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BOD, COD, and TSS Predictions from DO measurement results for the Surabaya River, Indonesia

Mohammad Razif

Environmental Engineering Masters Program, Institut Teknologi Adhi Tama Surabaya, Indonesia

Abstract: The fluctuation of water quality of Surabaya river requires anticipation of online monitoring of major pollution parameters of BOD, COD, TSS for input in the drinking water treatment process. The sustainability of long-term river water quality is also very important for the sustainability of the operation of Water Treatment Installation. The purpose of this study is modelling water quality parameters to find empirical equations to calculate the value of BOD, COD, TSS from DO values with regression method and test the sustainability of Surabaya river water quality parameters using a control chart. This study developed an empirical relationship to estimate BOD, COD, TSS based on DO which has been validated statistically. The results showed that BOD, COD and TSS decreased with increasing DO and among them COD parameters decreased at a higher level compared to BOD or TSS for each increase in DO. Research data with control charts and boxplot methods also show similarities in Surabaya river water quality data characteristics for BOD, COD, TSS and DO between 2014 and 2015 which can still be tested again for the next few years to ensure the sustainability of raw water quality for drinking water treatment plants in the city of Surabaya and has great potential to be tested on rivers where raw water is used for drinking water sources in many cities in Indonesia.

Key words: Surabaya River, BOD, COD, TSS, DO

1. Introduction

Drinking Water Treatment Plant (DWTP) is generally designed and operated based on the quality of raw water used. Surabaya like many cities in Indonesia still uses raw water from river water. The sustainability of river water quality is very important for the operation of DWTP. Every time the water quality changes significantly, it is necessary to adjust the DWTP process, such as adjustment of coagulant and flocculant dose, adjustment of filter washing period and so on. The sudden change in river water quality is very difficult to measure quickly because the conventional methods of lab analysis generally take several days to obtain the results of water quality analysis of the tested parameters [1]. Despite the difficult problems of predicting anytime the water quality changes online, it is also difficult to predict the long-term changes of water quality, especially if the river water always receives wastewater loads from industrial, domestic and agricultural activities that also fluctuate every day, week and month. Therefore, it is necessary to find a method to measure the water quality online by using DO meter which can be used to measure the pollutant parameters BOD, COD, TSS, and also find a method to measure the sustainability of water quality for an annual period. It is impossible to measure concentration of BOD, COD, TSS parameters values by using conventional DO meter so that it is necessary to find a method that can regress the BOD, COD, TSS parameters of DO parameter value. This empirical regression method must be validated statistically with P value from T-test. On the other hand, monitoring of Surabaya river water quality data from laboratory analysis is available every month which can actually be used to test the sustainability of water quality using a control chart method. Literature Review on the Water Quality of some Rivers around the World is outlined below.

Until now the river like many rivers in major cities in the world is still dominated by the amount of waste water discharge coming from industrial, domestic and agricultural activities. There are still many waste water treatment plants along the river in the form of a non-functional source point and fluctuations in the quality of their wastewater to deteriorate the quality of river water [2, 3, 4], although there are also well-treated waste water treatment plants [5, 6, 7]. Population growth and urbanization increase in big cities [8, 9, 10] did indeed affect the quality of river water within the city [11], in spite of the very limited supply of clean water worth consuming by the city population [12] experienced a water crisis in another region [13]. Therefore, water quality parameters that are important to be examined are always associated with the pollution characteristics derived from the three types of waste, which in this study used four key parameters: BOD, COD, TSS and DO. In order to determine whether a water quality monitoring process that times, the times series data fluctuates can be classified as stable in statistical control, it can use a control chart as has been done for monitoring data of wastewater sampling for BOD, COD, TSS and some other parameters [14]. In theory, much has been discussed about the effect of high BOD and TSS on water quality and aquatic wildlife. The high value of TSS that increases the BOD value and decreases in DO wastewater is also known. What is unknown is the mathematical empirical relationship between the parameters BOD, COD, TSS and DO in river water. If this relationship is known then there is a contribution in the form of novelty where the concentration of parameters BOD, COD and TSS in the river can be calculated from the DO value of river water. Of course this novelty is very useful for DWTP that use river water as their raw water. In particular, 6 DWTPs in the city of Surabaya will be more efficient and economical in operating because they can reduce the cost of analyzing water quality that must be released every day. The purpose of this study is to find empirical mathematical equations that can be used to calculate the concentration of BOD, COD, TSS from the results of DO concentration of river water, as well as proving the continuity of raw water quality stability in 6 DWTPs for Surabaya City. This research is very important because it can save the cost of laboratory analysis from 6 DWTPs in the city of Surabaya using raw water from the river. In addition to saving the cost of chemicals, the production process can more quickly determine the chemicals needed without waiting for the results of laboratory analysis for river water that needs 5 days for BOD parameters.

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2. Materials and Methods

2.1. Study Area

The object of this study is the Surabaya River in East Java Province, with a total length of 42 km. This river is the border of Surabaya City, Gresik Regency and Mojokerto Regency which is located on the north side of the river with Sidoarjo Regency which is located south of the river. The river regime includes a river that has several meanders but is relatively stable which is located in the middle of the river basin. The river daily discharge throughout 2016 ranged from a minimum of 13.50 m^3/s, an average of 43.64 m^3/s, and a maximum of 275.20 m^3/s. The width of the river varies from 20-35 m and the depth of the river varies from 3-5 m. There are at least 8 water quality monitoring stations whose data are used in this study. The locations of these 8 monitoring stations are: Canggu (1), Perning (2), Legundi (3), Cangkir (4), Bambe (5), Karangpilang (6), Sepanjang (7) and Gunungsari (8).

2.2. River Data

The data of this study was obtained from the East Java Provincial Environment Agency in the form of primary data from the river water quality monitoring conducted by Perum Jasa Tirta 1 for 2014 and 2015. This data was not published online, only allowed to be used for academic research purposes in universities. The original data included 7 water quality parameters namely temperature, TSS, pH, DO, BOD, phosphate and nitrate, but in this study only 4 parameters were used, namely TSS, BOD, COD and DO. The researcher did not collect data on the river discharge, water quality and discharge of wastewater fom industry, domestic and agriculture because they were not included in the scope of this study. Examples of data for January and February 2014 are shown in Table 1.

Table 1. Examples of data for January and February 2014

Monitoring Station	Concentration in January 2014 (mg/L)				Concentration in February 2014 (mg/L)			
	DO	**BOD5**	**COD**	**TSS**	**DO**	**BOD5**	**COD**	**TSS**
Canggu	6,9	3,6	6,1	1028,0	6,6	5,8	10,2	420,0
Perning	6,7	3,7	6,7	1040,0	4,3	5,2	11,8	324,0
Legundi	5,6	3,4	8,3	460,0	5,8	4,5	12,2	420,0
Cangkir	4,5	9,9	19,5	190,0	5,0	3,7	8,0	364,0
Bambe	4,1	3,6	6,7	119,0	4,9	5,2	13,4	282,0
Karangpilang	4,0	3,3	5,8	118,0	4,5	7,4	14,7	230,0
Sepanjang	4,4	3,5	5,8	122,0	4,3	5,4	12,2	206,0
Gunungsari	3,5	7,7	15,7	187,0	4,1	5,0	11,2	73,0

2.3. Metodology Approach

Due to the very large watershed monitoring data in cities in Indonesia, this study is limited to using only the river data which is considered to represent the average quality of river water in Indonesia. To be able to represent fluctuations in water quality, selected data from January to December 2014 and 2015 from 8 monitoring stations that are considered to represent fluctuations in the water quality data of the river which tend to range from mild to moderately contaminated water [15]. Data obtained from the primary data through the sampling process in the river. The first approach referred to in the objectives of this study is to establish a model of the continuous relationship between BOD, COD, TSS, and DO parameters to be performed by the regression approach. For each variable parameter has been collected each of 96 data coming from 8 stations for 12 months for 2014 which is predicted for the year 2015 (generated data) and then tested with T-test approach to 96 real data coming from 8 stations for 12 months for 2015 (real data). The second approach to be made is to create a sustainable threshold model through the control chart. A control chart is the time series data fluctuation to get the value of UCL (Upper Control Limit), CL (Control Limit) and LCL (Low Control Limit), where UCL and LCL are derived from deviation 3 times the standard deviation [16]. CL is obtained by averaging from existing data on one chart group. UCL and LCL are obtained by considering + and - from 3 standard deviations. The formation of control chart parameters is done by collecting each parameter of each parameter as much as 12 data derived from monthly data from 8 stations in the river for 2014. Formation of control chart consisting of UCL, CL, and LCL of 2014 data will be tested with 12 chart control data derived from monthly data from 8 stations in the river for 2015 with a T-test approach. If the T-test results between 2014 and 2015 data produce the same data pattern (H0 accepted) then the model will be validated and can be used for subsequent years.

2.4. Procedure of T-Test and P-Value

Validation for the regression model and control chart in this study uses the T test to see P Value. T-test is one of the statistical tests used to test the truth or false hypothesis falsity which states that between the two mean samples taken randomly from the same population there is no significant difference. Independent-sample t-test (T 2 sample test) is used to compare the mean of two existing data sets. This is possible because for example measurements are made at different times but different because of the treatment of the object/respondent. P value can be interpreted as the amount of opportunity to make mistakes if we decide to reject H0. In general, the P value is compared with a certain level of α, usually 0.05 or 5%. The real level of α is defined as our chance of making a mistake to conclude that H0 is wrong, when in fact the statement of H0 is correct. This kind of error can be known as a type I error. For example, α used is 0.05, if P value of 0.021 (<0.05), then we dare decide to reject H0. This is because if we decide to reject H0 (assuming the statement H0 is wrong), chances are we make a mistake is still smaller than α = 0.05, where 0.05 is the maximum threshold is possible we are wrong in making decisions. How to calculate P-value is get the area under the normal curve. How to determine the probability value (P value) of the Test Statistic T (Distribution T) begins by making hypothesis H0 (two data are statistically equal), H1 (two data are statistically different).

3. Analysis and discussion

3.1. Validation of Regression Model

The regression process in this research has been carried out using the Minitab software. Using 96 data in 2014 we have obtained empirical regression equation from BOD, COD, TSS to DO parameters as shown in Table 2 and 3.

Table 2. Model Generation

No	Regression equation in mg/L	N	Year of Data Used	Description : BOD, COD, TSS in mg/L
1.	BOD= 9.54 - 0.938 DO	96	2014	BOD data generation for year 2015 simulation
2.	COD= 24.1 - 2.60 DO	96	2014	COD data generation for year 2015 simulation
3.	TSS= 104 - 1.16 DO	96	2014	TSS data generation for year 2015 simulation

With the empirical correlation equation in Table 1 it can be simulated for 2014 data yielding BOD, COD, TSS value for 2015 prediction. The 2015 data of prediction results are then compared statistically with the 2015 real data and calculated the statistical descriptive as boxplot form shown in Fig. 1

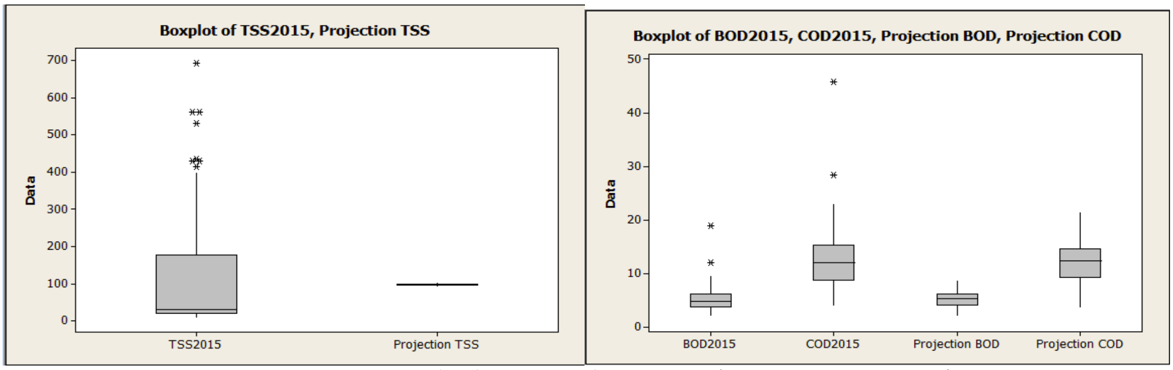

Fig. 1. Boxplot data 2015 and projection of TSS, BOD, COD in mg/L

Table 3. Detail Regression Analysis

Regression Equation: BOD= 9.54 - 0.938 DO					Analysis of Varians:					
Predictor	Coef	SE Coef	T	P	Source	DF	SS	MS	F	P
Constant	9.541	1.518	6.28	0.000	Regression	1	110.14	110.14	9.69	0.002
DO2014	-0.9382	0.3014	-3.11	0.002	Residual Error	94	1068.24	11.36		
S=3.37109	R-Sq = 9.3%		R-Sq(adj)= 8.4%		Total	95	1178.38			
Regression Equation: COD= 24.1 - 2.60 DO					Analysis of Varians:					
Predictor	Coef	SE Coef	T	P	Source	DF	SS	MS	F	P
Constant	24.138	3.716	6.50	0.000	Regression	1	848.80	848.80	12.47	0.001
DO2014	-2.6045	0.7376	-3.53	0.001	Residual Error	94	6399.52	68.08		
S=8.25106	R-Sq = 11.7%		R-Sq(adj)= 10.8%		Total	95	7248.32			
Regression Equation: TSS= 104 - 1.16 DO					Analysis of Varians:					
Predictor	Coef	SE Coef	T	P	Source	DF	SS	MS	F	P
Constant	104.30	47.47	2.20	0.030	Regression	1	167	167	0.02	0.903

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DO2014	-1.157	9.423	-0.12	0.903	Residual Error	94	1044368	11110
S=105.405	R-Sq = 0.0%		R-Sq(adj)= 0.0%		Total	95	1044535	

Note : DF = Degree of Fredom, SS = Sum of Square, MS = Mean of Square

From Table 2, the value of DF, SS and MS from the process in Minitab software will produce an F value that significantly affects the P value. The regression equation for BOD= 9.54 - 0.938 DO and COD= 24.1 - 2.60 DO shows the results of P value < 0.05 which means that DO variables affect the variables BOD and COD. While the regression equation TSS= 104 - 1.16 DO shows the results of P value > 0.05 which means that the DO variable has no effect on TSS variables. The model validation in this study used a P value of T-test to compare the 2015 real data with 2015 prediction data, the results are shown in Table 4.

Table 4. Validation Model with T-test

No	2 Sample T comparison in mg/L	Function Used in Minitab	T Value	P Value	Description
1.	BOD2015 and BOD2015 (Generated)	Not equal	0.49	0.62	The hypothesis is rejected, the p-value is more than 0.05. Two data are statistically equal
2.	COD2015 and COD2015 (Generated)	Not equal	1.24	0.22	The hypothesis is rejected, the p-value is more than 0.05. Two data are statistically equal
3.	TSS2015 and TSS2015 (Generated)	Not equal	1.21	0.23	The hypothesis is rejected, the p-value is more than 0.05. Two data are statistically equal

From boxplot in Figure 1 shows that for TSS the distribution of data projection is narrower than the original data, whereas for BOD and COD there is a similarity between the distribution of data projection and the original data. Although there are differences in the range of TSS data distribution, the results of the statistical tests in Table 3 show the original data and projections are the same.

3.2. Validation Control Chart Model

This control chart validation process also uses the Minitab software. Using monitoring data from 8 monitoring stations for each month of each concentration of BOD, COD, TSS, DO parameters have been obtained 12 control charts for 2014 and 2015 in the form of UCL, CL, LCL, the distribution of data is described in the boxplot form shown in Figures 2 and 3.

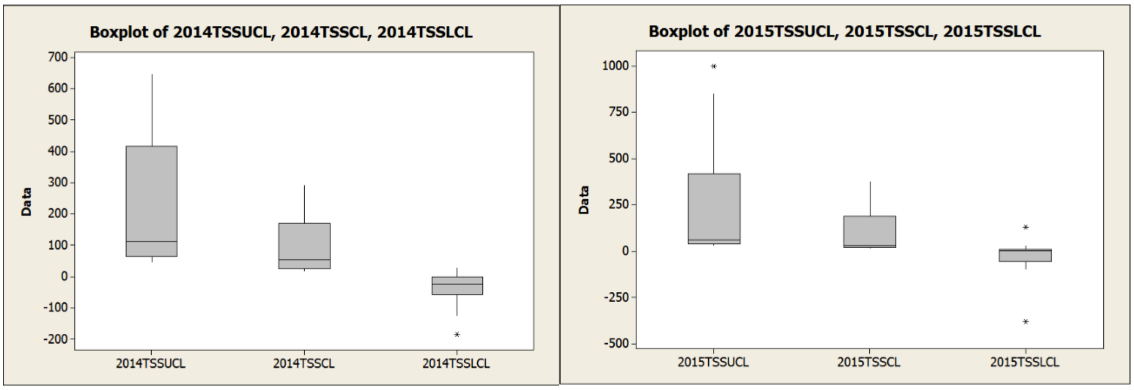

Fig.2 Boxplot TSS 2014 and 2015 in mg/L.

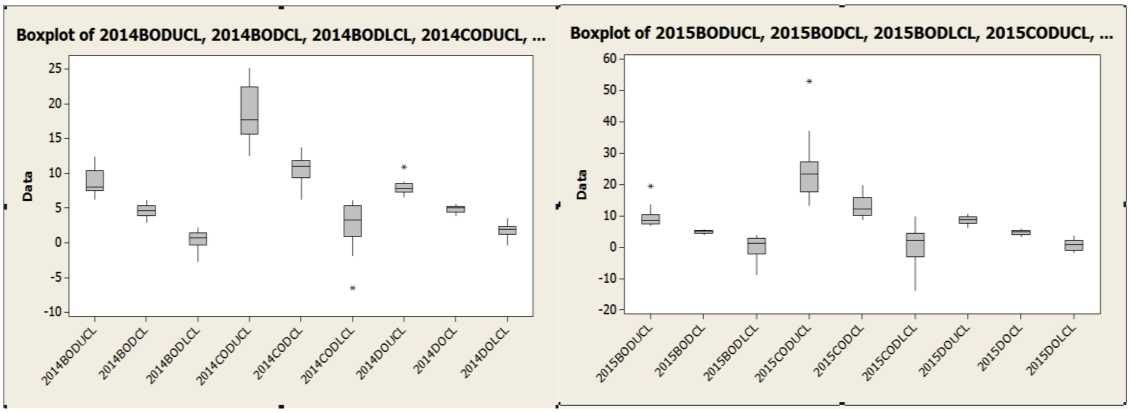

Fig.3 Boxplot BOD, COD, DO 2014 and 2015 in mg/L

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From the distribution of data for control chart charts in Figures 2 and 3, it can be seen that the majority of data distribution is generally not symmetrical and there are some data that have outliers. When compared with the range of data in the boxplot between 2014 and 2015, there are similar characteristics for all parameters, namely TSS 2014 with TSS 2015, BOD 2014 with BOD 2015, COD 2014 with COD 2015, DO 2014 with DO 2015. The similarity of statistical data has also been validated as shown in Table 5.

Table 5. Validation Chart with T-test

Control Chart in mg/L		T-Value	P-Value	Description
BOD2014 VS BOD2015	UCL	-0.73	0.48	The hypothesis is rejected, the p-value is more than 0.05. Two data are statistically equal
	CL	-0.97	0.35	The hypothesis is rejected, the p-value is more than 0.05. Two data are statistically equal
	LCL	0.24	0.81	The hypothesis is rejected, the p-value is more than 0.05. Two data are statistically equal
COD2014 VS COD2015	UCL	-1.99	0.06	The hypothesis is rejected, the p-value is more than 0.05. Two data are statistically equal
	CL	-1.98	0.06	The hypothesis is rejected, the p-value is more than 0.05. Two data are statistically equal
	LCL	0.89	0.39	The hypothesis is rejected, the p-value is more than 0.05. Two data are statistically equal
TSS2014 VS TSS2015	UCL	-0.24	0.81	The hypothesis is rejected, the p-value is more than 0.05. Two data are statistically equal
	CL	-0.4	0.69	The hypothesis is rejected, the p-value is more than 0.05. Two data are statistically equal
	LCL	-0.21	0.84	The hypothesis is rejected, the p-value is more than 0.05. Two data are statistically equal
DO2014 VS DO2015	UCL	-1.3	0.21	The hypothesis is rejected, the p-value is more than 0.05. Two data are statistically equal
	CL	1.01	0.327	The hypothesis is rejected, the p-value is more than 0.05. Two data are statistically equal
	LCL	2.00	0.06	The hypothesis is rejected, the p-value is more than 0.05. Two data are statistically equal

3.3. Dicussion

The T-test hypothesis seen in this research is a statistical data similarity of concentration BOD, COD, TSS, DO parameters in mg/L between generated data 2015 with real data year 2015. Because if the hypothesis shows between generated data and real data show similarity (H0 accepted), this indicates that the regression formulation has been valid and can be used for subsequent years. Regression formulation helps researchers to predict concentration value in mg/L from BOD, COD, TSS simply by looking at the sampling of numbers from DO concentration in mg/L. This will be very helpful in terms of speed and cost for the research sample taker. This empirical regression equation can help in the process of monitoring the quality of river water. By simply measuring the DO concentration of river water in the installation intake with DO meter, and can be monitored to generate real-time data online [17, 16] it can be directly calculated the concentration of BOD, COD, TSS in mg/L and if this formula is entered into the online system, BOD, COD, TSS concentration values can be obtained online simultaneously with DO concentration. To be more convincing, the value of this calculation can still be re-validated with the results of BOD, COD, TSS concentration measurements based on the results of water sampling analysis examined in the laboratory. If the result is valid, then the anticipation of the manager of the Drinking Water Treatment Plants (DWTP) can be faster to the contamination for a moment without having to wait for conventional laboratory analysis results that generally the results can only be known after 7 days after sampling time. The use of statistical methods generally ensures more accuracy in predicting water quality [18, 19]. Of the three regression models the coefficient of determination (R2) is very small, even though the data used is sufficient. This empirical equation has never been found in the technical literature and journals, so for improvement it still requires a lot of effort to increase the value of its significance such as by validating by increasing the frequency of sampling the Surabaya river water and measuring BOD, COD, TSS, and DO concentration in the laboratory and the results are validated with this empirical equation. With a lot of validation, it is possible to make corrections to the empirical equation so that empirical relationship will be more significant. In accordance with the regulations of the Governor of East Java, the Surabaya River has set water quality quality standards following the class II river. The physical meaning of the equation constant in Table 2 can be described as follows. For BOD= 9.54 - 0.938 DO, the value 9.54 indicates that this equation limits the concentration of BOD in the river water that can be used is a maximum of 9.54 mg/L, if the DO value is zero. This concentration is far above the class II river quality standard of 3 mg/L BOD. While constant 0.938 shows that the greater the DO value the smaller the BOD value. For COD= 24.1 - 2.60 DO, the value 24.1 indicates that this equation limits the concentration of COD in the river water that can be used is a maximum of 24.1 mg/L, if the DO value is zero. This means that this equation applies only to the river water which meets the COD quality standard of 25 mg/L. While the constant 2.60 shows that the greater the DO value the smaller the value of COD. For TSS= 104 - 1.16 DO, the value 104 indicates that this equation limits the concentration of TSS on the river water which can be used to a maximum of 104 mg/L, if the DO value is zero. This concentration is far above the class II river quality standard of 50 mg/L TSS. Whereas the constant 1.16 shows that the greater the DO value the smaller the TSS value. The results showed that BOD, COD and TSS decreased with increasing DO and between COD parameters decreased at a higher level compared to BOD or TSS for each increase in DO. Researchers have observed that in river water in India, COD is highly correlated with BOD, AMM and TKN [20].

Figure 3 and Table 4 give a plot of the comparison of observed values with generated values for indicators of BOD, COD, and TSS. Based on the value of the P value of T-test result, it is concluded that the 2015 real data is statistically no different from the data prediction in 2015. This means that the equation of mathematical empirical regression between BOD, COD, TSS and DO has been statistically valid for the water quality of the river. Hydraulics and river morphology are actually a lot of factors that influence the quality of river water for BOD, COD, TSS, DO such as sediment transport, accumulation of sludge in sediment, resuspension of mud and sediment due to discharge velocity, and the opening process of Gunungsari Water Gate at certain times to reduce sediment accumulation. Despite many factors that influence, the resultant of all these factors is reflected in the results of water river quality monitoring conducted every month. The existence of this empirical regression equation can help the manager in the DWTP that uses the river water as its raw material. Simply by measuring DO using DO meter online on the intake of the DWTP; BOD, COD, TSS parameters can be calculated by this empirical regression equation, and if this empirical formula is incorporated into the online system, BOD, COD, TSS will also be obtained its value online together with the value of DO. With the information of raw water quality online this can help the operator in DWTP to prepare a dose of coagulant and flocculant that will be used in the drinking water treatment process, without the need to do the jar-test analysis again for example. This method has great potential to be tested on rivers where raw water is used for DWTP in many cities in Indonesia. The method to find the empirical relationship to estimate the value of BOD, COD, TSS from the DO value is the novelty of this study. Distribution of control chart statistics on this boxplot shows that the river water quality data for 12 months in 2014 was statistically the same as Surabaya river water quality data for 12 months in 2015. Therefore, with the method of control chart test, we can see the sustainability of the river water quality between 2014 and 2015. The same method can be repeated for monitoring data for the following years. The sustainability of Surabaya river water quality is very important as a guarantee of the sustainability of the operation of the DWTP using the river water as raw water. Optimization steps for wastewater treatment before water is discharged into the river and conservation of river ecosystems must also be considered [21]. With the guarantee of sustainability of the river water quality, DWTP in Surabaya can be guaranteed to continue to operate in accordance with the processing that has been done so far without the need to anticipate pretreatment if water quality deteriorates. The sustainability validation method with this control chart has great potential to be tested on rivers where raw water is used for DWTP in many cities in Indonesia.

4. Conclusion

This study developed an empirical relationship to estimate BOD, COD, TSS based on DO which has been validated statistically. Three mathematical empirical equations generated for Surabaya river case are: BOD = 9.54-0.938 DO, COD = 24.1-2.60 DO, TSS = 104-1.16 DO. The results showed that BOD, COD and TSS decreased with increasing DO and between COD parameters decreased at a higher level compared to BOD or TSS for each increase in DO. Research data with control charts methods and boxplot also show similarities in Surabaya River water quality data characteristics for BOD, COD, TSS and DO between 2014 and 2015 which can still be tested again for the next few years to ensure the sustainability of raw water quality for drinking water treatment plants in the city of Surabaya and has great potential to be tested on rivers where raw water is used for drinking water sources in many cities in Indonesia.

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