed water quality at upstream and downstream sites, determined PI values using the method specified in Minister of Environment Decree No. 115 of 2003, and evaluated PLCC against Class IV criteria in Appendix VI of Government Regulation No. 22 of 2021. The findings are intended to support river water quality management and identify priorities for continued monitoring.

Method

Research design and study sites

A quantitative descriptive and explanatory approach was used. Field surveys, water sampling, laboratory analysis, PI calculations, and PLCC estimates were conducted for two sites in the Tondano River, North Sulawesi. Sites were selected purposively to represent upstream and downstream conditions with different levels of human activity.

Site	Coordinates	Site characteristics
Upstream	1°17′47.2″ N, 124°54′43.0″ E	Relatively lower human activity and more natural surrounding conditions.
Downstream	1°27′46.2″ N, 124°52′39.9″ E	Greater influence from settlements, agriculture, and local economic activities.

Water sampling and laboratory analysis

Water samples were collected approximately 30 cm below the surface using sterile sample bottles and stored according to standard procedures before laboratory analysis. One upstream site and one downstream site were sampled. The source manuscript does not specify the sampling date, number of replicates, preservation conditions, or laboratory quality assurance procedures.

The analytical scope described in the source included physical, chemical, and biological parameters. Laboratory methods were attributed to Standard Methods for the Examination of Water and Wastewater (APHA, AWWA, & WEF, 2022) [1]. Numerical results were supplied for seven parameters; the remaining listed parameters were not included in the reported results table.

Category	Parameters	Units
Physical	Total suspended solids (TSS); total dissolved solids (TDS)	mg/L
Chemical	pH; dissolved oxygen (DO); biochemical oxygen demand (BOD); chemical oxygen demand (COD); nitrate; phosphate; ammonia; cadmium; mercury; lead	pH is dimensionless; others in mg/L
Biological	Total coliforms	MPN/100 mL

Pollution Index calculation

Water quality status was evaluated using the PI method described in Minister of Environment Decree No. 115 of 2003. Measured concentrations were compared with the Class IV standards adopted in the source manuscript from Appendix VI of Government Regulation No. 22 of 2021. Nitrate, TDS, TSS, COD, and BOD were included in the reported index calculations.

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

Here, C_i is the measured concentration of parameter i, L_{ij} is its standard for water use j, and M and R denote the maximum and mean concentration-to-standard ratios, respectively. For COD, the source used 4 mg/L in its calculations although laboratory results were reported as <4 mg/L. The COD ratio and associated load calculations therefore use the reporting limit rather than a quantified concentration.

PI range	Water quality status
$0 \leq PI \leq 1$	Meets the selected standards
$1 < PI \leq 5$	Slightly polluted
$5 < PI \leq 10$	Moderately polluted
$PI > 10$	Heavily polluted

Pollution load carrying capacity

PLCC was estimated using a concentration and discharge mass balance approach. Existing pollutant loads and the remaining allowable loads were expressed in kilograms per day:

$PL = C \times Q \times 86.4$

$PLCC = (Cstandard - Cexisting) \times Q \times 86.4$

Here, PL is the existing pollutant load (kg/day), C is concentration (mg/L), Q is river discharge (m^3/s), Cstandard is the applicable concentration limit (mg/L), and Cexisting is the existing concentration (mg/L). The factor 86.4 converts mg/L multiplied by m^3/s into kg/day. A positive PLCC indicates remaining calculated capacity, whereas a negative value indicates an exceedance of the selected allowable load.

Calculation note: The source manuscript inconsistently gives conversion factors of 86.4 and 0.0864 while specifying Q in m^3/s. The latter factor applies when Q is expressed in L/s. The dimensionally consistent factor is used in the equations above, while all tabulated loads are retained as reported. Because discharge values and measurement procedures were not provided, those loads could not be independently reproduced. They should be checked against the original discharge records before publication.

Results and Discussion

Water quality at the upstream and downstream sites

Laboratory results showed differences between the two sites (Table 1). The downstream site had higher BOD, nitrate, and TSS concentrations, whereas upstream TDS and DO were higher. COD was below the reported laboratory threshold of 4 mg/L at both sites.

Table 1: Reported water quality measurements in the Tondano River

Parameter	Unit	Upstream	Downstream
BOD	mg/L	0.1	0.3
COD	mg/L	<4	<4
DO	mg/L	10	9
Nitrate	mg/L	2	5
TDS	mg/L	116	72
TSS	mg/L	2.2	37
pH	-	6.3	6.0

The pH values ranged from 6.0 to 6.3 and were within the Class IV range of 6–9 used in the source. These values indicate slightly acidic conditions at both sites, with no observed exceedance of that pH criterion. The two measurements do not establish temporal stability.

DO concentrations were 10 mg/L upstream and 9 mg/L downstream, exceeding the 1 mg/L minimum cited in the source. Both sites had substantial dissolved oxygen at the time of sampling. Temperature and oxygen saturation data were not reported, so the processes responsible for these concentrations cannot be determined.

BOD increased from 0.1 mg/L upstream to 0.3 mg/L downstream but remained below the adopted Class IV limit of 12 mg/L. The downstream increase is consistent with a greater concentration of biodegradable organic matter, potentially associated with human activities. However, no source-specific measurements were provided to establish its origin.

TSS increased from 2.2 mg/L upstream to 37 mg/L downstream. This was the most pronounced concentration difference among the reported parameters. Surface runoff, soil erosion, and land use activities are plausible contributors, although their individual effects were not quantified. Nitrate also increased, from 2 to 5 mg/L, which may reflect agricultural or domestic inputs. TDS decreased from 116 to 72 mg/L, showing that downstream increases did not occur uniformly across all measured parameters.

Pollution Index and water quality status

The source reports PI values of 0.0775 upstream and 0.1881 downstream (Table 2). Both values fall within the 0–1 category and indicate compliance for the five parameters included in the calculation. This classification is specific to the selected Class IV standards and does not establish suitability for other water uses or compliance for parameters without reported results.

Table 2: Reported concentration-to-standard ratios and Pollution Index values

Site	Nitrate	TDS	TSS	COD	BOD	Max.	Mean	PI
Upstream	0.1000	0.0580	0.0055	0.0500	0.0083	0.1000	0.0444	0.0775
Downstream	0.2500	0.0360	0.0925	0.0500	0.0250	0.2500	0.0907	0.1881

The higher downstream PI reflects higher ratios for nitrate, TSS, and BOD. Nitrate had the largest concentration-to-standard ratio at both sites, increasing from 0.1000 upstream to 0.2500 downstream. The TSS ratio increased from 0.0055 to 0.0925. These differences suggest greater downstream pressure from some pollutant indicators, while remaining below the selected standards.

The reported PI values are well below the threshold for slight pollution. Nevertheless, a low index cannot independently demonstrate effective dilution or self-purification because those processes were not measured. It also cannot exclude pollution involving phosphate, ammonia, heavy metals, or coliforms, for which numerical results were not supplied. Repeated sampling and a more complete parameter set would strengthen the assessment.

Pollution load carrying capacity

Reported PLCC values were positive for nitrate, TDS, TSS, COD, and BOD at both sites (Table 3). Within the source calculation framework, this indicates remaining capacity relative to the selected concentration limits. These estimates remain conditional on the discharge assumptions and conversion factor described in the Method section.

Table 3: Reported pollutant loads and remaining pollution load carrying capacity

Parameter	Site	Existing conc. (mg/L)	Standard (mg/L)	Load (kg/day)	PLCC (kg/day)
Nitrate	Upstream	2	20	2,739.74	24,657.70
Nitrate	Downstream	5	20	1,396.56	4,189.68
TDS	Upstream	116	2000	158,916.67	2,581,043.17
TDS	Downstream	72	2000	20,119.63	538,439.26
TSS	Upstream	2.2	400	3,014.71	544,932.55
TSS	Downstream	37	400	10,339.06	101,353.32
COD	Upstream	4	80	5,479.49	104,110.27
COD	Downstream	4	80	1,117.25	21,227.69
BOD	Upstream	0.1	12	136.99	16,301.48
BOD	Downstream	0.3	12	83.79	3,267.95

At the downstream site, the reported nitrate load was 1,396.56 kg/day and the remaining PLCC was 4,189.68 kg/day. Upstream values were 2,739.74 and 24,657.70 kg/day, respectively. Although downstream nitrate concentration was higher, the reported load was lower. This illustrates why concentration differences cannot be equated directly with load differences when discharge varies.

The reported downstream TSS load was 10,339.06 kg/day, compared with 3,014.71 kg/day upstream. This increase is consistent with the marked downstream rise in TSS concentration. Remaining TSS capacity was reported as 101,353.32 kg/day downstream and 544,932.55 kg/day upstream. The spatial contrast supports closer attention to suspended sediment inputs, but does not identify their sources.

BOD and COD also had positive reported PLCC values. These calculations indicate headroom relative to the adopted concentration limits rather than a direct measurement of ecological assimilation or biological recovery. Moreover, downstream BOD load was lower despite a higher concentration, again emphasizing the role of discharge in load estimates.

Management implications and study limitations

The observed downstream increases in nitrate, TSS, and BOD support continued monitoring and control of potential domestic and agricultural inputs. Useful measures include wastewater management, riparian vegetation conservation, erosion control, and reduction of pollutant runoff from agricultural land. Additional sites and wet- and dry-season sampling would help distinguish persistent patterns from short-term variation.

The study represents a comparison of two sampling sites. Sampling dates, replication, discharge measurements, and several analytical results were not documented in the source. Consequently, the findings should not be generalized to the entire river or interpreted as proof of year-round compliance. The inconsistency in load conversion factors should be resolved using the original hydrological records. Future work could combine expanded monitoring, water quality modeling, and geographic information systems to examine the distribution and sources of pollutants.

Conclusion

The reported PI values of 0.0775 upstream and 0.1881 downstream indicate that the five evaluated parameters met the selected Class IV criteria at the sampled sites. Higher downstream concentrations of nitrate, TSS, and BOD indicate a spatial increase in several pollution indicators, while TDS decreased. Positive reported PLCC values suggest remaining calculated capacity for nitrate, TDS, TSS, COD, and BOD under the source assumptions. Verification of discharge data and conversion factors is required before relying on the load estimates for management decisions.

Sustained pollutant source control and regular water quality monitoring are recommended, particularly downstream.

Future research should include additional sites, seasonal observations, complete analytical reporting, and documented discharge measurements to improve the reliability and representativeness of the assessment.

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