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Dissolved oxygen dynamic system model for the determination of the waste assimilating capacity at Brantas river Malang city

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Abstract. River quality standard in Indonesia still determined normatively. It apply for all river with various conditions. This is not appropriate for water quality management because each river have different characteristics to keep the optimal condition for the life in water body. With dynamic system model of dissolved oxygen (DO), DO's changes can be approached. DO is the most important parameter to know the quality of water body. Furthermore, it could be used for estimate waste assimilating capacity (WAC) for organic waste to be discharged to water body for optimal DO's condition. This research is to make dynamic system model of DO's river using Stella v9.1.3 application. Object research located on Brantas River at Malang city. The behaviors of DO's kinetics for each monitoring point at Brantas river Malang city are approached with the dynamic system model of DO that had done verified and validated with the constrain: (1) reaeration rate of the river for typical rivers as much 1.5 /day; (2) SOD's deoxygenation rate is assumed as much 5 grO₂/m² for Brantas river with moderately pollution. From the result of sensitivity analysis of DO's dynamic system model can be determined range value for optimal DO for fish's life. The WAC for pollutant of BOD, NH₃ and NO₂ can be determined also. For rainy season in 2015, the WAC for the river pollutant of BOD have used almost all. Different condition of used WAC for NH₃ and NO₂. The remaining WAC for NH₃ and NO₂ are still near the available WAC.

1. Introduction

In river water management, the WAC should be known [1-2]. The permit for wastewater discharge to the river based on the WAC because natural system has ability to assimilate the humankind's waste (John Cairns, 2008). All this time in Indonesia, the WAC is determined from the river quality standard that normative. This standard behave for all river. Actually each river have different condition. With the dissolved oxygen (DO) dynamic system approach that considering the DO kinetics, the WAC can be more objectively approach [3].

DO change process in river that is affected by physical, chemical and biological factors is dynamic in time and special scales [4-5]. Deficit DO problem from effluent discharge can be approached with dynamic DO change process in river that is affected by physical, chemical and biological factors are dynamic in time and special scales [6]. Deficit DO problem from effluent discharge can be approached with dynamic system modelling. According to [7], the system that defined as system is defined as a



collection of elements that constantly interact over time to form a unified whole. The fundamental relationship and the relationship between the components of the system is called the system structure. DO in the river system which is the object of this study, elements forming the DO system includes atmosphere reaeration, algae photosynthesis and respiration, nitrification and de-nitrifications, deoxygenation Corganic and sediment [8-12]. These elements interact over time determine DO river as described in Figure 1.

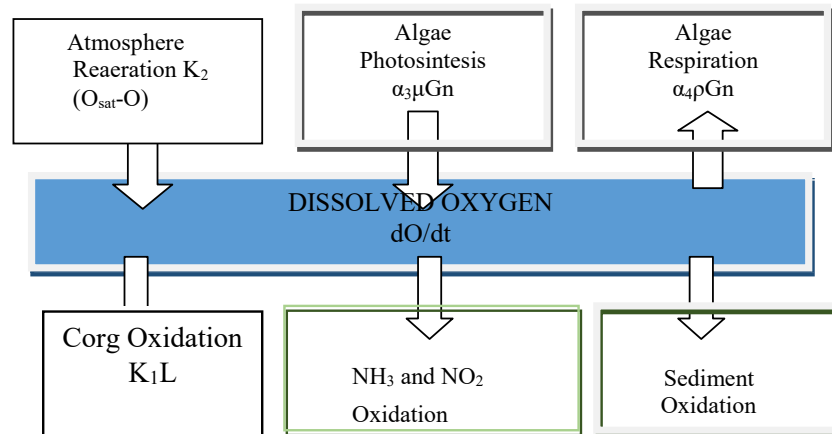


Figure 1. DOI kinetics

DO kinetics determine water body's self-purification as caused from effluent discharge. According to the illustration from the scheme above, DO kinetic is depend on some process that reduce the DO, including organic Carbon oxidation from organic waste discharge, Ammonia nitrification and Nitrite de-nitrification from organic waste oxidation and nutrient discharge, sediment oxidation from organic oxidation and solids discharge and algae respiration from organic oxidation and N and P discharge. Besides, another process that increase the DO, such as atmospheric re-aeration and algae photosynthesis.

2. Methodology

2.1 Steps of Modelling

DO dynamic system modelling have some steps that describes as follow:

(1) Problem approach

The first steps is analyzing the DO's kinetics problem from some factors that affect. This is complexes problem that are decomposed in to sub-problems. These sub-problems are Corganic oxidation from organic waste's discharge, Ammonia's nitrification and Nitrite's de-nitrification from oxidation of organic's waste and nutrient discharge, oxidation of from organic and solids discharge and algae's respiration from organic's oxidation and N and P discharge, atmospheric re-aeration and algae's photosynthesis.

(2) Analyses the System

From problem approach, the DO system is analyzed from the sub-system that form. Besides, also be determined how the relationship within these sub system and with the system are. In this step, the symbols of stock, flow, converter and connector in the model structure of DO's dynamic system are defined clearly. There are no stock and flow because DO is fluctuate value not accumulated value.

(3) Structuration and Formulation of the Model of DO Dynamic System

In this step, model structure of DO's kinetics system is built and formulated using Stella application like this following Figure 2.

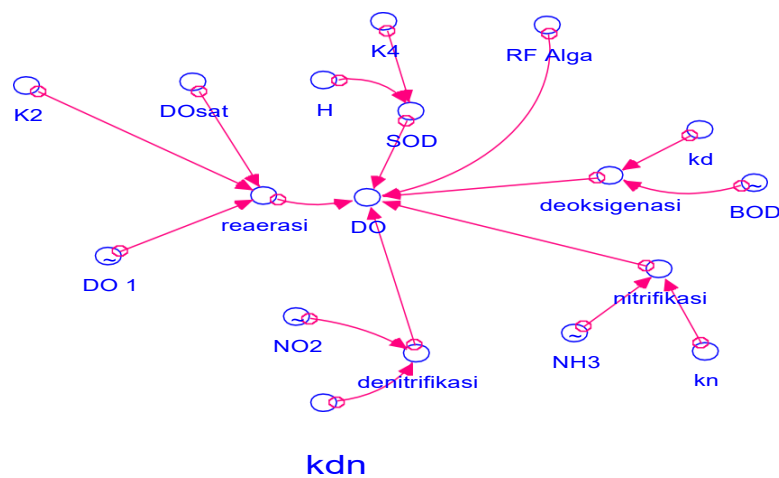


Figure 2. Model Structure of DO's Dynamic System

(4) Simulation and Verification of the Model

After model structure built with the formulation, then model is simulated. After simulation of the model, verification is done for make sure that the output of calculation result are appropriate with the system algorithm of the model (Chinneck, 2000). The simulation result is shown on Figure 3.

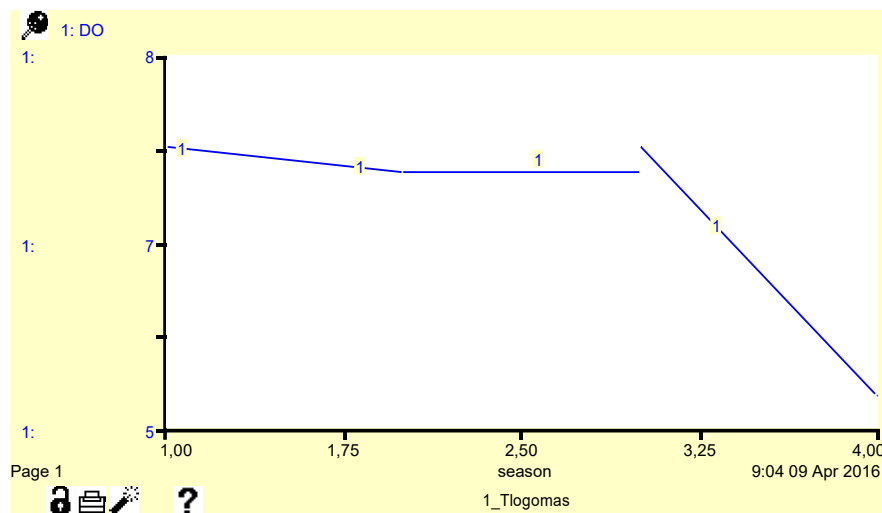


Figure 3. Graph of Simulation Result of the dynamic of DO Brantas River at Point of Monitoring of Tlogomas, Represent Rainy Season and Dry Season in year of 2014-2015.

(5) Calibration and Validation of the Model

Calibration is adjustment process of parameter value until model output (DO's model value) near field value. Next, validation is done to make sure model adjustment with field condition. In this step, dynamic model outputs compares with DO's field data using Chi Square Method of Statistic.

(6) Sensitivity Analysis

Analysis of sensitivity is used to determine until how far the change of parameter value not affect to the model output. Sensitivity analysis is done for optimal condition of DO for fish's life in Brantas River Malang City.

2.2. Input Data

Data that are inputted in DO's dynamic system model display at the following Table 1 and Figure 4.

Table 1. Water Quality Data for Rainy Season and Dry Season in Year of 2014-2015

NR.	LOCATION OF MONITORING POINT	SEASON	BOD	DO	NO2-N	NH3-N
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	Telogo Mas	rainy 2014	2.95	7.5	0.05	0.12
		dry 2014	4	7.6	0.02	0.09
		rainy 2015	8	7.35	0.102	0.45
		dry 2015	10.5	5.3	0.72	1.36
2	Dinoyo	rainy 2014	4.05	8.2	0.04	0.44
		dry 2014	3.75	7.2	0.02	0.07
		rainy 2015	7.53	7.53	0.122	0.49
		dry 2015	9.3	6.3	0.47	1.38
3	Jembatan Suhat	rainy 2014	3.8	7.3	4.13	0.07
		dry 2014	6.7	6.3	0.02	0.04
		rainy 2015	3	6.3	0.12	0.26
		dry 2015	20.4	6.3	0	13.88
4	Kasin Brantas	rainy 2014	3.15	7.8	0.06	1.52
		dry 2014	11.3	5.2	0.29	0.52
5	Jembatan Muharto	rainy 2015	5	6.81	0.26	0.13
		dry 2015	14.4	1.2	0.09	14.73
		rainy 2014	3.8	7.4	0.14	0.17
		dry 2014	9.9	6	0.44	1.22
6	Brantas Bangau Amprong	rainy 2015	9.9	6.27	0.3	0.45
		dry 2015	9.9	6.6	0.05	0.12
		rainy 2015	3	6.27	0.423	1.14
7	Bumiayu Mergosono	dry 2015	10.2	6.4	0.097	0.01
		rainy 2014	4	7.4	0.14	0.17
		dry 2014	12.5	6	0.44	1.22
		rainy 2015	5	6.27	0.3	0.45
8	Jembatan Bumiayu	dry 2015	12	6.6	0.05	0.12
		rainy 2014	4.05	7.8	0.11	0.2
		dry 2014	7.75	5.4	0.57	0.58
		rainy 2015	3	6.36	0.22	0.52
		dry 2015	15.9	2.6	0.71	12.27

Source: Environmental Agency of Malang City and Sampling Result of 2015

Notes: Result in column 3 to represent 2014 data and result of 2015 sampling

Monitoring point location at Brantas River Malang city is shown on Figure 4.

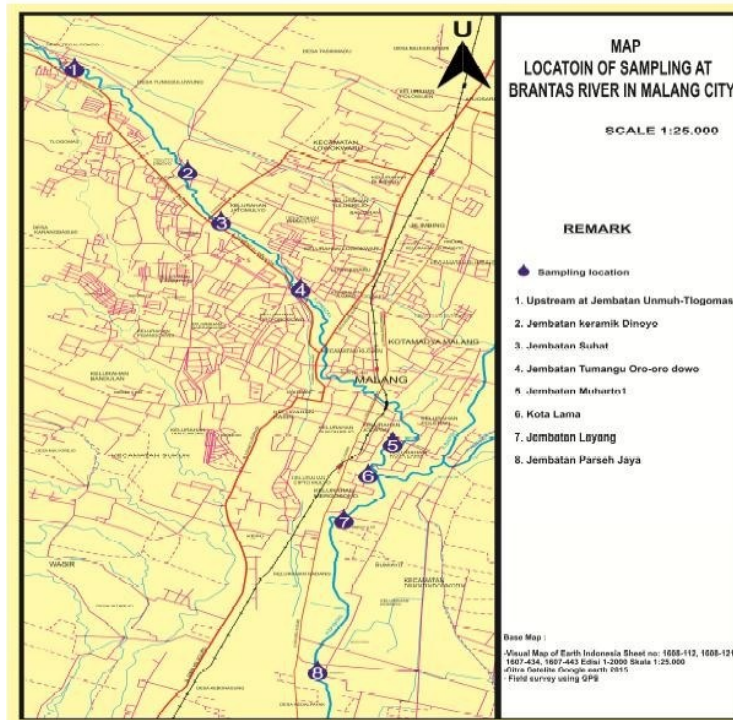


Figure 4. Segmentation of the River

Table 2. Rate of Reaeration, Rate of Deoxygenation SOD, Rate of Alga Photosynthesis- Respiration

VARIABEL	VALUE	REMARKS
Rate of Reaeration, K_2	1.5/day	Secondary data, Jones (2011) for river condition typically
Rate of Deoxygenation SOD	5 $\text{grO}_2/\text{m}^2.\text{day}$	Secondary data, Jones (2011) for river with moderately pollution
Rate of Alga Photosynthesis-Respiration	0.5 - 10 mg/L.day	Secondary data, Jones (2011)

Table 3. Rate of Corganic Deoxygenation, Rate of Nitrification, Rate of De-nitrification

NR	MONITORING POINT LOCATION	RATE OF DEOXYGENATION Corg./day		RATE OF NITRIFICATION, /day		RATE OF DENITRIFICATION, /day	
		kd_rainy	kd_dry	kn_rainy	kn_dry	kd_rainy	kd_dry
1	Tlogomas	0.039	0.050	1.663	0.475	1.530	14.446
2	Dinoyo	0.046	0.030	1.357	0.333	1.732	1.370
3	Jembatan Suhat	0.034	0.043	0.621	1.637	0.991	0.222
4	Kasin Brantas	0.030	0.095	0.412	2.211	1.160	0.020

5	Jembatan Muharto	0.026	0.075	1.117	3.219	0.503	1.186
6	Brantas Bangau Amprong	0.019	0.092	8.699	1.083	0.260	2.449
7	Bumiayu Mergosono	0.024	0.092	0.156	0.010	0.727	2.986
8	Jembatan Bumiayu	0.036	0.112	3.710	0.575	0.759	0.027

Source: research result, 2015

3. Results and discussion

3.1 Analysis of Verification, Calibration and Validation

The DO's dynamic system model had verified, calibrated and validated. Calibration of the model use monitoring data for year of 2015. Analysis of validation using Chi Square method shows $\chi^2_{\text{count}} < \chi^2_{\text{table}}$ for all monitoring point. This following table shows the validation analysis result with the p value 0.05.

Table 4. Validation Analysis Result

NR	MONITORING POINT LOCATION	χ^2_{count}	χ^2_{table}
1	Tlogomas	0.0003333	0.0039
2	Dinoyo	0.0005667	
3	Jembatan Suhat	0.0008667	
4	Kasin Brantas	0.0008667	
5	Jembatan Muharto	0.0027333	
6	Brantas Bangau Amprong	0.0001333	
7	Bumiayu Mergosono	0.0011333	
8	Jembatan Bumiayu	0.0003	

3.2 Analysis of Sensitivity

Sensitivity analysis is done to determine the limit of the DO's output model value that appropriate with the range value of DO for river biota. The minimal value is 3 mg/L and the maximal value is near the DO saturation value. Result of sensitivity analysis for Tlogomas monitoring point shows on Figure 5 and Figure 6. Result of sensitivity analysis for all monitoring point shows on Table 5.

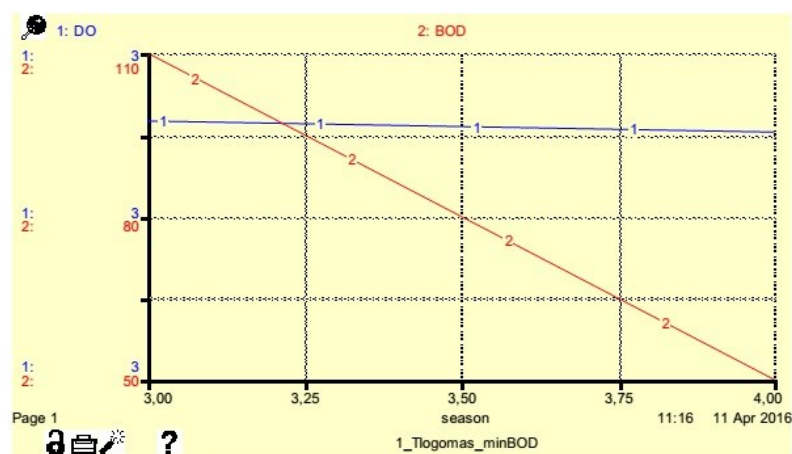


Figure 5. DO minimal For BOD Variable at Tlogomas Monitoring Point

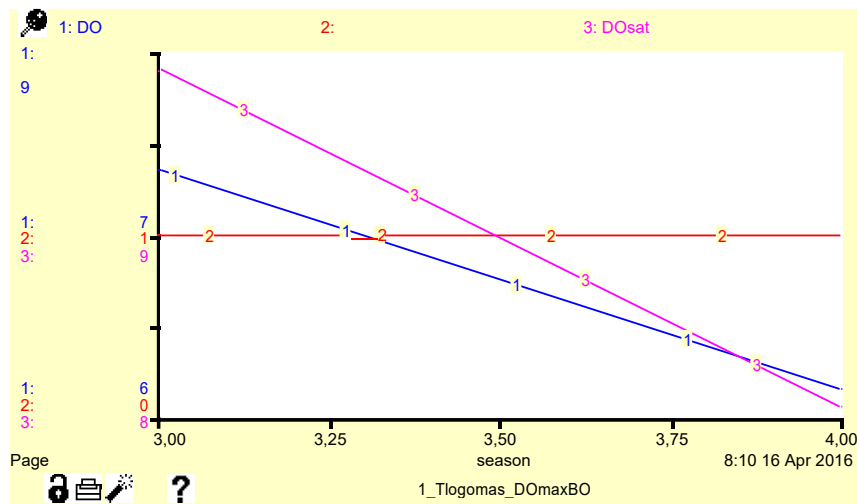


Figure 6. DO maximal For BOD Variable at Tlogomas Monitoring Point

From sensitivity analysis result at Tlogomas monitoring point shown that DO minimal 3.09 – 3.29 mg/L will happen if the value of BOD are 50 – 150 mg/L. And for DO maximal 5.78 – 7.58 mg/L will reached if the value of BOD is 0 mg/L.

Table 5. Result of Sensitivity Analysis

NR.	MONITORING POINT LOCATION	YEAR	2014				2015			
			SEASON	rainy		dry	rainy		dry	
				DOmin	DOmax		DOmin	DOmax	DOmin	DOmax
1	Tlogomas	DO (mg/L)	3.09	7.38	3.27	7.27	3.29	7.58	3.28	5.78
		BOD (mg/L)	110	0	80	0	120	0	50	0
		DO (mg/L)	3.39	7.94	3.16	7.22	3	8.69	3.08	7.46
		NH3 (mg/L)	0.8	0	2.5	0	1.2	0,2	3	0
		DO (mg/L)	3.34	7.35	3.23	7.35	3.08	7.44	3.11	8.38
		NO2 (mg/L)	2.3	0	0.25	0	2.5	0	0.85	0.53
2	Jembatan Dinoyo	DO (mg/L)	3.12	7.72	3.18	7.68	3.29	7.89	3.54	6.54
		BOD (mg/L)	100	0	150	0	100	0	100	0
		DO (mg/L)	3.1	8.21	3.54	7.64	3.32	8.42	3.39	7.84
		NH3 (mg/L)	1.4	0.3	3.6	0	1.4	0,3	3.9	0
		DO (mg/L)	3.09	7.63	3.37	7.58	3.07	7.44	3.09	8.38
		NO2 (mg/L)	2.3	0	2.7	0	0.25	0	2.5	0.53
3	Jembatan Suhat	DO (mg/L)	3.68	7.42	3	5.58	3.37	7.11	3.33	7.2
		BOD (mg/L)	110	0	60	0	110	0	90	0
		DO (mg/L)	3.33	7.35	3.3	5.54	3.22	7.24	3.13	8.22
		NH3 (mg/L)	4.5	0	0.4	0	4.5	0	14.45	13.54
		DO (mg/L)	3.37	7.63	3.02	7.58	3.02	3.56	3.28	7
		NO2 (mg/L)	7.6	0	0.3	0	0.3	0	12	0

4	Kasin Brantas	DO (mg/L)	3.14	7.94	3.38	6.23	3.04	6.94	2.6	2.6	
		BOD (mg/L)	160	0	40	0	40	0	0	0	0
		DO (mg/L)	3.36	8.29	3.41	8.77	3.16	6.97	3.35	8.27	
		NH ₃ (mg/L)	4.7	1.2	0.75	0.04	2.7	0	14.45	13.8	
		DO (mg/L)	3.29	7.91	3.44	5.15	3.16	7.13	1.24	1.24	
		NO ₂ (mg/L)	3.5	0	75	0	3	0	0	0	
5	Jembatan Muharto	DO (mg/L)	3.12	7.54	3.01	6.76	3.01	6.39	3.32	7.44	
		BOD (mg/L)	170	0	50	0	130	130	55	0	
		DO (mg/L)	3.13	8.1	3.04	8.32	3.04	6.39	3.07	8.02	
		NH ₃ (mg/L)	1.3	0	1.5	1.02	1.3	0	0.45	0	
		DO (mg/L)	3.09	7.63	3.37	7.58	3.07	3.56	3.09	7	
		NO ₂ (mg/L)	2.5	0	2.7	0	0.25	0	2.5	0	
6	BBA	DO (mg/L)					3.29	6.33	3.22	7.36	
		BOD (mg/L)					160	0	45	0	
		DO (mg/L)					3	8.35	3.12	6.46	
		NH ₃ (mg/L)					1.25	1.07	0.9	0	
		DO (mg/L)					3.43	6.4	3.06	6.69	
		NO ₂ (mg/L)					10	0	1.3	0	
7	Jembatan Bumiayu Mergosono	DO (mg/L)	3.34	8.14	3.07	5.83	3.22	6.58	3.01	7.15	
		BOD (mg/L)	200	0	30	0	140	0	45	0	
		DO (mg/L)	3.22	8.29	3.33	4.69	3.18	6.65	3.15	6.05	
		NH ₃ (mg/L)	9.5	0	40	0	6.5	0	85	0	
		DO (mg/L)	3.36	8.34	2.93	6.33	3.47	6.79	2.99	6.39	
		NO ₂ (mg/L)	6	0	1	0	4	0	1	0	
8	Jembatan Bumiayu	DO (mg/L)	3.2	7.88	3	6.36	3.27	6.87	3.23	4.35	
		BOD (mg/L)	130	0	30	0	100	0	10	0	
		DO (mg/L)	3.33	6.64	3.3	6.64	3.21	8.16	3.15	8.22	
		NH ₃ (mg/L)	0.55	1.7	1.7	0	0.8	0.41	12	9.4	
		DO (mg/L)	3.1	7.86	3.05	5.52	3.06	6.95	2.54	2.54	
		NO ₂ (mg/L)	5.5	0	70	0	4.5	0	0	0	

3.3 Application of DO Dynamic System Model for Determination of Waste Assimilating Capacity (WAC)

Waste assimilating capacity need to be known for water quality management. The permit of wastewater discharge based on the waste assimilating capacity of the river. For now in Indonesia, WAC is determined normatively from river quality standard. This condition apply for all river, not represent the each condition of the river. Through the approachment of the model of DO dynamic system, the WAC can be determined objectively from the kinetics of the DO.

From sensitivy analysis result, the WAC of BOD, NH₃ and NO₂ can be determined at optimal DO for

river biota. The value of the optimal DO is considered from DO demand for fish and the original Brantas fish species at upstream (3 mg/L) until saturation of DO value for each location of monitoring point. For example at upstream location, Tlogomas, range of optimal DO in rainy season 2015 is 3.09 – 7.38 mg/L. During other parameters that influence the kinetics DO fixed (reaeration, alga respiration-photosynthesis, SOD deoxygenation, nitrification and de-nitrification), so the range value of BOD at optimal DO is 0- 110 mg/L. With the river flow of 2.15 m³/s, the waste assimilating capacity of BOD is estimated of 20 kg/day. The result of WAC analysis of BOD, NH₃ and NO₂ can be seen on the Figure 7.

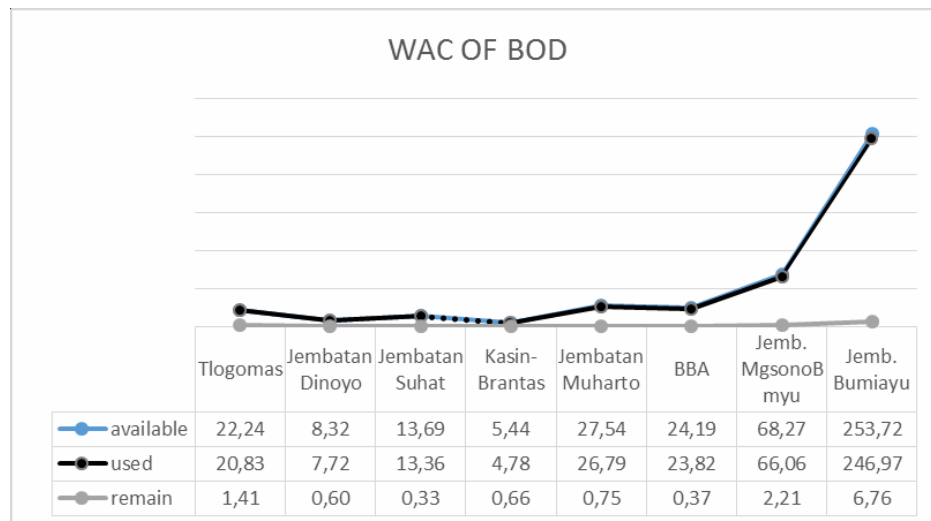


Figure 7. WAC of BOD at Brantas River Malang City for Rainy Season 2015

From Figure 7 at rainy season 2015, the WAC of BOD at Brantas river Malang city are almost used all. This is can be seen from the close lines of available WAC and used WAC. This condition is different with the result of WAC analysis for NH₃ and NO₂. Remain WAC for NH₃ and NO₂ are near the available WAC as shown on the Figure 8 and Figure 9.

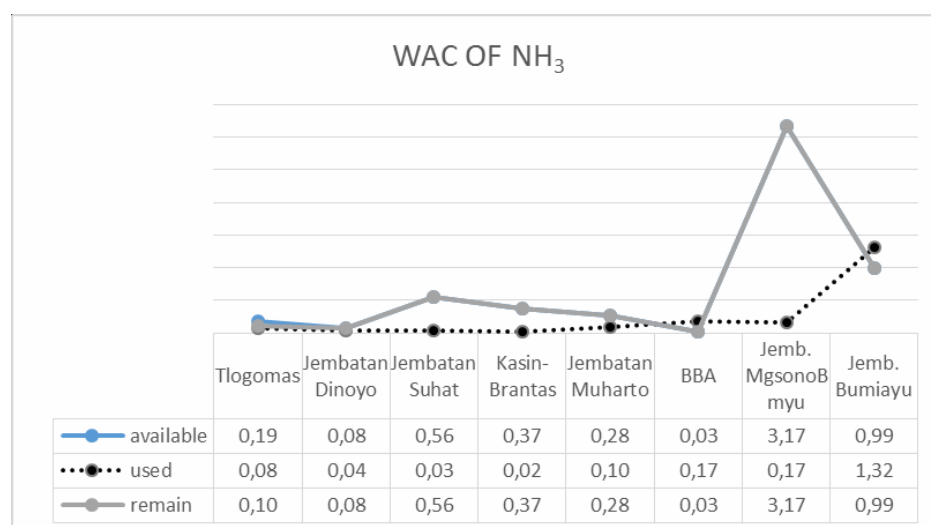


Figure 8. WAC of NH₃ at Brantas River Malang City for Rainy Season 2015

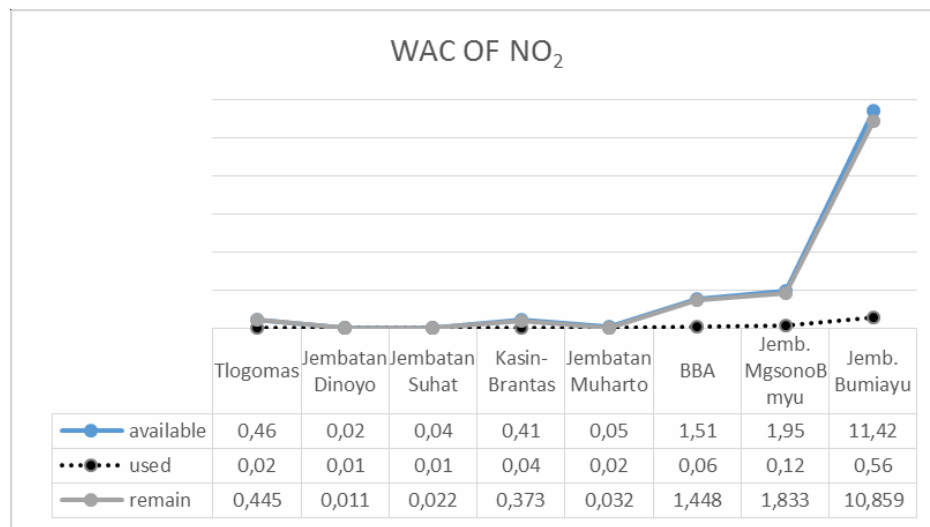


Figure 9. WAC of NO₂ at Brantas River Malang City for Rainy Season 2015

From the application of DO dynamic system model, we can conclude that DO dynamic system model can be used for determination of WAC. This approachment is more objectively than river quality standard regulation because through DO kinetics approach.

4. Conclusion

The result of sensitivity analysis of DO's dynamic system model can be determined range value for optimal DO for fish's life. And next, the WAC for pollutant of BOD, NH₃ and NO₂ can be determined also. For rainy season in 2015, the WAC for the river pollutant of BOD have used almost all. Different condition of used WAC for NH₃ and NO₂. The remaining WAC for NH₃ and NO₂ are still near the available WAC.

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