

ANALISIS KAPASITAS BEBAN POLUTAN RUAS HILIR SUNGAI CITARUM MENGGUNAKAN QUAL2KW

ANALYSIS OF POLLUTANT LOAD CAPACITY OF THE CITARUM RIVER DOWNSTREAM SEGMENT USING QUAL2KW

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Abstract. The downstream segment of Citarum River flows from Bendung Curug, Karawang Regency and ends at Muara Gembong, Bekasi Regency. The pollution of downstream segment of Citarum River is caused by settlement, agriculture, farm, and industrial activities that dump their waste into river bodies. This causes a decrease in water quality and reduce the carrying capacity of the downstream segment of Citarum River pollutant. The purpose of this research was to analyze the pollutant load capacity (PLC) in downstream segment of Citarum River using QUAL2Kw model. This research was carried out downstream of Citarum River from segments 16 to 20 which were divided into 9 sections with 11 locations monitoring water quality. Sampling was carried out for 3 periods of observation that the sampling is done twice at each location using grab sampling method. Water quality parameters being modeled are BOD, COD, nitrate, and phosphate. The results of the simulation model of PLC for BOD was 14556.67 kg/day-23456.84 kg/day, COD was 24261.12 kg/day-39094.73 kg/day, nitrate was 24261.12 kg/day-39094.73 kg/day, and phosphate was 485.22 kg/day-781.89 kg/day. Overload of BOD was 0%-26%, COD was 61%-68%, phosphate was 78%-7%. Meanwhile, nitrate load in the Citarum River downstream segment doesn't exceed its pollutant load capacity.

Keywords: Pollution Load Capacity, carrying capacity, Citarum River, Qual2Kw, water quality

INTRODUCTION

The downstream segment of Citarum River starts at Bendung Curug, Karawang Regency and ends at Muara Gembong, Bekasi Regency. Citarum River is included in the category of heavily polluted rivers (KLHK, 2016). Pollution of the river can cause a decrease in water quality. The decline in water quality of Citarum River occurs due to water pollution by industrial and domestic waste discharges that enter the river (KLHK, 2016). Water pollution is the release of all liquids, solids, gases, pathogenic organisms or other substances into the water which will cause the water to be disrupted and become dangerous for the health, safety or welfare of the community and the environment. Water pollution usually comes from human activities such as manufacturing, agriculture, mining, and poor waste management (Masere et al, 2012).

Water pollution occurs when unwanted wastes are spread in the water system so that the water quality changes (Alrumman et al, 2016).

River pollution is defined as a change in the quality of a waters due to human activities, which in turn will disrupt the lives of humans themselves or other living things. These changes can be caused by compounds that enter the river flow that moves downstream along with the water flow or are stored at the bottom, accumulating (especially on sediment) and someday there can also be washing or dilution. These compounds (mainly toxic) accumulate and become a certain concentration which is harmful to the life chain Patricia et al, 2018). Source of river pollution can be classified into point source and non-point source. Point sources refer to sources with discharges entering water bodies in certain locations such as through pipes such as discharges from industry, domestic, and wastewater treatment plants. While non-point sources come from scattered sources such as agricultural activities and runoff water (Afroz et al, 2017).

Pollutant load is the amount of a pollutant contained in water or wastewater. Pollution burden is essentially the amount of pollutant mass in a body of water in a certain period. Pollutant load is expressed in units of pollutant load per unit time (Komarudin, et al, 2015). Pollutant loads entering the downstream segment of Citarum River comes from domestic activities, industry, agriculture, restaurants, hotels, shopping centers, and hospitals. The high load of pollutants entering the river body can reduce the capacity of pollutant load (DTBP) of the river. The purpose of this study is to analyze the pollutant load capacity (PLC) using QUAL2Kw model.

PLC calculation can not be done directly because of the complexity of the factors that influence it, therefore modeling methods are used to simplify this complexity (Komarudin, et al, 2015). The QUAL2Kw model is one method of calculating the pollutant load capacity by making a model in which this model is based on simplifying conditions in the field. (Sara, 2018). QUAL2Kw is a model adapted from the QUAL2K model developed by Dr. Steven C. Chapra from Tufts University (Chapra and Pelletier, 2003). QUAL2Kw is a surface water quality model, one-dimensional, steady state (more specifically a stable flow model because the flow is assumed to be stable but water quality is calculated dynamically with water quality kinetics and heat balance) and implemented in a Microsoft Windows environment (Kannel et al, 2011).

QUAL2Kw can simulate a number of water parameters such as temperature, pH, BOD, COD, dissolved oxygen, organic nitrogen, ammonia nitrogen, nitrite and nitrate nitrogen, organic phosphorus, inorganic phosphorus, total nitrogen, total phosphorus, total phytoplankton and bottom algae (Kannel et al, 2007).

RESEARCH METHOD

Location and Time of Study

This research was conducted in 6 months from February upto July 2019 in downstream segment of Citarum River starting from segment 16 located at Jl. Demang, Karawang Regency upto segment 20 in Muara Gembong, Bekasi Regency. Sampling is done twice at each location using grab sampling method for 3 observation periods (March, April and June 2019) at 11 water quality monitoring points consisting of 10 main river points and 1 tributary point. The parameter analyzed were BOD, COD, nitrate and phosphate.

Table 1. The Monitoring Locations of The Water Quality

Point	Location of Monitoring	Coordinate Point	
		EL	SL
1	Jl. Demang, Karawang	107°22'06,8"	6°24'44,6"
2	Jl. Rumambe I, Karawang	107°19'28,3"	6°21'45,1"
3	Jembatan Teluk Jambe, Karawang	107°18'43,3"	6°19'36,8"
4	Jembatan Tarumanagara, Karawang	107°17'16,4"	6°17'54,7"
A	Labansari, Cikarang Timur, Bekasi (<i>point source</i>)	107°15'54,1"	6°16'56,2"
5	Jl. Raya Proklamasi, Karawang	107°16'34,7"	6°14'57,0"
6	Jl. Raya Pebayuran, Bekasi	107°16'21,4"	6°13'10,9"
7	Jl. Raya Tugu Proklamasi, Rengasdengklok, Karawang	107°17'14,1"	6°09'24,9"
8	Jl. Teluk Bango, Karawang	107°12'31,7"	6°05'52,1"
9	Jl. Raya Pakisjaya, Karawang	107°07'22,3"	6°02'50,2"
10	Muara Gembong, Bekasi	107°02'38,7"	5°59'04,5"

Pollutant Load Capacity Analysis

Analysis of pollutant load capacity in downstream segment of Citarum River was carried out using the QUAL2Kw model developed by Dr. Steven C. Chapra. Water quality modeling of downstream segment of Citarum River is divided into 9 reach from the point of 108.5 km at Jl. Demang, Karawang to the point of 0 km in Muara Gembong, Bekasi Regency. The distribution of reach is based on the physical condition of the river, the presence of pollutant sources both point source and non-point source that is suspected to have a major impact on changes in the quality and quantity of the downstream segment of the Citarum River can be seen in **Table 2**.

In this modeling, the shape of the downstream segment of Citarum River is considered square, the water quality parameters being modeled are BOD, COD, nitrate, and phosphate, input hydrological data comes from field measurements, input meteorological data, input the concentration of point source pollutant from tributaries, activities industry, hotel, shopping center, restaurant, and hospital sourced from the Environmental Agency, input the concentration of non-point source pollutants originate from agriculture and domestic waste of residents in Citarum watershed, water quality monitoring data in March, April and June 2019 are used as data for model verification. Model verification is done by calculating the percentage deviation of the simulation results with the results of field monitoring. Determination of the percentage of permissible deviations is 20% with a confidence level of the model of 80%.

Furthermore, the amount of the pollutant load capacity of the downstream segment of Citarum River is obtained by multiplying the flow rate of each segment by the water quality standard according to its designation. Meanwhile, the amount of pollutant load is obtained through the multiplication of river flow discharges with pollutant concentrations at each water quality monitoring location.

Table 2. Distribution of Reach in Downstream Segment of Citarum River

No .	Reach Name		Reach Length (Km)	Location of Reach (Km)	Elevation (usl)		Downstream Coordinate					
	Upstream	Downstream			Up-stream (m)	Down-stream (m)	SL			EL		
	Initial Reach	Final Reach					°	'	“	°	'	“
0		Headwater		108,5		20	6	24	44,6	107	22	6,8
1	Headwater	Jl. Rumambe	13,9	94,6	20	19	6	21	45,	107	19	28,

No .	Reach Name		Reach Length (Km)	Location of Reach (Km)	Elevation (usl)		Downstream Coordinate					
	Upstream	Downstream			Up-stream	Down-stream	SL			EL		
	Initial Reach	Final Reach			(m)	(m)	°	'	“	°	'	“
		I, Karawang							1			3
2	Jl. Rumambe I, Karawang	Jembatan Teluk Jambe	5,6	84,0	19	18	6	19	36,8	107	18	43,3
3	Jembatan Teluk Jambe	Jembatan Tarumanagara	10,6	74,8	18	16	6	17	54,7	107	17	16,4
4	Jembatan Tarumanagara	Jl. Raya Proklamasi, Karawang	9,2	69,2	16	13	6	14	57	107	16	34,7
5	Jl. Raya Proklamasi, Karawang	Jl. Raya Pebayuran, Bekasi	5,6	57,6	13	12	6	13	10,9	107	16	21,4
6	Jl. Raya Pebayuran, Bekasi	Jl. Raya Tugu Proklamasi, Karawang	11,6	39,3	12	11	6	9	24,9	107	17	14,1
7	Jl. Raya Tugu Proklamasi, Karawang	Jl. Teluk Bango, Karawang	18,3	22,9	11	7	6	5	52,1	107	12	31,7
8	Jl. Teluk Bango, Karawang	Jl. Raya Pakisjaya, Karawang	16,4	5,6	7	4	6	2	50,2	107	7	22,3
9	Jl. Raya Pakisjaya, Karawang	Muara Gembong, Bekasi	17,3	0	4	1	5	59	4,5	107	2	38,7

RESULTS AND DISCUSSION

Pollutant Load of Point Source

Point source pollutants in the downstream segment of Citarum River comes from tributaries, industrial activities, offices, shopping centers, hotels, hospitals and hospitals. Calculation of point source pollutant load can be seen in **Table 3**.

Table 3. Pollutant Load of Point Source

Reach	Location		Pollutant Load (kg/day)			
			BOD	COD	Nitrate	Phosphate
1	Jl. Demang, Karawang	Jl. Rumambe I, Karawang	3800.02	9899.54	0.11	1.80
2	Jl. Rumambe I, Karawang	Jembatan Teluk Jambe, Karawang	1027.97	4437.45	0.30	5.16
3	Jembatan Teluk Jambe, Karawang	Jembatan Tarumanagara, Karawang	565.32	800.94	0.11	1.91
4	Jembatan Tarumanagara, Karawang	Jl. Raya Proklamasi, Karawang	15317.74	81650.79	0.03	0.49
5	Jl. Raya Proklamasi, Karawang	Jl. Raya Pebayuran, Bekasi	0.46	0.54	0.001	0.01
6	Jl. Raya Pebayuran, Bekasi	Jl. Raya Tugu Proklamasi, Rengas dengklok, Karawang	1.50	2.60	0.001	0.02
7	Jl. Raya Tugu Proklamasi, Rengasdengklok, Karawang	Jl. Teluk Bango, Karawang	-	-	-	-
8	Jl. Teluk Bango, Karawang	Jl. Raya Pakisjaya, Karawang	-	-	-	-
9	Jl. Raya Pakisjaya, Karawang	Muara Gembong, Bekasi	-	-	-	-

Based on **Table 3.**, the highest pollutant load of point source was in reach 4, because in addition to the pollutant load originate from industrial activities, offices and hospitals, there is also a tributary (Cibeet River) which greatly contributes to the increase pollutant load of point source in that reach.

Pollutant Load of Non-Point Source

Pollutant load of non-point source in downstream segment of Citarum River comes from domestic activities and agricultural activities in watershed. Calculation of pollutant load of non-point source can be seen in **Table 4**.

Table 4. Pollutant Load of Non-Point Source

Reach	Parameter	Pollutant Load (kg/day)		
		Domestic	Agriculture	Total
1	BOD	6412.92	3.30	6416.22
	COD	8817.76	4.95	8822.71
	Total N	-	3.67	3.67
	Nitrat	1.60	-	1.60
	Fosfat	27.25	1.83	29.09
2	BOD	5671.72	2.76	5674.48
	COD	7798.62	4.13	7802.75
	Total N	-	3.06	3.06
	Nitrat	1.42	-	1.42
	Fosfat	24.10	1.53	25.64
3	BOD	5288.39	3.42	5291.81
	COD	7271.53	5.13	7276.66
	Total N	-	3.80	3.8
	Nitrat	1.32	-	1.32
	Fosfat	22.48	1.90	24.38
4	BOD	8318.21	3.79	8322.00
	COD	11437.54	5.68	11443.22
	Total N	-	4.21	4.21
	Nitrat	2.08	-	2.08
	Fosfat	35.35	2.11	37.46
5	BOD	2699.56	2.11	2701.67
	COD	3711.90	3.17	3715.06
	Total N	-	2.34	2.34
	Nitrat	0.67	-	0.67
	Fosfat	11.47	1.17	12.65
6	BOD	5160.50	2.15	5162.65
	COD	7095.68	3.23	7098.91
	Total N	-	2.39	2.39
	Nitrat	1.29	-	1.29
	Fosfat	21.93	1.19	23.13

Reach	Parameter	Pollutant Load (kg/day)		
		Domestic	Agriculture	Total
7	BOD	4266.52	4.00	4270.52
	COD	5866.46	6.00	5872.46
	Total N	-	4.44	4.44
	Nitrat	1.07	-	1.07
	Fosfat	18.13	2.22	20.36
8	BOD	6004.28	4.67	6008.94
	COD	8255.88	7.00	8262.88
	Total N	-	5.19	5.19
	Nitrat	1.50	-	1.50
	Fosfat	25.52	2.59	28.11
9	BOD	5893.37	4.43	5897.80
	COD	8103.38	6.65	8110.03
	Total N	-	4.92	4.92
	Nitrat	1.47	-	1.47
	Fosfat	25.05	2.46	27.51

Based on **Table 4**, the highest pollutant load of non-point source comes from domestic in watershed. The largest pollutant load of non-point source was in reach 4, because in that reach the population density is quite high compared to other reach and there was also a large enough agricultural land so that runoff that is generated can increase the burden of pollutants entering the river.

The results of Existing Condition simulation using QUAL2Kw

Model simulations are carried out to represent the actual river conditions. The model that has been run will produce a simulation graph of the parameters modeled from the downstream segment of Citarum River.

Based on **Figure 1**, it can be seen that the results of simulation models for BOD almost all approach the results of analysis. Model simulation results show that BOD concentrations almost entirely exceed quality standards according to KEPGUB West Java No. 39 of 2000 for class B, C, D. The simulation results of the model are influenced by the increase in debit and levels of pollutants entering downstream segment of Citarum River. The high BOD concentration in the downstream segment of Citarum River is caused by domestic activities that dump waste directly into river

bodies. Industrial activities around the river also contribute to increasing the BOD level in the river.

Large industries located in the upstream and downstream of Citarum watershed in the form of the textile industry, the food processing industry, and the footwear/shoes manufacturing industry act as contributors to waste in Citarum River sub-watershed. In addition, micro and small business activities also increase the burden of waste entering Citarum River bodies (Kusuma et al, 2018). A high BOD value indicates a decrease in DO value because the oxygen available in the water is being consumed by bacteria, causing fish and other aquatic organisms to be unable to survive in the river (Pathak and Limaye, 2011).

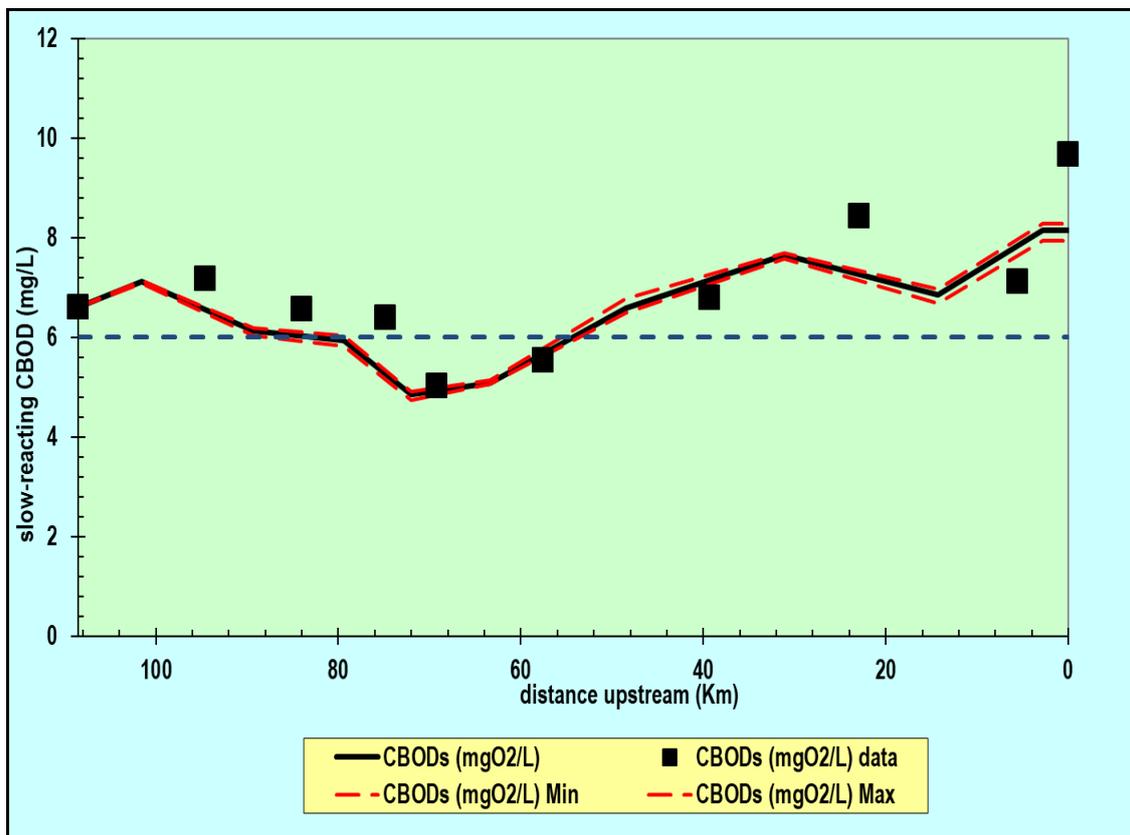


Figure 1. The results of BOD Model Simulation in Downstream Segment of Citarum River

Model simulation results and analysis data for COD can be seen in **Figure 2**. COD concentration both model simulation results and the results of analysis data have

far exceeded the quality standard based on KEPGUB West Java No. 39 of 2000 for classes B, C, D which is 10 mg/L. Similar to BOD, high levels of COD are also caused by waste originate from domestic and industrial activities in watershed. The COD reflects the amount of chemically oxidized organic compound or the amount of oxygen needed to oxidize organic substances to CO₂ and H₂O. Certain organic materials present in wastewater are immune to biological degradation and some are toxic even at low concentrations. COD levels in wastewater will decrease along with the reduction in the concentration of organic matter contained in wastewater (Metcalf and Eddy, 2003).

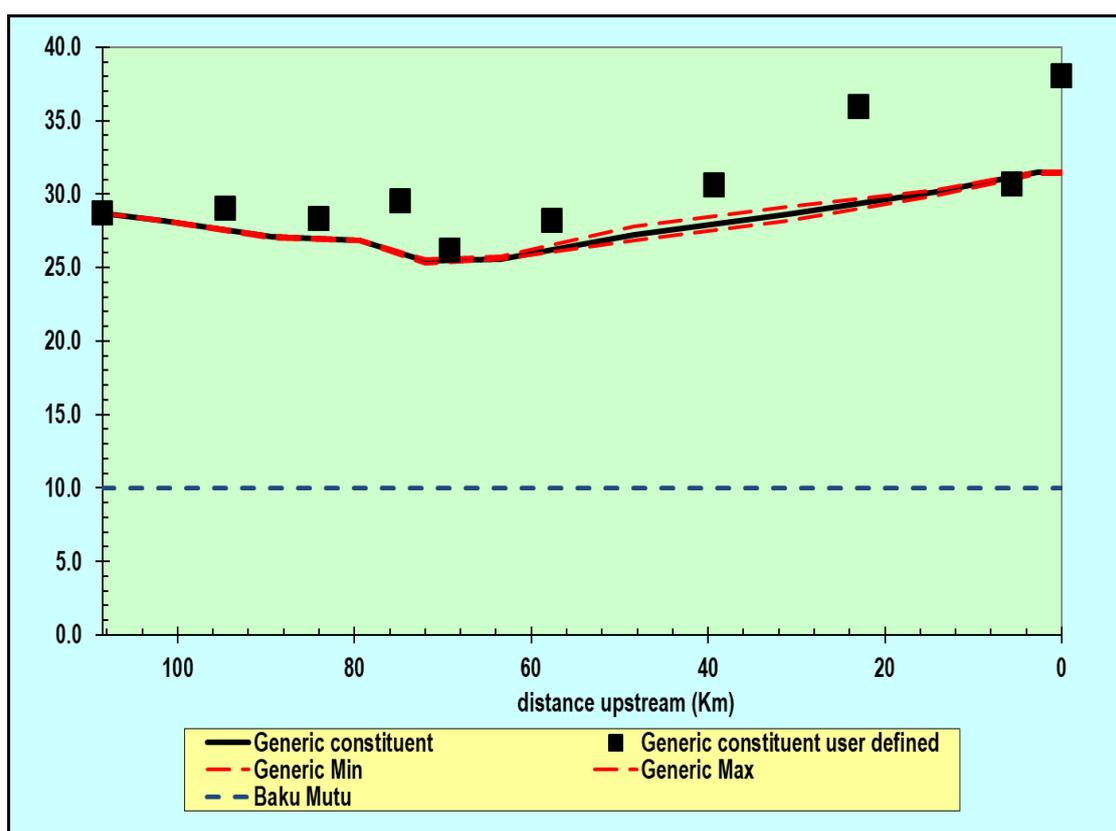


Figure 2. The results of COD Model Simulation in Downstream Segment of Citarum River

Based on **Figure 3**, it can be seen that the results of the nitrate model simulation have approached the analysis data. Both the model simulation results and analysis data results of nitrate concentrations in downstream segment of Citarum River were still below the quality standard according to KEPGUB West Java No. 39 of 2000 for classes B, C, D (10 mg/L). Sources of nitrate pollutants in downstream segment of Citarum

River comes from agricultural activities, the use of fertilizers, and settlement activities. Nitrates derived from ammonium that enter the river body mainly through domestic waste concentrations in the river will decrease when getting further from the point of disposal due to the activity of microorganisms in the water for example bacteria nitrosumonas (Mustofa, 2015). Nitrate-nitrogen levels in natural waters are almost never more than 0.1 mg/L, but if nitrate levels are greater than 0.2 mg/L will lead to eutrophication which further stimulates the growth of algae and aquatic plants rapidly (Effendi, 2003).

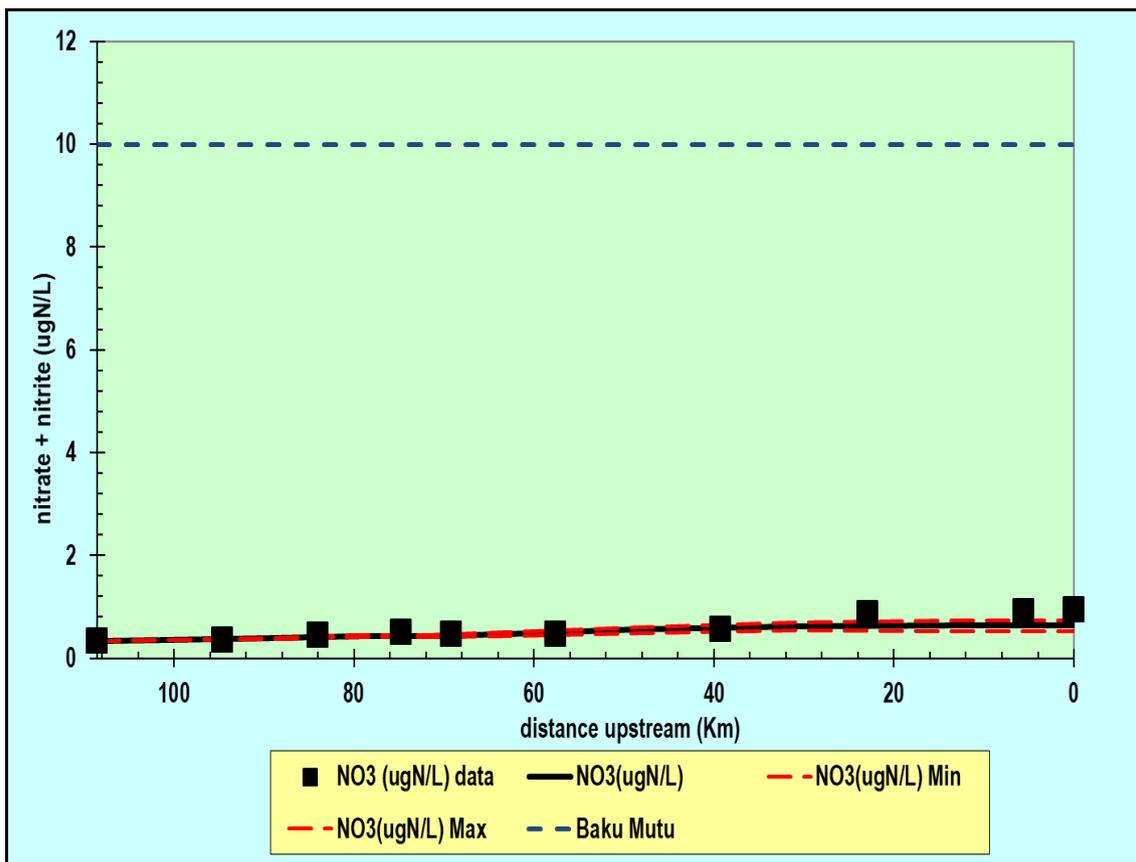


Figure 3. The results of Nitrate Model Simulation in Downstream Segment of Citarum River

Based on **Figure 4.**, the results of the phosphate model simulation almost all approach the analysis data. The model simulation results and analysis results of phosphate in downstream segment of Citarum River have far exceeded the quality standard for class 1 based on PP No. 82 of 2001 which is equal to 0.2 mg/L.

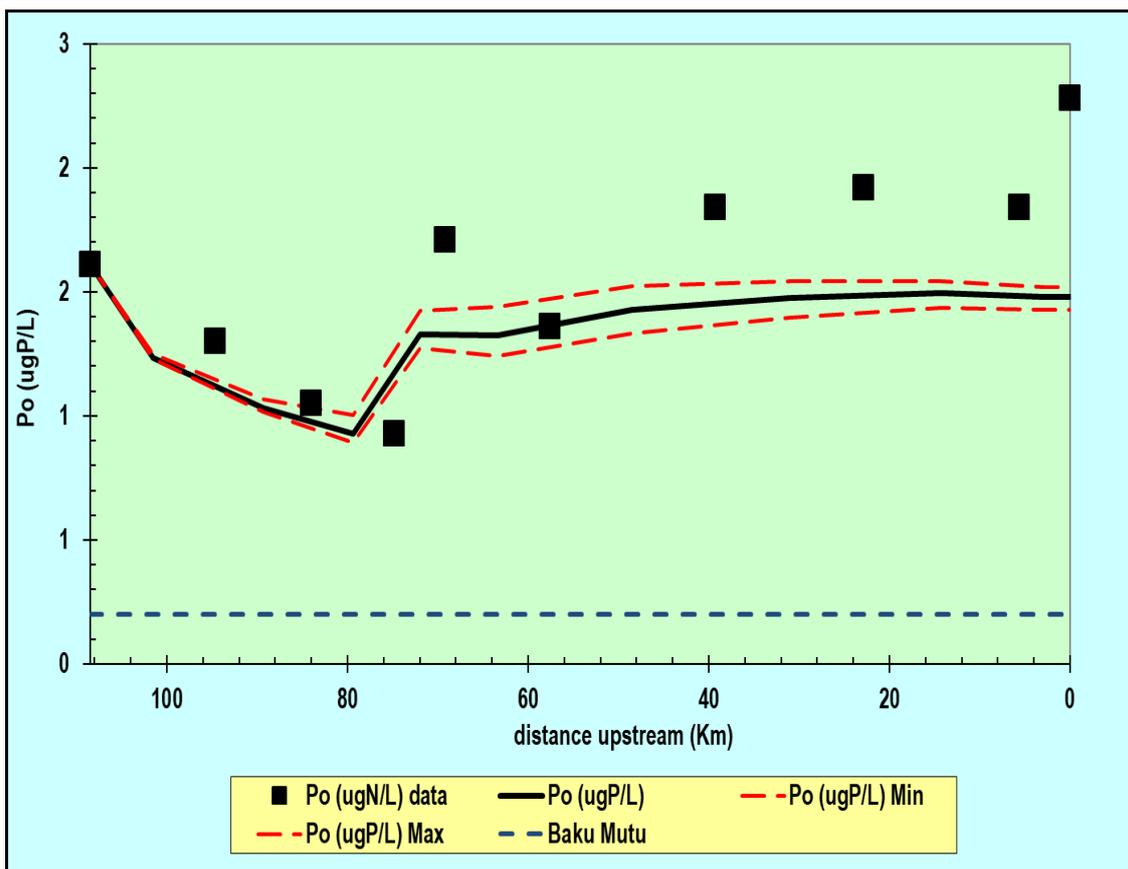


Figure 4. The results of Phosphate Model Simulation in Downstream Segment of Citarum River

High levels of phosphate in downstream segment of Citarum River occur due to agricultural runoff and domestic activity waste, especially human waste and laundry waste containing detergents that are discharged directly into river bodies. In agricultural areas orthophosphate is derived from fertilizer that enters rivers or lakes through drainage and rainwater flow. Polyphosphates can enter rivers through wastewater from residents and industries that use phosphate-containing detergents, such as the metal industry and so on. Organic phosphate is found in wastewater from residents (feces) and food scraps. Organic phosphate can also occur from orthophosphate which is dissolved through biological processes because both bacteria and plants absorb phosphate for its growth (Amirullah and Ismail, 2009).

Based on the model simulation results of the existing downstream segment of Citarum River, the percentage deviations from the BOD, COD, nitrate, and phosphate parameters were 5%, 8%, 13%, and 13%. Deviation values of less than 20% are

considered acceptable in predicting such concentrations in downstream segment of Citarum River and can be used to calculate river pollutant loads. The percentage of errors in modeling can occur due to water sampling activities at each monitoring point (Zhang et al, 2012). The model will be more accurate if adding various input variables including basic algae, sediment oxygen demand, organic nitrogen, total and organic phosphorus, etc. in the monitoring program (Hossain et al, 2014).

Pollutant Load Capacity Analysis

Determination of the pollutant load capacity is based on the value of the difference between the existing pollutant load in the river with the permissible pollutant load that is the concentration of each water quality parameter according to the water class in the quality standard. The difference can be negative or positive. If the difference between pollutant load and capacity was negative, it is necessary to reduce pollutant load. If the difference between pollutant load and capacity is positive, it can be said that the river is still able to accommodate the amount of loads before it exceeds its capacity.

Table 5. Pollutant Load Capacity

Reach	Parameter	Pollutant Load Capacity (kg/day)	Pollutant Load (kg/day)	Difference (kg/day)	Percentage of Overload (%)
0	BOD	14556.67	16012.34	-1455.67	9%
	COD	24261.12	69556.63	-45295.51	65%
	Nitrat	24261.12	800.62	23460.50	0%
	Fosfat	485.22	3906.04	-3420.82	88%
1	BOD	15709.79	18664.66	-2954.87	16%
	COD	26182.98	73820.25	-47637.27	65%
	Nitrat	26182.98	913.18	25269.80	0%
	Fosfat	523.66	3234.86	-2711.20	84%

Reach	Parameter	Pollutant Load Capacity (kg/day)	Pollutant Load (kg/day)	Difference (kg/day)	Percentage of Overload (%)
2	BOD	16596.52	16974.06	-377.54	2%
	COD	27660.87	74935.95	-47275.07	63%
	Nitrat	27660.87	1080.96	26579.91	0%
	Fosfat	553.22	2852.50	-2299.28	81%
3	BOD	17187.91	17043.88	144.04	0%
	COD	28646.52	76917.13	-48270.61	63%
	Nitrat	28646.52	1243.54	27402.99	0%
	Fosfat	572.93	2658.53	-2085.60	78%
4	BOD	20905.71	16885.16	4020.56	0%
	COD	34842.86	88669.93	-53827.08	61%
	Nitrat	34842.86	1517.58	33325.28	0%
	Fosfat	696.86	4623.32	-3926.46	85%
5	BOD	21217.11	17995.95	3221.16	0%
	COD	35361.86	90502.14	-55140.29	61%
	Nitrat	35361.86	1645.61	33716.25	0%
	Fosfat	707.24	4690.38	-3983.14	85%
6	BOD	21569.86	23702.44	-2132.58	9%
	COD	35949.77	97865.45	-61915.68	63%
	Nitrat	35949.77	1987.45	33962.32	0%
	Fosfat	719.00	5129.15	-4410.15	86%
7	BOD	22140.10	28233.06	-6092.96	22%
	COD	36900.17	105702.47	-68802.30	65%

Reach	Parameter	Pollutant Load Capacity (kg/day)	Pollutant Load (kg/day)	Difference (kg/day)	Percentage of Overload (%)
	Nitrat	36900.17	2298.86	34601.31	0%
	Fosfat	738.00	5445.75	-4707.75	86%
8	BOD	22814.02	26082.87	-3268.85	13%
	COD	38023.37	114634.33	-76610.96	67%
	Nitrat	38023.37	2438.54	35584.83	0%
	Fosfat	760.47	5686.16	-4925.69	87%
9	BOD	23456.84	31866.22	-8409.39	26%
	COD	39094.73	122959.31	-83864.58	68%
	Nitrat	39094.73	2473.37	36621.36	0%
	Fosfat	781.89	5784.25	-5002.36	86.5%

Based on **Table 4.**, pollutant load of BOD, COD, and phosphate in all reach exceeds pollutant load capacity (PLC), while for nitrate pollutant load does not exceed its PLC. The percentage of BOD overload is 0%-26%, COD overload was 61%-68%, and phosphate overload was 78%-87%.

CONCLUSION

Simulation results of existing conditions for pollutant load of BOD, COD, nitrate, and phosphate in downstream segment of Citarum River almost all have exceeded its pollutant load capacity (PLC). The results of the PLC for BOD model simulation was 14556.67 kg/day-23456.84 kg/day while pollutant load of BOD was 16012.34 kg/day-23456.84 kg/day so that the BOD overload was 0%-6%. The results of PLC for COD model simulation was 24261.12 kg/day-39094.73 kg/day while pollutant load of COD was 69556.63 kg/day-122959.31kg/day so that the COD overload was 61%-68%. The result of PLC for nitrate model simulation was 24261.12 kg/day-39094.73 kg/day while pollutant load of nitrate was 800.62kg/day-2473.37kg/day so

that the nitrate overload was 0%. The results of PLC for phosphate model simulation was 485.22 kg/day-781.89 kg/day while pollutant load of phosphate was 3906.04 kg/day-5784.25 kg/day so that the phosphate overload was 78% -87%.

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