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Assessment of the Water Quality of Jatiluhur Reservoir, the Downstream of Citarum Cascade River, Using Selected Physico-Chemical Parameters

Pengukuran Kualitas Air di Waduk Jatiluhur, Bagian Hilir Sistem Kaskade Citarum Menggunakan Parameter Fisika Kimia Tertentu

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Abstract

Physico-chemistry and biological data were investigated from October 2010 until April 2011 of Jatiluhur reservoir. A total of six sampling stations were selected for this study. The discharge and hidrological data were obtained from Perum Jasa Tirta II Jatiluhur. The results showed that the hydrological regime in the reservoir Jatiluhur was affected by global phenomenon La Nina events in 2010 and early in 2011. Stream flows were determined during sampling to range from 78 to 482.5 m^3/s. The water quality findings were as follows: pH (6.93-8.81), temperature (26.37-30.6°C), dissolved oxygen (0.733-5.2 mg/l), conductivity (2.45-233μmhos/cm), COD (7.36-96.9 mg/l), turbidity (4.063-65.6 NTU), total phosphate (0.002-0.324 mg/l), total nitrogen (0.99-5.96 mg/l), chlorophyl (2.237-43.37 mg/m^3), visibility (30-160 cm). The eutrophication was pronounced at Jatiluhur reservoir. Canonical Correspendence Analysis found that some water quality parameters correlated positively with the discharge and the water level.

Keywords: hidrological regimes, water quality parameter, Jatiluhur Cascade Citarum reservoir

Abstrak

Data fisika-kimia dan biologi waduk Jatiluhur telah diteliti dari Oktober 2010 hingga April 2011. Total enam stasiun pengambilan sampel telah dipilih untuk studi ini. Data keluaran dan hidrologi diperoleh dari Perum Jasa Tirta II Jatiluhur. Hasil tersebut menunjukkan bahwa daerah hidrologi di waduk Jatiluhur dipengaruhi oleh fenomena global kejadian La Nina pada 2010 dan di awal 2011. Aliran arus ditentukan selama pengambilan sampel pada range dari 78 hingga 482,5 m^3/s. Penemuan kualitas air adalah sebagai berikut: pH (6,93-8,81), temperatur (26,37-30,6°C), oksigen terlarut (0,733-5,2 mg/l), konduktivitas (2,45-233 μmhos/cm), COD (7,36-96,9 mg/l), turbiditas (4,063-65,6 NTU), total fosfat (0,002-0,324 mg/l), total nitrogen (0,99-5,96 mg/l), klorofil (2,237-43,37 mg/m^3), dan visibilitas (30-160 cm). Pertumbuhan tidak terkendali telah dinyatakan pada waduk Jatiluhur. Analisis Korespondensi Kanonikal menunjukkan bahwa beberapa parameter kualitas air terhubung secara positif dengan level air dan keluarannya.

Kata kunci: daerah hidrologi, parameter kualitas air, waduk Citarum air terjun Jatiluhur

1. Introduction

Reservoir or dam is a surface water resource that has played an important function throughout the history in the development of human civilization (Barzani *et al.*, 2007) and built to change natural flow regimes which is the most significant human interventions in the hydrological cycle (Akindele *et al.*, 2013). Thence, swamps and reservoirs are in the category of multi-purpose lake that has both ecological and social functions, economics and culture. Construction of reservoirs in Indonesia began with the construction of reservoirs in the Citarum cascade downstream of the reservoir is Ir.H.Djuanda (Jatiluhur) in 1967, which has 8.300 hectare area of inundation and a maximum depth of 107 m. Jatiluhur, if it is associated as a multiuse function, has been a major proponent of 80% of the raw water to Jakarta at 16.5 m^3/second (Tamim, 2008). The water from the waterfall weir of Jatiluhur divided in three channels, namely

West Tarum Channel, North Tarum Channel, and East Tarum Channel. Water at West Tarum channel is used to meet the needs of irrigation, domestic, and industrial. Citarum cascade reservoirs has the main function used for Hydroelectric Power Plant (HEPP), which Jatiluhur also has a function as a raw water source of drinking water and flood control and irrigation. Jatiluhur has run into decreased function and carrying capacity (Rizka *et al*., 2008). Erosion in the upper watershed Jatiluhur causes the input stream becomes increasingly turbid during the dry season (Hilda *et al*., 2007). This is because of high demand of water for agriculture, urban and industrial West Tarum along the channel, climate change, and land use in the catchment area Jatiluhur, Cirata and Saguling upstream. Instead of a reservoir raw water source or a place to store water (Suwignyo, 1996), it is also a productive freshwater ecosystems where productivity is dominated by phytoplankton.

In general, the utilization factor and the survival function of a body of water, among others, determined by the level of fertility waters. The level of fertility or marine productivity can be determined with the abundance and biomass of phytoplankton as primary producers in the water. The decline in water quality is also characterized by the presence of changes in aquatic community structure and the emergence of the dominance of a water biota. Something similar happened also in the waters of the Citarum Cascade Reservoir. The abundance of one type of aquatic biota, particularly phytoplankton may cause the food chain (food web), under-utilized by zooplankton and fish, and also the condition of the waters has decreased as a result of the poison (toxin) that is caused by certain types of phytoplankton (Na dan Park, 2006). The results of the analysis in Saguling, Cirata, and Jatiluhur stated that 55 genera of phytoplankton classes contained in the reservoir water. Phytoplankton species can be used as bioindicators to indicate water quality Saguling, Cirata and Jatiluhur that have undergone the process of eutrophication, i.e. cultural eutrophication (Prabandani, 2006; Prihadi, 2005; Umar, 2003).

2. Methods

2.1. Description of the Study Area

Jatiluhur Dam or reservoir is located in West Java Province, Java Island, Indonesia. It lies within the Citarum river. Based on geographic coordinates, body position of Jatiluhur dam is at 6°31 'south latitude and 107°23' east longitude. The Citarum river is the largest river system in West Java and drains before joining the Java sea about 6.000 square kilometres of the catchment area. The annual mean discharge of the Citarum river at Jatiluhur reservoir has been estimated as 175 m^3/s. Citarum reservoir system consists of three reservoirs including Jatiluhur, Cirata and Saguling. The Jatiluhur dam was built in 1957 and officially began operating in 1967. It is lower most and the largest reservoir of the Citarum reservoir system, and provides a multipurpose gross storage of about 2.448 m^3. The management of the dam has experienced many changes reflecting Indonesian macroeconomic changes and various interests in benefiting water from the dam. Jatiluhur Authority was first established in 1967 as Public Utility Company (*Perusahaan Umum*) whose main task was providing public services in the water resource sector. In 1999, a big change happened when Jatiluhur Authority was changed into Perum Jasa Tirta (PJT) II. In this study, six representative sampling stations were established on the dam

2.2. Water Samples Collection and In Situ Determination

Water samples were collected from six stations on monthly basis from October 2010 to April 2011. Determination of the horizontal sampling points is based on the direction of the flow of the river that brings water masses into the Jatiluhur. While the determination of the vertical sampling points was based on the difference in the depth of the epilimnion layer and hipolimnion, which the depth was 0 m, 2 m, 8 m, and base (varies in each station) using a 2 litre water sampler (Nastiti *et al*., 2001; Pratiwi *et al*., 2006). Water temperature and pH were determined in-situ using a mercury-in-glass bulb thermometer and field pH meter. Transparency was determined by Secchi disc and electrical conductivity was determined by using conductivity meter. The samples were stored in an icebox and transported back to the laboratory for analysis on the same day.

2.3. Laboratory Analysis

Dissolved oxygen was determined by azide modification of the winkler method; chemical oxygen demand was measured using the dichromate reaction method (Hach, 2003); total nitrogen and total phosphate were measured according to APHA (1995). Phytoplankton is collected in nets with a mouth diameter of 20 cm and mesh size 20 µm. Samples were preserved by adding 4% Lugol's Iodine. Identification was done to species level by using keys in Presscott (1970) (Nhiwatiwa *et al*., 2007). Water for chlorophyll-a analysis was obtained by taking samples with 2L water sampler and subsamples of 500 ml were placed in plastic bottles and were later filtered through Whatmann GF filter paper. Measurement of chlorophyll-a uses the method of Spectrophotometry (Radojefic *et al*., 1999).

2.4. Statistical Analysis of Data

Relationships between hydrological parameter and water quality parameter were analysed by canonical correspondence analysis (CCA). The program SPSS 16 was used. CCA is an exploratory statistical method to assess correlations between two sets of variables by maximizing correlation among them. It functions as method to reduce data (Chan *et al*., 2013). Defining X and Y are the two original data sets, U and V are the two new data sets that are linear combination of U and V ($U=\alpha X$ and $V=\beta Y$). CCA is used to maximize the correlation between U and V, within constraints that every canonical variable U and V has unit variance, and is unconnected to other constructed variables in the sets. Take the form below as the correlation matrix of $(p+q)\times(p+q)$ between $X_1, X_2, \ldots, X_p$ and $Y_1, Y_2, \ldots, Y_q$ variables. Then matrix of $q\times q$ for $B^{-1}C'A^{-1}C$ could be determined, and eigenvalues can be solved. The eigenvalues $\lambda_1>\lambda_2>\ldots>\lambda_r$ (r subscribe indicates the lower of p as well as q) are squares of the relationship between canonical variables and corresponding eigenvectors, $b_1, b_2, \ldots, b_r$ provide coefficients of Y

variables for canonical variables. Coefficients of U_i, the i^{th} canonical variable for X variables, are provided by elements of a a_i vector, $A^{-1}Cb_i$.

3. Results and Discussion

3.1. Hydrology

The results of the analysis of rainfall based on the data processing area is presented in Fig. 1 with a general description that the annual mean rainfall Jatiluhur basin is 2.869 mm/yr in accordance with the characteristics of rainfall in West Java between 2000-3000 mm/yr. The lowest monthly rainfall has occurred in the watershed Jatiluhur is 0 mm while the highest rainfall 687.25 mm and based on the monthly mean in 1994 to 2011 the lowest rainfall in August was 57.18 mm and the highest in February was 388.48 mm (Fig. 2).

These results indicate the general characteristics of the symptoms of rainfall in Indonesia, which is included in the tropical climate zone characterized by seasonal variations where very high rainfall during the rainy season and very low during the dry season (Park *et al*., 2010). Rainfall patterns in Indonesia, particularly in watershed Jatiluhur is monsoon type V or type, or annual rainfall graph shaped like the letter V (Fig.2). This type shows that Indonesia in general has large amounts of precipitation in the month of December to February and has a little precipitation in June-August. While the month of March to May and September to November is referred to as transitional season. In this transitional season, rainfall and wind are erratic, this is caused by changes in the trade winds and the monsoon.

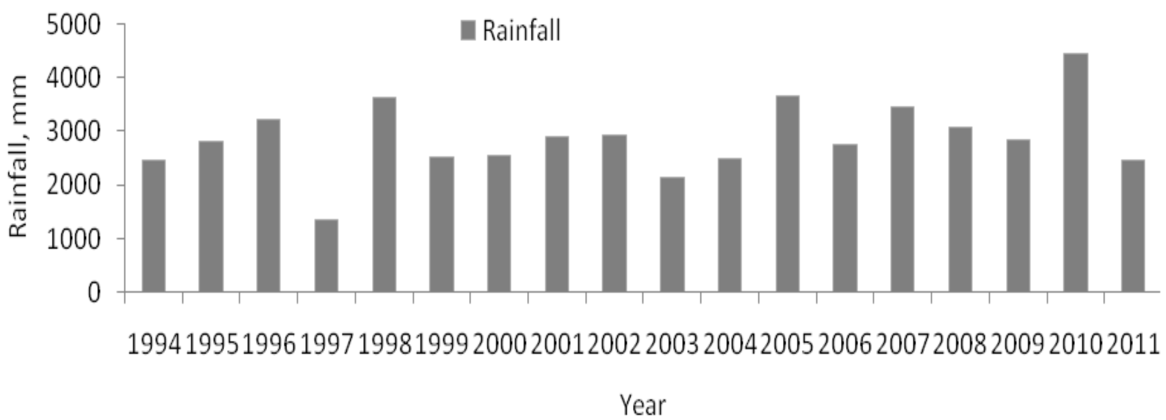

Figure. 1 Distribution of annual rainfall from 1994-2011

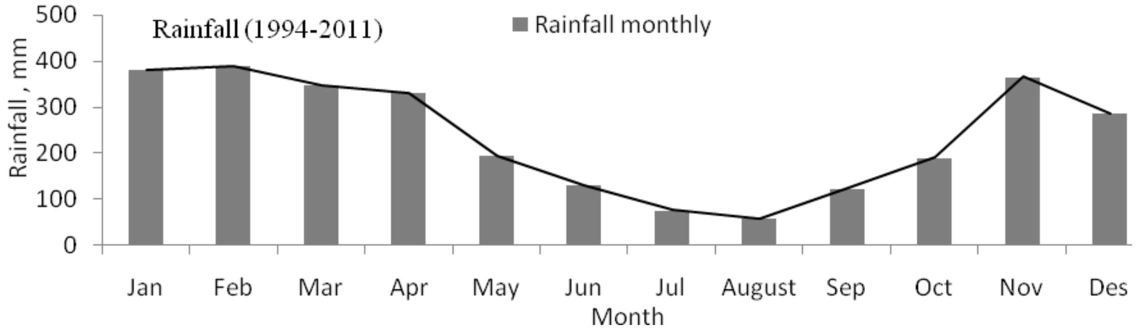

Figure. 2 Distribution of monthly mean rainfall from 1994-2011

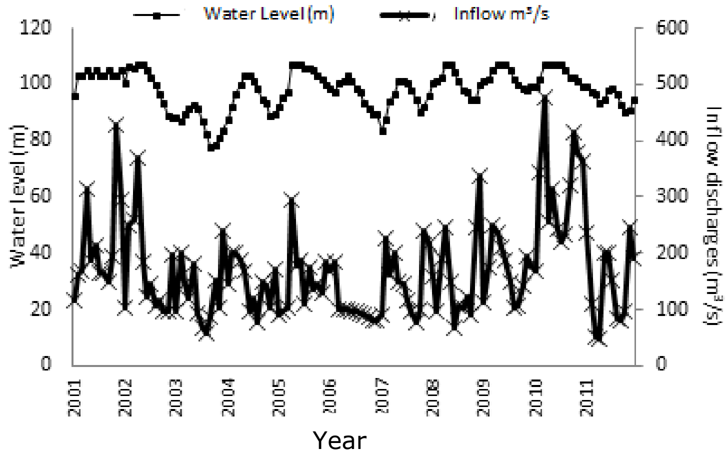

Figure. 3 Inflow discharge and water level in Jatiluhur during 2001 to 2011

3.2. Discharge and Water Level in Jatiluhur

Annual discharge and water level Jatiluhur (2001-2011) can be seen in Fig. 4. This graph has been demonstrated and proven that vision hydrology states that the components are random and stochastic. Extremity inflow discharge had occurred in 2003 in which there had been a minimum inflow discharge and in 2010 the maximum inflow discharge had occurred in the past 10 years.

3.3. Water Quality

Measurement of water quality in the primary study was conducted in six (6) observation stations based on differences in the depth of the reservoir. Name of Station 1: Parung Kalong, Station 2: Bojong, Station 3: Kerenceng, Station 4: KJA, Station 5: Cilalawi, and Station 6: Dam. Sampling was done by 2 (two) times decision or measure to stratify depth of 0 m, 2 m, 4 m, 8 m, and base. Differences depth is divided into two, the depth of the Epilimnion (surface water 0 m to 8 m), and Hipolimnion (depth of 8 m to the base reservoir). Division two lines because of the depth of the thermocline gradient could not be determined with certainty at each sampling. Vertical distribution of temperature is basically divided into three layers, namely the warm layer on top or epilimnion layer where the temperature gradient in this layer slowly changing, the thermocline layer is the layer where the temperature gradient changes rapidly according to the increase of depth, the cold layer at below the thermocline layer, also called hipolimnion (Effendi, 2003). The water quality analyzed in this work consist of pH, temperature, turbidity, conductivity, DO, COD, total nitrogen, total phosphate, dissolved Pb, and visibility. However, the discussion in this paper are focusing on pH, dissolved oxygen, COD, and dissolved Pb.

pH value during the observations have shown a decrease in line with increasing water depth (Fig. 4). Changes in the pH value of the water will affect the toxicity of chemical compounds in water. Under government regulations on drinking water standard in Indonesia, the pH of the water reservoir Jatiluhur is within the allowable limits. Measured range of pH values remained within the tolerance limits for the growth of phytoplankton. The degree of pH describes the ability of a body of water to neutralize hydrogen ions that enter the body of water where most of the aquatic biota is sensitive to changes in pH and likes the pH value in the range of 7-8.5. Observations on the pH is relatively the same as the condition of the waters in 1983, 2004, 2005 and 2006 (Tjahjo *et al.*, 2009).

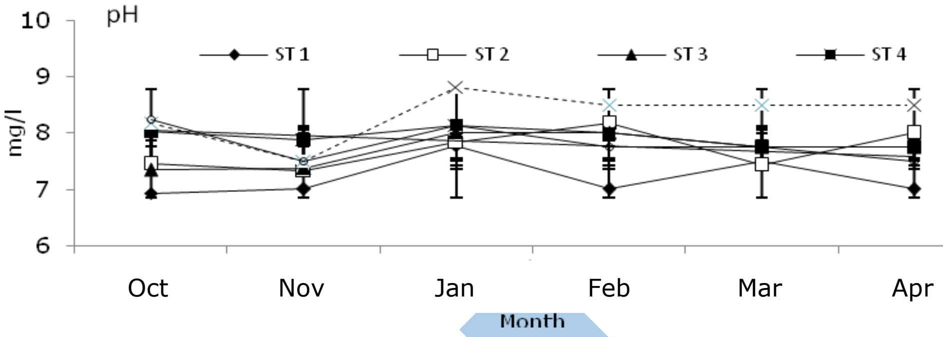

Figure 4. Distribution water quality for pH parameters

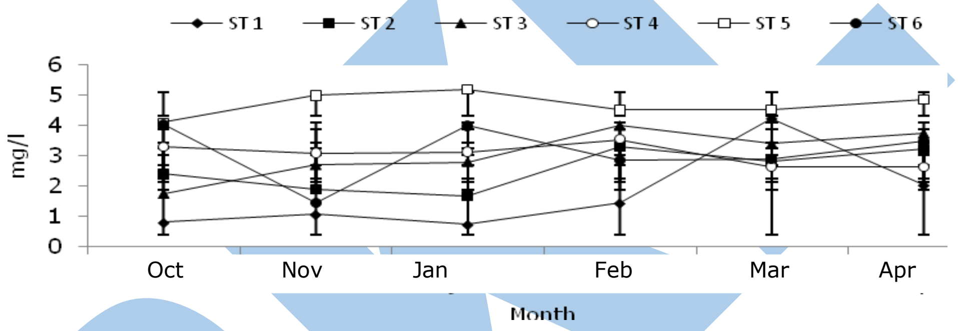

Figure 5. Distribution water quality for DO parameters

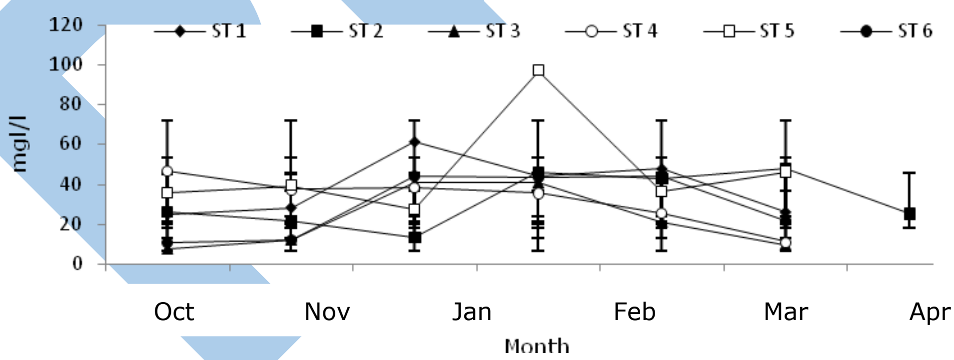

Figure 6. Distribution water quality for COD parameters

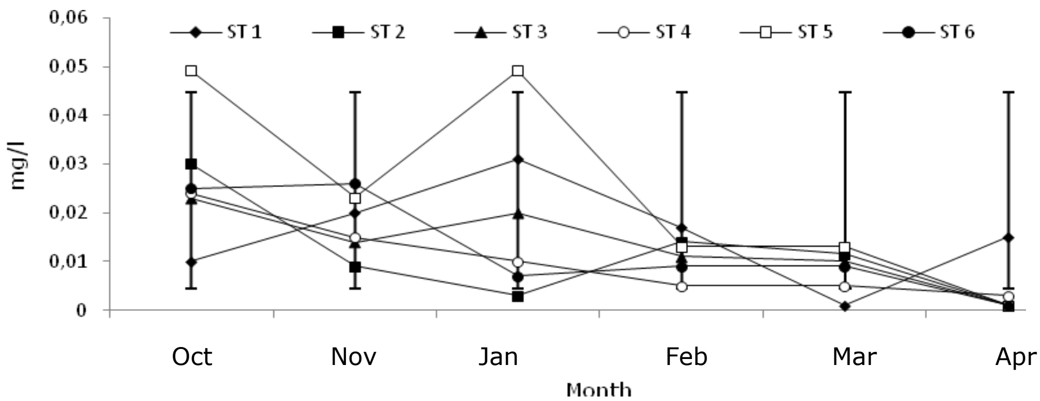

Figure 7. Distribution water quality for dissolved Pb parameters

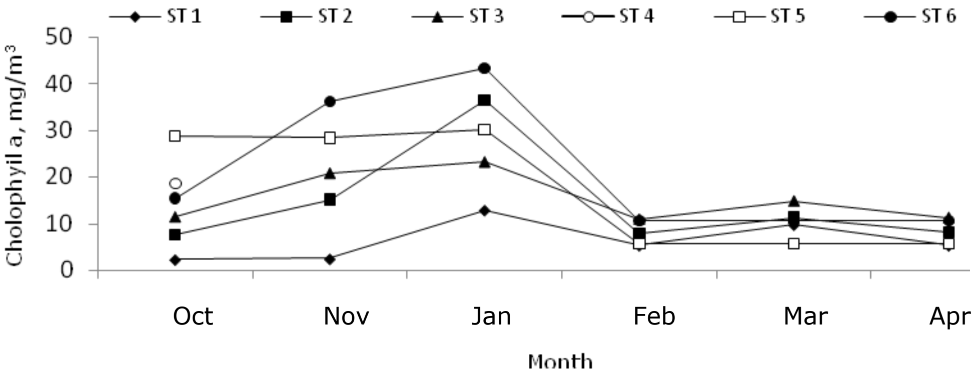

Figure 8. Distribution of Chlorophyll-a at 6 station sampling

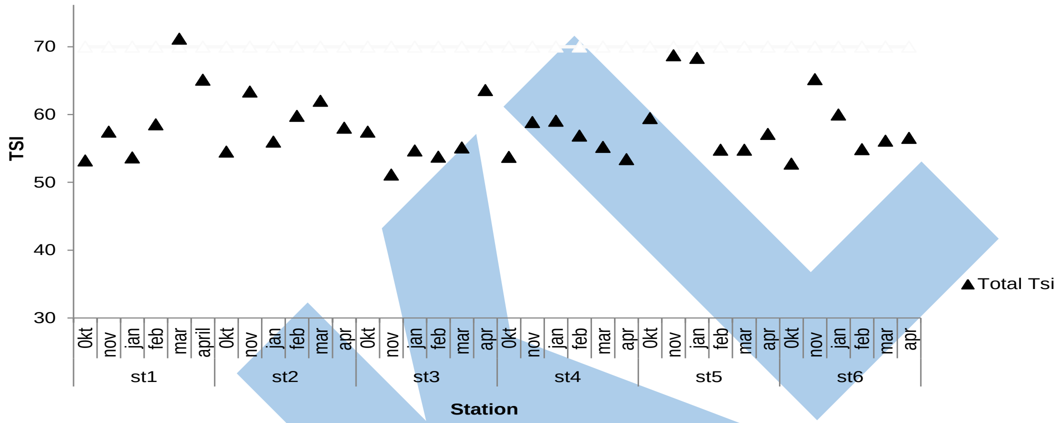

Figure 9. Distribution of Trophic State Index at 6 station

The concentration of dissolved oxygen conditions in the reservoir ranged from 1 mg/l to 5.5 mg/l (Fig. 5). Dissolved oxygen is an important parameter that determines the quality of the water. Stations that have the lowest dissolved oxygen levels are Stations 1 and 2 where the stations are located at the inlet Jatiluhur. Because of the input of the reservoir Cirata which carried organic material, Stations 1 and 2 have run decomposition of organic material in which the decomposition process requires oxygen levels.

The organic content derived from Cirata was high as a result of aquaculture activities and it was greater than the carrying capacity of reservoir (Tjahjo et al., 2009). Vertical distribution pattern indicates that the average of value of dissolved oxygen concentrations generally decreased with increasing of water depth. Significant differences occurred at a depth of epilimnion and hipolimnion for DO parameters. The mean measurement of dissolved oxygen in the epilimnion layer was 3.72 ± 1.29 mg/l while the mean dissolved oxygen at depth hipolimnion was 1.53 ± 0.65 mg/l. The deeper layers of the waters, the more diminished photosynthesis activities of phytoplankton.

Parameters that exceed the quality standards of class I (Regulation No. 82 of 2001 about Water Quality Standards) were COD (the mean was 31.97 ± 17.54 mg/l) (Fig. 6) and Pb (the mean was 0.01 ± 0.01 mg/l) (Fig. 7). Stations that have high levels of COD and the highest Pb are located in the inlet area and outlet streams Cilalawi river. The effect of human activities on watershed and reservoir are much identified in variations indicated in phosphate, nitrate, as well as probably sulphate concentrations (Mustapha, 2008) and dissolved heavy metal. Based on BPS data in 2005, along watershed Citarum there were 699 registered industries, which consist of 327 pieces of large-scale industries and 372 medium-sized industries. The number does not include small-scale industries that are home industry along the Citarum watershed.

Chlorophyll-a concentration in Jatiluhur showed that the concentration of chlorophyll-a was increased in January and tends to decrease in the following months (Fig.8). Chlorophyll-a is used as one of the parameters determining the trophic status or condition of eutrophication that occurs in Jatiluhur.

3.4. Trophic State Index

Lakes and reservoirs fertility rates can be calculated based on some very influential parameters in accordance with the calculation of Trophic Status Index (TSI), namely: Total Phosphorous, chlorophyll-a, and brightness using Sechi disc measurements. An attempt to evaluate the trophic state of the Jatiluhur reservoir was made by using the Modified Carlson Index (Sharma *et al*., 2010). The determination of the three parameters based on the close linkage of each parameter, where the elements of pollutants that enter the waters trigger phytoplankton growth characterized by the presence of chlorophyll-a, and because of the density of chlorophyll-a it will cause inhibition of the column of light that enters the lake which is characterized by more shortbrightness of the waters. Fig. 9 showed Jatiluhur trophic status using Carlson method in the category of eutro-phication (water pollution where indicated) that has been shown by TSI in the range of between 50-70 and TSI values calculated on the basis of Secchi disc depth, total phosphorus and chlorophyll-a that show a characteristic of seasonal variation.

3.5. Canonical Component Analysis

The six chemical variables were taken as the response data, and the six physical variables were treated as the predictor set. The CCA results were showed in Table 1. Although there are totally six canonical variates, only those with canonical correlation coefficients higher than 0.45 are considered as important parameters. Correlation coefficients for canonical variates 1 and 2 were 0.03 and 0.19 respectively, with the significance of F less than 0.01, indicating that they are all significant. In order to determine the dominant parameter, their outstanding coefficients with the highest values in each group were analyzed and highlighted in Table 1.

Considering the above-mentioned results, pH and DO have positive correlation. COD and dissolved Pb have negative correlation. Water level and discharge were the dominant variables in the physical; pH and DO were the dominant variable in the chemical parameters respectively. It indicated and reported the dominant water parameter as wells as the relationship between the physical parameters and the chemical parameters in Jatiluhur reservoir. Water level or discharge can be the represented physical water parameters, while pH or DO can be the represented chemical water parameter for the reservoir monitoring and management. However, other water parameters and the adopted measurement methods could limit the implications of this finding (Chan *et al*., 2013).

Tabel 1. CCA of the data sets

Canonical Variate	Function-1	Function-2
Canonical Correlations	0,03	0,19
Sig. of F	0,000	0,051
Variable	1	2
Total Nitrogen	-0,133	-0,235
Total Phosphate	-0,062	-0,3202
pH	0,972	-0,003
COD	0,344	0,455
Dissolved Pb	0,234	-0,872
Dissolved Oxygen	0,697	0,222
Covariate	1	2
Temperature	0,602	0,215
Visibility	0,079	-0,082
Conductivity	0,225	-0,043
Turbidity	-0,306	-0,111
Discharge inflow	-0,412	-0,716
Water level	-0,167	-0,853

4. Conclusion

The historical data of hydrological Jatiluhur showed that discharge is random and stochastic where there has been extremities of a minimum and maximum discharge that occurred in 2010 and 2011 because of climate change. It affects the management of reservoirs in the Citarum cascade. A detail physicochemical study of the Jatiluhur reservoir during the wet season showed different seasonal fluctuations in various parameters. The results of water quality trends showed that most water quality parameters were quite high in the wet season, such as COD, turbidity, Pb, total phosphate and Trophic Index. The eutrophication was occured in Jatiluhur that can significantly alter the rate of natural process and shorten the life expectancy of the affected water body (Sharma *et al*., 2010). Recently, there has not been yet significant efforts being made in Jatiluhur to protect, rehabilitate and restore the reservoir and impoundments contributing to the country's water resources. Two types of conservation can adopted to Jatiluhur: control of pollution at source and inreservoir treatment and control measures (Sharma *et al*., 2010).

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