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Original Research Article

Comparative Assessment of Water Quality Indices for Spatial and Temporal Evaluation in the Cidanau Watershed, Indonesia

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Abstract

Cidanau watershed is a water source in Banten Province, Indonesia. Changes in land use and human activities have made water quality worse. Many tests of water quality have been done. Only a few have compared results across tropical watersheds, especially when national and international methods were used together. This research investigates how water quality varies reliably in space and time using the Pollution Index (PI), Indonesian Water Quality Index (IDN-WQI) and National Sanitation Foundation Water Quality Index (NSF-WQI). During the transition and wet seasons in 2025 water samples were collected along the upstream, middle, and downstream along nine stations. PI values ranged from 0.58 to 2.99, which indicated relatively clean water with sporadic slight pollution. The IDN-WQI values of all samples ranged from 50.00 to 63.33, which always indicate moderately polluted water status. NSF-WQI values ranged from 46.11 to 87.21, showing water that could be poor or good. Temporal variations are very sensitive to NSF-WQI values. Analysis of real data produced three similar indices: PI best showed compliance, IDN-WQI showed watershed state, and NSF-WQI showed seasonal changes. In tropical river basins, they provide a framework for monitoring water quality and supporting evidence-based decisions.

Keywords: Cidanau watershed; pollution index; spatiotemporal analysis; water quality index; watershed management

1. Introduction

The Cidanau watershed is of great significance because it provides the majority of raw water for domestic, agricultural, and industrial uses. It also represents one of the most important water resources that sustain life, keep an ecosystem balanced, and provide the foundation for economic development and social progress (Aram et al., 2021). As such, the quality of river water in a watershed can be used as a measure of the overall "health" of the water resources within the watershed, since river water quality is a reflection of the interrelationships among natural phenomena, human actions, and environmental systems. However, as populations increase rapidly and agricultural practices expand, as industrial production grows and as climate change affects the hydrology of rivers, there is growing difficulty in

keeping river water quality at levels that will support these functions (Balla et al., 2024; Mummidivarapu and Rehana, 2026).

Cidanau Watershed is under growing stress because of changes in land use and rising population numbers. By the year 2024 the population is expected to increase to around 260,000 people. This will mean the population density reaches 600 people per square kilometer. The population is increasing at a rate of 2.5 percent ((BPS) Serang Regency National Statistics Agency, 2024; (BPS) Mandalawangi Subdistrict Central Statistics Agency, 2024). As more people move in, residential areas are spreading quickly. At the same time, agricultural land is also expanding. This expansion increases the need for water. More water use leads to pollutants flowing into the river. It has been stated that the World Health Organization (WHO) says that each day the quantity of water used in households in this area varies between thirteen million and twenty-six million liters. This amount is expected to increase. The WHO predicts that daily water consumption may reach a figure between fifteen point six million and thirty point two million liters (World Health Organization, 2022). A greater quantity of water is required since cities are growing, there are more homes producing wastewater, and farming activities are becoming more intensive. All of these factors are placing greater pressure on the rivers than ever before. Pollution comes from sources including households, farmland, and roads. Studies in the areas verify the same trend. Along with changes in land use and population growth, pollution is rising (Anh et al., 2023). Water quality is worsening. Other environmental factors also play a role. They can increase pollution levels. The extent to which pollution can be reduced depends on rainfall, soil conditions and other factors (Leko, 2023; Sar et al., 2024).

There is no biological indication of water quality in the Cidanau Watershed. These signs include pH, dissolved oxygen, biochemical oxygen demand, chemical oxygen demand, total suspended solids and fecal coliforms. These are all indicators of river health (Sokolova et al., 2022) . In the Rawa Danau Nature Reserve color of water and microbial contamination are issues. Not only are they harmful to the environment and water quality, but they also compromise public health. These problems are associated with land-use changes, specifically residential development and the establishment of peatland rice fields (Purwaningsih et al., 2023). Consequently, flat terrain and precipitation create surface runoff with distribute pollution. Coliform greater than $1.13 \times 10^{-}$ MPN per 100 mL (Krakatau Tirta Industri, 2024), Coliform that exceeded the above quality standard class 2, based on Government Regulation No.22 of 2021 and this weight is directly proportional to a BOD (Biochemical Oxygen Demand) & COD (Chemical Oxygen Demand), leaching in nutrients, so significantly increases pollution levels + oxygen expenditure increase. Also, the concentrations of color contained in Cidanau river reaches values 5 and 374 TCU was ~70 to 80% dissolved substances (tannins & lignin) derived from residual plant litter decomposition. The answer lies in the spread of Eichhornia crassipes. High concentrations of dissolved nutrients and suspended particulate material will also lead to even higher reduction in oxygen saturation, thus disrupting the natural processes. It suggests a concerning scenario, with stricter and wider methodology of studying and appropriate management of water quality.

Evaluation methods that are effective and practical according to the data available in the Cidanau River basin, can be used to evaluate poor water quality. Employing biological data in these approaches could bolster decision-making. High-impact information about water quality can help local authorities and polluters target strategies to reduce pollution loads, but also, it helps citizens to understand the status of their rivers. Instead of these parameters, PI is often utilized in the field, especially in Indonesia based on Minister of Environment Decree No. 115 of 2003 (which cites some studies from Sumitomo and Nemerow). This index measures pollution levels by comparing the water quality parameters with criteria from Government Regulation No. 22 of 2021 Regulation of the Minister of Environment and Forestry No. 27 of 2021 provides guidelines for nationwide water quality assessment in Indonesia using the Indonesia Water Quality Index (IDN-WQI) based on marked pollution index (PI) values. This second index – the Water Quality Index of the National Sanitation Foundation (NSF-WQI) was employed for assessing weighted parameters in order to compare water quality between sites throughout the water catchment.

The IDN-WQI is more appropriate for assessments based on regulation, while the NSF-WQI provides an alternative perspective on water quality overall. In evaluating an option, the index selection depends on the task at hand.

While the WQI is accepted and widely used, no single method reflects every river situation. WQIs vary in the parameters they choose, their relative importance and how the numbers are combined. Where they are used. Worldwide, twenty-three WQI models and ten Pollution Index models have been recently identified in a new study. This shows lack of consensus over how the working of these models and its construction for water quality assessment and management. The study also states that method selection should be governed by goal and rule, not index (Syeed et al., 2023).

The Pollution Index (PI) the Indonesian Water Quality Index (IDN-WQI) and the National Sanitation Foundation Water Quality Index (NSF-WQI) all show that we should not rely on an index. We need to look at how current laws and methods define water quality in warm-climate watersheds. The Pollution Index (PI) shows pollution levels compared to standards. The Indonesian Water Quality Index (IDN-WQI) assesses water quality. The National Sanitation Foundation Water Quality Index (NSF-WQI) uses traits to allow comparisons. This study looks at water quality, in the Cidanau Watershed using the Pollution Index (PI) the Indonesian Water Quality Index (IDN-WQI) and the National Sanitation Foundation Water Quality Index (NSF-WQI). It will also use correlation analysis and principal component analysis (PCA) to identify pollution drivers and assess how well these methods perform in this area.

2. Methods

The Cidanau River Basin is located in Serang Regency, Banten Province, Indonesia. It is located between 105°49′00″–106°04′00″ East Longitude and 06°07′30″–06°18′00″ South Latitude (**Figure 1**). Nine monitoring stations were used to monitor water quality conditions in the Cidanau River Basin. Water samples were collected over a three-month period in 2025 (based on the seasons): June (dry season), September (transitional season), and November (rainy season). This monitoring aims to understand how water quality changes with the seasons in the Cidanau Watershed. The selection of monitoring stations took into account how the Cidanau Watershed connects to other rivers, surrounding land use, the points where tributaries meet the main river, site accessibility, and the level of human activity in the area. Consequently, water quality varies significantly in spatiotemporal terms (**Table S1**).

Besides water quality and monitoring in the Cidanau, we performed secondary data-based Geographic Information System (GIS) analysis for depicting the landscape of Cidanau Watershed and human application on it. The data contained DEMNAS, Sentinel-2 imagery, land-use maps and population statistics from the Central Statistics Agency (BPS). We applied an additional application of the methods from American Public Health Association (APHA) (for Water and Wastewater Testing) in order to correlate our data of Cidanau River Basin study to achieve reliable data 8 month after collection based in Indonesian National Standard (SNI) 6989.57:2008. Using in-field measuring equipment, the Cidanau River Basin team detected pH, temperature, Total Dissolved Solids (TDS), Electrical Conductivity (EC) and Dissolve Oxygen (DO). The Cidanau River Basin team in the laboratory used a 2-liter container, kept it cold and sent them to Solid and Hazardous Waste Laboratory IPB and Hydrobiology Laboratory BRIN. The lab tests conducted at Cidanau River Basin including Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), nitrate, and phosphate, turbidity and fecal coliforms. The tools, reagents, and quality control processes shown in **Table S2** was used by all labs for tests on the Cidanau River Basin.

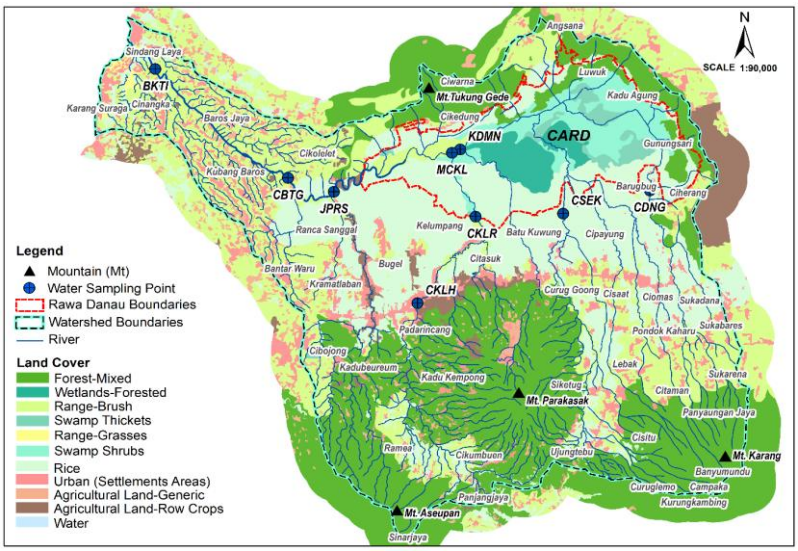


Figure 1. Map of sampling location, watershed area and land use in Cidanau Watershed, Banten

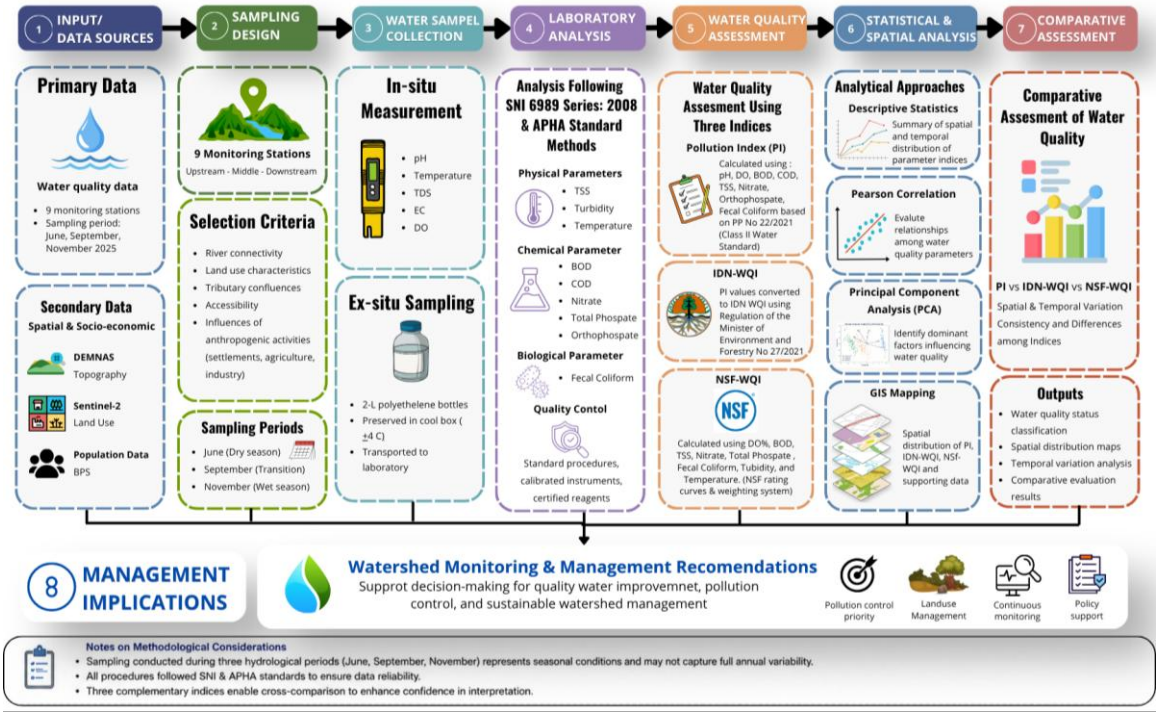
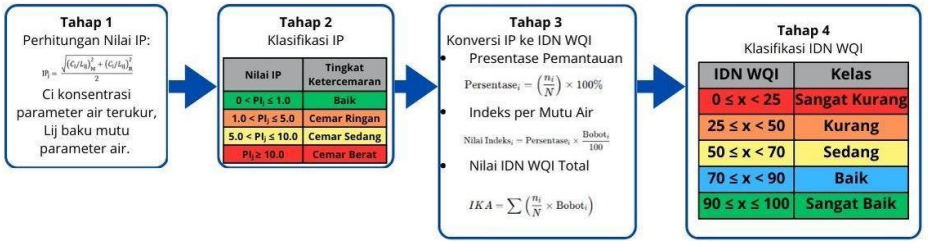


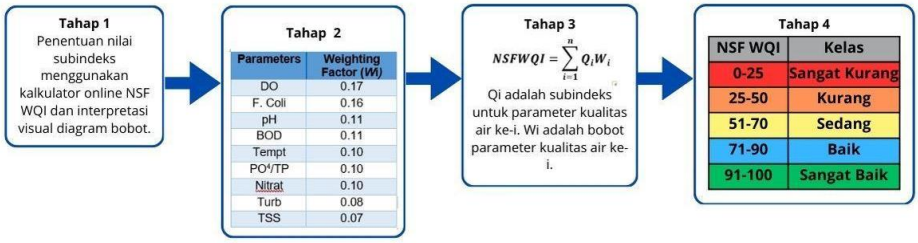
Figure 2. Methodological framework of the study

Water quality analysis of the river was done with three assessment frameworks: the Pollution Index (PI) the Indonesian Water Quality Index (IDN-WQI) and the National Sanitation Foundation Water Quality Index (NSF-WQI). PI values were calculated from pH, DO, BOD, COD, TSS, NO_3^-, PO_4^{3-} and fecal coliforms. For each of these parameters Water quality analysis compared the measured concentrations with the Class II water quality standards set in Government Regulation No. 22 Of 2021. After obtaining the PI value Water quality analysis converted it to the IDN-WQI following Minister of Environment and Forestry Regulation No. 27 Of 2021 (**Figure 3.a**). In contrast the NSF-WQI is calculated with a rating curve and a weighting system that uses DO saturation, BOD, TSS, nitrate, total phosphate, fecal coliforms, turbidity and temperature. Water quality analysis obtained the -index values from the Water Research Center's calculation platform (https://www.knowyourh2o.com). This platform uses the NSF-WQI rating curves and weighting factors ensuring that the index calculations are standardized and

consistent (**Figure 3.b**). Using these three indices Water quality analysis could compare river water quality from angles: pollution status, comparison with national environmental standards via PI, a nationally standardized assessment through IDN-WQI and an internationally recognized evaluation, with NSF-WQI.



(a)



(b)

Figure 3. Flowchart calculation index (a) IDN WQI (b) NSF WQI

3. Result and Discussion

The Cidanau Watershed is very important; 90% of its area lies in Serang Regency, Banten Province. The Cidanau Watershed is the source of raw water for homes, factories, and sanitation in both Serang and Pandeglang Regencies. Beyond its role, the Cidanau Watershed gives key ecological services through the Rawa Danau Nature Reserve, which sits upstream (Salminah et al., 2014). CARD acts like a hydrologic regulator, a water storage system and a buffer for ecology, keeping river flow steady, especially in the dry season (Grandis et al., 2020; Santika et al., 2020). The health of the Cidanau Watershed is also helped by land uses. There are 11 categories and four cover most of the land: forest (32.4%), paddy fields (27.4%), shrubland (20.8%) and settlements or built-up areas (6.9%) (**Figure 1**). These land covers help water seep into the ground reduce surface flow and hold back sediments and organic matter.



(a) (b) (c)

Figure 4. Anthropogenic activities (a) livestock (b) river use by resident's (c) domestic waste

However the Cidanau Watershed faces pressure because people are growing. By 2024, the Cidanau Watershed area had 191,474 people living there. In the downstream parts of the Cidanau Watershed, the density is more than 1,000 people per square kilometer. The growth in population has added human stress to water quality. Home use, sanitation discharge and changes in land use can raise surface runoff, add nutrients and bring waste into the water. I have seen in fieldwork along the Cidanau

River that farmers keep cattle near the riverbanks, people use river water for needs, and they throw garbage into the river (**Figure 4**). These problems can raise BOD, COD and TSS levels, lower DO, and raise bacterial pollution as shown by high coliform numbers. These observations show that human activity is putting pressure on the water flow of the Cidanau Watershed.

The spread and level of pollution in the Cidanau Watershed are not controlled by people. The shape of the land and its topography are the cause. The way land is shaped controls how water moves and where pollution ends up with what people do. Elevations range from sea level to 1,778 m above sea level. Most of the land is between 100 and 200 m, giving an area especially in the middle. The watershed is surrounded by Mount Tukung Gede to the north. Mount Karang was located on the side. To the south, the boundary is Mount Prakasak and Mount Aseupan. The west edge follows the Sunda Strait. Among these mountains Mount Karang is a stratovolcano. Mount Karang reaches its point at approximately 1,778 m with its summit at Sumur Tujuh. Mounts Prakasak and Aseupan are part of the caldera system inside the Rawa Danau Nature Reserve. The Rawa Danau Nature Reserve also has energy potential (Grandis et al., 2020; Santika et al., 2020; Sar et al., 2024).

In this landscape, the Rawa Danau Nature Reserve behaves like the heart of the watershed. The Rawa Danau Nature Reserve is flat with elevations between 85.5 and 93.3 meters above sea level. The floodplain areas are below 88.9 meters making them very sensitive to changes in water level. The Rawa Danau Nature Reserve supplies raw water to the Banten region. Therefore, it is crucial to ascertain the volume of water that the reserve can contain and the extent of its distribution, as these details are vital for effective water resource management. Additionally, topographic data revealed a pattern of slopes throughout the area. Gentle slopes from 0 to 8 percent dominate the Rawa Danau Nature Reserve, near the reserve. Over 40% of steeper slopes appear mainly in the parts, especially along the sides of Mount Tukung Gede, Mount Karang, Mount Prakasak, and Mount Aseupan. Across the reaches, the slope levels range from flat to steep (0 to 40 percent). Some riverbanks have inclines that can speed up the water flow and increase erosion (**Figure S1**).

The slope pattern observed from the topographic data across the area. In terms of slope, the pattern shows that slopes range from 0–8 percent dominate this section between one point and another in particular are: near Rawa Danau Nature Reserve. Generally, more than 40% of the slopes detected as too steep only appear in the areas along Tukung Gede mountain slope area, Karang mountain slope and area of Prakasak Aseupan. Slope levels range from flat to very steep (0 through 40 percent) across the reaches. Certain riverbanks are sloped, which may promote water flow and erosion (Figure S1). At the Cidanau Watershed, annual rainfall varies from 2,000 to 2,500 millimeters which produce high water discharge to the river and carry high amount of sediment and other pollutant number into the river. In both the upstream and downstream parts, the flow of water usually slows down. The problem is aggravated by slow-flow conditions, which hinder natural purification. River after river, water runs in and soon pollutants start to collect. Due to interrelationship between topography, weather pattern, and human activities the system becomes immensely complicated. Topography: What topographical & meteorological factors can explain the deterioration of the water quality. All of these factors must be incorporated into a management plan. In order to identify how and why water quality is getting worse we need to include topography, weather conditions, and human actions. These elements have to be integrated into management planning for the Cidanau River Basin.

3.1 Water Quality in Cidanau Watershed

Geomorphological conditions, weather, and the hydrological system in the Cidanau River Basin (DAS) impact water quality. Based on average measurements and standard deviations (**Figure 5**), water quality patterns across the river basin vary in both space and time. Land cover, the hydrological system, and human activities influence water quality, and these factors differ at each monitoring site.

The pH values at the time of sampling ranged from 5.10 to 8.24, but since India permits this range between 6 and 9 so many places were within standard limits. This example is the value of pH in Krakatau

Tirta Industri Dam 7.32 and Paris Bridge 7.37 while Cidaniang River got a value of 8.24. On other hand, Cikalumpang and Kandang Monyet particularly their river's very low as 5.10 (acidic) – consequently, if dissolved in water only capable to accompany lower acid well beyond into standard diversion values permitted by regulation. Wetlands surrounding Kandang Monyet decompose vegetation, releasing acids that have led to the localized low water pH there. On the other side, pH conditions in Cikalumpang appeared to have been disturbed due to nearby settlements of houses and surrounding vegetation. Because water is diluted by household waste & effluents, Sites that are close to such sites generally have low pH.

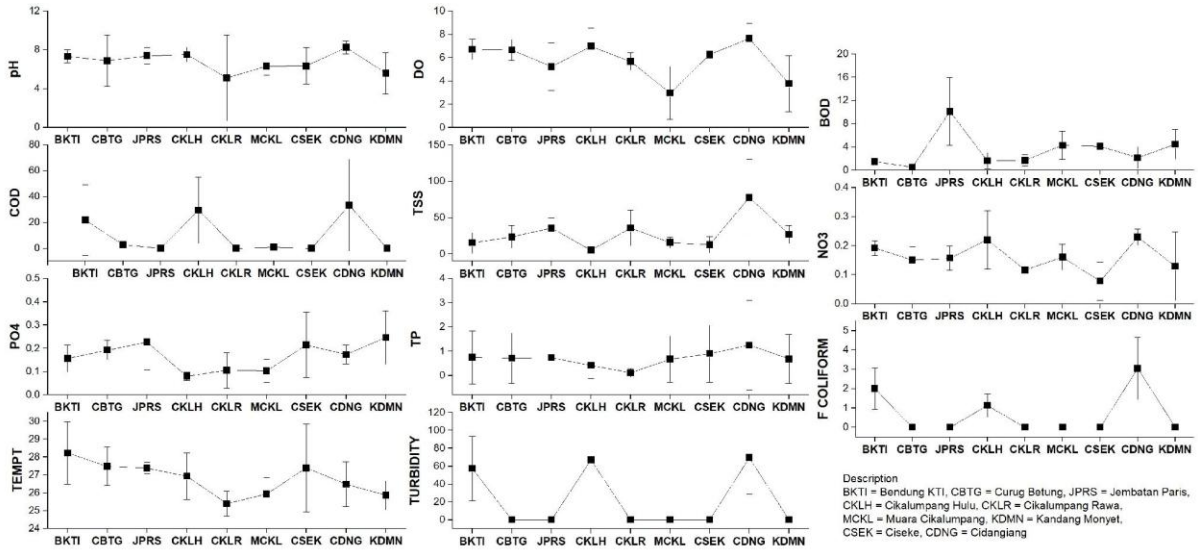


Figure 5. Spatial variation of water quality parameters in Cidanau Watershed, Banten

Land use and associated hydrological conditions at overlapping locations results in differences in water quality parameters. The dissolved oxygen (DO) has the lowest value around 2.96 and 7.63 mg/L which is less than standard minimum of 6 mg/L, where are Cidaniang River have the highest DO with result of 7.63 mg/ L and Muara Cikalumpang as the lowest only 2.96 mg/L while few locations met standards like Krakatau Tirta Industry Dam (6.71 mg/ L) and Ciseke (6.27 mg/ L). The swamp waters in the Muara Cikalumpang and Kandang Monyet regions have the lowest DO condition. In addition to that, the significant growth differences of fish among the studied sites remained constantly significantly different. Water residence times in these flow poor regions are long and promote normal decomposition processes as well as less oxygen replenishment, or transport; this indirectly contributes to low DO. However, DO in flowing river stations was greater. The answer, is because moving water can hold more oxygen. The average temperature was 25.40 ℃ ±3 ℃ and 28.24 higher temperature in Krakatau Tirta Industri Dam. Likely enjoyed by a little of the vegetation cover riparian shade so that they were not directly exposed to sunlight radiation However, these wetland and vegetated areas would generally have a caustic effect on keeping water temperatures cooler.

Signs of pollution indicate anthropogenic activities are having an increasing impact. Oxygen demand (BOD) was 0.50–10.10 mg/L but did exceed the Class II standard of 2 mg/L at sites. At Jembatan Paris the highest BOD was recorded at 10.10 mg/L, and at Kandang Monyet was 4.48 mg/L and Muara Cikalumpang was 4.29 mg/L This high BOD in Jembatan Paris is closely related to dirty water from urban sites that diami population density level takes place. BOD concentrations in Kandang Monyet and Muara Cikalumpang are very high due to the deposition and decay of material in wetland ecosystems. The COD concentrations behaved the same as BOD and ranged between 0.00 to 33.33 mg/L which exceeded the standard of 10 mg/L The presence of input pollutants, like runoff and liquid waste and nutrient sediments also influence DO concentration. It also results in low DO levels at various monitoring points including

Jembatan Paris, Cikalumpang Hulu, and Cidaniang. These results demonstrate that organic pollution is an important driver of water quality conditions in the wetland area.

Water physical characteristics also fluctuate. These results indicate that Total Suspended Solids (TSS) ranging from 5.44-77.70 mg/L values, the highest is in Cidaniang River with a value of more than Class II standard of 40 mg/L (77.70 mg/L), then also high TSS obtained in Cikalumpang Hulu and Jembatan Paris respectively of35.73 and 35.63 mg/L respectively. This pattern is in accordance with the turbidity measurements, which range from 0 – 69.79 NTU where Cidaniang River has the highest value of turbidity (69.79 NTU) and was followed by Cikalumpang Hulu River (66.99) Sediments with high concentrations show the correlation between sediment movement and soil erosion. Erosion is mostly very likely sourced from arable land, specifically rice areas. Thus, suspended materials enter the developing area via urban runoff. The strong correlation between TSS and turbidity implies that both land disturbance and surface runoff are responsible for high particle concentrations in the basin.

Higher nutrient concentrations in the watershed also correspond to land management practices. However, the concentration of nitrate (NO_3^-) which ranged at 0.08 to 0.23 mg/L also not exceeding the standard nitrates value (10 mg/L). Highest value of available nitrates obtained from rainfall runoff around two sampling stations, Cidaniang River (0.23mg/L) and Cikalumpang Hulu (0.22mg/L), most likely due to high levels of fertilizer use in agricultural areas would be followed by a significant contribution mixed domestic runoff contribution. Phosphate (PO_4^{3-}) concentrations were 0.08–0.25 mg/L, below the environmental standard value of 0.2 mg/L; total phosphorus behaviour was unequivocal (0.11–1.26 mg/L) and all but one monitoring point returned levels above guidelines. The most concentrated sites were at Sungai Cidaniang (1.26 mg/L), Ciseke (0.90 mg/L), and Krakatau Tirta Industri Dam (0.75 mg/L). Higher concentrations show input of nutrients from paddy farming, as well as agricultural runoff and urban sinks in the lower reach. No inhibition was found in roots, shoots and leaves growth at any tested nitrate concentration under low Na concentrations.

Microbiological contamination: Pollution from people 0–20,000 MPN per 100 mL (range), mostly going beyond the Class II standard of numerous figures/1,000 ml in every single area. Sungai Cidaniang has the highest value (20,000 MPN/0.90 mL) and Krakatau Tirta Industri Dam has the lowest one which is around 467 MPN/100 mL. Such levels point to sewage, badly regulated and agricultural runoff. We examined the watershed with three key water quality summary indicators: (1) various concentrating household waste as outlined by various zoning areas; (2) little propelled spread of homestead regions are more sullied with erosion sediments/and fertilizer nutrients than minimal yielding spreading regions, including wetlands related to these relatively slowly flowing waters being incredibly productive relative to dispersion due so their decay process declaring in the lower portion of dissolved oxygen. Such patterns illustrate the important role of land use in controlling water quality, and point to an important avenue for intervention through management.

3.2 Statistical Analysis

Sources of pollution originating from residential areas, nutrient and sediment runoff from agricultural land, accumulation of plant material, and decreased oxygen levels in wet areas are the main reasons why water quality in the Cidanau River Basin deteriorates. The relationships among these various factors are very complex. Therefore, correlation studies can evaluate how strong these relationships are and how the influencing factors are interconnected, as well as identify the main causes of changes in water quality over time and from one location to another.

Pearson correlation analysis is used to understand the relationship between elements that influence water quality (**Figure S2**). Pollution originating from vegetation, nutrients, and oxygen levels in the water are closely interconnected. However, causality cannot be determined solely based on correlation, so the correlation analysis must be carefully examined and reviewed based on the condition of the river area, land use, and water flow. The strongest relationship is between BOD and COD (r = 0.97), suggesting that both often indicate similar pollution originating from plant sources. Microorganisms in

the water are also highly connected with BOD (r = 0.97) and COD (r = 0.91), indicating that microbes tend to grow when plant material content is higher. These pollution sources can include settlements, animals, and runoff from surrounding areas, which make up approximately 6.9% of the river landscape. A similar pattern between plant pollution and microbes is also found in other rivers receiving runoff from residential areas (Byekwaso et al., 2026; Syeed et al., 2023).

The relationships among nutrient concentrations in water are complex. Nitrate shows a strong positive correlation with Biochemical Oxygen Demand (BOD) (r = 0.79), Chemical Oxygen Demand (COD) (r = 0.76), and fecal coliforms (r = 0.85), which means that higher nutrient levels are often accompanied by higher levels of organic pollution. This is consonant with its major land use, as over 27.4% of the watershed is covered by paddy fields that permit for fertilizer-based nitrogen to enter the river by means of rain runoff. On the other hand, phosphate had significant negative relationships with BOD (r = –0.46), COD (r = –0.52) and fecal coliforms (r = –0.44) and a stronger positive association with dissolved O2 saturation DO% r = 0.79). They represent a variety of relationships, which implies that numerous processes such as agricultural practices determining release into adjacent waters, uptake by aquatic plants, sediment-water interactions before or after floods, and seasonal variation in flow have the potential to drive nutrient levels. The relationship between nutrients and organic pollution indicators does not always hold true in terms of timing or direction.

A weak positive correlation was found among dissolved oxygen (DO) and other parameter measured such as biochemical oxygen demand (BOD), chemical oxygen demand (COD), and fecal coliforms r = 0.63 r = 0.65; r=0.68 respectively Such differences reflect enumeration of natural air mixing, flow increase of river water and aquatic plant contribute significantly for DO increasing especially on the Rawa Danau wetland area where Eichhornia crassipes have abundance enrichment†. Prior research has found that wetlands with abundant macroplants can become supersaturated in dissolved oxygen (DO) during day time hours, even when organic carbon and oxygen demanding substrates are present at levels indicative of anaerobic degradation because the balance between biogenic production and degradation can sustain water-column DO above zero at levels sufficient to offset respiration from available organic substrates. Thus the strong positive correlations found in this study do not mean that more organic pollution causes higher dissolved oxygen concentrations, rather these factors co-vary as both are responding to multiple spatial-temporal environmental processes occurring at different locations. In general, bivariate correlation analysis indicate that the new patterns in water quality of Cidanau watershed are caused by a multitude process of organic pollution, nutrient enrichment, land use and stream regime. Therefore, this analysis serves as an advance to the next step of Principal Component Analysis (PCA).

We performed principal component analysis to determine which of the m environmental actors are responsible for water quality, and five core variables were analysed, dissolved oxygen saturation (DO%), BOD, TSS and TP. Taccounchange: Up to 38.3% of the variation on PC1, and up to 22.3% on PC2 (figure6 Yet both component Environment Module Approximately one it stand forin Fluencing water quality by an approximate roximatelyiindicace 2.3 % for PCModule could be tabulated see Tab). Like pure wells, and the form of the river affect. As a result, many broad conclusions can be drawn based on the PCA that had an effect of the principal on outcome. The dataset includes data up to October 2023, although hithis. This comprehensive set of PCA includes human settlements, transportation networks, agricultural areas, etc., and provides the ecological and water-quality impact of land uses (including a whole gamut that impacts surface/ground water resources) to monitor or quantify through weights; however, we do not use all for the watershed analysis.

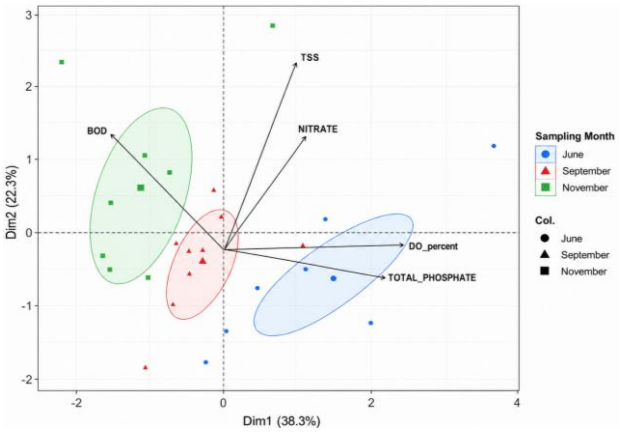


Figure 6. Principal Component Analysis score plot multiparameter

The PCA score plot (**Figure 6**) shows that seasonal changes and differences in sampling by month result in greater variability in water quality samples. This indicates that seasonal changes have a greater influence than location. Most June samples clustered along one side of PC1, while November samples were associated with PC2. September samples fell between these groups, reflecting a transition between seasonal conditions. The results suggest that the factors influencing water quality shifted over time: nutrient and oxygen levels were more prominent earlier in the season, whereas wet-season rainfall increased runoff and the transport of suspended solids and organic matter. These seasonal shifts may explain the patterns observed in the data.

Table 1. Matrix of Principal Component Analysis of selected water quality parameters

Parameter	PC1	PC2	PC3	PC4	PC5
DO (%)	**0.587**	0.012	-0.222	-0.494	-0.602
BOD	-0.396	**0.487**	-0.406	-0.607	0.27
TSS	0.232	**0.735**	-0.27	0.564	-0.122
Nitrate	0.274	0.439	**0.788**	-0.264	0.203
Total Phosphate	**0.608**	-0.173	-0.303	-0.015	**0.713**

Table 1 explains the effects tied to the principal components. Principal Component 1 (PC1) is mostly shaped by phosphate (loading = 0.608) and dissolved oxygen saturation (DO%) (loading = 0.587). The availability of nutrients and fluctuations in oxygen levels over time are factors that indicate environmental changes. Principal Component 2 (PC2) is mainly affected by TSS (loading = 0.735) and BOD (loading = 0.487). This reflects a pattern linked to sediment and organic pollution from surface runoff, soil erosion, and moving organic material. This fits with what we know about the watershed. Paddy fields make up 27.4% of the area, which makes it more likely that rain will carry sediment and organic matter into the water.

Although nitrate has the highest load on Principal Component 3 (PC3) through Principal Component 5 (PC5), we do not discuss these components. That's because PC1 and PC2 together explain 60.6% of the variation in the data. This suggests they capture environmental changes in the area. Regionally, Cidaniang River and Paris River Bridge both had PC2 scores in November. At the time, Cidaniang River showed the strongest positive PC1 score in June. Overall, the principal component analysis shows that seasonal changes in water flow affect water quality. During the season, nutrient levels and oxygen dynamics were more important. In the season, the main concerns shifted to sediment transport and pollution from organic material.

3.3 Water Quality Index

Nine monitoring stations have a Pollution Index in range from 0.59 to 2.99 (**Figure 7**). This range indicating generally is good water quality index. However, some locations show signs of localized stress associated with human activities. A comparable pattern occurs in the Tukad Badung River, where rice cultivation and urban development are prevalent and contribute to nutrient and organic pollution. Together, these findings suggest that water-quality problems in river basins with residential areas tend to be localized rather than indicative of widespread degradation (Harmayani et al., 2023).

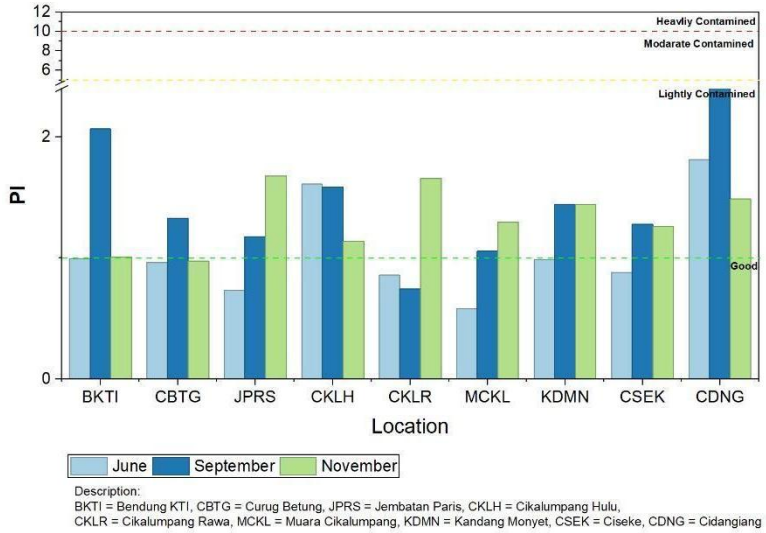


Figure 7. Results of the Pollution Index (PI) in the Cidanau Watershed, Banten

Water movement and pollutant transport change the Pollution Index over time, Conditions at all the sites shifted from dry to wet and then back again — from June when drier, September when it transitioned into wetter conditions, and November when wetter. The highest Pollution Index value obtained by cidangiang in September was 2.99. Surface runoff after the early rain likely transported nutrients, sediment, and plant detritus from surrounding farms and houses to the river. Because the level of the river water was still low, pollutants were poorly diluted and so stayed at relatively high concentrations. But by November, the stronger rains and rise in river flows must have mixed and washed away those contaminants, resulting in lower Pollution Index values at most sites.

The type of site also affected PI. Differences among sites were therefore more closely tied to land uses surrounding the sites than to the distance of each site from the point on river (break at 0 m). It also indicates that, dry forrest class some of the locations such as Cidangiang, Ciseke, Muara Cikalumpang, Cikalumpang Rawa, Kandang Monyet and Jembatan Paris with PI value 1.28 – 2.99. Rice extents, which accounted for 22.1% of the surface region, may likewise be a wellspring of toxins when runoff including fertilizers enters your stream occasionally amid rainy seasons. At these sites, nitrate and phosphate measured in the effluents correspond well with agricultural runoff being the most obvious source of such high levels of PI produced. The high PI in Cikalumpang Hulu was due to residential land use and a method of disposal that dumped poorly treated household waste directly into the river, with TSS found at those sites at a relatively high level.

We computed the Indonesian Water Quality Index from converted PI values using a method developed by the Ministry of Environment and Forestry. It is the national water quality indicator (IDN-WQI). When the PI results of two or more sampling periods are aggregated into a single value, it helps in comparing different sites and also facilitates management decisions on environmental and local policies

The IDN-WQI values varied between 50.00 and 63.33, which means that all the sites were classified as being in the medium category. At Curug Betung and Cikalumpang Rawa the IDN-WQI values were relatively high, showing that the water quality was comparatively better. On the other hand,

Cikalumpang Hulu and Cidangiang had lower values, this being due to an increase in PI at the time of the transition from the dry season to the wet season. For example, the PI at Cidangiang reached 2.99 in September, which accounted for its lower IDN-WQI. The index therefore not only indicates the level of pollution but also shows how consistent the water quality is over time (**Figure 8**).

The IDN-WQI values were correlated with land use along the river. Water quality did improve in forested and wetland areas compared to areas dominated by farmland and homes. They can reduce runoff and consequently soil erosion as well as the retention of pollutants by wetlands. The pollution from agroactivities and domestic use of river can also be increased due to rainwater dissolving them where they enter the water. In this region, particularly in Cidanau, where is rainy season and the rest of the year it rains as well, so land/use influence to type of rain (and also quality) This evidenced the better water quality at sites within forests and wetlands, relative to those close to farmland or urban areas that many of these sites were located in by the study.

The IDN-WQI provides an overview of the water quality in general, especially in the Cidanau area. This enables aggregation of results into a single value that corresponds to Indonesia's own water-quality assessment framework, making the data more interpretable and comparable across locations — and locally relevant for decision-making. The main characteristics allow the index to be used not only in real time monitoring but also for long-term assessment of water resources in the region.

PI results mainly follow the direction of changing weather conditions, but all sites are within one class. Nevertheless, the outcome of the IDN-WQI conversion suggest that PI data cannot be represent as a total value without risking to lose important changes in water quality. Most importantly, this index will not readily identify short-term pollution events in areas such as Cidanau where rainfall is regionalized throughout the year and land use exerts strong control on how efficiently water flows in river basins. Thus, although the IDN-WQI is useful for general conditions appraisal, it might not be capable of identifying short-term pollution events or seasonal variation such as cold season vs.

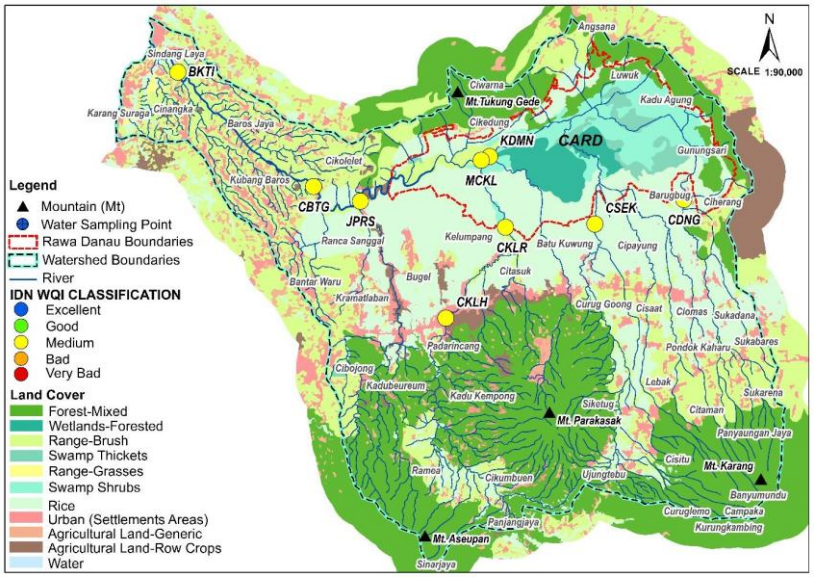


Figure 8. Result of IDN-WQI in Cidanau Watershed, Banten

Compared with other assessment methods, each index gives unique information. The Pollution Index is especially sensitive when the water quality standards are exceeded. The IDN-WQI provides an overall summary of the environmental conditions by means of a standardised composite score, whereas the NSF-WQI assesses water quality for each monitoring period. The fact that this is done on a detailed timescale helps in identifying seasonal changes. When both the NSF-WQI and the IDN-WQI are used together, a more complete view of how water quality varies over time in the Cidanau watershed is obtained.

The IDN-WQI compiles the data gathered over a period of time into a single score for each monitoring station, whereas the NSF-WQI is calculated for each sampling event. As a result, the NSF-WQI is able to pick up on short-term and sudden changes in water quality. Since the two indices concentrate on different aspects, their results do not always agree. The NSF-WQI values varied from 46.11 to 87.21, this showing a water quality ranging from poor to good (**Figure 9**). The latter also sees the best water quality in June, collecting data from six good stations where Cikalumpang Rawa received 8.721 points. By September, the water quality was weakened, NSF-WQI value with a range 46.11 (Cidangiang) to 71.44 and only three stations is classified as good namely Semburan, Budi Luhur and Brantas River at Taman Jasa Piala Timnas site. However, it also reflects that in November the values representing water quality ranged from 67.80 to 74.36 and seven stations were classified as good. Note that it peels downward during the transition season and then recovers in the next.

The main drivers containing high impact on the NSF-WQI index throughout September were corresponding to coliform levels, Dissolved Oxygen and BOD respectively, which explained most of the fall in the NSF-WQI. Domestic waste, livestock and organic debris (such as grass) from runoff to the river can lead to higher coliform counts. This organic matter, which can increase BOD and decrease dissolved oxygen for both sources of water, causes lower NSF-WQI scores during the transition season. That uptick in November implied those troubles had abated as conditions improved. Overall, the variations of NSF-WQI in short term are attributed to weather and human activities that lead to changes in water quality.

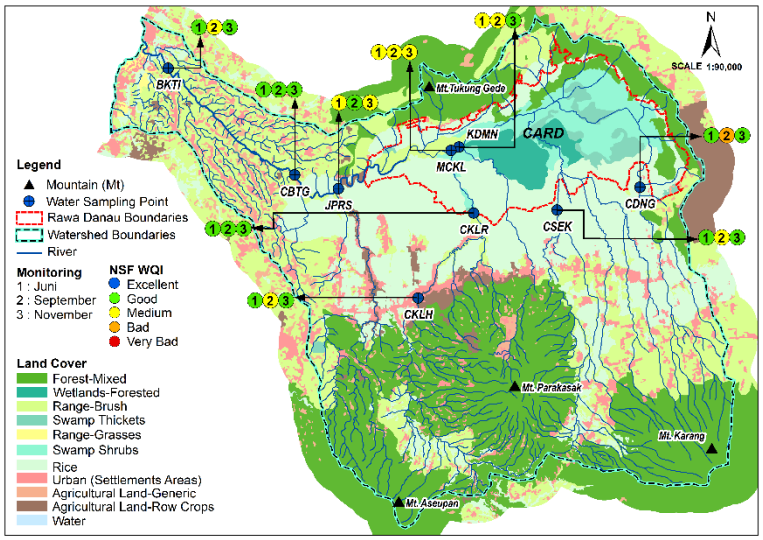


Figure 9. Results of NSF-WQI in Cidanau Watershed, Banten

Looking at it from one point of view, the NSF-WQI has a clear benefit in that it assesses each monitoring event on its own. This enables it to react promptly to changes in water quality over time, and so the index is able to effectively pick up on sudden changes and pollution events that methods which average the data over longer periods could fail to detect. The increased sensitivity is highly beneficial for monitoring programs designed to identify the earliest indicators of deteriorating water quality. On the other hand, because of its high sensitivity to changes in those parameters, and as a drawback, short-term oscillations do affect globally all watersheds analysed in their NSF-WQI score despite year-on-year relative stability of such watershed health; in other words, small perturbations due to pollution events can widely skew this index.

Water samples were compared in the laboratory, considering various processes and analytical parameters; however IDN-WQI and NSF-WQI are also two different devices that do not affect quality conditions. IDN-WQI achieves this by aggregating all the to the statistics through time, providing a single figure that represents stable characteristics of water quality at each location. By contrast, the NSF-WQI records every sampling occasion separately which highlight short-term fluctuations in and declines of

water quality that may not be detected by methods based on averaging calculations such as IDN-WQI. NSF-WQI method is best used for long term monitoring to detect short-term pollution associated with rain and runoff at a time scale of a day in rivers with major influence from local precipitation. The IDN-WQI gives a long-term view of what is going on in the general well-being of water systems. Combined with the Pollution Index, both deliver a strong measure for assessing water quality, regulatory compliance and watershed health. The site-specific IDN-WQI is based on the methodology for national assessment and it combines data from multiple sampling periods, Spearman's rank correlation was employed to compare the (PI) and NSF-WQI with IDN-WQI (**Figure 10**).

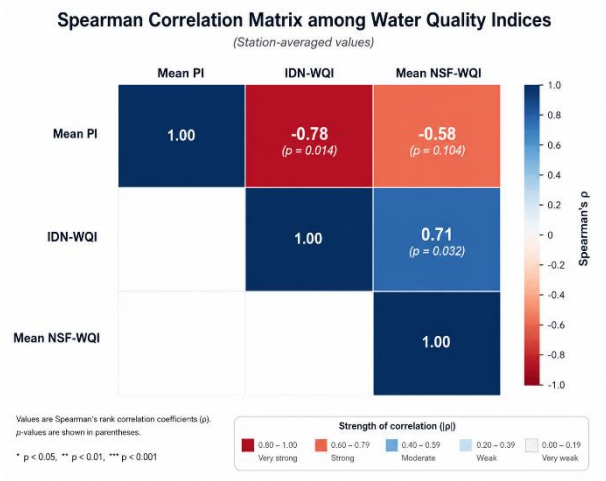


Figure 10. Spearman correlation matrix among station-averaged PI, IDN-WQI, and NSF-WQI.

A strong negative correlation between the average Pollution Index (PI) and the IDN Water Quality Index (IDN-WQI) ($\rho = -0.778$, $p = 0.014$) indicates that the higher the pollution, the lower the IDN-WQI value. This indicates the transition from PI to IDN-WQI gives clear information about levels of pollution at all monitoring sites. A negative relationship was also observed between the PI and the average National Sanitation Foundation Water Quality Index (NSF-WQI) ($\rho = -0.577$, $p = 0.104$), although it was not statistically significant. This weaker relationship may be due to the NSF-WQI's focus on discrete monitoring events, making it highly responsive to short-term changes in factors such as dissolved oxygen (DO), biochemical oxygen demand (BOD), and fecal coliforms. Because of this, quick changes in these factors can affect the NSF-WQI even if the overall condition of the watershed stays the same. A strong positive link was found between the IDN-WQI and the average NSF-WQI ($\rho = 0.710$, $p = 0.032$). However, it indicates that despite the different calculation and time resolution, both index represent a general description of the overall water quality variation in Cidanau Watershed. These associations are illustrated on the Spearman correlation matrix (Figure 10). The strongest negative correlation coefficient was -0.625 between the PI and IDN-WQI. Linkage between PI and NSF-WQI was less pronounced. This close relationship between the IDN-WQI and the NSF-WQI indicates that both indices give estimates from the water quality in the basin. They each concentrate on a piece of the environment. On average, the correlation analysis support using all three methods. The Pollution Index can be used to identify situations in which the water quality standards are not achieved. Based on Indonesian system, IDN-WQI generates a long-term condition exist inside the watershed. In contrast, NSF-WQI is more responsive to temporal variations in pollution events. In this way, an outlook on the water quality of tropic watersheds was obtained by combining these three indices. composite is composed of 3 parts that fulfill rules, go by way of their environmental surroundings and modify normal H2O high quality by means of your series.

4. Conclusions

The water quality in the Cidanau watershed is changed due to changing water flow, land use change and human intervention. The values of the pollution index (PI) vary from 0.58 to 2.99, indicating

that the water quality ranges from compliant to slightly polluted. IDN-WQI scores range from 50.00 (unsatisfactory) to 63.33 (moderate) revealing Cidanau water quality with moderate condition. Meanwhile, the NSF-WQI ranges from 46.11 to 87.21 and depicts quite a strong seasonal feature of poor–good water conditions among sampling months. However, correlation analysis shows that all three methods yield very similar results even though they are computed by different types of calculations and at a different time. The focus of this research is to compare the PI against IDN-WQI and NSF-WQI. Each of the indices was designed for specific uses: IP is used to evaluate quality standards based on water quality conditions, IDN-WQI river condition (using regional regulation), and NSF-WQI to monitor short-term changes. Hence the combined strength of these 3 indices serves as a clear cue. It is also less suited to detecting incremental or extreme change, as the study comprised only three observations per year and involved just nine sites. Future studies should be done in a more real time continuous sampling mode with flow modelling and land-use assessment included, to further insight the dynamics of pollutant behaviour. Such results strengthen the case for integrated watershed management that include a synergy of wastewater control, sustainable agriculture and conservation of upstream forest and downstream wetlands. These indexes assist in the development of monitoring programmes as well as informing selection of tools for assessments and adaptive management in tropical watersheds.

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CRediT Author Statement

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Declaration of Generative AI and AI-Assisted Technologies

The process of drafting, writing, editing, or revising this manuscript did not use Generative AI technology or AI-assisted technology.

References

Anh, N.T., Can, L.D., Nhan, N.T., Schmalz, B. and Luu, T. Le 2023. Influences of key factors on river water quality in urban and rural areas: A review. Case Studies in Chemical and Environmental Engineering 8, 100424.

Aram, S.A., Saalidong, B.M. and Lartey, P.O. 2021. Comparative assessment of the relationship between coliform bacteria and water geochemistry in surface and ground water systems. PLoS One 16.

Balla, D., Kiss, E., Zichar, M. and Mester, T. 2024. Spatiotemporal dynamics of water quality: long-term assessment using water quality indices and GIS. ISPRS International Journal of Geo-Information 13.

(BPS) Badan Pusat Statistika Kabupaten Serang 2024. Kabupaten Serang Dalam Angka 2024. Badan Pusat Statistika Kabupaten Serang.

(BPS) Badan Pusat Statistika Kecamatan Mandalawangi 2024. Kecamatan Mandalawangi dalam Angka 2024. Badan Pusat Statistika Kabupaten Pandeglang.

Byekwaso, F., Langergraber, G., Weigelhofer, G., Kaggwa, R., Kansiime, F. and Hein, T. 2026. Anthropogenic and natural factors impacting microbiological and physicochemical surface water quality

along an urban tropical wetland. Journal of Water Sanitation and Hygiene for Development 16, 108–123.

Grandis, G., Indra, T.L. and Syahputra, R. 2020. The distribution and petrography characteristics of material eruption in the south of Rawa Danau, Banten Province. In: IOP Conference Series: Earth and Environmental Science. Institute of Physics Publishing.

Harmayani, K.D., Jaya, N.M.P., Widhiawati, I.A.R., Parahita, I.G.A.A., Wiryananda, N.G.A.K., Supriyani, N.N.D., Mahendra, D.R., Baskhara, I.G.A.G.W. and Hutagalung, D.S.F. 2023. Assessment of surface water quality status using the pollution index method in Tukad Badung River. Jurnal Presipitasi 20, 175–185.

Krakatau Tirta Industri 2024. Sungai Cidanau. Kabupaten Serang.

Leko, L.L. 2023. Pengaruh curah hujan terhadap kualitas air berdasarkan parameter mikrobiologi di DAS Kali Dendeng. ENVIROTECHSAINS: Jurnal Teknik Lingkungan | 1, 33–37.

Mummidivarapu, S.K. and Rehana, S. 2026. Spatiotemporal risk assessment of river water quality for tropical river systems using hydrological dynamics, anthropogenic influences, and ecological health index. Science of the Total Environment 1013.

Purwaningsih, I., Nur Aziz, K. and Fitrianingtyas, R. 2023. Identifikasi patahan dan struktur bawah permukaan kawasan potensi panas bumi Rawa Dano Provinsi Banten menggunakan data gravitasi GGMPlus. Jurnal Geosains dan Teknologi 6, 43–52.

Salminah, M., Alviya, I., Arifanti, V.B. and Maryani, R. 2014. Characteristics of ecology and social economics of forest landscape in a critical and a non critical watershed: case study Baturusa and Cidanau Watersheds. Jurnal Penelitian Sosial dan Ekonomi Kehutanan 11, 119–136.

Santika, A.D., Syahputra, R. and Indra, T.L. 2020. Quaternary volcanostratigraphy setting in Rawa Danau Caldera, Banten Province. In: IOP Conference Series: Earth and Environmental Science. Institute of Physics Publishing.

Sar, M., Musa, R. and Umam, C.Z. 2024. Kajian pola hujan akibat pengaruh perubahan iklim pada DAS Cidanau Kabupaten Serang Provinsi Banten. Jurnal Teslink: Teknik Sipil dan Lingkungan 6, 330–344.

Sokolova, E., Ivarsson, O., Lilliesträm, A., Speicher, N.K., Rydberg, H. and Bondelind, M. 2022. Data-driven models for predicting microbial water quality in the drinking water source using E. coli monitoring and hydrometeorological data. Science of the Total Environment 802.

Syafrudin, Sarminingsih, A., Juliani, H., Sejati, A.W., Ramadan, B.S., Budihardjo, M.A. and Nugraha, W.D. 2023. Examining the water quality situation in Klampok River, Semarang through the application of the NSF-WQI (National Sanitation Foundation-Water Quality Index) Model. Jurnal Presipitasi 20, 247–253.

Syeed, M.M.M., Hossain, M.S., Karim, M.R., Uddin, M.F., Hasan, M. and Khan, R.H. 2023. Surface water quality profiling using the water quality index, pollution index and statistical methods: A critical review. Environmental and Sustainability Indicators.

World Health Organization 2022. Guidelines for drinking-water quality: fourth edition incorporating the first and second addenda, Fourth. ed. Geneva.