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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

The Cidanau watershed is a water source in Banten Province, Indonesia. Changes in land use and human activities have worsened water quality. Many water quality tests have been conducted. Only a few have compared the results across tropical watersheds, especially when national and international methods were used together. This study investigated 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).

The 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% ((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. Increased 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 because 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 area have verified 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 (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), and fecal coliforms. These are indicators of river health (Sokolova et al., 2022). In the Rawa Danau Nature Reserve, the color of the water and microbial contamination are issues. These issues not only harm the environment and water quality but also jeopardize public health in the region. They are associated with land-use changes, particularly residential development and the establishment of rice fields on peatlands (Purwa ningsih et al., 2023). Consequently, flat terrain and precipitation create surface runoff with distributed pollution. Coliform greater than 1.13×10^7 MPN/100 mL (Krakatau Tirta Industri, 2024) that surpassed quality standard class 2, as stipulated by Government Regulation No.22 of 2021, were directly proportional to the BOD and COD. This relationship results in nutrient leaching, which significantly elevates pollution levels and increases oxygen consumption. Additionally, the color concentrations in the Cidanau River, reaching values of 5 and 374 TCU, consisted of approximately 70 to 80% dissolved substances, such as tannins and lignin, originating from the decomposition of residual plant litter. The proliferation of Eichhornia crassipes is a contributing factor. Elevated concentrations of dissolved nutrients and suspended particulate matter further exacerbate the reduction in oxygen saturation, disrupting natural processes. This 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 can bolster decision-making. High-impact information about water quality can help local authorities and polluters target strategies to reduce pollution loads, and also help citizens 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 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 to compare water quality between sites throughout the water catchment. The IDN-WQI is

more appropriate for assessments based on regulations, 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, 23 WQI models and 10 pollution index models have been recently identified in a new study. This shows a lack of consensus over the working of these models and their 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 PI, IDN-WQI, and 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 PI shows pollution levels compared to standards. The IDN-WQI assesses water quality. The NSF-WQI uses traits to allow comparisons. This study looks at water quality in the Cidanau Watershed using the PI of IDN-WQI and the NSF-WQI. It will also use correlation and principal component analyses (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 aimed to understand how water quality changes with the seasons in the Cidanau watershed. The selection of monitoring stations considered 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 varied significantly in spatiotemporal terms (**Table S1**).

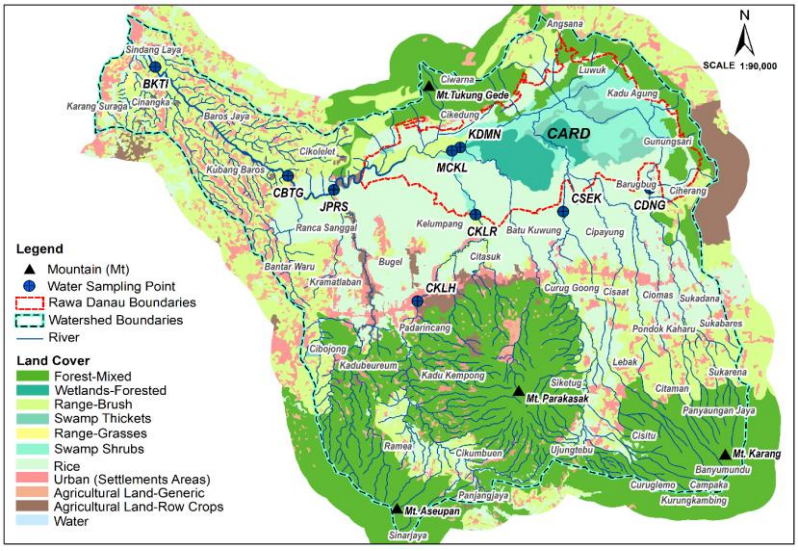


Figure 1. Map of sampling location, watershed area and land use in Cidanau Watershed, Banten

In addition to water quality and monitoring in Cidanau, we performed secondary data-based geographic information system (GIS) analysis to depict the landscape of the Cidanau watershed and human activities 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 the American Public Health Association (APHA) (for Water and Wastewater Testing) to correlate

our data of the Cidanau River Basin study to achieve reliable data eight months after collection based on 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 DO. The Cidanau River Basin team in the laboratory used a 2-liter container, kept it cold, and sent them to the Solid and Hazardous Waste Laboratory IPB and Hydrobiology Laboratory BRIN. The lab tests conducted at the Cidanau River Basin included BOD, COD, TSS, nitrate, phosphate, turbidity, and fecal coliforms. The tools, reagents, and quality control processes shown in **Table S2** were used by all labs for tests on the Cidanau River Basin.

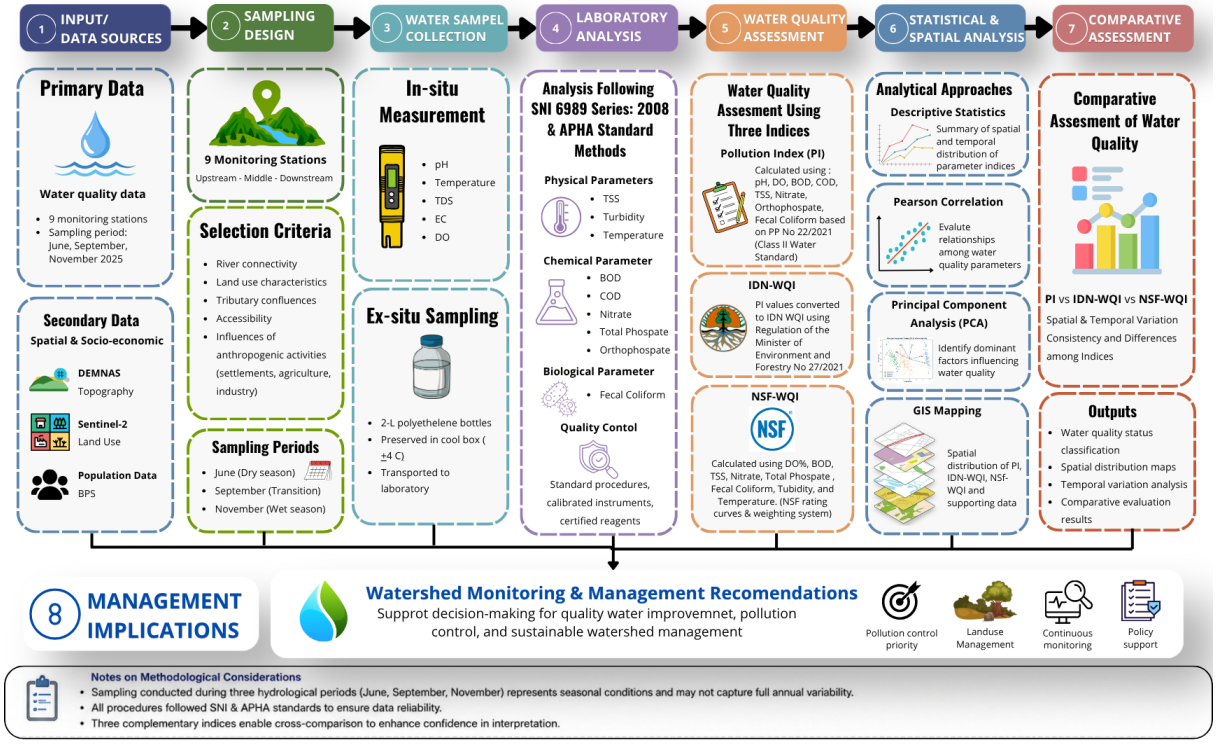
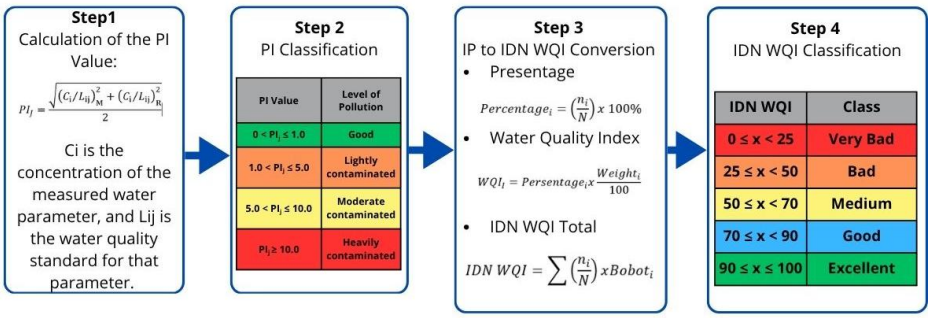
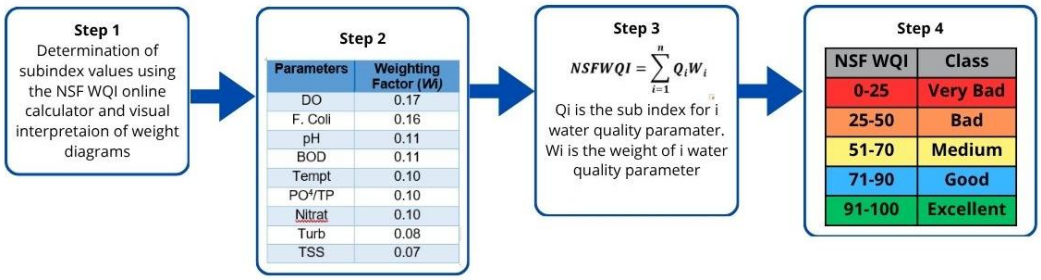


Figure 2. Methodological framework of the study

Water quality analysis of the river was performed using three assessment frameworks: PI of IDN-WQI and the NSF-WQI. PI values were calculated from pH, DO, BOD, COD, TSS, NO_3^-, PO_4^{3-}, and fecal coliforms. For each parameter, the 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 3a**). In contrast, the NSF-WQI was calculated using 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 to ensure that the index calculations are standardized and consistent (**Figure 3b**). Using these three indices, water quality analysis could compare river water quality from three 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, as 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 provides key ecological services through the Rawa Danau Nature Reserve, which is located upstream (Salminah et al., 2014). CARD acts as 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 use. 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 of population growth. 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 increase 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 their needs, and

they throw garbage into the river (**Figure 4**). These problems can raise BOD, COD, and TSS levels, lower DO, and increase 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 (0–8%) dominated the Rawa Danau Nature Reserve near the reserve. Over 40% of steeper slopes appeared 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 (0–40%). Some riverbanks have inclines that can speed up the water flow and increase erosion (**Figure S1**).

Slope patterns observed from the topographic data across the area. In terms of slope, the pattern shows that slopes range from 0%–8% and dominate this section between one point and another, in particular 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 produces high water discharge to the river and carries 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 the 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) affect 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, 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. In contrast,

Cikalumpang and Kandang Monyet rivers recorded very low pH values (5.10), indicating acidic conditions; consequently, if dissolved in water, they are capable of accompanying lower acid values beyond the 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 and effluents, sites close to such sites generally have low pH.

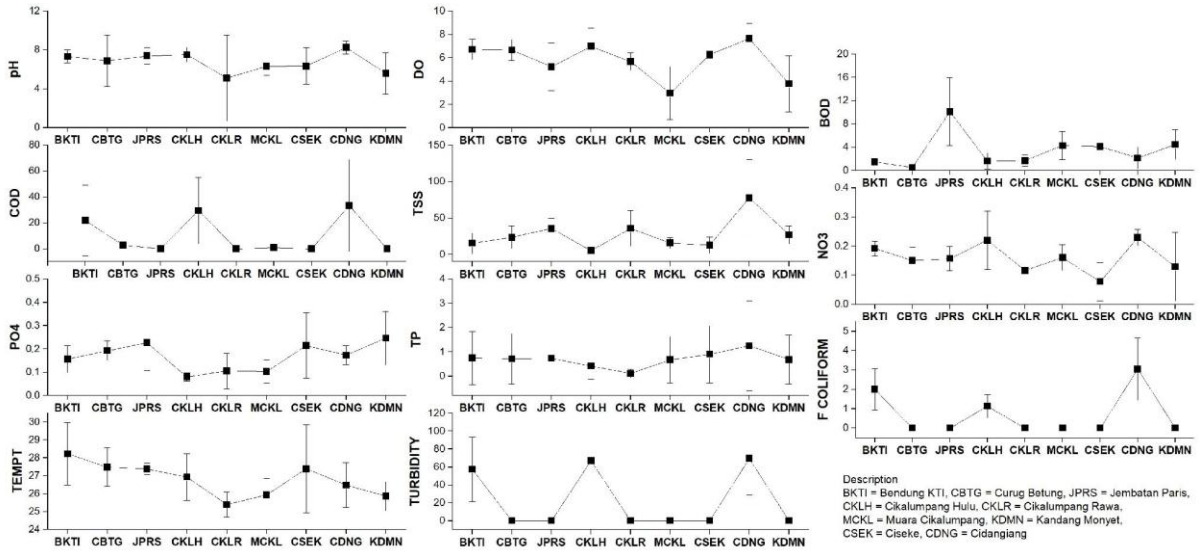


Figure 5. Spatial variation of water quality parameters in Cidanau Watershed, Banten

Land use and associated hydrological conditions at overlapping locations result in differences in water quality parameters. DO had the lowest value of 2.96 and 7.63 mg/L, which is less than the standard minimum of 6 mg/L, where Cidaniang River had the highest DO of 7.63 mg/ L and Muara Cikalumpang had the lowest value of 2.96 mg/L, while few locations met the standards, such as 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 had the lowest DO levels. In addition, the significant growth differences of fish among the studied sites remained significantly different. In regions with limited water flow, extended residence times facilitate standard decomposition processes while reducing oxygen replenishment and transport, thereby indirectly contributing to low DO levels. Conversely, DO levels were higher at flowing river stations because of the increased capacity of moving water to retain oxygen. The average water temperature was 25.40 °C ±3 °C, with the highest value of 28.24 °C recorded at the Krakatau Tirta Industri Dam. This relatively high temperature may be associated with limited riparian vegetation cover, which provides less shading and allows greater exposure to direct solar radiation. Conversely, areas with denser vegetation and wetland cover may help maintain lower water temperatures by reducing direct solar exposure.

The signs of pollution indicate an increasing influence of anthropogenic activities on water quality. The BOD concentrations ranged from 0.50–10.10 mg/L, with several monitoring locations exceeding the Class II water quality standard of 2 mg/L. The highest BOD concentration was recorded at Jembatan Paris (10.10 mg/L), followed by Kandang Monyet (4.48 mg/L) and Muara Cikalumpang (4.29 mg/L). The elevated BOD concentration at Jembatan Paris may be associated with domestic wastewater inputs and anthropogenic activities from nearby densely populated residential areas. Meanwhile, the relatively high BOD concentrations at Kandang Monyet and Muara Cikalumpang may be attributed to the accumulation and decomposition of organic matter in wetland ecosystems.

Water physical characteristics also fluctuate. These results indicate that TSS ranged from 5.44–77.70 mg/L, the highest value was in Cidaniang River, which was above the Class II standard of 40 mg/L

(77.70 mg/L), followed by Cikalumpang Hulu and Jembatan Paris, with TSS values of 35.73 and 35.63 mg/L, respectively. This pattern is in accordance with the turbidity measurements, which ranged from 0 – 69.79 NTU, with the highest value in the Cidaniang River (69.79 NTU), followed by Cikalumpang Hulu (66.99) and Jembatan Paris (66.99). Sediments with high concentrations show a correlation between sediment movement and soil erosion. Erosion is mostly 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 are also associated with land management practices. However, the nitrate (NO_3^-) concentration, which ranged from 0.08 to 0.23 mg/L, did not exceed the standard nitrate value (10 mg/L). The highest value of available nitrates was obtained from the rainfall runoff around two sampling stations, Cidaniang River (0.23 mg/L) and Cikalumpang Hulu (0.22 mg/L), most likely due to high levels of fertilizer use in agricultural areas, followed by a significant contribution of mixed domestic runoff. Phosphate (PO_4^{3-}) concentrations were 0.08–0.25 mg/L, below the environmental standard value of 0.2 mg/L; total phosphorus levels were unequivocal (0.11–1.26 mg/L), and all but one monitoring point returned levels above the guidelines. The most concentrated sites were 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.

Microbiological contamination: Pollution from people 0–20,000 MPN per 100 mL (range), mostly exceeding the Class II standard of numerous figures/1,000 ml in every single area. Sungai Cidaniang had the highest value (20,000 MPN/100 mL), and Krakatau Tirta Industri Dam had the lowest value, which was approximately 467 MPN/100 mL. These elevated concentrations may indicate contamination from domestic wastewater, livestock activities, and agricultural runoff. The spatial distribution of microbial contamination also reflects the influence of surrounding land use. Residential areas may contribute fecal contamination through inadequate domestic wastewater management, while agricultural activities may introduce pollutants through surface runoff. In addition, wetlands with relatively slow water circulation may promote the accumulation and decomposition of organic matter, potentially contributing to increased oxygen demand and reduced dissolved oxygen concentrations. These findings highlight the important role of land use and hydrological conditions in influencing water quality and emphasize the need for integrated watershed management to control pollution sources.

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 the strength of these relationships 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 'scorrelation analysis was used to understand the relationship between the elements that influence water quality (**Figure S2**). Pollution originating from vegetation, nutrients, and oxygen levels in the water is closely interconnected. However, causality cannot be determined solely based on correlation; therefore, 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 was 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 was 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 showed a strong positive correlation with BOD (r = 0.79), COD (r = 0.76), and fecal coliforms (r = 0.85), which indicates 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 the entry of fertilizer-based nitrogen into the river via rain runoff. In contrast, phosphate showed a significant negative relationship 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). These relationships imply that numerous processes, such as agricultural practices determining the release of nutrients 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 DO and other parameters measured, such as BOD, COD, and fecal coliforms (r = 0.63, r = 0.65, r=0.68, respectively). Such differences reflect the natural air mixing, flow increase of river water, and aquatic plants, which contribute significantly to DO increase, especially in the Rawa Danau wetland area, where Eichhornia crassipes is abundant. Prior research has found that wetlands with abundant macroplants can become supersaturated in DO during daytime 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. 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 respond to multiple spatial-temporal environmental processes occurring at different locations. In general, bivariate correlation analysis indicates that the new patterns in water quality of the Cidanau watershed are caused by multiple processes, including organic pollution, nutrient enrichment, land use, and stream regime. Therefore, this analysis serves as an advance for the next step of PCA.

PCA was performed to determine which environmental factors were responsible for water quality, and five core variables were analyzed: DO, BOD, TSS, nitrate, and TP. The first principal component (PC1) explained 38.3% of the total variance, while the second principal component (PC2) accounted for 22.3%. Together, these two components explained 60.6% of the overall variation in the dataset (**Figure 6**). These results indicate that PC1 and PC2 captured a substantial proportion of the variation in water quality characteristics across the monitoring locations. The PCA results provide insights into the relationships among water quality parameters and help identify the variables most strongly associated with spatial variations in water quality. These patterns may also reflect differences in surrounding land use and hydrological conditions, including the influence of residential areas, agricultural activities, and river flow characteristics.

The PCA score plot (**Figure 6**) shows that seasonal changes and differences in sampling by month resulted in greater variability in the water quality samples. This indicates that seasonal changes have a greater influence than location. Most of the June samples clustered along one side of PC1, whereas the November samples were associated with PC2. September samples fell between these groups, reflecting a transition in 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 this study.

Table 1 presents the effects of the principal components. Principal Component 1 (PC1) was mostly shaped by phosphate (loading = 0.608) and 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) was predominantly influenced by TSS (loading = 0.735) and BOD (loading = 0.487).

This pattern is indicative of sediment and organic pollution resulting from surface runoff, soil erosion, and organic material transport. These findings are consistent with the existing knowledge of the watershed, where paddy fields constitute 27.4% of the area, thereby increasing the likelihood of rainwater transporting sediment and organic matter into the aquatic system.

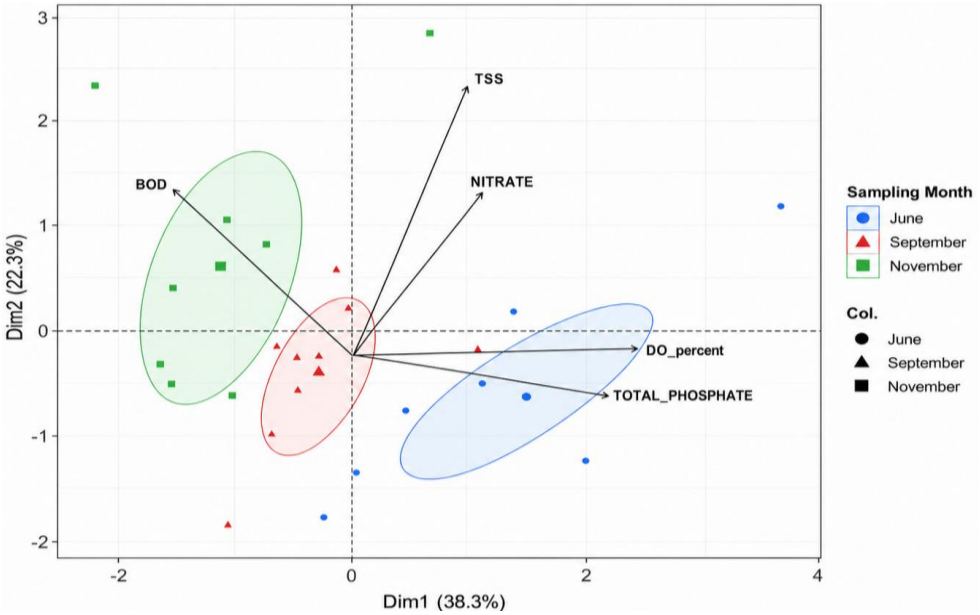


Figure 6. PCA score plot multiparameter

Table 1. Matrix of PCA 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**

Although nitrate had the highest load on Principal Component 3 (PC3) through Principal Component 5 (PC5), we did not discuss these components. This is because PC1 and PC2 together explain 60.6% of the variation in the data. This suggests that they capture environmental changes in the area. Regionally, the Cidaniang River and Paris River Bridge both had PC2 scores in November. At that time, the Cidaniang River showed the strongest positive PC1 score in June. Overall, PCA 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 had a pollution index in the range of 0.59–2.99 (**Figure 7**). This range indicating generally is good water quality index. However, some locations showed signs of localized stress associated with human activities. A comparable pattern occurred 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).

Water movement and pollutant transport changed the Pollution Index over time, and the conditions at all 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 remained at relatively high concentrations. However, 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.

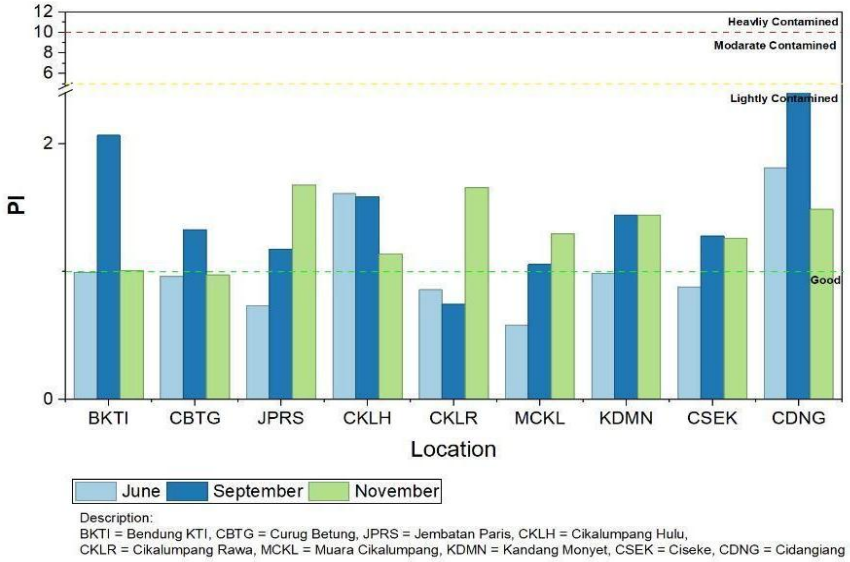


Figure 7. Results of the PI in the Cidanau Watershed, Banten

The site type also affected the PI. Therefore, the differences among sites were more closely tied to the land uses surrounding the sites than to the distance of each site from the point on the river (break at 0 m). This also indicates that the dry forest class is present in some of the locations, such as Cidangiang, Ciseke, Muara Cikalumpang, Cikalumpang Rawa, Kandang Monyet, and Jembatan Paris, with PI values of 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, occasionally enters the stream amid rainy seasons. At these sites, the nitrate and phosphate levels measured in the effluents corresponded well with agricultural runoff, which was the most obvious source of such high levels of PI production. 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 relatively high levels.

We computed the Indonesian Water Quality Index from the converted PI values using a method developed by the Ministry of Environment and Forestry. It is the 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, indicating that all 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. However, Cikalumpang Hulu and Cidangiang had lower values, which was due to an increase in PI at the time of the transition from the dry to 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 improved 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. Pollutants originating

from agricultural activities and domestic activities can be transported into rivers through surface runoff, particularly during rainfall events. In the Cidanau Watershed, where rainfall occurs throughout the year with a distinct rainy season, runoff can mobilize pollutants from surrounding land surfaces and carry them into nearby water bodies. The extent and type of pollutants entering the river may vary depending on the surrounding land use. This pattern is reflected in the observed water quality, which was generally better at monitoring sites surrounded by forest and wetland areas than at sites located near agricultural and urban areas. These findings suggest that land use plays an important role in influencing pollutant inputs and the spatial variation of water quality in the Cidanau Watershed.

IDN-WQI provides an overview of water quality in general, especially in the Cidanau area. This enables the 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 for real-time monitoring but also for long-term assessment of water resources in the region.

The 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 suggests that PI data cannot be represented as a total value without risking the loss of important changes in water quality. The index is limited in its ability to detect short-term pollution events in regions such as Cidanau, where rainfall is distributed regionally throughout the year and land use significantly influences the efficiency of water flow in river basins. Consequently, although the IDN-WQI is effective for assessing general conditions, it may not adequately identify short-term pollution events or seasonal variations, such as those occurring during the cold season.

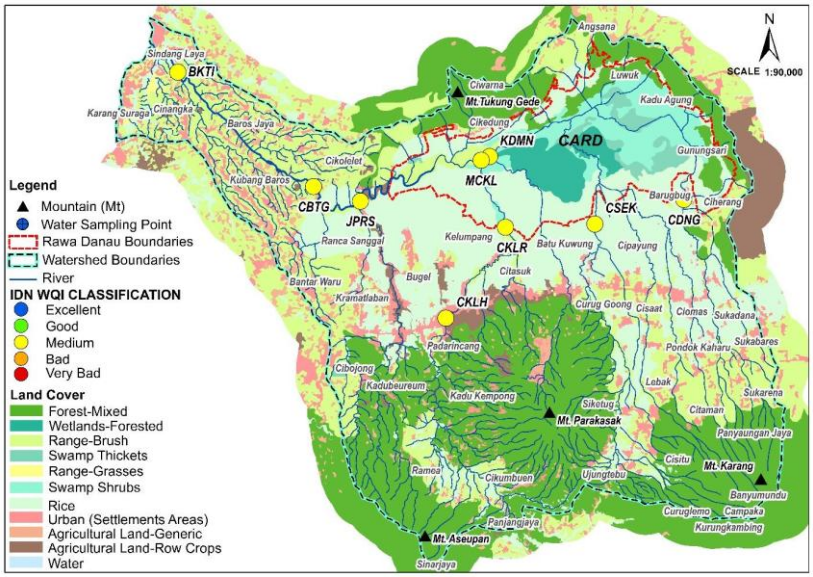


Figure 8. Result of IDN-WQI in Cidanau Watershed, Banten

Each index provides unique information compared to other assessment methods. The pollution index is especially sensitive when water quality standards are exceeded. The IDN-WQI provides an overall summary of environmental conditions using a standardized 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. Consequently, the NSF-WQI is able to detect 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 ranged from 46.11 to 87.21, indicating water quality ranging from poor to good (**Figure 9**). The latter also recorded the best water

quality in June, collecting data from six good stations, where Cikalumpang Rawa received 8.721 points. By September, the water quality weakened, with an NSF-WQI value ranging from 46.11 (Cidangiang) to 71.44, and only three stations were classified as good: Semburan, Budi Luhur, and Brantas River at Taman Jasa Piala Timnas site. In November, the water quality values ranged from 67.80 to 74.36, with seven stations classified as having good quality. These values declined during the transition season and subsequently recovered.

The main drivers with high impact on the NSF-WQI index throughout September were coliform levels, DO, 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. The uptick in November implied that these problems had abated as conditions improved. Overall, the variations in the NSF-WQI in the short term were attributed to weather and human activities that lead to changes in water quality.

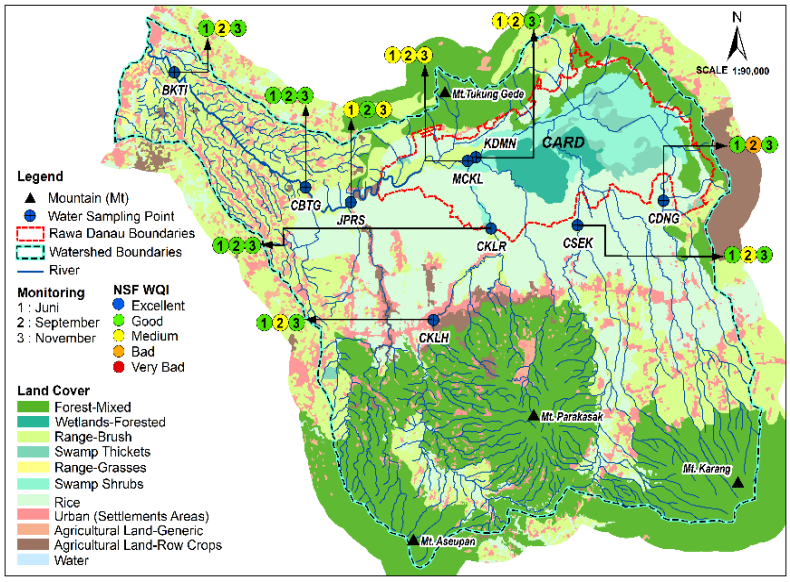


Figure 9. Results of NSF-WQI in Cidanau Watershed, Banten

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 the index is able to effectively pick up on sudden changes and pollution events that methods that 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. However, because of its high sensitivity to changes in these parameters, and as a drawback, short-term oscillations affect all watersheds analyzed 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 two different devices that do not affect the quality conditions. IDN-WQI achieves this by aggregating all the to the statistics through time, providing a single figure that represents the stable characteristics of water quality at each location. By contrast, the NSF-WQI records every sampling occasion separately, which highlights short-term fluctuations in and declines of water quality that may not be detected by methods based on averaging calculations, such as IDN-WQI. The 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 provides a long-term view of 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, and Spearman's rank correlation was employed to compare the PI and NSF-WQI with IDN-WQI (**Figure 10**).

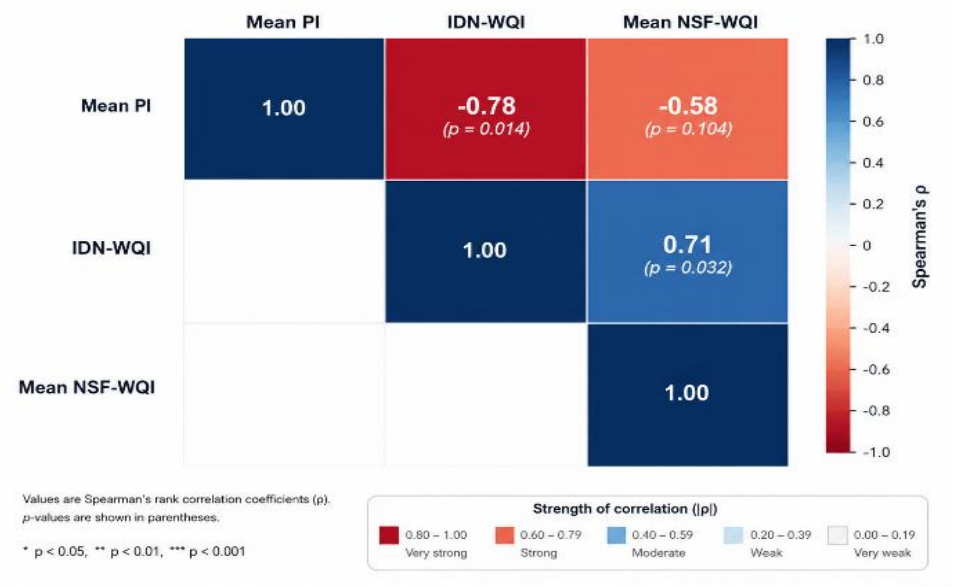


Figure 10. Spearman correlation matrix of station-averaged PI, IDN-WQI, and NSF-WQI.

A strong negative correlation between the average PI and IDN-WQI (ρ = –0.778, p = 0.014) indicates that the higher the pollution, the lower the IDN-WQI value. This indicates that the transition from PI to IDN-WQI provides clear information about the levels of pollution at all monitoring sites. A negative relationship was also observed between PI and the average NSF-WQI (ρ = –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 DO, 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 remains the same. A strong positive link was found between the IDN-WQI and the average NSF-WQI (ρ = 0.710, p = 0.032). However, it indicates that despite the different calculation and time resolution, both indices represent a general description of the overall water quality variation in the Cidanau Watershed. These associations are illustrated in the Spearman correlation matrix (**Figure 10**). The strongest negative correlation coefficient was -0.625 between the PI and IDN-WQI. The linkage between PI and NSF-WQI was less pronounced. This close relationship between the IDN-WQI and the NSF-WQI indicates that both indices provide estimates of water quality in the basin. They each concentrate on a piece of the environment. On average, the correlation analysis supports the use of all three methods. The Pollution Index can be used to identify situations in which the water quality standards are not achieved. Based on the Indonesian system, IDN-WQI generates a long-term condition that exists 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 tropical watersheds was obtained by combining these three indices. The composite is composed of three 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 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 behavior. 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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Ethic Statement

This study was conducted in accordance with Government Regulation No. 22 of 2021 and Minister of Environment and Forestry Regulation No. 27 of 2021. Water samples were collected according to the Indonesian National Standard (SNI) 6989.57:2008, with laboratory analyses referring to the American Public Health Association (APHA) Standard Methods for the Examination of Water and Wastewater. Sampling activities in the Cidanau watershed were conducted under the authorization of the West Java Natural Resources Conservation Agency (BKSDA Jawa Barat).

CRediT Author Statement

Alya Sekar Hapsari: Ide Development, Research Design, Investigation, Data Curation, Manuscript Draft Preparation. **Allen Kurniawan**: Supervision, Resources, Manuscript Review and Revision. **Satyanto Krido Saptomo:** Supervision, Validation, Resources. **Yuli Suharnoto:** Supervision, Validation, Resources. **Yanuar Chandra Wirasembada**: Supervision, Validation.

Declaration of Generative AI and AI-Assisted Technologies

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

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