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Study of Determining Water Quality Status and Water Distribution Using Five Methods in Selorejo Reservoir.

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Abstract

A reservoir is a place to store river water formed by the construction of a dam. The main problem of reduced water quality for Selorejo Reservoir is caused by the inflow of water from livestock, agricultural, and household wastes containing high amounts of nitrates and phosphates. The objective of this study is to determine the water quality status of Selorejo Reservoir using the DOE-WQI, Pollution Index, DWQI, Ved Prakash Index, and Prati Index methods; to find out the distribution of characteristics for water quality status using the IDW method and to find out the capacity of water pollution load for Selorejo Reservoir using Total-P. The research showed that the characteristics of water contamination for Selorejo Reservoir in 6 years indicate light pollution. Through the DWQI method, the contamination percentage became smaller downstream, while the DOE-WQI, Pollution Index, Ved Prakash Index, and Prati Index methods showed the opposite results. Total-P levels in the 2021 dry season were 42.475 mg/m^3 (upstream), 35.767 mg/m^3 (middle), and 37.567 mg/m^3 (downstream). The pollution load capacity is 71.77 mg/m^3 (upstream), 80.14 mg/m^3 (middle), and 77.9 mg/m^3 (downstream). It can thus be said that Selorejo Reservoir is still within the maximum reservoir pollution load limit.

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1. Introduction

Within the past year, specifically in July 2021, Selorejo Reservoir was the site of a peculiar incident where hundreds of fish died and floated suddenly in mass. According to the Chief Director of Perum Jasa Tirta 1 regarding the incident, the cause originated from agricultural and farming wastes that entered the reservoir, along with rainwater and surface runoff, and deprived the fish of oxygen. In addition, the growth of water hyacinths also became the cause of water quality reduction. Agricultural waste caused the water to become fertile, which instead accelerated the growth of water hyacinths (https://jatimnow.com/baca-36356-ikanikan-di-waduk-selorejo-malang-mati-warga-geger).

Water quality is a level of the polluted condition or good condition of a water source during a certain period and in comparison to a water quality standard that has been established [1]. Factors such as population growth, migration, and industrialization may worsen the quality and availability of water on the surface and in the soil [2]. One of the methods to determine river water quality is the water quality index. This method has been proven to be an effective method for evaluating water quality.

Water Quality Index (WQI) is a simple method that is used as a part of the general survey of water quality with the usage of a group of parameters that reduce a large amount of information into single values, usually dimensional, in a manner that is easily reproducible [3].

Water quality reduction may cause various problems for living creatures and humans who utilize water as their source of life. Reduced water quality may lead to problems such as damage, hazards, and disruptions of the living creatures within it [4]. Poor water quality will impact the functions of Selorejo Reservoir as one of the resources that the local people utilize.

Water pollution is evident from physical properties such as watercolor and smell and may be determined through several parameters such as water's chemical, physical, and biological parameters [5]. Previously, there had been researched discussing water quality using the methods of DOE-WQI, Pollution Index, Oregon-WQI, and Prati Index for Sutami Reservoir. In that research, [6] explained that evaluating the water quality status of Sutami Reservoir with the four methods showed light pollution.

Based on the above problem, it becomes necessary to conduct a further study to determine the water quality values or status of Selorejo Reservoir. The objective of this research is to find out the water quality status of Selorejo Reservoir using the DOE-WQI, Pollution Index, DWQI (Dinius Water Quality Index), Ved Prakash Index, and Prati Index methods; to find out the distribution of characteristics of water quality status using the IDW (Inverse Distance Weighted) method, and to find out the magnitude of water pollution carrying capacity of Selorejo Reservoir using the Total-P parameter. After finding out the carrying capacity, it then becomes possible to determine the maximum limiting value for the pollution load that Selorejo Reservoir can accommodate.

2. Materials and Methods

2.1. Materials

2.1.1. Study Location

Selorejo Reservoir is a reservoir located in Pandansari Village, Ngantang Sub-District, at the foot of Mount Kelud, at a distance from the main road of approximately 3 km. Selorejo Reservoir is located within the coordinates of 7° 50'- 7° 53' South Latitude and 112° 18' - 112° 2' East Longitude at a height of 650 m above sea level. Selorejo Reservoir functions as a tourist site, fish farming, agricultural irrigation, and a source of hydropower. Selorejo Reservoir utilizes water from springs in the Argowayan Mountains and Anjasmoro Mountains and receives water from the Pinjal, Kwayangan, and Konto Rivers. Konto River is a water supplier for Selorejo Reservoir for hydropower and irrigation. Selorejo Reservoir has several stations for monitoring water quality: the monitoring stations at the upstream, middle, and downstream parts. The detailed location of Selorejo Reservoir is shown in Figure 1.

2.1.2. Research Data

The composition of this research required several sets of data that were obtained from relevant places. The data comprised the following:

1. Data on rainfall for the Selorejo Reservoir for 2012-2021 from the Department of Public Works and Natural Resources of Malang Regency. The required rainfall data cover the rain stations of Pujon, Ngantang, Sekar, Kedungrejo, and Jombok.
2. Data on water quality variables BOD, DO, COD, NO_3-N, NH_3-N, pH, PO_4, TSS, and Fecal Coliform for Selorejo Reservoir from July-October from 2016 to 2021. Water parameters were collected by taking samples at the following observation points:
   - Upstream Observation Point at depths of 0.3 m and 5 m
   - Middle Observation Point at depths of 0.3 m, 5 m, and 10 m
   - Downstream Observation Point at depths of 0.3 m, 5 m, and 10 m.
3. Data on Total-P parameter, reservoir volume, and outflow discharge during the dry season of 2021
4. Data of DEM for Malang Regency
5. Coordinate Map of Observation Points of Selorejo Reservoir (Secondary Data)
   This map is required to determine the distribution of the location points from where samples were taken. This map was obtained from PJT 1.

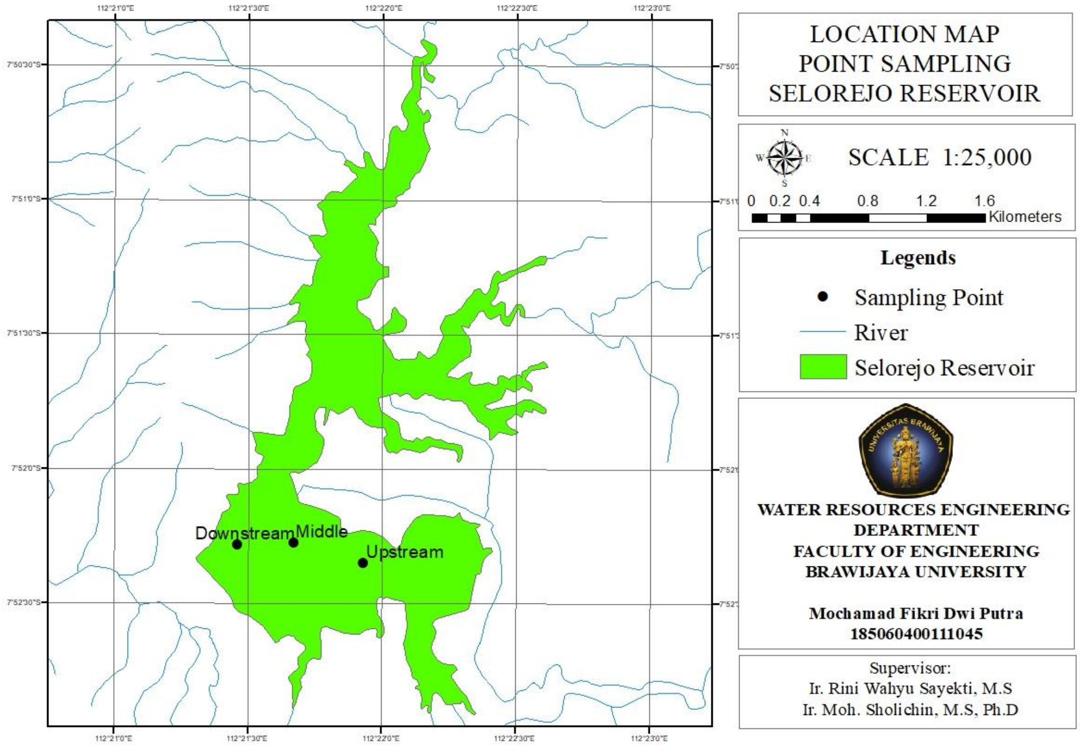

Figure 1. Location of Selorejo Reservoir Based on Observation Points

2.2. Method

The research method began by testing rainfall data by data consistency testing, absence of trends testing, F-test, T-test, arithmetic mean evaluation, and Schmidt and Ferguson classification. Next, water quality status was analyzed using the methods of DOE-WQI, Pollution Index, DWQI, Ved Prakash Index, and Prati Index. After analyzing the water quality data, a distribution map was created with the ArcMap 10.6 application with the IDW (Inverse Distance Weighted) method. The limit for the pollution load may be known by evaluating the trophic status of Selorejo Reservoir. The trophic status of Selorejo Reservoir was determined based on the Total-P parameter for the fry months. Next, the carrying capacity for the pollution load of Selorejo Reservoir was evaluated.

The following were the utilized methods to analyze water quality:

1. DOE-WQI (DOE Water Quality Index) Method
   The DOE-WQI method was developed by the Department of the Environment of Malaysia with the usage of the parameters of BOD, COD, DO, SS, AN, and pH [7]. This method can transform water quality data into a single value that illustrates the overall water quality with a score between 0 and 100. The following is the equation for the DOE-WQI method.

   $$WQI = (0.22 \times \text{SI DO}) + (0.19 \times \text{SI BOD}) + (0.16 \times \text{SI COD}) + (0.15 \times \text{SI AN}) + (0.16 \times \text{SI TSS}) + (0.12 \times \text{SI pH}) \quad (1)$$

   Remarks: WQI = DOE-WQI Index Value; SI = Sub-index of each parameter

2. Pollution Index Method
   This method is used to determine the water quality status in Indonesia based on the permitted water quality standard [1]. The following is the equation for the Pollution Index method.

   $$\text{PIj} = \text{m} \sqrt{PIJ^2{}_R + \left(\frac{Ci}{Lij}\right)^2_M} \quad (2)$$

   Remarks: m = Balancing factor; PIj_R = Mean Pollution Index value; $(Ci/Lij)_M$ = Maximum Ci / Lij value.

3. DWQI (Dinius Water Quality Index) Method
   This method involves the evaluation of the weighted value of the sub-index. The DWQI (Dinius Water Quality Index) method covers 12 pollutants, which are dissolved oxygen (DO), BOD, coliform, E coli, pH, alkalinity, hardness, chloride, specific conductivity, temperature, color, and nitrates for six categories of water as water for public use, supply, recreation, fish, shellfish, agriculture, and industry [3]. The following is the equation for the DWQI method.

   $$DWQI = \sum_{i=1}^{n} wi\ Ii \quad (3)$$

   Remarks: *DWQI* = Dinius Water Quality Index; *Ii* = Sub-index function of the variable of each parameter; *wi* = Weight unit of each parameter; *N* = Number of parameters.
4. Ved Prakash Index Method
   This method was first developed to evaluate the water of the Ganges River and to identify the range for which the gap between what is desired and the existing water quality is sufficiently significant to ensure urgent actions for pollution control. The index calculation is based on NSF-WQI, with slight weight modification to confirm the water quality criteria [3]. The following is the equation for the Ved Prakash Index method.

   $$\sum_{i=1}^{P} wi\ Ii \quad (4)$$

   Remarks: *Ii* = Sub-index function of the variable of each parameter; *wi* = Weight unit of each parameter; *p* = Number of parameters.
5. Prati Index Method
   Prati [8], who comes from Italy, discovered the Prati Index method. The Prati Index uses 13 pollution parameters that are classified into five water quality classes (good, acceptable, lightly polluted, moderately polluted, and heavily polluted. The following is the equation for the Prati Index method.

   $$I = \frac{1}{n} \sum_{i=1}^{n} Ii \quad (5)$$

   Remarks: I = *Prati Index;* i = Sub-index of each parameter.

3. Results and Discussion

3.1. Hydrologic Analysis

3.1.1 Consistency Testing

The utilized method was the double mass curve method. Double mass curve analysis tests data consistency by comparing the total cumulative annual rainfall at the primary station with the alternative rain station [9]. After correction at the Selorejo Reservoir catchment area in Ngantang, Pujon, Sekar, Kedungrejo, and Jombok, the double mass curve method evaluation results showed the annual rainfall data.

3.1.2 Absence of Trends Testing

The absence of trend testing has the objective to check for the presence of many variants. For this research, the implemented method was the Mann and Whitney test. The correlation coefficient was determined from the following equation.

$$Z = \frac{U - \left(\frac{N1\ x\ N2}{2}\right)}{\frac{1}{12}\left(N1\ x\ N2\ (N1 + N2 + 1)\right)^{1/2}} \quad (6)$$

The data hypothesis was based on a 5% level of confidence tested on two sides, as ±1.96. If Z count < Z table, then the data may be used, but if Z count > Z table, the data needs to be rechecked.

Because the calculation results were -1.671 < 1.96, the data was considered homogenous (no trends were present). The results of an absence of trend testing are shown in Table 1.

3.1.3 F-Test

The F-test was performed by grouping rainfall data into two sets for each station. The test of variance stability utilized the following equation.

$$F = \frac{n1.s1^2\ (n2-1)}{n2.s2^2\ (n1-1)} \quad (7)$$

The hypothesis was based on α = 5% tested on two sides; thus, the value of F table = 6.39. If F count < F table, the hypothesis is accepted; if F count > F table, the hypothesis is rejected. Because 0.26 < 6.39, the data had a stable variance. Based on the calculations, the results of variance stability testing were obtained, as shown in Table 1.

3.1.4 T-Test

The principle of the T-test involved the separation of annual rainfall data into two sets at each station. The test utilized the following equation.

$$t = = \left(\frac{ABS\ (X1 - X2)}{\alpha \left(\frac{1}{5} + \frac{1}{5}\right)^{0,5}} \right) \quad (8)$$

The data hypothesis was based on α = 0.025 on two sides; thus, the t table value = 2.306. An evaluation was performed by comparing the t count and t table values. If t count < t permitted, then the data may be used. Should t count > t permitted, the data must be reconsidered. Because 1.01 < 2.306, the rainfall data was thus uniform (stationary). The following are the results of the mean stability, which are shown in Table 1.

Table 1. Summary of Trend Absence Test, F-Test, and T-Test for Five Stations

Rain Station	Test		
	Mann-Whitney	F-Test	T-Test
Ngantang	Homogenous	Homogenous	Homogenous
Pujon	Homogenous	Homogenous	Homogenous
Sekar	Homogenous	Homogenous	Homogenous
Kedungrejo	Homogenous	Homogenous	Homogenous
Jombok	Homogenous	Homogenous	Homogenous

3.1.5 Mean Arithmetic Evaluation

Arithmetic mean evaluation involves a method that calculates the mean rainfall height based on the mean value of a rainfall station measurement in a certain area. This method is perfectly suited to be used for the area of Selorejo Reservoir since the area of Konto watershed < 250 Ha, the rainfall is uniform, and there are many rainfall measurement posts in the area of Selorejo Reservoir. Evaluation of the rainfall used equation 9.

$$\text{Mean Rainfall} = \frac{\sum CH}{n} \quad (9)$$

3.1.6 System for Determining Seasonal Division

The data on parameters were taken from the dry season. It is because the research focuses on the reservoir water in its initial neutral condition, without being fouled by rainwater runoff or other variables. According to Schmidt and Ferguson, if the mean rainfall value is> 100 mm/month, then the month is wet, and if the mean rainfall value is < 100 mm/month, then the month is dry [10]. The results of the classification of wet and dry months for Selorejo Reservoir are shown in Table 2.

Table 2. Determining the Division of Wet Months and Dry Months According to the BMKG for the Area of Selorejo Reservoir

	Month											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
2012	566	466	349	172	63.4	16.4	0.2	0	0.6	69.6	261	407
2013	915	508	353	414	204	246	124	0.4	0	87.4	345	640
2014	637	631	307	193	86.6	23.8	45.2	11	0	0	250	595
2015	175	416	450	303	129	42.4	0.4	0	4.6	1	133	423
2016	395	567	475	160	208	246	119	64	132	225	309	347
2017	571	339	452	300	224	95.2	44.8	6.8	24.2	91.2	412	390
2018	870	597	335	141	69	46	2	2	9.2	16.4	214	349
2019	593	477	482	326	75.2	2	2	2	3	32.2	132	345
2020	452	850	538	349	243	64.6	24.4	26.6	31	171	367	696
2021	1026	1042	401	274	48.4	242	17	52.6	111	92.8	758	362
Max	1026	1042	538	414	243	246	124	64.0	132	225	758	696
Min	175	339	307	141	48.4	2	0.2	0	0	0	132	345
Mean	620	589	414	263	135	102	37.8	16.5	31.5	78.6	318	455
Total	6199	5893	4142	2633	1351	1023	378	165	315	786	3180	4553
Remarks	W	W	W	W	W	W	D	D	D	D	W	W

Remarks: W = Wet month; D = Dry month

Table 2 shows that in July-October, the mean regional monthly rainfall values from 2012-2021 are less than 100 mm/month and are thus considered dry months.

3.2. Analysis of Water Quality Data

3.2.1 Testing of Water Quality Data

The F-test is an evaluation method useful in the variance analysis of data from various sources. The summary of the results of testing the water quality data is indicated in Table 3.

Table 3. Summary of F-Test on Water Quality Data of Three Depths

Monitoring Station	Parameter	Evaluation
Selorejo Reservoir Depths I, II, III	BOD	Homogenous
	DO	Homogenous
	COD	Homogenous
	NO_3-N	Homogenous
	NH_3-N	Homogenous
	pH	Homogenous
	PO_4	Homogenous
	TSS	Homogenous
	Fecal Coliform	Homogenous

3.2.2 Determination of Water Quality Status

Below are the results of determining the water quality status obtained from several evaluation methods for Selorejo Reservoir, as indicated in Table 4.

Table 4. Summary of Pollution Status for Selorejo Reservoir Using the Water Quality Index Methods

Observation Points of Selorejo Reservoir	DOE-WQI		Pollution Index		DWQI		Ved Prakash Index		Prati Index	
	%	Status	%	Status	%	Status	%	Status	%	Status
Upstream, Depth 0.3 m	92%	TR	96%	TR	67%	SB	50%	B	100%	TR
Upstream, Depth 5 m	88%	TR	96%	TR	58%	SB	29%	BR	100%	TR
Middle, Depth 0.3 m	100%	TR	965	TR	71%	SB	54%	B	100%	TR
Middle, Depth 5 m	100%	TR	100%	TR	50%	SB	17%	BR	100%	TR
Middle, Depth 10 m	92%	TR	96%	TR	42%	S	25%	BR	100%	TR
Downstream, Depth 0.3 m	100%	TR	100%	TR	46%	S	75%	B	100%	TR
Downstream, Depth 5 m	100%	TR	96%	TR	42%	S	38%	BR	100%	TR
Downstream, Depth 10 m	100%	TR	100%	TR	42%	B	25%	BR	100%	TR

Remarks: TR: Lightly Polluted; B: Good; BR: Poor; SB : Excellent

This research involved the determination of water quality status using the five methods of DOE-WQI, Pollution Index, DWQI, Ved Prakash Index, and Prati Index. These five methods have equal application to determine the level of pollution and water quality, but in principle possess different systems and references from one another. The DOE-WQI method used the six parameters of BOD, DO, COD, pH, TSS, and NH_3-N. The Pollution Index method used the nine parameters of BOD, DO, COD, NO_3-N, NH_3-N, pH, PO_4, TSS, and Fecal Coliform. The DWQI method used the five key parameters: DO, BOD, Fecal Coliform, NO_3-N, and pH. The Ved Prakash Index used the key parameters of DO, BOD, pH, and Fecal Coliform. Finally, the Prati Index method used the seven parameters of BOD, DO, COD, NO_3-N, NH_3-N, pH, and TSS.

Based on the five applied methods, it can be seen that the water pollution characteristics of Selorejo Reservoir at the Upstream Observation Point (Depths 0.3 m and 5 m), Middle Observation Point (Depths 0.3 m, 5 m, and 10 m), and Downstream Observation Point (Depths 0.3 m, 5 m, and 10 m) showed nearly similar results, in that most methods showed a lightly polluted water quality condition. However, the water quality status results showed a slight difference, as indicated by the DWQI method, which resulted in a mostly Good water quality status.

The above situation is because the performed evaluation for this method very much considers and considers the pH value. As an example, the calculation for observation points of Selorejo Reservoir for July 2021 with a pH value of 7.4 used the sub-index with the formula for pH > 7.1, as $10^{(3.65-0.2216pH))}$, which after the input resulted in a value of 102.37. Considering the evaluation criteria for the DWQI method, this falls into a very good condition. In addition, differences in the used water quality parameters may also have affected the results of evaluating water pollution with DWQI, becoming Excellent. For example, the DWQI method did not use the parameters of COD, NH_3, and PO_4.

3.2.3 Distribution Mapping for the Water Quality of Selorejo Reservoir

Below are the resulting maps for the distribution of water quality characteristics of Selorejo Reservoir using the five methods. The distribution maps are shown in Figures 2-6.

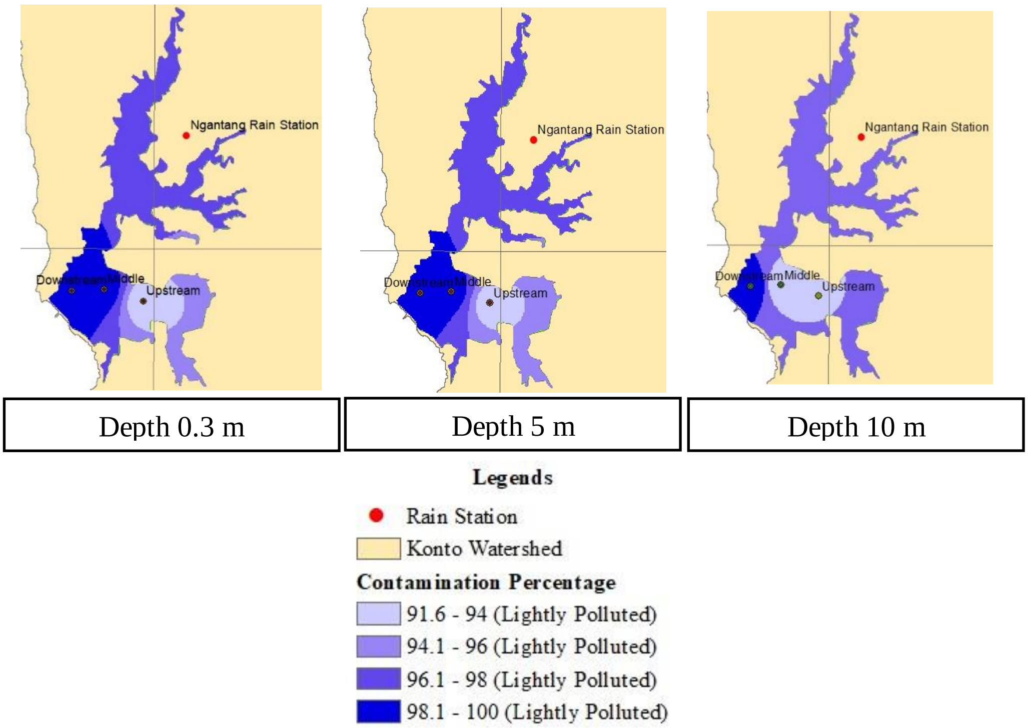

Figure 2. Map of Water Quality Distribution Using the DOE-WQI Method

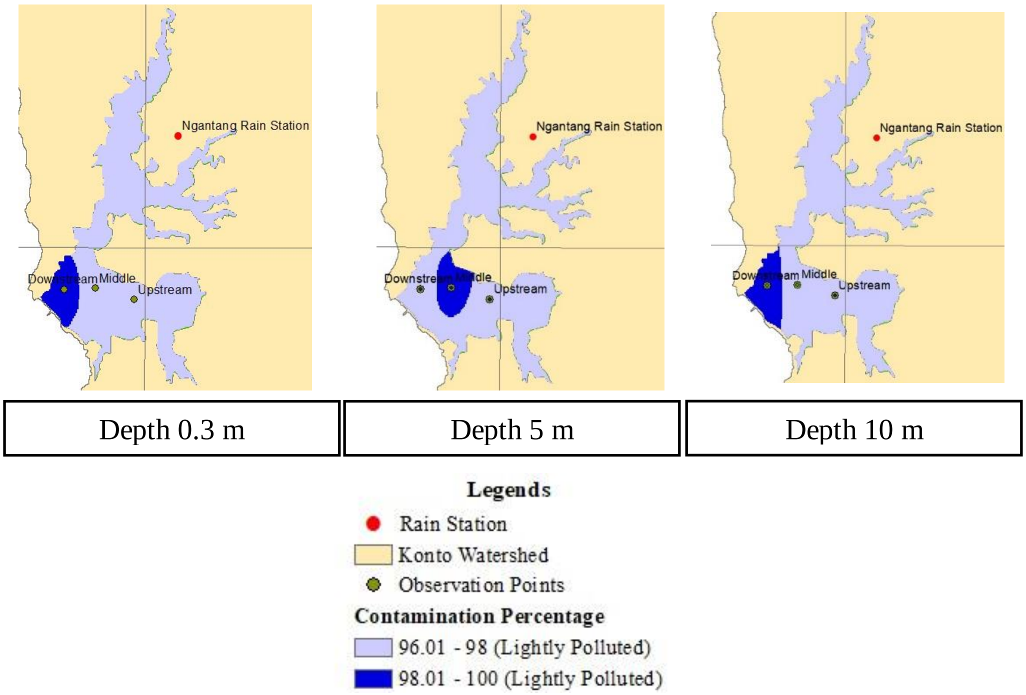

Figure 3. Map of Water Quality Distribution Using the Pollution Index Method

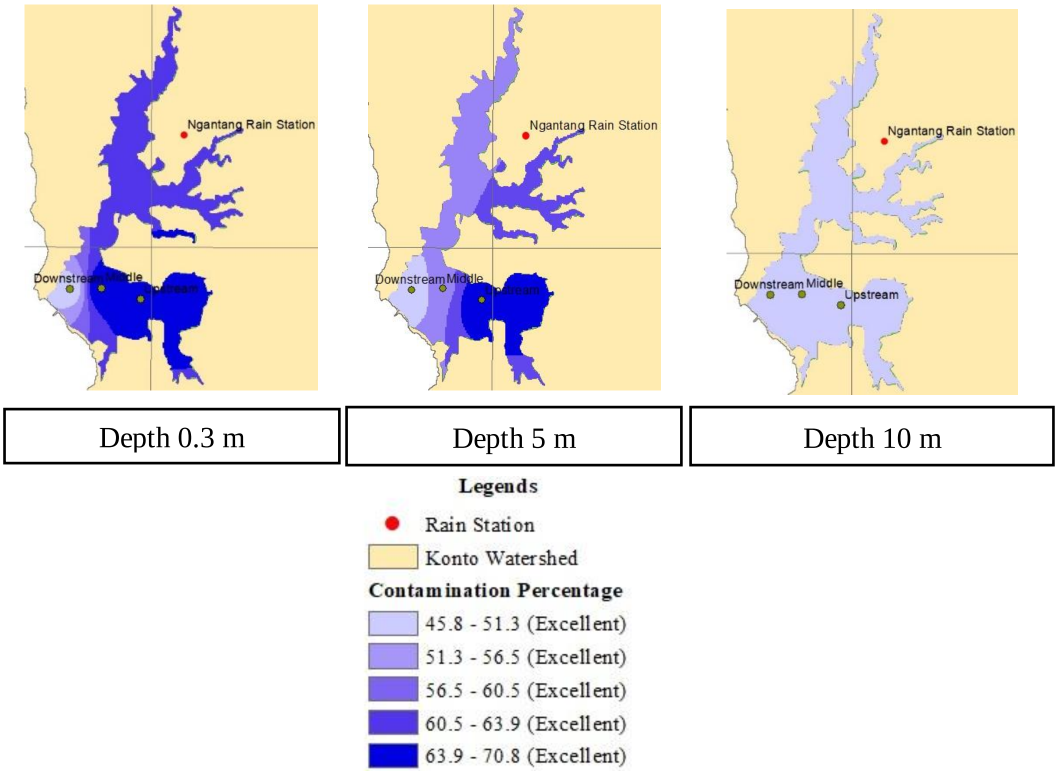

Figure 4. Map of Water Quality Distribution Using the DWQI Method

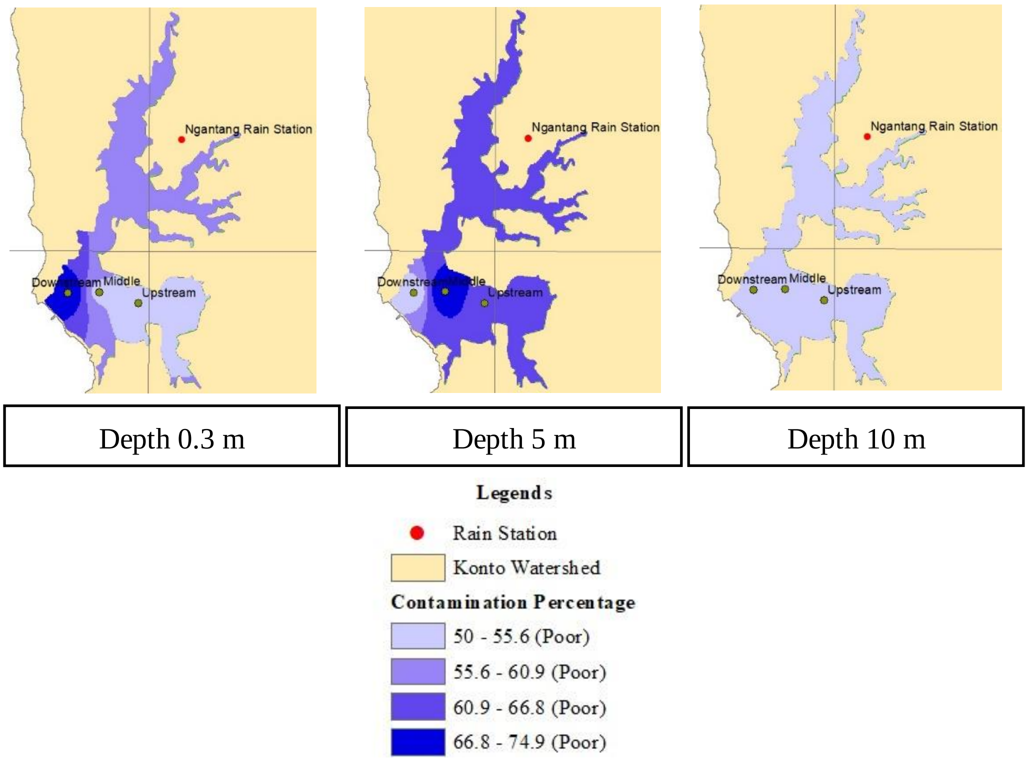

Figure 5. Map of Water Quality Distribution Using the Ved Prakash Index Method

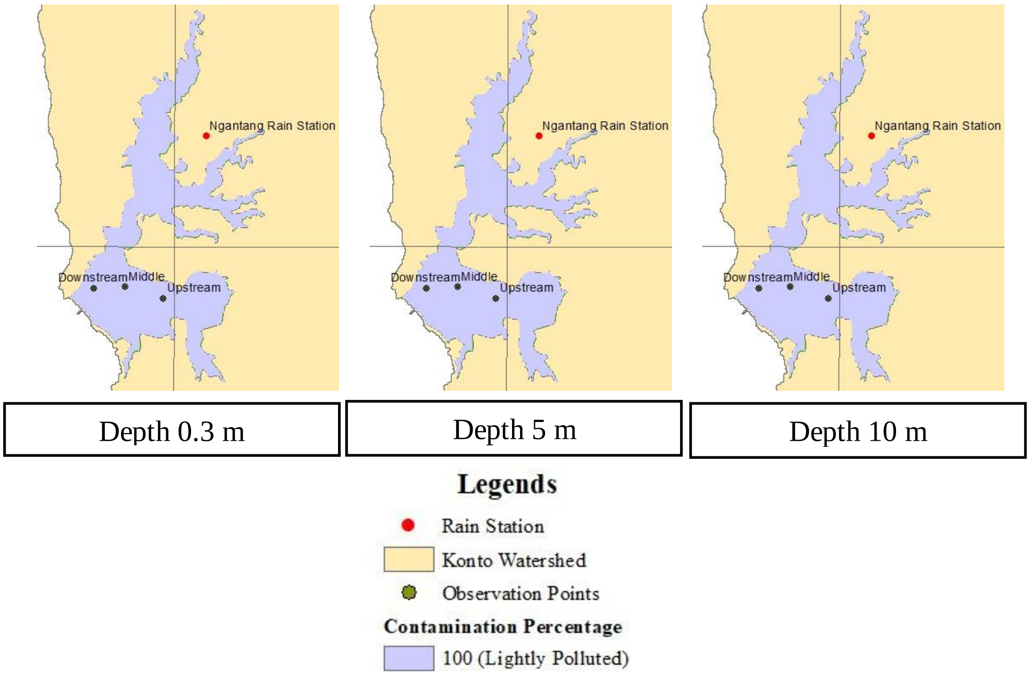

Figure 6. Map of Water Quality Distribution Using the Prati Index Method

3.3. Analysis of Water Quality Data

3.3.1 Determination of Pollution Load Carrying Capacity for 2021

Below is the summary of the results of analyzing the pollution load of Selorejo Reservoir for the dry months of 2021 with the eutrophic status.

Table 5. Summary of Pollution Load Carrying Capacity for Selorejo Reservoir

No.	Points	CC for 2021 with the Eutrophic Status	
		(kg/P/dry season)	(mg/m^3)
1.	Selorejo Reservoir, Upstream	762,712.17	71.77
2.	Selorejo Reservoir, Middle	851,656.59	80.14
3.	Selorejo Reservoir, Downstream	827,790.76	77.9

After obtaining the value for the pollution load carrying capacity for Selorejo Reservoir, this was compared to the pollutant load value Total-P. The resulting mean of the Total-P load contained upstream of Selorejo Reservoir in the dry season of 2021 was 42.475 mg/m^3; compared to the upstream pollution load carrying capacity value of 71.77 mg/m^3, this indicates that the Total-P content is still within the maximum limit of phosphorus pollutant intake. It was also true for Selorejo Reservoir in the middle and downstream in the dry season of 2021, for which the Total-P content had values of 35.77 mg/m^3 and 37.57 mg/m^3. Therefore, it is still within the maximum capacity of Selorejo Reservoir, which can contain up to 80.14 mg/m^3 and 77.9 $mg/m^{3,}$ respectively.

4. Conclusion

Based on the results of calculations with various methods, it is shown that the water quality status condition of Selorejo Reservoir for the dry season of 2016-2021 has results of 88-100% lightly polluted with DOE-WQI, 96-100% lightly polluted with Pollution Index, 42-71% excellent with DWQI, 17-75% poor with Ved Prakash Index, and 100% lightly polluted with Prati Index. The DWQI method led to different results because of the differences in sub-index calculations and the used parameters. It may be concluded that from the five methods of testing the water quality status of Selorejo for six years, the results are lightly polluted. However, fundamentally, the five methods cannot be compared with each other because they possess calculation formulas, evaluation class categories, and parameter selections that are different from one another. Through evaluation of distribution with the IDW method for the methods of DOE-WQI, Pollution Index, Ved Prakash Index, and Prati Index, it is found that the interpolated IDW values at each depth are sufficiently similar. Considering the resulting interpolation map for the four methods, it can be seen that in the upstream direction, the percentage of pollution becomes larger.

Meanwhile, for the DWQI method, the interpolated IDW values appear to have few differences at each depth. Furthermore, with the DWQI method, the percentage of pollution becomes smaller in the upstream direction. The Total-P content for the dry season 2021 is 42.475 mg/m^3 upstream, 35.767 mg/m^3 in the middle, and 37.567 mg/m^3 downstream. The values for the pollution load carrying capacity of Selorejo Reservoir are 71.77 mg/m^3 in the upstream, 80.14 mg/m^3 in the middle, and 77.9 mg/m^3 in the downstream. By comparing the value of Total-P content with the carrying capacity value, it may be concluded that the Total-P content of Selorejo Reservoir is still within the limits of the pollution load carrying capacity of the reservoir. Thus the Total-P value of Selorejo Reservoir is still in a safe condition.

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