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Spatial and temporal assessment of surface water quality using water quality index The Saguling Reservoir, Indonesia

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Abstract

Developments in agriculture, industry, and urban life have caused the deterioration of water resources, such as rivers and reservoirs in terms of their quality and quantity. This includes the Saguling Reservoir located in the Citarum Basin, Indonesia. A review of previous studies reveals that the water quality index (*WQI*) is efficient for the identification of pollution sources, as well as for the understanding of temporal and spatial variations in reservoir water quality. The *NSFWQI* (The National Sanitation Foundation water quality index) is one of *WQI* calculation methods. The *NSFWQI* is commonly used as an indicator of surface water quality. It is based on nitrate, phosphate, turbidity, temperature, faecal coliform, pH, *DO*, *TDS*, and *BOD*. The average *NSFWQI* has been 48.42 during a dry year, 43.97 during a normal year, and 45.82 during a wet year. The *WQI* helped to classify water quality in the Saguling Reservoir as “bad”. This study reveals that the strongest and most significant correlation between the parameter concentration and the *WQI* is the turbidity concentration, for which the coefficient correlation is 0.821 in a dry year, and faecal coli, for which the coefficient correlation is 0.729 in a dry year. Both parameters can be used to calculate the *WQI*. The research also included a nitrate concentration distribution analysis around the Saguling Reservoir using the Inverse Distance Weighted method.

Key words: *inverse distance weight, spatial and temporal assessment, surface water, water quality index*

INTRODUCTION

The deterioration in surface water quality has become a major problem due to several key issues, such as increased pollution, climate change, and insufficient law enforcement [BARKI, SINGA 2014; BORDALO *et al.* 2001; GHODRATOLA *et al.* 2014]. Access to drinking water supply in terms of its quality, quantity, and continuity has always been a challenge for countries in Southeast Asia, including Indonesia. One of reasons for the shortage of drinking water is the poor quality of water sources caused by pollution [HORTON 1965; JOHN *et al.* 2014]. According to the 2012 river and lake monitoring in Indonesia by the Indonesian Ministry of Environment (Ind. Kementerian Lingkungan Hidup dan Kehutanan), more than 50% of water quality parameters have been below quality standards for surface water quality class I (surface water which is used for drinking water purposes) as defined by Government Regulations Number 82 of 2001. These parameters included biochemical oxygen demand (*BOD*), chemical oxygen demand (*COD*), faecal coli, and total coliform [ADB 2016].

Monitoring conducted on 44 major rivers in Indonesia shows that only 4 rivers meet class II (surface water which is used for irrigation purposes). Besides, monitoring has also been carried out on 15 major lakes in Indonesia and all lakes have been proven to have the hypertrophic status. Water quality monitoring is important to determine a baseline status for surface water, such as reservoirs and rivers. As in other countries, Indonesia itself has implemented water pollution control and monitoring activities regularly to obtain reliable spatial and temporal information about water quality.

Water quality assessment is generally performed by calculating the water quality index (*WQI*). The *WQI* is a unique and valuable measure to describe the status of water quality. The single index is very useful in determining policies and strategies, and selecting of technologies that can be applied to improve surface water quality [KOÇER, SEVGILI 2014; TODD *et al.* 2012; ZEINALZADEH, REZAEI 2017]. Besides, the water quality index can be used to communicate water quality changes and the effectiveness of pollution control to the community and policymakers. KANNEL *et al*. [2007] showed the water quality index from the different perspectives, including the *WQI* (min), which are calculated based on five parameters, such as *TDS*, *DO*, pH, temperature, and electrical conductivity (*EC*). Moreover, there is also the *WQI* (*DO*) used to determine water pollution based on *DO* (dissolved oxygen) parameters only. The *WQI* (min) and *WQI* (*DO*) are a simplification of the National Sanitation Foundation water quality index (*NSFWQI*). They can translate into effective use of cost and time, which is very important when implemented in developing countries.

NSFWQI water quality criteria for the classification of water quality are based on turbidity, temperature, phosphate, nitrate, faecal coliform, pH, *DO*, *TS*, and BOD_5. After measuring, each parameter is assigned a numerical weight or a value of the index from the curves, and the mathematical equations are used to calculate the final index. The lower the *NSFWQI*, the higher water pollution is. Water quality can be excellent, good, fair, poor, or very poor [KANNEL *et al.* 2007; PESCE, WUNDERLIN 2000; SÁNCHEZ *et al.* 2007].

In Indonesia, the calculation of the water quality index has to be conducted using the STORETS's method and the pollution index method which are regulated by the Decree of the Ministry of Environment and Forestry Number 115 of 2003 concerning Guidelines for Determining Water Quality Status [Keputusam … 2003].

The *NSFWQI* calculation in this study was conducted for the Saguling Reservoir, a series of three reservoirs located on the Citarum River. The Citarum River itself is important for the survival of Indonesian people, especially in the West Javanese region. The river is used as a source of clean water, irrigation water, and electricity. Surface water samples are analysed under two conditions (wet and dry year), with a total of 44 water quality parameters. This study provides a seasonal and temporal assessment of the Saguling Reservoir as an important aspect of surface water condition. It also provides a better understanding of water pollution that results from anthropogenic sources, such as agriculture, households, and industry. Based on *NSFWQI* values, the highest *WQI* has been noted at the Nanjung station, an upstream representative of the Citarum watershed. In order to prove that the pollution concentrates at the Saguling Reservoir inlet, the nitrate concentration distribution was also analysed in this study using the inverse distance weighted method.

METHODS

SAMPLING POINTS AND STUDY LOCATION

Eleven water quality monitoring locations have been set up in the Saguling Reservoir area. Details can be found in Table 1 and Figure 1. These eleven locations are representative because they show each segment of the Saguling Reservoir, from the reservoir inlet, the middle of the reservoir, to the reservoir's outlet.

Table 1. Water quality monitoring locations in the Saguling Reservoir

Monitoring station	Location	GPS (decimal unit)	
		North	South
1a	Citarum River	107°32'10.7"	06°56'29.8"
1b	Citarum River Trash Boom Batujajar	107°28'35.0"	06°54'58.0"
2	Cihaur Cipeundeuy Village	107°28'32.3"	06°53'13.5"
3	Cimerang	107°27'09.0"	06°53'13.4"
4	Cihaur Estuary Maroko Village	107°25'54.4"	06°54'13.0"
5	Cipatik Estuary	107°27'25.5"	06°56'07.6"
6	Ciminyak Estuary – floating nets fishing location	107°26'03.8"	06°57'14.6"
7	Cijere Estuary	107°24'50.8"	06°56'14.9"
8	Cijambu Estuary	107°22'22.4"	06°56'00.4"
9	near intake structure	107°22'26.3"	06°54'54.4"
10a	Tailrace	107°20'57.0"	06°51'49.8"

Source: own elaboration.

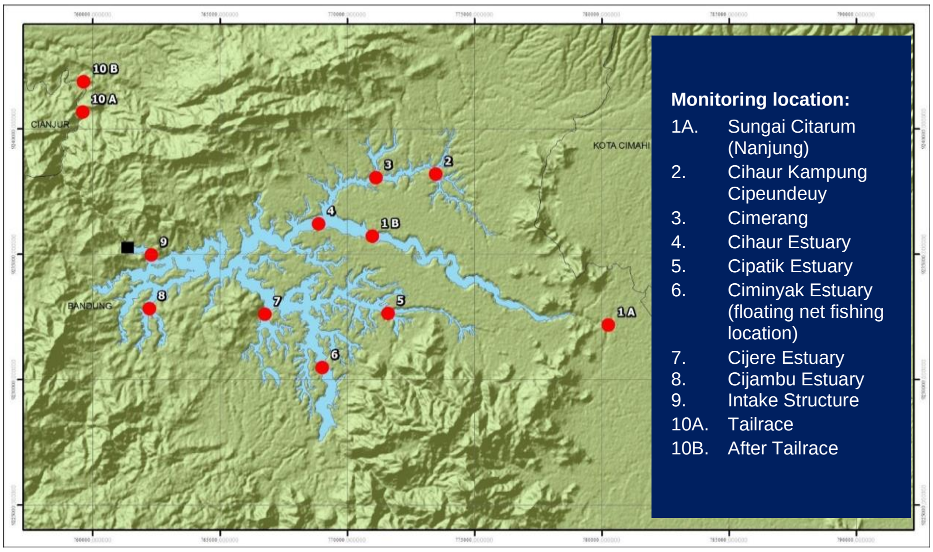


Fig. 1. Water quality monitoring locations in the Saguling Reservoir; source: own study

WATER QUALITY ANALYSIS

The data used in this research is primary data and secondary data. The secondary data include the discharge data of the Saguling Reservoir from 2003 to 2015. The primary data were the results of water quality sampling. Parameters such as temperature, *DO*, pH, and *EC* were measured in situ by the YSI instrument. Total phosphate was also calculated using the ascorbic acid method [GREENBERG *et al.* 1999]. *BOD* was determined by a five-day incubation process, whereas *COD* was determined using the close reflux method. Additionally, total coliform and faecal coliform were determined using a membrane filter and incubation at 41.5°C for 7 hours. The assessment of all water quality parameters was done by following standard methods for the examination of water and wastewater [GREENBERG *et al.* 1999].

WATER QUALITY INDEX

The *NSFWQI* is one of the calculation methods to determine surface water quality indices for rivers and lakes [SHARMA, KANSAL 2011]. This method uses 9 parameters, such as nitrate, phosphate, turbidity, temperature, faecal coliform, pH, *DO*, *TDS*, and *BOD*. Apart from the *NSFWQI*, the study is based on other water quality index calculation methods, including weighted arithmetic water quality index (*WAWQI*), Canadian Council of Ministers of the Environment water quality index (*CCMEWQI*), and the Oregon water quality index (*OWQI*) [PAUN *et al.* 2016]. The calculation method has been formulated by several national and international organizations.

In this study, the calculation method used was the *NSFWQI*. Each of them measured the concentration of nine parameters transformed into unit-less sub-index values. Sub-index values can be determined by transforming each parameter into 0 to 100 scales by using linear sub-index curves. This index is generally determined by the Delphi method, which is based on the weight (*Wi*) and sub-indices of the nine main parameters.

The weighting factor indicates the importance of each test as the overall measure of water quality. The weighting factors underlying the *NSFWQI* after KANNEL *et al.* [2007] are as follows:
– temperature (°C) – 0.10,
– total dissolved solid (mg·dm^{-3}) – 0.07,
– turbidity (NTU) – 0.08,
– pH – 0.11,
– nitrates (mg·dm^{-3}) – 0.10,
– total phosphate (mg·dm^{-3}) – 0.10,
– dissolved oxygen (mg·dm^{-3}) – 0.17,
– biochemical oxygen demand (mg·dm^{-3}) – 0.11,
– faecal coli (colony per 100 cm^{3}) – 0.16.

After several steps, the *NSFWQI* value can be determined using the equation:

$$NSFWQI = \sum_{i=1}^{n} Q_i W_i \tag{1}$$

$$WQI_{\min} = \frac{\sum_{i=1}^{n} C_i W_i}{n} \tag{2}$$

Ratings of the water quality index were determined acc. to KANNEL *et al.* [2007]:
– 91–100 – excellent water quality,
– 71–90 – good water quality,
– 51–70 – medium or average water quality,
– 26–50 – fair water quality,
– 0–25 – poor water quality.

After *NSFWQI* values were obtained, they were compared to Table 3 to determine the water quality status in each sampling location.

THE CORRELATION MATRIX

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

RESULTS AND DISCUSSION

WATER QUALITY DATA OF THE SAGULING RESERVOIR DURING DRY, NORMAL, AND WET YEARS

Below are water quality monitoring data in the Saguling Reservoir during dry, normal, and wet year.

Table 2 shows the average water quality data of the Saguling Reservoir at several monitoring locations during a dry year. At 11 monitoring locations, water temperatures were generally normal, which are around 26–27°C, and slightly lower at the Cimerang location, which was 25°C. The concentration of dissolved residue or *TDS* at 11 monitoring locations was still below quality standards for surface water class I (surface water used for drinking) based on Government Regulations Number 82 of 2001.

The highest *TDS* concentration was found at the Cihaur location (330.5 mg·dm^{-3}), while the lowest at the Ciminyak Estuary. When compared with *TDS* data during normal years, *TDS* concentrations during dry years tend to be larger. As regards turbidity, the highest concentration was found in water samples from the Nanjung location, which was 220.9 NTU, while in the other 10 locations, turbidity was below 60 NTU. The lowest turbidity concentration was measured at Tailrace. Water pH at the monitoring location was generally normal, in the range of 7–8. But in the monitoring location, intake water was determined to be alkaline with a pH of more than 11. Other information that can be found in Table 3 is that nitrate measurements at all 11 locations are still below clean water quality standards (class I in Government Regulation Number 82 of 2001). As regards phosphate, water samples from 11 locations are also below class III of water quality standards based on Government Regulation Number 82 of 2011, which is a maximum of 1 mg·dm^{-3}. The concentration of *DO* in water samples from all 11 locations was determined to be very small, in the range of 0–1.2 mg·dm^{-3}. Faecal coliform measurements from 11 locations did no deviate from class III of water quality. BOLSTAD and SWANK [2003] concluded that transportation of coliforms in water can occur mainly through land or direct input by warm-blooded animals (e.g. livestock). By reviewing 9 test

Table 2. Water quality data of the Saguling Reservoir during a dry year

No.	Location	Temperature °C	Total dissolved solids mg·dm^{-3}	Turbidity mg·dm^{-3}	pH	Nitrate mg·dm^{-3}	Phospate mg·dm^{-3}	Dissolved oxygen mg·dm^{-3}	Biochemical oxygen mg·dm^{-3}	Faecal coli colony per 100 cm^{-3}
1	Nanjung	25.9±0.7	320.4±117.0	220.9±187.9	7.4±0.1	3.3±1.1	0.4±0.2	0.6±1.0	50.3±5.3	1100.0±0.0
2	Batujajar	27.5±0.6	296.9±52.0	50.2±49.2	7.6±0.1	2.6±0.6	0.3±0.1	0.9±1.2	26.0±4.1	1100.0±0.0
3	Cihaur	27.7±0.5	330.5±52.7	62.5±45.4	8.2±0.3	2.4±1.0	0.3±0.1	0.8±1.1	21.3±3.7	1100.0±0.0
4	Cimerang	25.0±5.8	266.7±31.6	45.6±55.8	8.0±0.3	2.1±0.7	0.2±0.1	0.9±1.3	14.4±3.7	1100.0±0.0
5	Cihaur Estuary	27.4±0.5	250.3±34.8	44.0±50.4	7.7±0.1	2.0±0.5	0.3±0.1	1.0±1.4	15.2±3.3	210.0±0.0
6	Cipatik Estuary	26.1±3.0	139.5±15.9	41.9±53.1	7.7±0.4	1.6±0.4	0.3±0.1	1.0±1.4	10.3±2.6	150.0±0.0
7	Ciminyak Estuary	27.3±0.4	136.9±19.9	40.7±52.0	7.5±0.1	1.6±0.4	0.3±0.1	0.9±1.3	9.3±2.6	1100.0±0.0
8	Cijere Estuary	26.2±3.0	162.1±27.0	27.8±25.8	7.6±0.3	1.7±0.4	0.3±0.1	1.1±1.5	9.3±2.5	1100.0±0.0
9	Cijambu Estuary	27.3±0.3	162.2±5.3	39.5±53.9	7.6±0.2	1.4±0.4	0.2±0.1	1.0±1.4	8.5±1.5	210.0±0.0
10	Intake	26.9±0.2	182.5±26.0	39.6±39.5	11.6±9.1	1.6±0.4	0.3±0.1	1.2±1.7	10.6±3.0	64.0±0.0
11	Tailrace	26.8±0.2	209.6±0.0	27.6±0.0	7.2±0.0	1.6±0.0	0.2±0.0	1.0±0.0	9.7±0.0	23.0±0.0

Source: own study.

Table 3. Water quality data of the Saguling Reservoir during a normal year

No.	Location	Temperature °C	Total dissolved solids mg·dm^{-3}	Turbidity NTU	pH	Nitrate mg·dm^{-3}	Phosphate mg·dm^{-3}	Dissolved oxygen mg·dm^{-3}	Biochemical oxygen mg·dm^{-3}	Faecal coli colony per 100 cm^{3}
1	Nanjung	26.3±1.0	241.8±108.4	196.3±135.8	7.5±0.4	2.6±1.5	0.5±0.2	0.8±1.4	40.4±11.7	1100.0±0.0
2	Batujajar	26.8±0.5	228.7±93.3	87.7±71.0	7.4±0.3	1.8±0.9	0.3±0.1	1.0±1.3	19.5±3.6	1100.0±0.0
3	Cihaur	27.4±0.4	308.2±104.4	71.6±59.4	7.9±0.4	1.9±0.8	0.3±0.1	1.0±1.4	19.5±4.6	1100.0±0.0
4	Cimerang	27.3±0.2	252.8±66.7	43.6±40.7	8.1±1.9	2.5±2.0	1.3±2.2	1.1±1.5	16.0±3.2	1100.0±0.0
5	Cihaur Estuary	27.3±0.2	203.8±55.8	33.6±38.0	7.6±0.3	1.2±0.4	0.4±0.2	1.2±1.5	15.6±2.4	210.0±0.0
6	Cipatik Estuary	27.2±0.2	123.1±32.4	41.9±38.5	7.6±0.3	1.2±0.2	0.4±0.1	1.1±1.6	12.8±4.3	150.0±0.0
7	Ciminyak Estuary	27.9±1.3	111.1±25.5	35.8±31.2	7.5±0.2	1.4±0.4	0.3±0.1	1.1±1.4	12.0±3.1	1100.0±0.0
8	Cijere Estuary	27.2±0.3	143.7±37.5	34.3±34.4	7.7±0.2	1.6±0.6	0.3±0.2	1.3±1.9	12.5±2.8	1100.0±0.0
9	Cijambu Estuary	27.7±1.1	155.1±42.8	57.2±60.2	10.7±6.7	1.2±0.6	0.3±0.1	1.1±1.5	11.6±3.8	210.0±0.0
10	Intake	27.0±0.6	161.4±41.3	37.4±42.5	7.8±0.3	1.4±0.6	0.3±0.1	1.4±1.9	13.0±4.3	64.0±0.0
11	Tailrace	26.7±0.1	181.8±0.0	32.9±0.0	12.0±0.0	1.7±0.0	0.2±0.0	1.0±0.0	12.3±0.0	23.0±0.0

Source: own study.

parameters, water quality from the Najung site was found to have worse quality compared to other locations with regards to turbidity, nitrate, phosphate, *DO*, *BOD*, and faecal coli. Overall data regarding water quality during dry years show that concentrations are higher than water concentrations for various parameters during normal years.

Table 3 shows average water quality data at 11 monitoring locations in the Saguling Reservoir during normal years. Water temperatures were generally in normal, that is around 26–27°C. The concentration of dissolved residue or *TDS* remained below quality standards for surface water quality class I (surface water used for drinking) based on Government Regulation Number 82 of 2001.

The highest *TDS* concentration of 308.2 mg·dm^{-3} was found at Cihaur, while the lowest *TDS* concentration was measured at the Ciminyak Estuary. As regards turbidity, the highest concentration was found in a water sample from Nanjung, which was 196.3 NTU, while in 10 other locations, the turbidity concentration was below 100 NTU. The lowest turbidity concentration was measured at Tailrace, whereas pH was generally normal, in the range of 7–8. However, at the monitoring location of the Cijambu Estuary and Tailrace, water was alkaline, with pH of more than 10. Alkaline conditions in water can be caused by various factors. The quality of water in Tailrace is the result of turbine corrosion. That condition is also an indicator of polluted waters. Other information in Table 2 refers to water samples from 11 monitored locations. In all locations, nitrate concentration remained below clean water quality standards (class I in Government Regulation Number 82 of 2011). As regards phosphate, water samples at the Cimerang location exceeded class III of water quality standards based on Government Regulation Number 82 of 2001, which is a maximum of 1 mg·dm^{-3}. As regards *DO*, all 11 monitoring locations showed a very small concentration of *DO* in water samples, which was 0–1.5. As for the faecal coliform parameter, the monitoring of 11 locations shows that water quality is still below class III of water quality standards. By reviewing 9 test parameters, the water quality from the Najung site was found to have a worse quality compared to other locations in terms of turbidity, nitrate, *DO*, *BOD*, and faecal coli.

Table 4 shows the average water quality data of the Saguling Reservoir at several monitoring locations during a wet year. At 11 locations, water temperature was generally normal around 25–27°C. It was slightly lower than water temperature during normal and dry years. The highest *TDS* concentration was found at Cihaur (299.1 mg·dm^{-3}), while the lowest *TDS* concentration at the Ciminyak Estuary.

When compared to *TDS* data during normal and dry years, *TDS* concentrations during wet years tend to be smaller than water quality data from dry years and are not much different than measurements during normal years. The highest concentration of turbidity was in the water sample from Nanjung (193.6 NTU), while in the other 10 locations the turbidity concentration was below 65 NTU. The lowest

Table 4. Water quality data of the Saguling Reservoir during a wet year

No.	Location	Temperature °C	Total dissolved solids mg·dm^{-3}	Turbidity NTU	pH	Nitrate mg·dm^{-3}	Phosphate mg·dm^{-3}	Dissolved oxygen mg·dm^{-3}	Biochemical oxygen mg·dm^{-3}	Faecal coli colony per 100 cm^3
1	Nanjung	25.8±0.4	245.5±83.4	193.6±101.6	7.4±0.2	2.5±1.5	0.3±0.1	1.5±1.4	29.2±19.7	1100.0±0.0
2	Batujajar	26.9±0.7	213.8±49.6	62.9±50.4	7.4±0.2	1.7±0.8	0.3±0.1	2.9±3.4	15.7±4.5	1100.0±0.0
3	Cihaur	26.1±3.3	299.1±77.1	56.0±53.0	7.4±1.4	2.1±1.3	0.3±0.2	2.2±2.7	20.2±9.2	1100.0±0.0
4	Cimerang	25.8±3.2	240.7±58.8	40.1±35.3	7.4±0.9	1.7±1.0	0.2±0.1	2.5±3.2	13.6±4.4	1100.0±0.0
5	Cihaur Estuary	25.8±3.3	200.4±52.4	38.7±31.0	7.1±0.8	2.0±0.8	0.2±0.1	1.7±1.5	12.1±2.8	210.0±0.0
6	Cipatik Estuary	25.9±3.2	123.5±22.0	45.3±35.2	7.0±0.9	1.3±0.7	0.3±0.1	1.8±1.7	9.3±3.4	150.0±0.0
7	Ciminyak Estuary	25.9±3.2	114.8±23.2	40.0±35.2	6.9±0.8	1.2±0.6	0.3±0.1	1.7±1.6	7.6±2.9	1100.0±0.0
8	Cijere Estuary	25.9±3.3	146.1±26.5	39.6±34.8	7.0±0.9	1.5±1.0	0.2±0.1	1.7±1.5	11.2±3.8	1100.0±0.0
9	Cijambu Estuary	25.9±3.5	154.6±33.9	43.9±40.8	7.1±0.8	1.4±0.9	0.2±0.1	1.6±1.5	9.0±1.7	210.0±0.0
10	Intake	25.6±3.4	165.1±39.4	39.4±38.8	6.8±0.9	1.5±1.0	0.2±0.1	1.9±1.8	11.0±3.6	64.0±0.0
11	Tailrace	25.2±3.2	181.5±0.0	49.3±0.0	6.8±0.0	1.4±0.0	0.2±0.0	1.0±0.0	10.0±0.0	23.0±0.0

Source: own study.

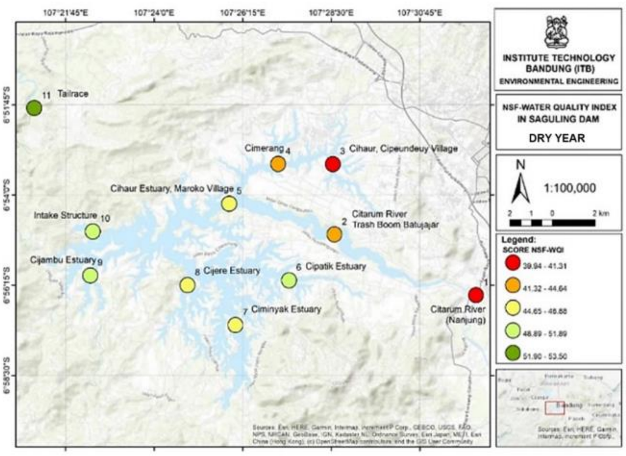
turbidity concentration was at the Cihaur Estuary. Water pH was generally normal, in the range of 6–8. Other information that can be gathered from Table 4 is that in all locations nitrate concentrations were in line with clean water quality standards. Phosphate measurements at all 11 locations were also still below class III of water quality standards based on Government Regulation Number 82 of 2001, which is a maximum of 1 mg·dm^{-3}. The concentration of *DO* in water samples from all locations was very small, in the range of 1–3 ppm, slightly better than *DO* during normal and dry years. The faecal coliform measurements were still below class III of water quality standards based on Government Regulation Number 82 of 2001. By reviewing 9 test parameters, water quality from the Nanjung site was found to have worse quality compared to the other locations for turbidity, nitrate, phosphate, *BOD*, and faecal coli. Overall water quality data during a wet year show lower concentrations of various parameters during a dry year, with little difference from concentrations during a normal year.

THE NATIONAL SANITATION FOUNDATION WATER QUALITY INDEX (*NSFWQI*) VALUES FOR THE SAGULING RESERVOIR DURING DRY, NORMAL, AND WET YEARS

In this part of the article, the *NSFWQI* value is discussed from spatial and temporal points of view for each monitoring location based on conditions during dry, normal, and wet years.

The distribution of monitoring points is shown in Figure 2a where Figure 2b shows the *NSFWQI* in the Saguling Reservoir during a dry year period. *NSFWQI* values obtained were then compared to Table 3 on the *NSFWQI* water quality rating. During dry years, at the Nanjung monitoring point, water quality was fair with an index score of 45. The same was observed at monitoring points of Batujajar and Cihaur, with index scores of 49 and 46, respectively. In Cimerang, Cihaur Estuary, Cipatik Estuary, Ciminyak Estuary, Cijere Estuary, Cijambu Estuary, Intake, and Tailrace, the water quality ratings were medium. Index scores are as follows: Cimerang – 51, Cihaur Estuary – 53, Cipatik Estuary – 56, Ciminyak Estuary – 55, Cijere Estuary – 54, Cijambu Estuary – 57, Intake – 59, and Tailrace – 61. The highest index score during a dry year was at Tailrace, whereas the lowest at Nanjung.

The distribution of monitoring points is shown in Figure 3a, whereas Figure 3b shows results of NSFWQI water quality monitoring in the Saguling Reservoir during a normal year. *NSFWQI* values obtained were then compared to Table 3 regarding NSFWQI water quality ratings. The value of *NSFWQI* for the Saguling Reservoir during dry years shows that all monitoring points have a medium water quality. Index scores obtained at each monitoring point are as



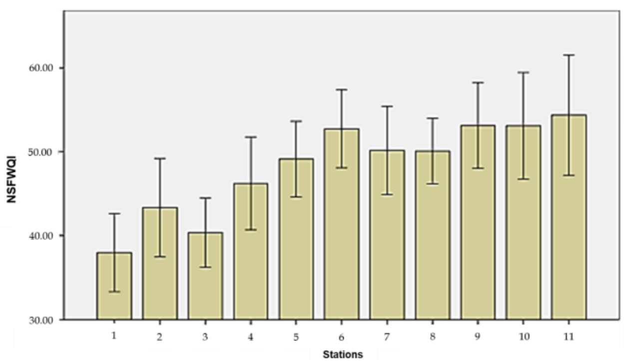


Fig. 2. The National Sanitation Foundation water quality index (*NSFWQI*) value in the Saguling Reservoir during a dry year; a) map, b) for each monitoring location; source: own study

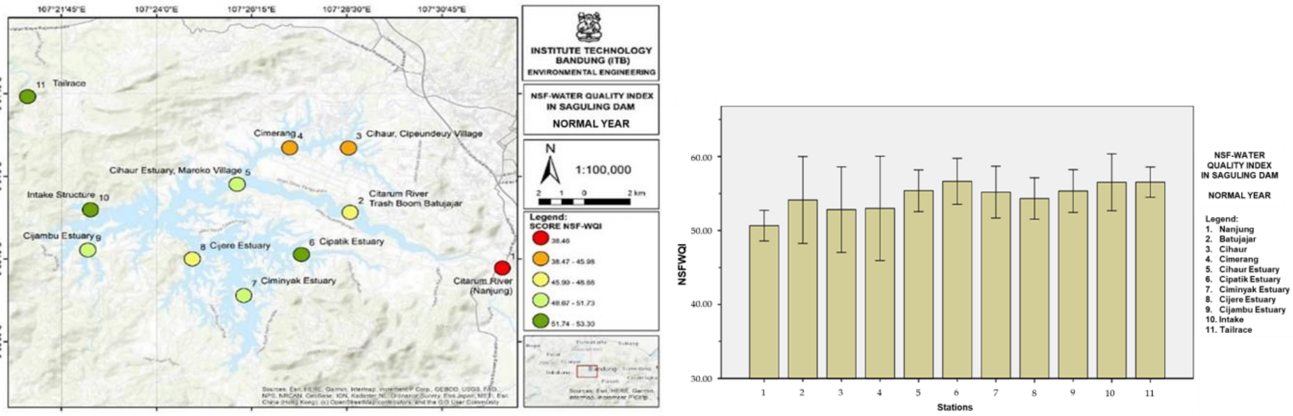


Fig. 3. The National Sanitation Foundation water quality index (*NSFWQI*) value in the Saguling Reservoir during a normal year; a) map, b) for each monitoring location; source: own study

follows: Nanjung – 43, Batujajar, Cimerang and Intake have scores of 60, Cihaur – 58, Cihaur and Ciminyak Estuaries have scores of 57, Cipatik Estuary, Cijambu Estuary, and Tailrace – 59 each, and Cijere Estuary – 56. During a normal year, the highest index score was found at Batujajar and Cimerang, while the lowest at Nanjung.

The distribution of monitoring points is shown in Figure 4a, whereas Figure 4b shows results of the *NSFWQI* water quality in the Saguling Reservoir during a wet year. *NSFWQI* values obtained were then compared to Table 3 on *NSFWQI* water quality ratings. The value of the *NSFWQI* for Saguling Reservoir during a wet year shows that Nanjung, Batujajar, and Cihaur are of a fair water quality category according to their *NSFWQI* scores, which are 43, 48, and 47, respectively. Meanwhile, in Cimerang, Cihaur Estuary, Cipatik Estuary, Ciminyak Estuary, Cijere Estuary, Cijambu Estuary, Intake, and Tailrace have water quality that is classified as medium. Index scores are as follows: Cimerang – 51, Cihaur Estuary – 53, Cipatik Estuary – 56, Ciminyak Estuary – 55, Cijere Estuary – 54, Cijambu Estuary – 57, Intake and Tailrace – 59. During a wet year, the highest index score is found at the Intake and Tailrace, while the lowest at Nanjung.

CORRELATION WATER QUALITY MATRIX AND NATIONAL SANITATION FOUNDATION WATER QUALITY INDEX VALUES FOR THE SAGULING RESERVOIR DURING DRY, NORMAL, AND WET YEARS

The correlation water quality matrix for the Saguling Reservoir during dry, normal, and wet years is shown in Table 5.

From Table 7 it can be seen that the strongest and most significant correlation between concentration parameters and *WQI* scores is the turbidity concentration and faecal coli. This indicates that these parameters provide a major contribution to the *WQI* value or water quality data at the Saguling Reservoir during dry, normal, or wet years. Based on these two parameters (obtained from correlation matrix), the calculation of the *NSFWQI* can be cost-effective as well as save time and energy. These are fundamental aspects of an effective monitoring programme in water quality determination [WU *et al.* 2017].

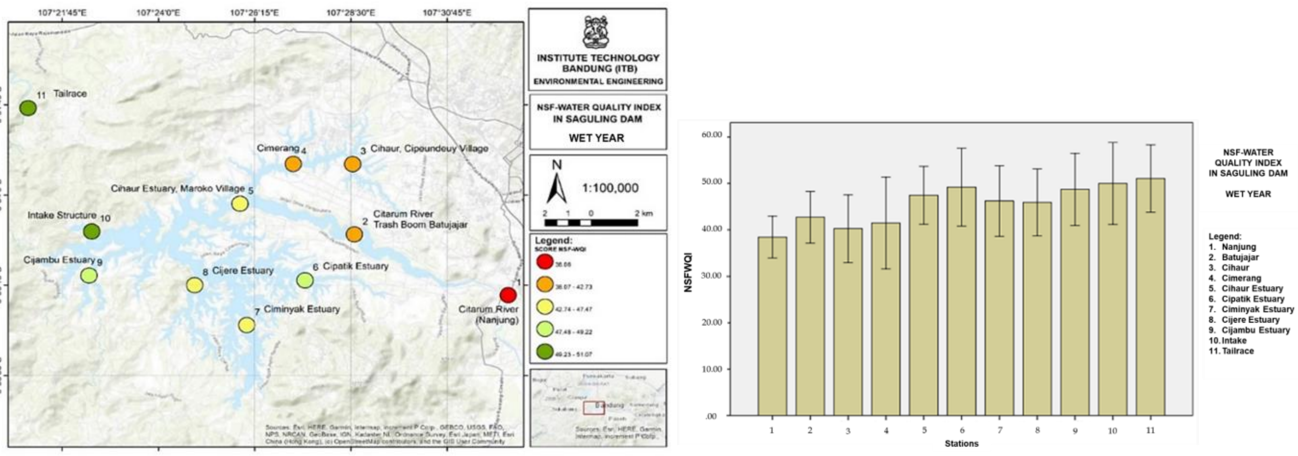


Fig. 4. The National Sanitation Foundation water quality index (*NSFWQI*) value in the Saguling Reservoir during a wet year; a) map, b) for each monitoring location; source: own study

Table 5. Correlation matrix of the Saguling Reservoir water quality during a dry, normal, and wet year

Parameter	Temperature	*TDS*	Turbidity	pH	Nitrate	Phosphate	*DO*	*BOD*	Faecal coli	*WQI*
Water quality during the dry year										
Temperature	1									
TDS	0.043	1								
Turbidity	–0.260	0.542	1							
pH	0.044	–0.117	–0.141	1						
Nitrate	–0.111	0.874	0.818	–0.188	1					
Phosphate	–0.062	0.529	0.828	0.071	0.742	1				
DO	0.047	–0.724	–0.779	0.516	–0.863	–0.625	1			
BOD	–0.133	0.749	0.938	–0.176	0.958	0.822	–0.850	1		
Faecal Coli	–0.172	0.454	0.343	–0.319	0.596	0.358	–0.593	0.459	1	
WQI	0.023	–0.747	–0.821	–0.320	–0.639	–0.745	0.579	–0.566	–0.759	1
Water quality during the normal year										
Temperature	1									
TDS	–0.363	1								
Turbidity	–0.620	0.454	1							
pH	–0.031	–0.124	–0.230	1						
Nitrate	–0.545	0.670	0.633	–0.115	1					
Phosphate	0.039	0.364	0.033	–0.169	0.647	1				
DO	0.420	–0.413	–0.674	–0.142	–0.442	–0.024	1			
BOD	–0.662	0.542	0.969	–0.315	0.701	0.133	–0.660	1		
Faecal coli	0.006	0.420	0.412	–0.529	0.617	0.375	–0.224	0.436	1	
WQI	0.272	–0.645	–0.762	–0.273	–0.570	–0.529	0.635	–0.479	–0.643	1
Water quality during the wet year										
Temperature	1									
TDS	0.215	1								
Turbidity	0.041	0.403	1							
pH	0.652	0.765	0.389	1						
Nitrate	0.210	0.846	0.797	0.717	1					
Phosphate	0.414	0.488	0.451	0.624	0.628	1				
DO	0.833	0.391	–0.132	0.705	0.232	0.388	1			
BOD	0.218	0.764	0.875	0.665	0.986	0.628	0.171	1		
Faecal coli	0.529	0.410	0.326	0.639	0.487	0.703	0.509	0.492	1	
WQI	–0.305	–0.735	–0.914	–0.708	–0.720	–0.680	–0.220	–0.700	–0.920	1

Explanations: *TDS* = total dissolved solids, *DO* = dissolved oxygen, *BOD* = biological oxygen demand, *WQI* = water quality index.
Source: own study.

NITRATE CONCENTRATION DISTRIBUTION USING INVERSE DISTANCE WEIGHTING (IDW)

With regard to *NSFWQI* values above, the highest *NSFWQI* for dry, normal, and wet conditions has been measured in Nanjung, which is located in the most upstream area before entering the Saguling Reservoir. This may be caused by upstream river basin conditions of the Saguling Reservoir determined by pollution sources, such as agriculture, households, and industry. In order to prove that the pollution is concentrated at the Saguling Reservoir inlet, the nitrate concentration distribution was analysed using the inverse distance weighting method.

Nitrate concentrations have been included in the IDW analysis because nitrate is one of parameters that shows pollution of a reservoir, especially reservoir's fertility conditions (reservoir tropic status).

The IDW method is a simple deterministic method that includes the analysis of points in the vicinity. The assumption of this method is that the interpolation value is more similar to near sample data than to more distant data. Weights change linearly according to the distance. Thus, the weight is not affected by the location of sample data. The IDW assumes each point size that decreases with distance. Points that are closer to the estimated location are given greater weight than those located further away, so this is called the inverse distance weighting. The general equation for the inverse distance weighting is shown below:

$$\hat{Z}(S_0) = \frac{\sum_{i=1}^{n} z\,(S_i)\, d_{i0}^{-p}}{\sum_{i=1}^{n} d_{i0}^{-p}} \tag{3}$$

where: S_0: = estimation location, N = number of nearest neighbours, $\hat{Z}(S_0)$ = prediction location value, $\hat{Z}(S_i)$ = sample location value, which is i = 1,2, …, n, p = exponent, which determines the weight value by every prediction; the p parameter affects the weighting of each location value measured against the estimated location value; thus, if the sample size of the network measured by the estimated location increases, the weight (or influence) of the size point on the estimate will decrease exponentially; d = distance from sample location point S_i to prediction location S_0, the greater the distance d, the more the weight decreases by factor p.

Below presented is the use of the IDW to determine nitrate concentrations in the Saguling Reservoir.

The distribution of nitrates at 11 monitoring locations in the Saguling Reservoir during a wet year is shown in Figure 5a. At the monitoring point in Nanjung, the concentration

a) b) c)

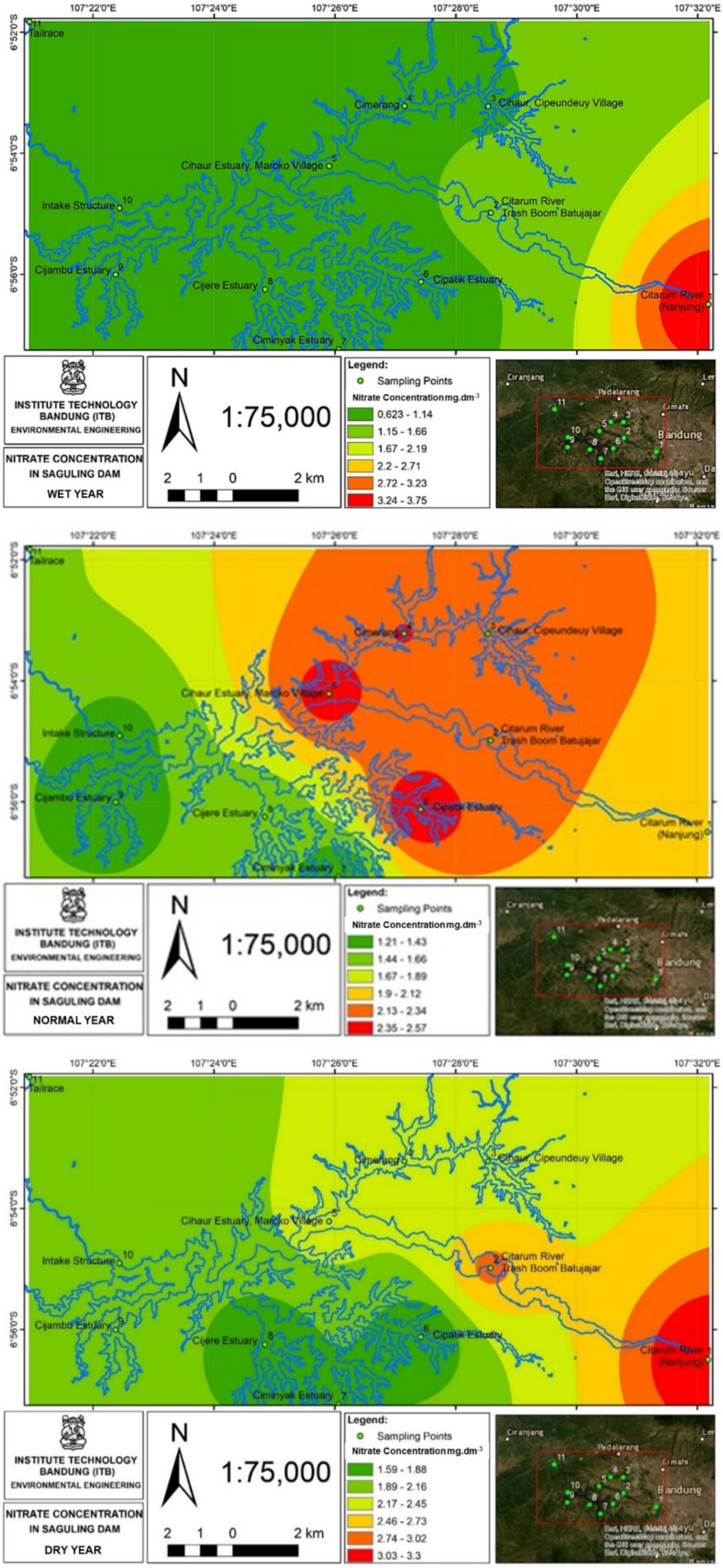


Fig. 5. Nitrate distribution during: a) wet year, b) normal year, c) dry year; source: own study

of nitrate is shown in red and ranges between 3.24 and 3.75 mg·dm^{-3}, whereas at the monitoring point in Batujajar (shown in light green), nitrate concentration values are between 1.15 and 1.66 mg·dm^{-3}. In other monitoring points, which include Cihaur, Cimerang, Cihaur Estuary, Cipatik Estuary, Ciminyak Estuary, Cijere Estuary, Cijambu Estuary, Intake, and Tailrace (shown in dark green), nitrate concentration values range between 0.623 and 1.14 mg·dm^{-3}. During a wet year, the highest nitrates value is in Nanjung, while the lowest is found at Cihaur, Cimerang, Cihaur Estuary, Cipatik Estuary, Ciminyak Estuary, Cijere Estuary, Cijambu Estuary, Intake, and Tailrace. However, nitrate levels in water samples from 11 locations are still below class III of water quality standards based on Government Regulation Number 82 of 2001, which is a maximum of 20 mg·dm^{-3}.

Nitrate concentrations of more than 0.2 mg·dm^{-3} can lead to eutrophication (enrichment) of waters and subsequently stimulate a rapid growth of algae and aquatic plants (blooming). This is detrimental because it can affect health and biodiversity of the local aquatic ecosystem. Naturally, the concentration of nitrate in natural waters is only a few mg·dm^{-3} and is one of components that stimulate the growth of aquatic biomass so that it directly controls the development of primary production. This function is closely related to the fertility of water. PRICE *et al*. [2015] concluded that high nitrate concentration is caused by agriculture, aquaculture, industry and household waste or municipal waste.

The distribution of nitrates during a normal year at each monitoring location in the Saguling Reservoir is shown in Figure 5b. At the monitoring point in Nanjung, the concentration of nitrate is shown in red and the range value is 3.24–3.75 mg·dm^{-3}. Meanwhile, at the monitoring point in Batujajar, nitrate concentration values between 2.74 and 3.02 mg·dm^{-3} are indicated in orange. Furthermore, other monitoring points, namely Cihaur, Cimerang, Cihaur Estuary (shown in green), have nitrate concentration values between 2.17 and 2.45 mg·dm^{-3}. Monitoring points of Cipatik, Ciminyak and Cijere Estuaries (shown in dark green) have nitrate concentration values between 1.59 and 1.88 mg·dm^{-3}, whereas Cijambu Estuary, Intake, and Tailrace (shown as light green) have nitrate concentrations of 1.89–2.16 mg·dm^{-3}. The highest value of nitrate concentration during a normal year is in Nanjung, while the lowest in Cijambu, Intake, and Tailrace. However, nitrate values in water samples from 11 locations are still below class III of water quality standards based on Government Regulation Number 82 of 2001, which is a maximum of 20 mg·dm^{-3}.

The distribution of nitrates at each monitoring location during a dry year in the Saguling Reservoir is shown in Figure 5c. At the monitoring point in Nanjung, the concentration of nitrate is shown in red, the value range of 3.24–3.75 mg·dm^{-3}, while the same in the monitoring point in Batujajar is shown in orange, with nitrate concentration values between 2.74 and –3.02 mg·dm^{-3}. Other monitoring points, namely Cihaur, Cimerang, Cihaur Estuary, marked green have nitrate concentration values of 2.17–2.45 mg·dm^{-3}. The monitoring points of Cipatik, Ciminyak and Cijere Estuaries are shown in dark green and have nitrate concentration values between 1.59 and 1.88 mg·dm^{-3}. Furthermore, Cijambu Estuary, Intake, and Tailrace (light green) have nitrate concentration values of 1.89–2.16 mg·dm^{-3}. The highest value of nitrate concentration during a dry year is in Nanjung, while the lowest in Cijambu, Intake, and Tailrace. However, nitrate measurements for all 11 locations are still below class III of water quality standards based on Government Regulation Number 82 of 2001, which is a maximum of 20 mg·dm^{-3}.

CONCLUSIONS

Water quality assessment is usually conducted by calculating the water quality index. The water quality index (*WQI*) is a valuable and unique rating used to describe an overall water quality status in a single term that is helpful for the selection of appropriate treatment techniques to resolve various issues. The National Sanitation Foundation water quality index (*NSFWQI*), which is the commonly used indicators for surface water quality, is based on the following parameters: turbidity, temperature, phosphate, nitrate, faecal coliform, pH, *DO*, *TDS*, *BOD*. The *NSFWQI* values for the Saguling Reservoir during a dry year (study period) show a clear increasing trend from Nanjung to the Tailrace station (upstream to downstream). *NSFWQI* fluctuations occur in several locations, such as Cihaur and Cipatik Estuary. Water quality at the Nanjung station is classified as class IV fair water quality with the *WQI* value between 26 and 50. This value reveals the poorest condition in the Saguling Reservoir compared to normal and wet years. This study also shows that the strongest and the most significant correlation between parameter concentration and the *WQI* score is the turbidity concentration and faecal coli. The two parameters are useful to determine required parameters if the calculation of the *WQI* (with reduced parameters) is needed.

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