Water quality index assessment methods for surface water: A case study of the Citarum River in Indonesia

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ABSTRACT

Water quality index (WQI) can express overall water quality status in a single term. As such, the application of daily WQI assessment should help the general public be more aware of the condition of the surface water around them. As the longest and biggest river in the West Java Province, the Citarum River plays an important role in the life of the community and ecosystem around it. Therefore, this research evaluated which WQI assessment method was best suited for determining the Citarum River’s water quality. We utilized West Java Province monitoring data collected from four monitoring stations along the Upstream Citarum. The WQI was calculated using the National Sanitation Foundation WQI (NSF WQI), Canadian Council of Ministers of the Environment WQI (CCME WQI), and Oregon Water Quality Index (OWQI) assessment methods. Nine years of monitoring data were grouped and analyzed according to wet vs. dry months, wet vs. dry years, monitoring station, and year. Using the NSF WQI assessment method, the Citarum River obtained a ‘Fair’ and ‘Bad’ water quality grade with WQI ranging between 38.212 and 60.903 during dry months, 49.089 and 62.348 during wet months, 42.935 and 65.696 during dry years, and 39.002 and 58.898 during wet years. The data ranged from 41.458 and 61.206 from each monitoring station, and between 35.920 and 58.713 for the data from each monitoring year. The CCME WQI assessment method showed that the Citarum River had ‘Fair’, ‘Marginal’, and ‘Bad’ water quality with WQI ranging between 12.683 and 31.503 during dry months, 21.231 and 33.127 during wet months, 12.683 and 31.503 during dry years, 12.134 and 28.748 during wet years, 13.621 and 30.569 for the data from each monitoring station, and 13.219 and 68.808 for the data from each monitoring year. The OWQI assessment method gave the Citarum River a ‘Very Bad’ water quality rating with WQI ranging between 11.528 and 18.827 during dry months, 13.898 and 24.563 during wet months, 11.528 and 25.782 during dry years, 11.528 and 15.997 during wet years, 11.528 and 18.842 for each monitoring station, and 11.523 and 16.528 for the data from each monitoring year. Based on these results and the collated advantages and disadvantages of each method, the NSF WQI assessment method was deemed to be the best for determining the Citarum River’s water quality.

1. Introduction

The water quality index (WQI) can express the water quality status in a single term. The application of WQI makes the general public more aware of the state of the surface water around them [24, 28]. The Citarum River plays a key role in the life of the community and ecosystem around it, and thus accurately determining its WQI daily should help the community readily understand its condition. Marganingrum et al. [12] used the pollution index to show that the water in the Citarum River was ‘slightly polluted’ and ‘heavily polluted’; fecal coliform, sulfide, and phenol were the main contaminants.

Many WQI assessment methods can be used to determine the quality status of surface water. However, since each method was designed for a different purpose, location, and expert assessment, the WQI results obtained using each method can differ even when applied to the same surface water [9]. For example, research conducted by Darvishi et al. [5] showed that the Talar River had different water quality status when it was determined by OWQI and NSF WQI. Other research evaluated water quality and showed a significant difference between the classes of the water quality in the same eight sites of water sources but with different indices [2]. Some studies have shown that the use of a same parameters used for determining WQI using different methods leads to different
classification [1, 10, 22]. While there are many index methods available, no one single method is recognized globally to fulfill the objective of water quality management. The suitability of any given WQI entirely depends on the sources, the parameters, the weightage assigned, the classification scale, and the final interpretation of the obtained WQI [20].

Therefore, this research aims to determine which WQI assessment method is most suitable for use in Indonesia using the Citarum River as a case study. Three WQI assessment methods were selected after reviewing the existing literature. The steps and parameters used in each method are different. The National Sanitation Foundation Water Quality Index (NSF WQI) is the most common method to determine surface water’s WQI worldwide and also serves as the reference for developing novel WQI assessment methods [21]. The Canadian Council of Ministers of the Environment WQI (CCME WQI) is based on the actual water quality standards for surface water in Indonesia, and thus it is expected to be more comprehensive. No prior work has yet applied the Oregon WQI (OWQI) to the Citarum River, and this method was used to determine whether it is applicable in this case or not. However, there is one study that applied OWQI in a surface water in East Java, Indonesia. It was conducted by Rahayu et al. [18] and showed that the water quality status of the Sutami Reservoir is heavily polluted based on the Oregon WQI method. This research also used the DOE-WQI, Pollution Index, and Prati Index: These metrics were different and showed the water to be only lightly polluted. A thorough review summarizing the current literature of the main WQI applications by Kachroud et al. [10] revealed that the WQI reflects the combination of many monitored water quality parameters in relation to specific water use objectives. The most important factor that affects the final classification of the water body is the number of parameters involved in WQI computation. This generally depends on water use, study objectives, site location, sampling frequency, funding, staff, and facilities.

This study was performed to achieve two objectives. The first was to determine the Citarum River’s water quality status based on the National Sanitation Foundation WQI (NSF WQI), the Canadian Council of Ministers of the Environment WQI (CCME WQI), and the Oregon WQI (OWQI) assessment methods. The second was to determine the most suitable WQI assessment method for Indonesia especially in the Upper Citarum Watershed.

2. Materials and methods

2.1. The study areas and data sources

This research was carried out for nine months and started with data collection on February 2021 and ended with the research result presentation and the revision of the research report on October 2021. The research site was located along the Citarum River, specifically the Upper Citarum, which starts in Situ Cisanti and ends at Nanjung Station.

The conditions did not allow direct sampling and testing; thus, this research utilized secondary data regarding Citarum River water quality which obtained from the Environmental Protection Agency of West Java Province. There are four monitoring station (Wangisaagara, Koyod, after IPAL Cisirung, and Nanjung) as can be seen in Figure 1. By considering the data availability, this research used monitoring data set from nine monitoring years (2011–2019) and four monitoring stations (Wangisaagara, Koyod, after IPAL Cisirung, and Nanjung) for 16 parameters (temperature, dissolved solids, suspended solids, pH, DO, BOD, COD, free ammonia, nitrate, total phosphate, oil and grease, detergent, phenol, free chlorine, fecal coliform, and total coliform). This research utilized data from nine monitoring years (2011–2019), and the effect of time (monitoring year) on the fluctuation of Citarum River water quality and WQI could be determined. From the secondary data, 2,688 data points (168 data sets) were collected. Supporting data regarding Bandung City’s total rainfall for the last 9 years (2011–2019) were obtained from the Bureau of Meteorology Climatology and Geophysics of Bandung City.

2.2. Water quality data correction methods

Some smoothing techniques were applied to improve the data to ensure accuracy and prevent erroneous conclusions. We first eliminated datasets with empty, nil, or censored values. During the elimination process, 1 out of every 2,688 datasets were empty. One dataset with empty data was eliminated. Validity and reliability were established through standardization and outlier tests. The standardization process was carried out using the z-score formula [14] as follows:

![Map of monitoring station.](image-url)
different times within the same period are required; furthermore, each parameter must have a standard that can be used as a reference [24, 25]. In this study, PP 22/2021 for class two served as the standard and the CCME WQI was determined using two groups of parameters. The first group consisted of the eight parameters and also used the NSF WQI and OWQI assessment methods; the second group included 14 parameters upon addition of COD, oil and grease, detergent, phenol, free chlorine, and total coliform. The WQI was calculated using Eq. (3) for the CCME WQI assessment method, while the water quality status was assigned based on the classification system developed by CCME (2002) in Khan et al. (2005) (Table 1) [6, 11].

\[
QI = 100 - \frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732}
\]  

(3)

Here, \( F_1 \) is the percentage of the total parameters that do not meet the standards calculated by Eq. (4); \( F_2 \) is the percentage of the individual tests that do not meet the standards calculated by Eq. (5); and \( F_3 \) is the amount of relativity by which the test values fail to meet the standards calculated by Eq. (6).

\[
F_1 = \frac{\text{Number of failed parameters}}{\text{Total number of parameters}} \times 100
\]  

(4)

\[
F_2 = \frac{\text{Number of failed tests}}{\text{Total number of tests}} \times 100
\]  

(5)

\[
F_3 = \left( \frac{nse}{0.01 \times \text{Total number of tests}} + 0.01 \right)
\]  

(6)

Where nse is the collective amount by which the test values fail to meet the standards calculated by Eq. (7).

\[
nse = \sum_{i=1}^{n} \text{excursion}_i
\]  

(7)

Here, \( \text{excursion}_i \) is the number of times the individual tests failed to meet the standard. When the test must exceed the standards, it is calculated using Eq. (8). When the test must not fall below the standards, it is calculated using Eq. (9).

\[
\text{excursion}_i = \left( \frac{\text{Failed test value}_i}{\text{Water quality standard}} \right) - 1
\]  

(8)

\[
\text{excursion}_i = \left( \frac{\text{Water quality standard}}{\text{Failed test value}_i} \right) - 1
\]  

(9)

The Oregon Water Quality Index (OWQI) incorporates eight selected parameters: total solids, temperature, pH, DO, BOD, ammonia and nitrate, total phosphate, and fecal coliform. Each parameter is weighted equally because unequal weighting is only suitable for WQI assessment methods developed for a specific purpose. The determination of the sub-indices for each parameter is based on the equation from sub-index curves established by Mitchell & Stapp [14] in Wills & Irvine [27]. WQI was calculated using Eq. (2) for the NSF WQI assessment method, while the water quality status was assigned using the classification system developed by Brown et al. (1970) in Table 1 [27].

\[
WQI = \sum_{i=1}^{n} Q_i W_i
\]  

(2)

Here, \( Q_i \) is the sub-index for i-th water quality parameter; \( W_i \) is the weight of the i-th water quality parameter; and n is the number of water quality parameters.

The parameters used to calculate the Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI) have not been previously determined, which allows flexibility regarding how many and which to include. However, at least four parameters measured and four

| NSF WQI | CCME WQI | OWQI |
|---------|----------|-------|
| Quality Status | Quality Status | Quality Status |
| 91–100 | Very Good | 95–100 | Very Good | 90–100 | Very Good |
| 71–90 | Good | 80–94 | Good | 85–89 | Good |
| 51–70 | Fair | 60–79 | Fair | 80–84 | Fair |
| 26–50 | Bad | 45–59 | Marginal | 60–79 | Bad |
| 0–25 | Very Bad | 0–44 | Bad | 0–59 | Very Bad |

The Oregon Water Quality Index (OWQI) incorporates eight selected parameters: total solids, temperature, pH, DO, BOD, ammonia and nitrate, total phosphate, and fecal coliform. Each parameter is weighted equally because unequal weighting is only suitable for WQI assessment methods developed for a specific purpose. The determination of the sub-indices for each parameter is based on the equation from sub-index curves established by Mitchell & Stapp [14] in Wills & Irvine [27]. WQI was calculated using Eq. (2) for the NSF WQI assessment method, while the water quality status was assigned using the classification system developed by Brown et al. (1970) in Table 1 [27].

\[
WQI = \sqrt{\frac{n}{\sum_{i=1}^{n} Q_i W_i^2}}
\]  

(10)

Here, \( Q_i \) is the sub-index for i-th water quality parameter; n is the number of water quality parameters.

All parameters of water quality used in each index are presented in Table 2 below.
2.4. Determining the most suitable WQI assessment method for the Citarum River

To determine the most suitable WQI assessment method for assessing the water quality status of the Citarum River, the advantages and disadvantages of each method were considered concerning the water quality monitoring process (the amount and frequency of testing needed and the type of monitoring parameters required), the WQI determination process (the calculation process required and evidence from the literature), as well as the WQI.

2.5. Correlation matrix

The correlation matrix was used to determine the relationship between water quality parameters and the result of water quality index. The correlation matrix used SPSS during dry, normal, and wet years.

3. Results

3.1. Wet vs. dry months

The WQI and water quality status of the Citarum River during the wet and dry months was obtained using the three WQI assessment methods presented in Table 3 and Figure 2.

The results show that based on each WQI assessment method, the wet months had better WQI results than the dry months. The higher rainfall could cause a better surface water quality because it dilutes the pollutants on the surface water naturally, thus causing the pollutant concentration in the water to decrease and the water quality to increase [16]. Clean water also helps dilute the organic compounds in water, and water that falls from a higher place (i.e., rainwater) facilitates the breakdown of organic matter [19]. Given that the average monthly rainfall during the wet months is higher than the dry months, the increased quality of the Citarum River

Table 2. Parameters used in each index.

|          | NSF WQI | CCME WQI 8 Parameters | CCME WQI 14 Parameters | OWQI |
|----------|---------|-----------------------|-------------------------|------|
| 1        | Total solids | Total solids | Total solids | Total solids |
| 2        | Temperature | Temperature | Temperature | Temperature |
| 3        | pH       | pH       | pH       | pH       |
| 4        | DO       | DO       | DO       | DO       |
| 5        | BOD      | BOD      | BOD      | BOD      |
| 6        | Nitrate  | Nitrate  | Nitrate  | Ammonia and nitrate |
| 7        | Total phosphorus | Total phosphorus | Total phosphorus | Total phosphate |
| 8        | Fecal coliform | Fecal coliform | Fecal coliform | Fecal coliform |
| 9        | COD      | Oil and Grease | Detergent | Phenol |
| 10       |         |          |          | Free Chlorine |
| 11       |         |          |          | Total Coliform |

Table 3. The Citarum River's WQI and water quality status for wet and dry months.

| Monitoring Point | Month Type | Water Quality Index | Water Quality Status | Monitoring Point | Month Type | Water Quality Index | Water Quality Status |
|------------------|------------|---------------------|----------------------|------------------|------------|---------------------|----------------------|
|                  | National Sanitation Foundation Water Quality Index (NSF WQI) | Canadian Council of Minister of the Environment Water Quality Index (CCME WQI) with 14 Parameters | | | | | |
| 1 Wet 62.348     | 1 Wet 27.760 | Bad | | | | | |
| 1 Wet 60.903     | 1 Dry 27.693 | Bad | | | | | |
| 2 Wet 57.116     | 2 Wet 26.874 | Bad | | | | | |
| 2 Dry 38.212     | 2 Dry 12.683 | Bad | | | | | |
| 3 Wet 51.459     | 3 Wet 22.507 | Bad | | | | | |
| 3 Dry 41.153     | 3 Dry 16.240 | Bad | | | | | |
| 4 Wet 49.089     | 4 Wet 21.231 | Bad | | | | | |
| 4 Dry 38.886     | 4 Dry 15.406 | Bad | | | | | |
|                  | Canadian Council of Minister of the Environment Water Quality Index (CCME WQI) with 8 Parameters | Oregon Water Quality Index (OWQI) |
| 1 Wet 33.127     | 1 Wet 24.563 | Very Bad | | | | | |
| 1 Dry 31.503     | 1 Dry 18.827 | Very Bad | | | | | |
| 2 Wet 29.883     | 2 Wet 15.837 | Very Bad | | | | | |
| 2 Dry 12.849     | 2 Dry 12.518 | Very Bad | | | | | |
| 3 Wet 26.677     | 3 Wet 14.431 | Very Bad | | | | | |
| 3 Dry 18.905     | 3 Dry 11.528 | Very Bad | | | | | |
| 4 Wet 25.535     | 4 Wet 13.898 | Very Bad | | | | | |
| 4 Dry 17.666     | 4 Dry 11.528 | Very Bad | | | | | |
during the wet months is most likely due to the dilution of pollutants in the water. Therefore, this research exemplifies the effect of rainfall on surface water quality based on the wet vs. dry month data. This indicates that more rainfall was followed by improved surface water quality.

3.2. Wet vs. dry years

The WQI result and water quality status of the Citarum River during the wet vs. dry years obtained using each WQI assessment method are described in Table 4 and Figure 3.

![Figure 2. The Citarum River's WQI results for wet and dry months based on (a) NSF WQI; (b) CCME WQI with 14 water quality parameters; (c) CCME WQI with 8 water quality parameters; and (d) OWQI.](image)

| Monitoring Point | Year Type | Water Quality Index | Water Quality Status | Monitoring Point | Year Type | Water Quality Index | Water Quality Status |
|------------------|-----------|---------------------|----------------------|------------------|-----------|---------------------|----------------------|
| NSF WQI          | Wet       | 58.898              | Fair                 | 1 Wet            | 27.395    | Bad                 |
|                  | Dry       | 65.696              | Fair                 | 1 Dry            | 35.555    | Bad                 |
|                  | Wet       | 39.002              | Bad                  | 2 Wet            | 12.134    | Bad                 |
|                  | Dry       | 46.771              | Bad                  | 2 Dry            | 18.597    | Bad                 |
|                  | Wet       | 41.252              | Bad                  | 3 Wet            | 17.984    | Bad                 |
|                  | Dry       | 46.962              | Bad                  | 3 Dry            | 20.761    | Bad                 |
|                  | Wet       | 40.209              | Bad                  | 4 Wet            | 14.571    | Bad                 |
|                  | Dry       | 42.935              | Bad                  | 4 Dry            | 20.328    | Bad                 |
| CCME WQI with 14 Parameters | Wet       | 28.748              | Bad                  | 1 Wet            | 15.997    | Very Bad            |
|                  | Dry       | 40.336              | Bad                  | 1 Dry            | 25.782    | Very Bad            |
|                  | Wet       | 13.008              | Bad                  | 2 Wet            | 12.530    | Very Bad            |
|                  | Dry       | 19.955              | Bad                  | 2 Dry            | 13.795    | Very Bad            |
|                  | Wet       | 22.852              | Bad                  | 3 Wet            | 12.453    | Very Bad            |
|                  | Dry       | 24.495              | Bad                  | 3 Dry            | 11.528    | Very Bad            |
|                  | Wet       | 17.481              | Bad                  | 4 Wet            | 11.528    | Very Bad            |
|                  | Dry       | 23.490              | Bad                  | 4 Dry            | 11.528    | Very Bad            |

The results show that the dry years had better WQI values than wet years with every WQI assessment method. This conflicting result is likely due to inconsistencies in the Citarum River's water quality monitoring periods and the lack of water quality monitoring held each year. The higher rainfall could cause a better surface water quality because it naturally dilutes the pollutants in the surface water, thus decreasing pollutant concentrations and improving water quality [16]. Moreover, clean water helps dilute the organic compounds in water, and the water that falls from a higher place (i.e., rainwater) facilitates the breakdown of organic matter [19]. Bandung City's rainfall data from 2012, 2013, 2014,
2016, and 2017 were classified as wet years due to their average yearly rainfall being higher than the other four years. Therefore, the quality of the Citarum River should be better during the wet year due to the dilution of pollutants. However, the water quality was only monitored during relatively dry months during those years, i.e., July, September, and October. As such, the water quality monitoring data likely does not accurately reflect this wet year’s river water quality. The was inconsistency during the monitoring period. Monitoring was done during different months each year or only 4–5 times per year. Therefore, this study failed to show the effect of rainfall on surface water quality according to whether the year was mostly wet or dry overall. The available data were insufficient to determine whether more rainfall improved the surface water quality. The U.S. EPA [26] reported that increased precipitation and intense rainfall can transport water and contaminants into waterbodies. More pollution and sedimentation might be produced by runoff in regions with increased rainfall frequency and intensity.

Various studies have been conducted to confirm the contradiction seen when using different WQIs. In most cases, the indices qualify the samples in adjacent water quality classes. In fact, the result can be explained by aggregation of the indices. However, the quality of the water varies according to the spatio-temporal dimensions of its course during the cycle and according to allocations and uses. The latter determines the choice of water quality variables, the analytical method, and the sampling period [10].

3.3. Monitoring station

The WQI and water quality status of the Citarum River at each monitoring station obtained using the three WQI assessment methods are presented in Table 5 and Figure 4.

The results show that Station 1 (Wangisagara) had the best WQI regardless of which method was used. Station 2 (Jembatan Koyod), Station 3 (Setelah IPAL Cisirung), and Station 4 (Nanjung) had decreasing WQI results (from best to worst) for each WQI assessment method. The main pollution sources for the river segment represented by Station 1 are waste from industrial, farming, and agricultural activities; Station 2 is subject to waste from textile and agricultural activities; Station 3 receives domestic and industrial waste from Bandung City, South Bandung Regency, and Cisirung WWTP; and Station 4 includes industrial waste [17].

![Figure 3. The Citarum River’s WQI results for wet vs. dry years based on (a) NSF WQI; (b) CCME WQI with 14 water quality parameters; (c) CCME WQI with 8 water quality parameters; and (d) OWQI.](image-url)

Table 5. The Citarum River’s WQI and water quality status at each monitoring station.

| Monitoring Point | Water Quality Index | Water Quality Status | Monitoring Point | Water Quality Index | Water Quality Status |
|------------------|---------------------|----------------------|------------------|---------------------|----------------------|
| NSF WQI          |                     |                      |                  |                     |                      |
| 1                | 61.206              | Fair                 | 1                | 26.864              | Bad                  |
| 2                | 41.563              | Bad                  | 2                | 13.621              | Bad                  |
| 3                | 43.852              | Bad                  | 3                | 16.588              | Bad                  |
| 4                | 41.458              | Bad                  | 4                | 15.874              | Bad                  |
| CCME WQI (14 Parameters) |                   |                      |                  |                     |                      |
| 1                | 30.569              | Bad                  | 1                | 18.842              | Very Bad             |
| 2                | 13.942              | Bad                  | 2                | 12.552              | Very Bad             |
| 3                | 19.244              | Bad                  | 3                | 11.528              | Very Bad             |
| 4                | 18.201              | Bad                  | 4                | 11.528              | Very Bad             |

| CCME WQI (8 Parameters) | OWQI |                   |                  |                     |                      |
| 1                | 30.569 | Bad | 1                | 18.842              | Very Bad             |
| 2                | 13.942 | Bad | 2                | 12.552              | Very Bad             |
| 3                | 19.244 | Bad | 3                | 11.528              | Very Bad             |
| 4                | 18.201 | Bad | 4                | 11.528              | Very Bad             |
Landuse condition at the study location was demonstrated by an aerial map around the monitoring stations as can be seen at Figure 5. In general, it can be seen that the residential area becomes denser as indicated by the red-colored area. There was less activity and fewer pollution sources around Sta. 1. Thus, the pollution load of the river segment represented by Sta. 1 is also lighter (relative to the other monitoring stations), which then caused the river water quality to be better and the WQI result to be higher than the other monitoring stations. In contrast, the river segments represented by the other three stations were subject to greater and more diverse pollutant sources. The water quality parameters failed to fulfill the water quality standard and increased accordingly. The pollution load of the river segment represented by Sta. 2, Sta. 3, and Sta. 4 are also heavier (relative to Sta. 1), which then caused the river water quality to be worse and the WQI result to be lower than Sta. 1. The pollutant sources for the river segment represented by Sta. 2, Sta. 3, and Sta. 4 were more diverse, and the type and number of water quality parameters that failed to fulfill the water quality standard also became more diverse. The diversity of the pollutant sources as well as differences during the WQI determination process of each WQI assessment method (e.g., parameter, weight, sub-indices, water quality standard, and
equation) are likely responsible for the different order of the monitoring stations when sorted based on WQI result (from best to worst). Regardless, this research shows the effect of the monitoring location on surface water quality using data from each monitoring station.

This result is also similar to a related study, which found that the upstream station has higher water quality versus the downstream station. This is clearly explained by the location of the latter at a near distance from the agricultural areas of the watershed and next to the wastewater treatment plant of the city. This matter concerning the spatial changes in water quality along the river can be more easily detected when examining the numerical values of the individual WQIs [29].

### 3.4. Monitoring year

The annual WQI and water quality status of the Citarum River obtained using the three WQI assessment methods are presented in Table 6 and Figure 6.

These results indicate that there was a decrease in the WQI results in 2012 with every WQI assessment method. This is likely because no additional efforts were made to improve the water quality of the Citarum River from 2011 to 2012. Despite the steady increase in Bandung Raya’s population, no actions have been taken to improve the wastewater and solid waste management systems [3]. This condition is assumed to be the cause of the decreasing water quality of the Citarum River in 2012. From 2013 to 2018, the Citarum Bestari Program was enacted to improve the water quality of the Citarum River with various monitoring and improvement efforts like the Ecovillage Program and the Gebrak Citarum Program.

Since 2018, the Citarum Harum Program has been held to improve the Citarum River’s water quality with five main priorities: the Citarum River monitoring system, wastewater and sanitation management, solid waste management, revitalization of the catchment areas in the upper stream, and clean water management [3]. The results in Table 5 indicate that these improvement efforts were not always successful because the WQI still decreased in some years. In general, the NSF WQI, OWQI, and CCME WQI (eight quality parameters) reflected similar fluctuation for each monitoring year; however, the CCME WQI (14 quality parameters) did not seem to align with this pattern. This is likely because the CCME WQI also considers the effect of six additional quality parameters (detergent, phenol, COD, oil and grease, free chlorine, and total coliform) on the water quality. Therefore, the Citarum Bestari and the Citarum Harum Programs did not impact every water quality parameter equally.

For example, in 2013 and 2014, there was an increase in the WQI according to the NSF WQI, OWQI, and CCME WQI (8 parameters) but a decrease according to the CCME WQI (14 parameters). This discrepancy suggests that the Citarum Bestari Program only successfully improved eight quality parameters during this period: TDS, TSS, total phosphate, BOD, nitrate, dissolved oxygen, pH, and fecal coliform. It failed to improve the six aforementioned additional quality parameters. Differences in the WQI determination process of each WQI assessment method (e.g., parameter, weight, sub-indices, water quality standard, and equation used) probably underlie the different order of monitoring year when these are sorted based on WQI (from best to worst). Despite these

| Monitoring Year | NSF WQI | CCME WQI (14 Parameters) | CCME WQI (8 Parameters) | OWQI |
|-----------------|---------|--------------------------|-------------------------|------|
| 2011            | 48.683  | CCME WQI 23.762          | CCME WQI Marginal 56.681 | 20.446 |
| 2012            | 35.920  | CCME WQI 18.903 Bad      | OWQI 13.219 Bad          | 11.523 |
| 2013            | 45.291  | CCME WQI 14.776          | OWQI 18.441 Bad          | 12.476 |
| 2014            | 46.809  | CCME WQI 17.565          | OWQI 24.451 Bad          | 12.594 |
| 2015            | 58.713  | CCME WQI 48.705          | OWQI 56.681 Bad          | 15.763 |
| 2016            | 51.163  | CCME WQI 38.669          | OWQI 35.295 Marginal 56.681 | 11.523 |
| 2017            | 45.993  | CCME WQI 28.107          | OWQI 29.130 Bad          | 12.605 |
| 2018            | 47.517  | CCME WQI 26.118          | OWQI 33.238 Bad          | 13.823 |
| 2019            | 47.808  | CCME WQI 25.290          | OWQI 28.491 Bad          | 12.548 |

Figure 6. The Citarum River’s WQI according to monitoring year based on (a) NSF WQI; (b) CCME WQI with 14 water quality parameters; (c) CCME WQI with eight water quality parameters; and (d) OWQI.
Table 7. Advantages and disadvantages of each water quality index determination method.

| Determining Factor | National Sanitation Foundation Water Quality Index (NSF WQI) | Canadian Council of Minister of the Environment Water Quality Index (CCME WQI) | Oregon Water Quality Index (OWQI) |
|--------------------|-----------------------------------------------------------|---------------------------------------------------------------|---------------------------------|
| Observation Processes | • Uses a reduced number of water quality parameters. | • Allows flexibility regarding the type and amount of water quality parameters used; chosen based on the water's utilization purpose and data availability. | – |
|                      | • Only shows the effect of the one water quality parameter being used. | • Much more expensive because it needs more funding for sampling and testing purposes. | • Only shows the effect of the one water quality parameter being used. |
| Determination Processes | • The aggregation method is straightforward and easy to use. | • The aggregation method used is more complex because it has to calculate the F1, F2, and F3 values first. | • Equal weighting is more suitable to determine the surface water's quality for general use. |
|                      | • Individual weights for each parameter determined by experts are subjective. | • The sub-indices equation is too ideal for the Citarum River. | • The sub-indices equation is too ideal for the Citarum River. |
|                      | • Individual weighting creates sensitivity issues. | • The aggregation method is prone to an ‘eclipsing’ problem. | • The aggregation method is prone to an ‘eclipsing’ problem. |
| WQI Results | • Accurately reflects fluctuations in the Citarum River's water quality. | • Could not determine the Citarum River's daily water quality. | • Could determine the Citarum River's daily water quality. |
|                      | • Indicates the Citarum River's water quality on a daily basis | • Could not be used to determine the Citarum River's WQI on time. | • Fails to show fluctuations in the Citarum River's water quality. |

3.5. Identifying the most suitable water quality index assessment method for the Citarum River

The advantages and disadvantages of each WQI assessment method were combined based on the literature (Table 7) [8,21,23,24]. By considering the advantages and disadvantages of each WQI assessment method and the fact that the Environmental Protection Agency of West Java Province held the Citarum River's water quality observation 4 to 5 times per year, the National Sanitation Foundation Water Quality Index (NSF WQI) method was found to be the most suitable WQI assessment method for determining the quality status of surface waters in Indonesia specifically the Citarum River. The OWQI assessment method is not suitable because it fails to show fluctuations in the Citarum River's water quality. The sub-indices equation used here was too ideal for this application because the water quality data was almost always worse than the ‘worst case’ scenario stated by Cade (2001). Moreover, the sub-indices obtained were almost always the same, which is the lowest value available. Therefore, the WQI results end up being similar to one another. The CCME WQI assessment method was also deemed unsuitable because it needs at least four different observation times within the same monitoring period. Even if it were feasible to determine the Citarum River's WQI daily using this method, it would be too expensive. Informing the general public of the water quality status daily is very important and can help them properly utilize and protect the surface water around them.

A related study can help explain why the Oregon WQI is stricter than the NSF. According to Zotou et al. [29], Oregon and CCME WQIs were found to be relatively ‘stricter’, thus giving results ranging between the lowest classes of the qualitative ranking. Bhargava's Index along with NSF WQI tend to classify water bodies into superior quality classes, whereas CCME WQI is suggested as the most appropriate among the examined indices because it is both “conservative” and adequately “sensitive” to reflect changes in water quality. A similar result also reported that the NSF WQI leads to the highest qualitative classification with Oregon WQI as the lowest [2].

Marselina et al. [13] performed a principal component analysis of pollutant parameters in the Saguling Reservoir (Citarum Hulu DAS) and found that the dominant pollutant sources in the Upper Citarum Watershed came from domestic activities, agriculture, and sedimentation. Parameters representing domestic pollutant sources include BOD, DO, and fecal E. coli. Parameters representing agricultural pollutant sources include nitrate and phosphate. Other physical parameters such as TDS and turbidity indicate the presence of sedimentation from surface runoff. These parameters have been included in the NSFWQI parameters so that the NSFWQI has been selected for Citarum River.

Table 8 below shows about correlation between the concentration parameters and WQI scores in dry, normal, wet years. The relationship between the WQI values and each parameter is quite strong. A negative value in the correlation relationship shows an inverse relationship: The WQI value has poor water quality when the parameter concentration is high. The weakest correlation is shown between the WQI value and temperature.

The Citarum River is a strategic river in West Java, Indonesia. It is traverses ten different cities, and each city uses it as a source of clean

Table 8. Correlation between concentration parameters and WQI scores in dry, normal, wet years.

| Parameter | Temperature | TDS | Turbidity | pH | Nitrate | Phosphate | DO | BOD | Fecal E. coli |
|-----------|-------------|-----|-----------|----|---------|-----------|-----|-----|--------------|
| WQI       | 0.203       | -0.747 | -0.821     | -0.520 | -0.639  | -0.745    | 0.579 | -0.566 | -0.759       |

| Parameter | Temperature | TDS | Turbidity | pH | Nitrate | Phosphate | DO | BOD | Fecal E. coli |
|-----------|-------------|-----|-----------|----|---------|-----------|-----|-----|--------------|
| Temperature | -0.305 | -0.735 | -0.914 | -0.708 | -0.720 | -0.680  | 0.720 | -0.700 | -0.920       |
water, irrigation, and industrial activities. Pollution control in the Citarum River is shown by the issuance of Presidential Regulation Number 15 of 2018 concerning the Acceleration of Pollution Control and Damage to the Citarum River Basin. One of the supporters of this regulation is the issuance of Cooperation Agreements between ten cities and the West Java Environmental Service regarding the integration of water quality monitoring that must be carried out by each city. Integration of water quality monitoring results can be realized by having the same quality parameters in every monitoring activity carried out by each city government that the Citarum River passes through. The results of this study can lead to recommendations for water quality parameters that must be monitored by the city government when these parameters agree with the parameters of the NSF-WQI calculation.

4. Conclusion

The results indicate that the National Sanitation Foundation WQI (NSF WQI) method, the Canadian Council of Ministers of the Environment WQI (CCME WQI) method, and the Oregon WQI (OWQI) method generated different water quality status values for the Citarum River. The wet months tended to have a better WQI and water quality status than the dry months. The dry year tended toward a better WQI and water quality status than the wet year. Water monitoring St. 1 had better WQI metrics. The WQI obtained for each year always fluctuates. Therefore, based on these findings, the most suitable WQI assessment method for determining Indonesian surface water quality—specifically the Citarum River—was the National Sanitation Foundation Water Quality Index (NSF WQI).

Declarations

Author contribution statement

Mariana Marselina: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.
Fachriah Wibowo: Performed the experiments; Analyzed and interpreted the data; Wrote the paper.
Arini Musfiroh: Analyzed and interpreted the data; Wrote the paper.

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Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

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