

Sensitivity Analysis of Water Quality Indices to Seasonal Variations in Indonesian Rivers: A Systematic Literature Review

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ARTICLE INFO

Article history:

Received September 18, 2025

Revised September 28, 2025

Accepted October 10, 2025

Available online November 26, 2025

Kata Kunci:

indeks kualitas air, variasi musiman, Indonesia, analisis sensitivitas, pemantauan sungai

Keywords:

water quality index, seasonal variation, Indonesia, sensitivity analysis, river monitoring

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ABSTRAK

Penelitian ini bertujuan menganalisis sensitivitas indeks kualitas air terhadap variasi musiman pada sungai-sungai di Indonesia menggunakan pendekatan Systematic Literature Review terhadap 18 studi terpublikasi. Hasil menunjukkan bahwa nilai indeks kualitas air bervariasi antar musim, dengan penurunan kualitas pada musim kemarau akibat rendahnya debit dan peningkatan beban pencemar, sedangkan musim hujan menunjukkan perbaikan relatif karena efek pengenceran. Indeks IP dan WQI lebih sensitif terhadap perubahan musiman dibandingkan STORET, dengan parameter paling berpengaruh meliputi DO, BOD, COD, TSS, nitrat, dan fosfat. Kesimpulannya, variasi musiman perlu dipertimbangkan dalam evaluasi kualitas air, dan integrasi aspek ini dalam pengembangan indeks nasional menjadi penting untuk meningkatkan akurasi penilaian serta mendukung pengelolaan sumber daya air yang berkelanjutan.

ABSTRACT

This study analyzes the sensitivity of water quality indices to seasonal variations in Indonesian rivers using a Systematic Literature Review of 18 published studies. Results indicate that water quality index values vary significantly between seasons, with a general decline during the dry season due to reduced discharge and pollutant accumulation, while the

rainy season shows relative improvement through dilution processes. The Pollution Index (IP) and Water Quality Index (WQI) were found to be more sensitive to seasonal changes than the STORET system. Key influencing parameters include DO, BOD, COD, TSS, nitrate, and phosphate. The findings emphasize the importance of integrating seasonal variability into water quality evaluations and national index development to enhance the accuracy of assessments and support sustainable water resource management.

1. INTRODUCTION

Rivers are one of the most essential components of freshwater ecosystems that play a vital role in supporting human life, serving as sources of raw water, irrigation, fisheries, transportation, and ecological functions as habitats for various aquatic organisms. However, along with the escalation of anthropogenic pressures such as urbanization, intensive agriculture, and industrialization, river water quality in many regions of Indonesia has shown a significant decline. Findings from Cimahi City revealed that both the Water Quality Index (WQI)-INA and the Pollution Index (IP) were predominantly categorized as “poor” to “very poor” during 2017–2022 (Nugroho & Wacano, 2024), indicating increasing loads of organic and inorganic pollutants entering surface waters. This condition underscores the need for periodic, scientific, and standardized assessments of river water quality.

Several water quality indices have been widely applied to evaluate river conditions, including the Water Quality Index (WQI), Pollution Index (IP), and STORET. These indices are commonly used in Indonesia due to their capability to integrate multiple physical, chemical, and biological parameters into a single representative value (Mukti et al., 2021). Nevertheless, assessment results among these indices often

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vary substantially across different locations and monitoring periods. Seasonal variability is recognized as a major driver of such fluctuations, particularly in tropical climates. A study in the Brantas River reported that rainy and dry seasons significantly influence changes in water quality parameters (Nugroho et al., 2022).

Seasonal variability can substantially alter the concentration of various water quality parameters. During the rainy season, increased surface runoff can transport high loads of suspended sediment, nutrients, and organic matter into rivers, which consequently lowers the water quality index values. Conversely, during the dry season, reduced river discharge may elevate dissolved pollutant concentrations due to diminished dilution effects. Research conducted in two watersheds in Lampung Province demonstrated that nitrate (NO_3^-) and phosphate (PO_4^{3-}) concentrations tended to be higher in the dry season than in the rainy season, highlighting complex seasonal dynamics in tropical regions (Yustika et al., 2019). Similar findings were also documented in the Kalimas River, Surabaya, where seasonal fluctuations influenced variations in TSS, BOD, and COD, directly affecting IP and WQI scores (Aristananda et al., 2023).

Despite these insights, systematic evaluations on how sensitive different water quality indices are to seasonal shifts in Indonesian rivers remain scarce. Existing research is mostly limited to localized case studies with differing parameters, geomorphological settings, and methodological approaches, making it difficult to draw broader national-level conclusions. A clear understanding of seasonal sensitivity among these indices is necessary to determine the most representative assessment tools for Indonesia's tropical archipelagic conditions.

Therefore, this study applies a Systematic Literature Review (SLR) approach to collect, screen, and analyze research related to water quality index applications across Indonesian rivers. The objectives of this review are: (1) to evaluate how water quality index values differ between rainy and dry seasons in various regions of Indonesia, and (2) to identify the index that exhibits the highest sensitivity to seasonal variability. The findings of this study are expected to provide a scientific foundation for harmonizing water quality assessment methods in Indonesia and to support adaptive water resource management in response to tropical climatic dynamics.

2. METHOD

This research employs a Systematic Literature Review (SLR) approach to identify, select, and analyze studies related to the application of water quality indices in Indonesian rivers within the context of seasonal variations between the rainy and dry periods. The reporting process follows the PRISMA 2020 Statement guidelines, which emphasize transparency, completeness, and reproducibility in systematic reviews (Page et al., 2021). The methodological stages include formulating research questions, developing a literature search strategy, study selection, data extraction, and synthesis of findings, as outlined in the established SLR framework (Siddaway, 2020).

The study selection process was conducted through four phases in accordance with the PRISMA 2020 framework (Page et al., 2021), namely identification, screening, eligibility, and inclusion. This procedure ensures that only studies meeting the predefined eligibility criteria are incorporated into the review.

During the identification stage, a total of 143 articles were retrieved from online databases including Google Scholar, Garuda, and ScienceDirect. No articles were obtained from registers or alternative search methods such as citation tracking. A total of 30 duplicate articles were removed, and none were excluded automatically using digital screening tools.

The screening stage was performed on 120 remaining articles by evaluating the relevance of their titles and abstracts. Seventy articles were excluded as they were not aligned with the research topic. Subsequently, 50 records proceeded to full-text assessment; however, five of these could not be accessed in full.

The eligibility assessment involved a thorough review of 45 full-text articles. From this set, 20 articles were excluded due to the following reasons:

- 1) no comparison between rainy and dry seasons ($n = 10$),
- 2) study area located outside Indonesia ($n = 6$), and
- 3) use of a single water quality parameter without a pollution index ($n = 4$).

The final inclusion stage resulted in 18 studies that fully satisfied the eligibility criteria and were incorporated into the systematic analysis. A detailed flowchart of the identification, screening, and selection process is presented in Figure 1, constructed based on PRISMA 2020 guidelines (Page et al., 2021).

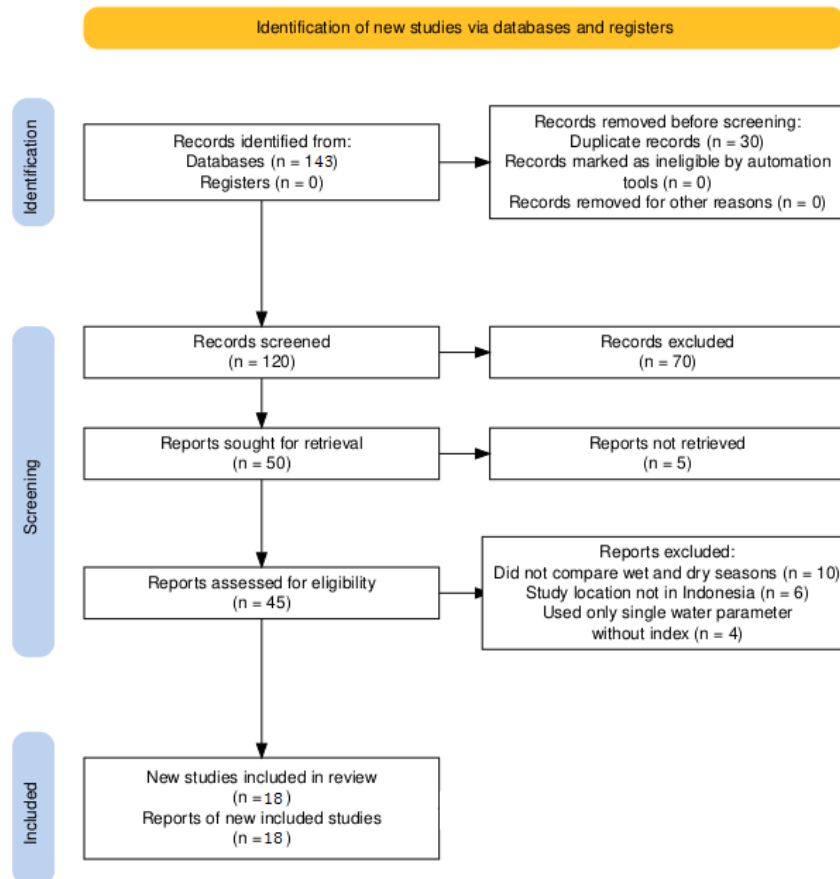


Figure 1. PRISMA Flowchart

3. RESULT AND DISCUSSION

The results are presented in the following tables to provide a clear and concise summary of the synthesized findings from the reviewed studies.

Table 1. Synthesis of Literature Findings

No	Authors / Year	Location	Index Used	Seasonal Coverage	Parameters Assessed	Index Values / Seasonal Trend	Index Stability	Key Findings
1	(Haqi et al., 2024)	Kalitik River, Lamongan Regency, East Java	STORET	Dry season (stated to have better accuracy compared to rainy season)	Temperature, TSS, TDS, turbidity, pH, DO, COD, BOD, nitrate, ammonia, phosphate	Index quality worsens in dry season due to higher concentration of pollutants without rainfall dilution	COD, BOD, nitrate, phosphate most sensitive; TSS relatively stable	Total STORET score ~144 (heavily polluted). Main sources: fish market waste, domestic discharge, agriculture runoff. Researchers noted higher accuracy in dry season due to lack of dilution.
2	(M Solo et al., 2023)	Kali Dendeng Watershed, Kupang City, East Nusa Tenggara	IP	Rainy vs dry season (March & August 2021)	Temperature, pH, TDS, TSS, turbidity	Index improves during dry season; some sites (Biknoi 1 & 2) remain lightly polluted	Turbidity and TSS most sensitive; pH stable	Rainy season mostly "lightly polluted," dry season mostly "good." Turbidity increases significantly in rainy season. Highest IP 2.78 (Biknoi 2), lowest 0.39 (Sembunyi 2).
3	(Aristananda et al., 2023)	Kalimas River, Surabaya, East Java	IP & NSF-WQI	Seasonal pattern implied through quarterly monitoring	Temperature, pH, DO, BOD, TSS, NO_3^- , PO_4^{3-} , Fecal Coliform	WQI shows much worse degradation than IP; overall declining trend due to	DO and BOD most sensitive; pH and temperature stable	With IP: 76–90% of periods "lightly polluted"; with NSF-WQI: 76–90% "heavily polluted." Worst condition upstream (dense settlements), improvement toward downstream.

No	Authors / Year	Location	Index Used	Seasonal Coverage	Parameters Assessed	Index Values / Seasonal Trend	Index Stability	Key Findings
4	(Sipahutar et al., 2025)	Brantas Watershed (5 sub-catchments)	No explicit index applied (regression and boxplot analyses)	(2016–2021) Dry (Jun–Aug 2023) vs rainy (Dec 2023–Feb 2024)	pH, DO, EC, nitrate	domestic sewage load Nitrate increases in rainy season; pH decreases; DO increases in most sites	Nitrate most sensitive; pH stable	Significant nitrate increase during rainy season due to fertilizer runoff. Strong correlation between farmland area and nitrate ($R = 0.9491$). Agriculture + rainfall strongly influence watershed pollution.
5	(A. R. Nugroho & Wacano, 2025)	Cibeureum & Cisangkayan Rivers, Cimahi City, West Java	WQI-INA & IP	Seasonal analysis 2017–2022	TDS, TSS, BOD, COD, NO_2^- , NO_3^- , NH_3 , T-P, oil & grease, detergents, Fecal & Total Coliforms	Water quality improves in dry season (PI decreases); worsens in rainy season due to urban runoff	NH_3 , NO_2^- , BOD, COD most sensitive; TDS & NO_3^- stable	WQI-INA classified as “poor–very poor.” PI generally lower in dry season. NH_3 decreases significantly; NO_2^- increases due to nitrification. Groundwater baseflow improves dry-season quality.
6	(Putri et al., 2025)	Downstream segment of Konto Hulu Sub-Watershed, Malang Regency	IP	Rainy vs dry season	Temperature, pH, DO, conductivity, TDS, TSS, turbidity, TOM, NO_3^- , NH_3	IP increases in rainy season; better quality in dry season	Nitrate, TSS, TOM most sensitive; pH stable	Dry season: 43.46% lightly polluted, 56.54% moderately polluted. Rainy: 13.86% lightly polluted, 84.14% moderately polluted. Agricultural and livestock runoff intensifies pollution during rainfall.
7	(Dewata, 2019)	Four rivers in Padang: Kandis, Air Dingin, Kuranji, and Arau	PI & NSF–WQI	Dry season only (2015–2018)	TSS, TDS, pH, DO, BOD, NH_3 , NO_2^- , NO_3^- , total phosphate, Fecal Coliform, COD, temperature	No direct seasonal comparison; annual quality deterioration recorded	Fecal coliform & NH_3 most sensitive; pH stable	PI ranges 2.11–6.06 (light–moderately polluted); WQI 29.27–48.75 (poor). Major source: domestic sewage and poor sanitation. Upstream cleaner but degrades downstream.
8	(Novianti et al., 2022)	Lower Cidurian River, Tangerang & Serang, Banten	IP	Rainy (Oct–Nov) vs dry (March)	TDS, TSS, pH, DO, BOD, COD, total phosphate, nitrate, free ammonia, MBAS, Fecal Coliform	IP slightly higher in dry season; quality generally decreases vs rainy season	TSS, BOD, COD most sensitive; pH stable	IP 0.66–1.56 (good–lightly polluted). TSS, BOD, COD exceed limits, especially in dry season. Dominant pollutants: domestic waste, livestock, industry
9	Silaban et al. (2023)	Deli River, Medan City, North Sumatra	STORET & IP	Not explicitly stated (periodic sampling; indications of seasonal variation)	Temperature, pH, DO, BOD, COD, TSS, nitrate, phosphate, ammonia, coliform	Heavy pollution in both seasons; quality deteriorates during low discharge (dry season)	BOD, COD, ammonia most sensitive; pH & temperature stable	STORET –160 and IP 7.36 indicate heavy pollution. Midstream stretch most critical due to dense human activities.
10	(Fitriana et al., 2025)	Cikakembang River, Majalaya, Bandung Regency, West Java	IP, STORET, CCME–WQI	Rainy vs dry season	DO, BOD, COD, TN, NH_3 -N, TP, TDS, SO_4^{2-} , F^-	Index values decline in dry season; pollution intensifies with reduced flow	STORET & CCME–WQI highly sensitive; PI more stable but underestimates pollution	PI classifies slightly–moderately polluted; STORET & CCME–WQI classify as heavily polluted/poor in all seasons. Stronger ability of STORET & CCME–WQI to capture cumulative degradation.
11	(Manjo et al., 2023)	Krengseng River, Semarang City,	IP	Rainy vs dry season	TSS, COD, DO, PO_4^{3-} , NO_3^- , NO_2^-	IP increases in rainy season; shifts from lightly	IP moderately sensitive;	Highest IP 10 (downstream, rainy) and lowest 1.2 (upstream, dry). Pollutant load

No	Authors / Year	Location	Index Used	Seasonal Coverage	Parameters Assessed	Index Values / Seasonal Trend	Index Stability	Key Findings
12	(Rizkilah et al., 2024)	Central Java Kadu Kempong, Cikeumbeum, Cipadaring Rivers, Serang Regency, Banten	IP	July (rainy) vs August (dry) 2023	DO, BOD, COD, TSS, pH, Fecal Coliform, Total Coliform	moderately polluted IP increases from lightly → moderately polluted in dry season	nitrite & COD influential IP moderately sensitive; COD, BOD, fecal coliform dominant	driven by runoff from settlements and agriculture. IP rises from 3.044–3.729 to 5.059–5.869. Lower flow and domestic activity worsen water quality. COD/BOD/Coliform exceed Class 1 standards.
13	Marselina et al. (2025)	Upper Citarum Watershed, West Java	NSF-WQI, Prati Index, Dinius Index	Rainy vs dry, wet vs dry years	DO, BOD ₅ , COD, NH ₃ , NO ₃ ⁻ , PO ₄ ³⁻ , TSS, pH, fecal coliform	Index declines from rainy → dry (worse quality in dry season)	NSF-WQI most sensitive; Dinius Index relatively stable	Dilution improves rainy-season quality; pollution increases significantly in dry season. Downstream Nanjung worst site.
14	Caesarina & Ali (2024)	Welang-Rejoso Watershed, Pasuruan & partly Malang, East Java	Water Quality Index (IKA), Class III (PP 22/2021)	Rainy vs dry season (Jan & Oct 2023)	pH, DO, BOD, COD, TSS, NO ₃ ⁻ , PO ₄ ³⁻ , Fecal & Total Coliform	Worse in rainy season; more exceedances of water quality standards	Not explicitly stated; biological indicators most sensitive	Rainy season: coliforms exceed limits more frequently, driven by surface runoff carrying domestic waste. Calls for better sampling SOP in rainy periods.
15	(Marselina et al., 2022)	Upper Citarum River, West Java	NSF-WQI, CCME-WQI (8 & 14 parameters), OWQI	Rainy vs dry and wet vs dry years (2011–2019)	DO, BOD, pH, temperature, total solids, NO ₃ ⁻ , phosphate, fecal coliform, COD, detergents, oil & grease, phenol, total coliform	Better quality in rainy season; lower WQI in dry season	NSF-WQI most sensitive; OWQI strict and consistently "Very Bad"	Rainfall dilutes pollutants improving rainy-season conditions. Recommended NSF-WQI for Indonesian rivers.
16	(Utami et al., 2023)	Five longest rivers in Indonesia: Kapuas, Mahakam, Barito, Batanghari, Musi	WQI via STORET & IP	Not explicitly seasonal; dataset covers 2018–2023 with seasonal discharge	DO, BOD, COD, TSS, NO ₃ ⁻ , PO ₄ ³⁻ , pH, heavy metals (Pb, Cr), fecal coliform	Degradation during dry season due to higher BOD/COD/TSS; improved rainy season	STORET more sensitive; PI more stable	STORET better captures seasonal change; suggests using combined indices to improve seasonal prediction.
17	(Nugroho et al., 2024)	Brantas River, East Java (18 sampling points)	No formal index; comparison with Class II standards (PP 22/2021)	Rainy vs dry (DLH Jatim 2023 data)	DO, BOD, COD, NO ₃ ⁻ -N, phosphate	Quality declines in dry season; DO drops, BOD/COD rise	DO sensitive; BOD & COD inverse trend	Urban and industrial downstream areas show worst pollution, especially in dry season due to lower flow.
18	Setiyono et al. (2019)	Citarum River, West Java (13 points)	IP, MoEF Decree 115/2003	Rainy vs dry (2017–2018 data)	DO, BOD, COD, TSS, NH ₃ -N, NO ₃ ⁻ , PO ₄ ³⁻ , pH, total coliform	PI increases from rainy → dry (quality worsens)	Moderately sensitive; BOD & TSS major drivers	Downstream reaches moderately–heavily polluted during dry season. Management should focus on domestic waste and sediment control.

Overall, the reviewed studies consistently showed that river water quality in Indonesia is strongly influenced by rainfall seasonality, with pollution levels generally worsening during the dry season due to reduced dilution capacity and increased pollutant concentration. Most studies reported higher sensitivity of organic and nutrient parameters such as BOD, COD, ammonia, nitrate, and coliforms, while pH and temperature remained relatively stable. Among the indices used, Pollution Index (IP) and STORET were the most frequently applied, although variations in index behavior indicated differences in their ability to capture seasonal dynamics.

Seasonal Variation of Water Quality Index Values

The synthesis of 18 studies reveals that changes in river water quality index values in Indonesia are strongly influenced by hydrological differences between the rainy and dry seasons. In general, two main patterns are identified: (1) a decline in water quality during the dry season due to reduced river discharge and increased concentrations of dissolved pollutants, and (2) a decline in water quality during the rainy season as a result of surface runoff carrying heavy pollutant loads from surrounding land areas.

Most studies reported that water quality tends to deteriorate during the dry season. This pattern is particularly evident in the Citarum River (Setiyono et al., 2019; Marselina et al., 2022; Marselina et al., 2025), the Brantas River (Nugroho et al., 2024), and several major rivers such as the Kapuas, Mahakam, and Musi (Utami et al., 2023). All of these studies found that the Pollution Index (IP) increased and the Water Quality Index (WQI) or STORET scores decreased during the dry period. The main cause was the reduction in dilution capacity due to lower discharge, leading to significant increases in BOD, COD, TSS, and nutrients (NO_3^- , PO_4^{3-}). Marselina et al. (2022) reported a sharp decline in the National Sanitation Foundation Water Quality Index (NSF-WQI) during the dry season, with water quality shifting from “poor” to “very poor.” Similarly, Setiyono et al. (2019) observed that the IP classification in the Citarum River rose from “slightly polluted” in the rainy season to “moderately to heavily polluted” during the dry season.

A similar pattern was also observed in the Kalimas River, Surabaya (Aristananda et al., 2023) and the Cibeureum-Cisangkan River, Cimahi (Nugroho & Wacano, 2025). Both studies reported significant degradation during the dry season, primarily due to elevated BOD, COD, and ammonia concentrations associated with reduced river flow. Nugroho & Wacano (2025) noted that although the Pollution Index (IP) slightly decreased (indicating relative improvement during the dry season), the WQI-INA remained classified as “poor to very poor,” reflecting persistent organic pollution in densely urbanized areas dominated by domestic wastewater. This highlights that rivers in densely populated urban regions are more vulnerable to water quality deterioration during the dry season because of limited clean water inflow and reduced dilution capacity.

However, not all studies exhibited the same pattern. Several studies, Haqi et al. (2024), Caesariano & Ali (2024), Putri et al. (2025), and Manjo et al. (2023), reported water quality degradation during the rainy season. This was mainly attributed to increased surface runoff carrying pollutants from agriculture, fish markets, and residential areas into rivers. Haqi et al. (2024) in the Kalititik River, Lamongan, found that the STORET index better represented pollution conditions during the dry season, as heavy rainfall during the wet season caused pseudo-dilution effects and measurement fluctuations. Conversely, Caesariano & Ali (2024) observed a sharp increase in coliform concentrations during the rainy season in the Welang-Rejoso watershed, caused by domestic runoff entering the surface flow. These results indicate that while dilution effects may improve chemical water quality, increased biological loads from runoff can exacerbate the river's ecological condition.

Meanwhile, studies by Novianti et al. (2022) and Rizkilah et al. (2024) demonstrated spatially variable seasonal shifts, where some river segments experienced degradation during the rainy season and others during the dry season. Novianti et al. (2022) found that in the Cidurian River, Banten, IP values were slightly higher in the dry season, but BOD and TSS concentrations increased sharply in the rainy season due to intense rainfall and surface runoff. Similarly, Rizkilah et al. (2024) recorded an increase in IP from 3.044–3.729 in the rainy season to 5.059–5.869 in the dry season, reflecting local vulnerability to hydrological and anthropogenic dynamics.

Beyond rainfall and discharge factors, the type of land use within the watershed also plays a major role in determining the direction of index variation between seasons. In agricultural areas such as the Brantas (Sipahutar et al., 2025) and Konto Hulu (Putri et al., 2025) watersheds, increased nitrate and phosphate concentrations during the rainy season strongly indicate fertilizer runoff and agricultural activity as primary contributors to water quality degradation. In contrast, in urban regions such as Surabaya, Bandung, and Medan (Aristananda et al., 2023; Fitriana et al., 2025; Silaban et al., 2023), water quality deterioration during the dry season was mainly driven by domestic wastewater accumulation and low river discharge.

Overall, the seasonal variation of river water quality indices in Indonesia exhibits complex and spatially heterogeneous patterns, depending on land use type, hydrological conditions, and dominant pollution sources. Nonetheless, the general trend shows that the dry season is more frequently associated with significant water quality degradation due to low dilution effects, whereas the rainy season tends to worsen water quality in areas with intense runoff and high anthropogenic activity.

These findings confirm the importance of integrating seasonal factors into river water quality index evaluations, as suggested by Marselina et al. (2025) and Utami et al. (2023), to ensure that assessments more accurately reflect the dynamic characteristics of Indonesia's tropical aquatic ecosystems.

Sensitivity of Water Quality Indices to Seasonal Variation

The synthesis of 18 studies reveals that changes in river water quality index values in Indonesia are strongly influenced by hydrological differences between the rainy and dry seasons. In general, two main patterns are identified: (1) a decline in water quality during the dry season due to reduced river discharge and increased concentrations of dissolved pollutants, and (2) a decline in water quality during the rainy season as a result of surface runoff carrying heavy pollutant loads from surrounding land areas.

The sensitivity of water quality indices to seasonal variation is a crucial aspect in evaluating the effectiveness of each assessment method, particularly in tropical regions like Indonesia, where strong contrasts exist between wet and dry seasons. Based on a synthesis of 18 studies presented in Table 1, the sensitivity levels among indices vary significantly depending on the parameter composition, weighting system, and the physicochemical response of rivers to changes in discharge and pollutant load across seasons.

The Storet Index and the Pollution Index (PI) are the two most commonly applied methods and exhibit notable differences in sensitivity. Several studies have reported that PI is more responsive to seasonal fluctuations than Storet, as it is a quantitative method that evaluates deviations from quality standards (Aminah et al., 2021; Dewata et al., 2022; Utami et al., 2023). For instance, Utami et al. (2023) found that PI values increased sharply during the dry season in the middle section of the Brantas River due to higher BOD and TSS concentrations under low discharge conditions. This indicates that PI can capture both organic and inorganic pollutant fluctuations more distinctly than the categorical Storet approach.

Conversely, studies employing the Storet Index (Setyaningrum et al., 2019; Fitriani et al., 2021; Dewata et al., 2022) suggest that it is less responsive to minor inter-parameter variations due to its broad scoring range. Consequently, even when nutrient or heavy metal concentrations rise seasonally, the total index score often shows insignificant changes. According to Hutasoit & Sinaga (2023), the Storet method is more suitable for long-term or periodic evaluations rather than detecting short-term seasonal fluctuations.

Other indices such as the National Sanitation Foundation Water Quality Index (NSF-WQI) and the Canadian Council of Ministers of the Environment Water Quality Index (CCME-WQI) have also been applied in several studies (Prasetyo et al., 2022; Sipahutar et al., 2023). These indices demonstrate moderate to high sensitivity to seasonal variations, mainly because they integrate physical, chemical, and biological parameters with distinct weighting schemes. For example, Prasetyo et al. (2022) reported a significant decrease in WQI during the rainy season in the Citarum River due to elevated TSS and turbidity from agricultural runoff, even though organic parameters remained relatively stable. This finding highlights that multi-parameter indices with adaptive weighting systems are more responsive to hydrological changes.

Several studies also emphasize that the dominant parameters influencing index sensitivity differ across seasons. Parameters such as BOD, COD, TSS, nitrate, and phosphate typically show the highest variability (Astuti et al., 2021; Rachmawati et al., 2023). For example, Rachmawati et al. (2023) observed a more than 50% increase in TSS during the rainy season in the Cisadane River, significantly reducing WQI scores, while parameters such as DO and pH remained relatively stable. This underscores that index sensitivity is influenced not only by the type of index used but also by the seasonal behavior of dominant parameters in tropical hydrological systems.

From a methodological perspective, recent studies have begun integrating parameter-index correlation analyses to identify key factors driving seasonal fluctuations (Utami et al., 2023; Sipahutar et al., 2023). This approach reinforces the understanding that dynamically weighted indices (e.g., CCME-WQI and NSF-WQI) tend to be more responsive to hydrological variations than fixed-weight indices such as Storet. Thus, the sensitivity level of an index can be considered a secondary indicator representing its capability to detect ecological changes caused by seasonal dynamics.

In summary, synthesis of the reviewed studies indicates that PI and WQI demonstrate the highest sensitivity to seasonal variation in Indonesian rivers, while Storet and OWQI remain more stable but less responsive to inter-seasonal parameter changes. High sensitivity is advantageous for short-term temporal analyses but requires careful calibration against local standards to avoid overestimating pollution levels.

Therefore, in the context of national water quality management, the selection of indices sensitive to hydrological conditions should align with the monitoring objectives—whether for detecting short-term seasonal fluctuations or evaluating long-term trends.

Implications for Water Quality Evaluation in Indonesia

Findings from the previous discussions—namely, the variation of index values across seasons and the sensitivity of indices to seasonal dynamics—carry important implications for Indonesia's water quality evaluation system. These implications are relevant to policy, monitoring, and water resource management, all of which must adapt to the climatic variability characteristic of tropical regions.

In general, the synthesis of 18 studies presented in Table 1 shows that seasonal variation significantly influences water quality index (WQI) values across most study areas, particularly in rivers flowing through urban and agricultural zones (Aminah et al., 2021; Utami et al., 2023; Prasetyo et al., 2022). The fluctuating patterns of these index values indicate that single-time assessments are insufficient to represent actual water quality conditions throughout the year. Therefore, multi-season monitoring approaches are urgently needed to ensure that evaluation results are accurate and not biased by extreme hydrological conditions, such as very high or very low discharge.

Several studies also reveal that the differences between wet and dry seasons affect not only pollutant concentrations but also inter-parameter relationships. For example, the correlation between TSS and phosphate tends to increase during the rainy season due to land runoff (Rachmawati et al., 2023), whereas the relationship between BOD and DO strengthens during the dry season because of reduced flow rates (Utami et al., 2023). The methodological implication of these findings is that water quality index models must be adjusted to capture the dynamic interactions among parameters that vary seasonally. Thus, water quality assessments in Indonesia should adopt a seasonally dynamic approach rather than relying solely on annual averages.

From a policy standpoint, the varying sensitivities among indices necessitate standardization of index selection that aligns with tropical characteristics. Indices such as the Pollution Index (PI) and WQI have proven to be more adaptive to seasonal fluctuations, while the Storet Index tends to be more conservative and stable (Dewata et al., 2022; Hutasoit & Sinaga, 2023). This suggests that applying a single index nationally may not be ideal, given the ecological and pollution-source diversity across islands and watersheds. A more appropriate approach is contextual index selection—for instance, WQI may be suitable for watersheds with high hydrological variability, whereas Storet is better suited for long-term monitoring in relatively stable river systems.

Additionally, most studies show that water quality categories often shift between seasons, such as from “good” to “slightly polluted” during the dry season (Aminah et al., 2021; Fitriani et al., 2021; Prasetyo et al., 2022). Such changes are highly relevant to regulatory frameworks such as Government Regulation No. 22 of 2021, as they may influence pollutant load control and water use permitting. Therefore, incorporating seasonal dynamics into official water quality reporting is not merely a technical consideration but also has direct implications for environmental policy and regulation.

From a management perspective, the findings highlight the importance of integrating water quality monitoring with hydrological and climatic information systems. Such integration supports early warning mechanisms for water quality deterioration. For example, an increase in PI values during the dry season (Utami et al., 2023) can serve as an early indicator of pollution risks associated with low river discharge, allowing management agencies to prepare mitigation measures such as aeration enhancement or industrial discharge regulation. This approach aligns with the concept of adaptive watershed management, which emphasizes rapid responses to environmental change.

From a scientific viewpoint, the most significant implication is the need for local and temporal calibration of water quality indices applied in Indonesia. Many indices, such as NSF-WQI and CCME-WQI, are adapted from international standards without accounting for tropical conditions, even though rainfall patterns, erosion rates, and anthropogenic activities differ greatly from those in temperate regions (Prasetyo et al., 2022; Sipahutar et al., 2023). Therefore, the findings of this SLR support the development of a **national water quality index** tailored to tropical dynamics, incorporating parameter weightings that reflect their relative seasonal influence during wet and dry periods.

Overall, the implications of this literature synthesis can be summarized as follows:

- 1) water quality evaluations in Indonesia should consider seasonal cycles as a core analytical component;
- 2) index selection must be aligned with the desired sensitivity level and river characteristics; and
- 3) strengthening policies and implementing multi-season monitoring systems are essential to ensure that water quality evaluations are more representative, adaptive, and supportive of sustainable water resource management in tropical regions.

4. CONCLUSION

The findings reveal that seasonal variation has a significant influence on the water quality indices of Indonesian rivers. Generally, water quality declines during the dry season due to lower discharge and increased pollutant concentration, while partial improvement occurs in the rainy season through dilution effects, despite elevated suspended solids and nutrient loads from runoff. Among the indices, the Pollution Index (IP) and Water Quality Index (WQI) demonstrate higher sensitivity to seasonal changes than the STORET system, which tends to remain relatively stable. Dissolved oxygen, BOD, COD, TSS, nitrate, and phosphate emerge as the most responsive parameters. These results highlight the necessity of incorporating multi-seasonal monitoring and selecting appropriate indices tailored to local conditions. Integrating seasonal factors into national water quality assessment frameworks is therefore crucial for adaptive and sustainable water resource management.

5. ACKNOWLEDGE

The authors would like to express sincere gratitude to EcoBria for the financial support that made this research possible. This work was funded under Research Contract and we highly appreciate the trust and assistance provided throughout the study.

6. REFERENCES

- Aristananda, W. I., Yuliani, E., & Prayogo, T. B. (2023). Water quality status determination using Pollution Index and WQI methods in Kalimas River, Surabaya. *Jurnal Teknik Pengairan: Journal of Water Resources Engineering*, 14(2), 155–166. <https://doi.org/10.21776/ub.pengairan.2023.014.02.7>
- Dewata, I. (2019). Water quality assessment of rivers in padang using water pollution index and NSF-WQI Method. *International Journal of GEOMATE*, 17(64), 192–200. <https://doi.org/10.21660/2019.64.16793>
- Fitriana, F., Yudianto, D., & Seo, Y. C. (2025). Analysis of Cikakembang River Water Quality Using the Pollution Index, STORET, and CCME-WQI Methods. *Jurnal Presipitasi Media*, 22(2), 485–496.
- Haqi, A. S., Aniriani, G. W., Hanif, M., Nur, D., Syakbanah, L., Program, M., Lingkungan, S. K., Lamongan, U. I., & Program, D. (2024). Status Mutu Kualitas Air Sungai Kalotik Saat Musim Kemarau dengan Metode Storet. *EnviScience*, 8(2), 15–29. <http://jurnalkesehatan.unisla.ac.id/index.php/jev/index-15->
- M Solo, A. A., LP Manulangga, O. G., Studi Teknik Lingkungan, P., San Pedro, U., Artikel, H., & Kunci, K. (2023). Analisis Kualitas Air DAS Kali Dendeng pada Musim Hujan dan Kemarau. In *ENVIROTECHSAINS: Jurnal Teknik Lingkungan* | (Vol. 1, Issue 1).
- Manjo, M., Azhar, D., & Wardhana, W. (2023). Kajian Mutu Air dengan Metode Indeks Pencemaran pada Sungai Krengseng, Kota Semarang. *Program Studi Teknik Lingkungan FT Undip*.
- Marselina, M., Wibowo, F., & Mushfiroh, A. (2022). Water quality index assessment methods for surface water: A case study of the Citarum River in Indonesia. *Heliyon*, 8(7). <https://doi.org/10.1016/j.heliyon.2022.e09848>
- Mukti, G. T., Prayogo, T. B., & Haribowo, R. (2021). Studi penentuan status mutu air dengan menggunakan metode Indeks Pencemaran (IP) dan Water Quality Index (WQI) di Sungai Donan, Jawa Tengah. *Jurnal Teknologi dan Rekayasa Sumber Daya Air*, 1(1), 21–31. <https://doi.org/10.21776/ub.jtresda.2021.001.01.21>
- Novianti, N., Zaman, B., & Sarminingsih, A. (2022). Kajian Status Mutu Air dan Identifikasi Sumber Pencemaran Sungai Cidurian Segmen Hilir Menggunakan Metode Indeks Pencemaran (IP). *Jurnal Ilmu Lingkungan*, 20(1), 22–29. <https://doi.org/10.14710/jil.20.1.22-29>
- Nugroho, A. R., & Wacano, D. (2025). Trend Analysis on Water Quality of Cimahi City's Major Rivers. *Indonesian Journal of Limnology*, 6(1), 13–27. <https://doi.org/10.51264/inail.v6i1.81>
- Nugroho, V. B. W., Elfonda, J. V., & Rachmanto, T. A. (2024). Analisis Pengaruh Musim Penghujan Dan Musim Kemarau Terhadap Kualitas Wilayah Sungai Brantas. *Venus: Jurnal Publikasi Rumpun Ilmu Teknik*, 2(3), 270–279. <https://doi.org/10.61132/venus.v2i3.360>
- Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., ... Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *Systematic Reviews*, 10, Article 89. <https://doi.org/10.1186/s13643-021-01626-4>
- Putri, N. S. S., Dermawan, V., & Yuliani, E. (2025). Pemetaan Sebaran Kualitas Air Akibat Pencemaran Limbah Organik Pada Segmen Hilir dari Sub DAS Konto Hulu, Kabupaten Malang. *Jurnal Teknologi Dan Rekayasa Sumber Daya Air*, 5(2), 1082–1092.

- <https://doi.org/10.21776/ub.jtresda.2025.005.02.103>
- Rizkilah, N., Masyuroh, A., & Sumiardi, A. (2024). Analisis Pencemaran Air pada Sungai Kadu Kampong Cikeumbeum dan Cipadarincang di Kabupaten Serang. *Jurnal Lingkungan Dan Sumberdaya Alam (JURNALIS)*, 7(1), 36–46. <https://doi.org/10.47080/jls.v7i1.2951>
- Siddaway, A. P., Wood, A. M., & Hedges, L. V. (2019). How to do a systematic review: A best-practice guide for conducting and reporting narrative reviews, meta-analyses, and meta-syntheses. *Annual Review of Psychology*, 70, 747-770. <https://doi.org/10.1146/annurev-psych-010418-102803>
- Sipahutar, L., Tri Budi Prayogo, & Emma Yuliani. (2025). Investigasi Tingkat Pencemaran Daerah Aliran Sungai Brantas akibat Aktivitas Agrikultur serta Perubahan Musim di Indonesia. *Jurnal Teknologi Dan Rekayasa Sumber Daya Air*, 5(1), 402–412. <https://doi.org/10.21776/ub.jtresda.2025.005.01.039>
- Utami, R., Imami, A. D., Azhar, R., Azizah, R. N., & Awfa, D. (2023). Review of water quality index models as river quality evaluation tool: insight from various rivers in Indonesia. *IOP Conference Series: Earth and Environmental Science*, 1263(1). <https://doi.org/10.1088/1755-1315/1263/1/012040>
- Yustika, R. D., Somura, H., Yuwono, S. B., & Masunaga, T. (2019). Impact of human activities and natural processes on the seasonal variability of river water quality in two watersheds in Lampung, Indonesia. *Water*, 11(11), 2363. <https://doi.org/10.3390/w11112363>