DOI: 10.2478/jwld-2018-0010

JOURNAL OF WATER AND LAND DEVELOPMENT
2018, No. 36 (I–III): 99–104
PL ISSN 1429–7426

Available (PDF): http://www.itp.edu.pl/wydawnictwo/journal; http://www.degruyter.com/view/j/jwld

Received 08.08.2017
Reviewed 02.10.2017
Accepted 12.10.2017

A – study design
B – data collection
C – statistical analysis
D – data interpretation
E – manuscript preparation
F – literature search

Phosphorus load concentration in tropical climates reservoir for each water quantity class

Mariana MARSELINA ACDF ✉, **Muhamad BURHANUDIN** BE

Institut Teknologi Bandung, Faculty of Civil and Environmental Engineering, Jl. Ganesha No 10, Bandung, Indonesia; e-mail: mariana.marselina@yahoo.com

For citation: Marselina M., Burhanudin M. 2018. Phosphorus load concentration in tropical climates reservoir for each water quantity class. Journal of Water and Land Development. No. 36 p. 99–104. DOI: 10.2478/ jwld-2018-0010.

Abstract

Saguling Reservoir has a potential to be used as a raw water supply for Bandung Metropolitan Area (BMA), with the discharge of 1.622 $dm \cdot s^{-1}$. However, further studies are needed to ensure that the water quality is in accordance with the government regulations. This study shows that the reservoir's P concentration was 315.0 $mg \cdot m^{-3}$ on average in 1999–2013. This value only meets the class III of government standards of water quality for the cultivation of freshwater fish, livestock, and to irrigate landscaping, but does not belong to the class I standard of 200 $mg \cdot m^{-3}$ for drinking water. The total-P concentration in wet, normal, and dry years was 796.3, 643.8, and 674.8 $mg \cdot m^{-3}$, respectively. The pollution load was highest in wet years due to the high levels of sediment. The pollution load of the reservoir did not exceed the class III classification of 29 405.01 $kg \cdot year^{-1}$. The pollution load in wet, normal, and dry years was 38 790.1, 25 991.9, and 23 929.0 $kg \cdot year^{-1}$, respectively. The phosphorus pollution is caused by the use of floating net cages in the reservoir, which makes it difficult to meet the standards. In wet years, the pollution load was higher than in normal and dry years. The P load could be higher in the wet season due to dilution and could probably decrease the pollutant concentration in the reservoir.

Key words: *phosphorus pollution, pollution load, reservoir, water quality*

INTRODUCTION

The main area in the upper watershed of Citarum River is Bandung Metropolitan Area (BMA), which is a National Strategic Area with economic interests according to the attachment of Government Regulation No. 26 of 2008. The raw water supply of BMA currently comes from springs and water sources. If all plans for raw water utilization in BMA are realized, these sources would produce a raw water supply of 3400 $dm^3 \cdot s^{-1}$ [MARGANINGRUM 2013]. However, the current supply will only be sufficient until 2017. Thus, an additional source needs to be found.

One of the alternatives as a raw water supply for Bandung Metropolitan Area with high discharge is Saguling Reservoir. Saguling reservoir is also located in the upper watershed of the Citarum River. Besides Saguling Reservoir, Citarum River also includes the Cirata Reservoir and Jatiluhur Reservoir. Currently, Saguling Reservoir is concentrated used as a hydroelectric power plant (PLTA), but it is also used for cultivation using floating net cages, which contribute to nutrient pollution.

The Saguling Reservoir could supply high quantities of water to BMA of around 1622 $dm^3 \cdot s^{-1}$ [MARGANINGRUM 2013]. However, further studies are needed to ensure that the water quality satisfies the class I standards according to Government Regulation No. 82 of 2001. The reservoir's water quality is determined by not only natural processes such as weathering and soil erosion, but also anthropogenic activities [KAZI *et. al.* 2009; SINGH *et. al.* 2004]. From year to year, anthropogenic activities have been increasing and causing damage to the water quality. There are about 500 companies and a densely populated area that dispose their waste along the Citarum watershed, and some of it ends up in Saguling reservoir [FARES, YUDIANT 2003].

Assessing the human impact on water quality requires consideration of the variations in time and space, as well as the biological, physical and chemical processes of the natural system [AUBERT *et al*. 2013; LAI *et al*. 2013]. This study determined the pollution load of Saguling Reservoir in terms of phosphorus (P) pollution. The results could be sued to help assess Saguling Reservoir as a potential raw water source for BMA.

METHODS

STUDY LOCATION

The study location is Saguling Reservoir in West Java Province, Indonesia. The reservoir acts as a trap for pollutants discharged into the Citarum River and around the residential area of Bandung. The location is illustrated in Figure 1.

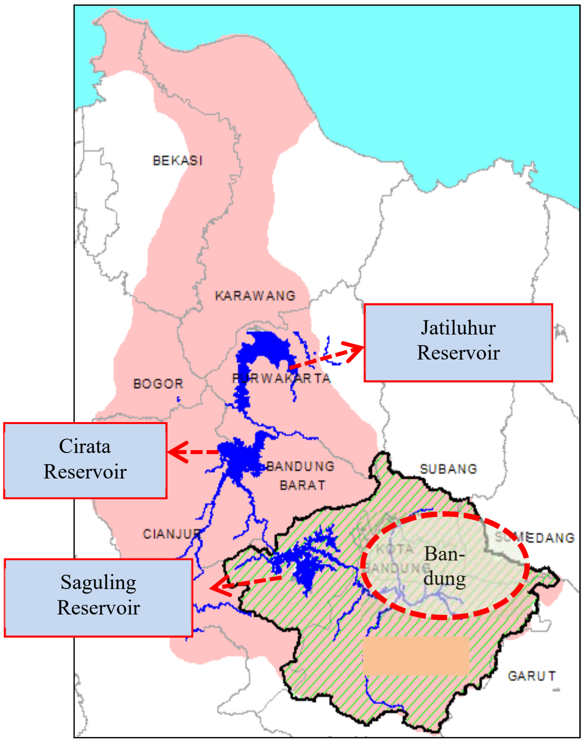

Fig. 1. The location of Saguling Reservoir and Citarum watershed; source: own elaboration

Saguling is heavily polluted, particularly by domestic sewage and industrial waste. Most of the contaminants come from Bandung such as organic matter, nutrients, and heavy metals. Thus, Saguling Reservoir has been identified as highly trophic [HART *et al*. 2002].

MONITORING DISCHARGE AND QUALITY STATIONS IN SAGULING RESERVOIR

The output of Saguling was monitored once per year from 1999 until 2013, and the water quality was observed regularly every three months [March, June, September, and December). There are 11 quality monitoring stations: Nanjung (input), Batujajar, Cipatik Muara, Muara Ciminyak, Cimerang, Tjihaur, Muara Cijere, Cijambu Muara, Muara Tjihaur, Turbine Intake, and Tailrace. A total of 44 water quality parameters which consist of physical and chemical parameters were monitored.

Fig. 2. The location of monitoring quality stations in Saguling Reservoir; source: own elaboration

DETERMINATION OF WET, NORMAL, AND DRY YEARS WITH A MARKOV MODEL

Wet, normal, and dry years were determined using a Markov model according to the water discharge that enter the reservoir. A stochastic matrix could be created for each month to classify the historical data. The stages of the Markov model processing in dividing discharge category is as follows [MARSELINA 2017].

The second phase is the distribution of water discharge classes. A first-order process is investigated for the following three classes:
1) dry discharge (represented by 0),
2) normal discharge (represented by 1),
3) wet discharge (represented by 2).

Class intervals for each class division were obtained by dividing the probability curve of the distribution of the selected population into 3 equal parts at 0.333, 0.667, and 1, as shown in Figure 3. The range value of each class is the middle value in the probability curve at 0333, 0.667, and 1. The probability of each data was determined using the Weibull method as follows [MARSELINA 2017]:

$$P(Xm) = \frac{m}{N+1} \tag{1}$$

Where: $P(Xm)$ = the probability of a set of values that are expected during the observation period, N = the total number of observations, m = the rate of each event.

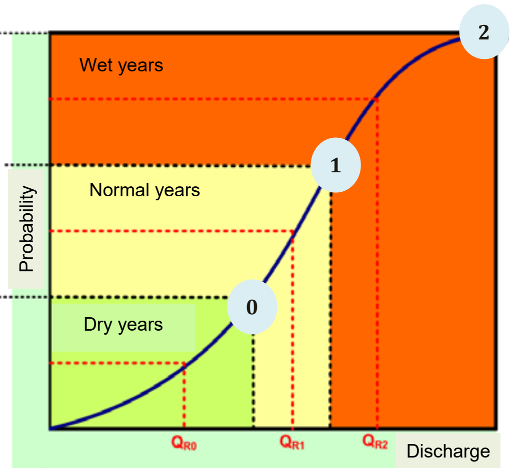

Fig. 3. The class divisions based on probability in the Markov model; source: own elaboration

DETERMINATION OF PHOSPHORUS POLLUTION

The water pollution of the Saguling Reservoir was determined using equation in Appendix I of the Regulation of the Ministry of Environment Indonesia Number 28 of 2009 about pollution lake or reservoir [Peraturan… 2009].

Morphology and hydrology of lakes or reservoirs

$$Z = 100V/A \tag{2}$$

Where: Z = average depth of reservoir (m); V = water volume of reservoir (million m^3); A = wide area of reservoir (ha).

$$\rho = Q_0/V \tag{3}$$

Where: ρ = turnover rate of reservoir water (per year); Q = amount of water discharge from the reservoir (million m^3·year^{-1}).

Pollution concentration of *Pa* parameters

$$[Pa]_d = [Pa]_{STD} - [Pa]_i - [Pa]_{DAS} \tag{4}$$

Where: $[Pa]_d$ = allocation of total-P concentration **of** waste activities in reservoirs (mg·m^{-3}); $[Pa]_{STD}$ = maximum total-P level in accordance with the water quality standard or water class (mg·m^{-3}); $[Pa]_i$ = observed total-P level of the reservoir (mg·m^{-3}); $[Pa]_{DAS}$ = total-P concentration from the watershed (mg·m^{-3}).

WATER POLLUTION LOAD OF PA PARAMETER ON LAKE OR RESERVOIR WATER

$$L = \Delta[Pa]_d\, Z\rho/(1 - R) \tag{5}$$

$$R = 1/(1 + 0.747\rho^{0.507}) \tag{6}$$

$$La = L\frac{A}{100} \tag{7}$$

Where: L = total-P waste storage per unit area of the reservoir (mg·m^{-2}·year^{-1}); La = total P waste in reservoir waters (kg·year^{-1}); R = total-P left with sediment.

The pollution concentration was analyzed by comparing the calculation results of the average data (discharge from the reservoir and total-P) for wet, normal, and dry years.

RESULTS AND DISCUSSION

THE DIVISION OF DISCHARGE CLASS OF SAGULING WATER BY YEAR

Dry, normal, and wet years were classified using data from the Nanjung, Muara Ciminyak, and Turbine Intake Stations, as shown in Table 1.

Table 1. The determination of dry, normal, wet years according to discrete Markov method

Distribution of observation years (1999–2013)		
dry (0)	normal years (1)	wet years (2)
2002	1999	2002
2003	2000	2003
2004	2008	2004
2006	2009	2006
2011	2012	2011

Source: own study.

LOAD ALLOCATION OF PHOSPHORUS POLLUTION AT SAGULING RESERVOIR

Phosphorus pollutant parameter was selected in this research because in a smaller concentration than nitrogen, phosphorus can support the eutrophication process. Phosphorus content >0.010 mg·dm^{-3} and nitrogen >0.300 mg·dm^{-3} in the water body will stimulate the phytoplankton to grow and multiply rapidly [HENDERSON, MARKLAND 1987], resulting in blooming as a result of maximum photosynthesis and causing biomass improvements of the water

Carrying capacity indicates the maximum phosphorus concentration that could be accommodated by Saguling Reservoir based on its morphology and hydrology as long as the conditions do not change [SAMUDRA 2013]. The carrying capacity was calculated by referring to the equation in Appendix I of the Regulation of the Ministry of Environment Indonesia Number 28 of 2009 about pollution lake or reservoir [Peraturan… 2009]. The results are shown in Table 2.

The average depth of the reservoir was sufficient at 10.9 m, which is less than the depth of 17.5 m COSTA-PIERCE [1998]. This indicates that silt has been building up for the past two decades. In addition, the reservoir had also filled up with garbage and water plants such as water hyacinth, which aggravates the sedimentation process in the reservoir. The rate of replacement of Saguling Reservoir water was calculated 4.3 times per year. This result indicates that the water dwell time in the reservoir is long enough which is 82.9 m^3·s^{-1} of water to be discharged, which is similar to the inlet flow rate of 74.4 m^3·s^{-1}.

The rates of water change in wet, normal, and dry years were 5.5, 4.0, and 3.4 times per year. The rate of

Table 2. Calculation results of resilient capacity of Saguling Reservoir pollution for 1999–2013 in wet, normal, and dry years

No	Parameter	Value in			
		1999–2013	wet year	normal year	dry year
1.	Average depth (Z), m	10.9			
2.	Rate of water change (ρ) – per year	4.3	5.5	4.0	3.4
3.	Total-P concntration ($[Pa]_d$), mg·m^{-3}	685.0	736.3	643.8	674.8
4.	Total-P per unit area (L), mg·m^{-2}·year^{-1}	52,443.4	69,181.6	46,356.1	42,677.0
5.	Total of P-waste (La), kg·year^{-1}	29,405.1	38,790.1	25,991.9	23,929.0
6.	Total-P left in sediment (R), kg·year^{-1}	0.39	0.36	0.40	0.42

Source: own study.

water change was highest in the wettest year and smallest in the driest year. The rate of change affects the content of organic matter and impacts the growth of water plants, which is accumulated when there are high amounts of incoming organic material.

The average total-P level ($[Pa]_i$) for 1999–2013 was 315.0 mg·m^{-3}. This value only meets the class III of water quality standard (1,000 mg·m^{-3}), which indicates suitability for the cultivation of freshwater fish, livestock, and to irrigate the landscape. However, class I water quality is required for drinking water, which states that the required total-P level should not exceed 200 mg·m^{-3}. Because the total-P content was only able to meet class III, the pollution load was determined based on this class to prevent the water quality from degrading further.

The total-P allocation of the watershed (DAS) was considered zero because the measured total-P level in the reservoir was considered to be an accumulation from the various rivers that emptied into the reservoir. Accordingly, the total-P pollution concentration ($[Pa]_d$) of the Saguling Reservoir was 685 mg·m^{-3}. This was related to the power plant fish cultivation activities. In addition, the reservoir collects pollution from various sources along the Citarum basin, such as factories, livestock, agriculture, and households [FARES, YUDIANTO 2003].

The total-P contamination concentration in wet, normal, and dry years was 736.3, 643.8, and 674.8 mg·m^{-3}, respectively. The pollution concentration was the highest in wet years due to high amounts of sediment. The next highest total P pollution concentration was in the dry years due to pollutants that tends to increase in low discharge conditions.

The overall pollution load calculated for Saguling Reservoir was 29,405.1 kg·year^{-1}, and the load calculated for wet, normal, and dry years was 38,790.1 kg·year^{-1}, 25,991.9 kg·year^{-1}, and 23,929.0 kg·year^{-1}, respectively. The pollution load indicates that phosphorus pollution caused by floating net cage activity in the Saguling Reservoir will not be expected to meet the required values for drinking water. In the wet years, the pollution load was higher than in normal and dry years. Dilution in the reservoir during wet years could decrease the pollutant concentration in the reservoir. In dry years, it is expected that the P concentration would be minimized.

THE RELATIONSHIP BETWEEN PHOSPHORUS CONTAMINATIONS WITH THE FLOATING NET CAGE

In general, floating net cage is a fish fattening business with the nets floated by the farmer like the drum or stereo foam. In Saguling Reservoir, floating net cage is usually made with a surface area of 7×7 m^2 and the depth varies between 3–4 m [NASTITI, KRISMONO KARTAMIHARJA 2001].

Floating net cage with such area is targeted to maintain fish 3–4 times in a year with the production of about 4 tons of carp (*Cyprinus carpio*) and 1,200 tons of Nile tilapia (*Oreochromis nilotica*) every year.

With the high level of extensive unity production and very low land rent and adequate security, it is not surprising that KJA is growing rapidly in almost all the reservoirs in Indonesia including Saguling Reservoir. Intensive fish cultivation activities with KJA are quite profitable and it can help the community's economic condition around the reservoir where the farmland is submerged by the reservoir development. The reason is that by being a KJA worker, they will have a fixed monthly income, although very few of them are KJA owners. Furthermore, the development of intensive fish farming in the reservoir also provides the assurance of freshwater fish supply for its customers in major cities in Java, which also means that it increases the regional revenues and reviving the local and national economy. Good markets and attractive benefits have made fish farmers compete to accelerate the growth and increase the production of fish they are maintaining. To achieve the maximum production of fish, the farmers/fishers have equipped their fish feed with a "pump" system which is a system of continuous feed for fish to eat, and it will be stopped only if the fish is completely full (do not want to eat).

Actually, the feed pump system is clearly inaccurate, since it is possible that some feeds have been suppressed (superfluous feeding) and if it is swallowed, it cannot be properly digested.

Reservoir area as a place of fish cultivation will gradually change the chemical composition of the lake base sediment due to continuous feeding with fish absorption to feed only about 70–80%. If the downstream occurs due to seasonal changes, it can cause rotation of the water source on the ground to the surface (up willing) by bringing the waste and causing mass death to the fish due to poisoning.

Although Saguling Reservoir contamination is very detrimental, the fishery system in the region has impacted on the procurement of jobs for the surrounding community who rely their life as fish farmers. According to the result of interview with fish farmers, most of the administrators are fisher and some are owner. Worker earns the salary from the owner of KJA of about 400,000 up to 600,000 each month.

KJA has contributed to the economic development of the reservoir area, especially with floating net fishery taxes. In addition, the sale of fish floating net fishing that has not been left behind by the community can still support the income of non-farmer community by selling the processed floating net fish to visitors in the form of take-out processed.

Excessive fish cultivation activities at Saguling Reservoir as listed in Table 3 have polluted the environment, reduced water quality, and disrupted biodiversity in the area. Therefore, the management of fisheries, both fish catch and cultivation of KJA Citarum should be integrated in partnership with ecosystem based on the partnership approach so that the sustainable fisheries development can be achieved.

Table 3. The fish production data of Saguling Reservoir (2000–2015)

Year	Number of KJA (unit)
2000	3786
2005	4554
2010	6581
2015	7025

Source: Balai Penelitian dan Pengembangan, kementrian kelautan dan peikanan, Indonesia [2015].

Strategic management steps that should be done include the rationalization of the number of KJA units that can operate from 7,025 units of KJA which should be reduced to 3,625 units and reorganized of the zone should be conducted.

In addition, the ownership of KJA for every family should be distributed fairly and rationally in accordance with the economic scale, the arrangement of fish biomass maintained fairly amongst cultivators. Furthermore, the development of regulation should be pursued and followed with the law enforcement through the development of partnership between KJA cultivators and reservoir authorities. The development of early warning system for the cultivators and the development of eco-friendly KJA cultivation principles should be conducted.

CONCLUSIONS

This study investigated the pollution load in the Saguling Reservoir to be used as a potential source of raw water for Bandung Metropolitan Area (BMA). The phosphorus pollution is increased by the use of floating net cages in the reservoir. The rate of water replacement was 4.3 times per year, which is enough to affect the content of organic matter and impact the growth of water plants due to organic matter accumulation. The average total-P level for 1999–2013 was 315.0 $mg \cdot m^{-3}$, which only meets the class III water quality standard for the cultivation of freshwater fish, livestock, and landscaping irrigation.

The calculated pollution load of the reservoir was 29,405.1 $kg \cdot year^{-1}$, and the capacities in wet, normal, and dry years were 38,790.1, 25,991.9, and 23,929.0 $kg \cdot year^{-1}$. The pollution load is expected to be insufficient to accommodate the pollution caused by floating net cage activity. In wet years, the pollution load was higher than in normal and dry years. The P load could be higher in the wet season because of the dilution in the reservoir, which could reduce the pollutant concentration in the reservoir. In the dry years, the P load is expected to be minimized.

This study really can be used to determine the water quality of water body such as river or reservoir in many area which have the wide range of rainfall and discharge from high until low discharge, especially area in tropical zone with two seasons (rainy season and dry season). Besides, formula calculation of phosphorus concentration in this research will be useful for assessing the water quality of reservoir which more utilized as floating net cages. The usage of reservoirs as floating net cages was mostly done in developing countries.

REFERENCES

AUBERT A.H., GASCUEL-ODOUX C., MEROT P. 2013. Annual hysteresis of water quality: A method to analyse the effect of intra and inter-annual climatic condition. Journal of Hydrology. Vol. 478 p. 29–39.

Balai Penelitian dan Pengembangan, kementrian kelautan dan peikanan, Indonesia [Research and Development Agency of Ministry of Marine Affairs and Fisheries Indonesia] 2015.

COSTA-PIERCE B.A. 1998. Constraints to the sustainability of cage aquaculture for resettlement from hydropower dams in Asia: An Indonesian case study. The Journal of Environment and Development. Vol. 7. Iss. 4 p. 333–363

FARES Y.R., YUDIANTO D. 2003. Assessment of hydrological characteristics in the Upper Citarum Catchment West Java. Ecology and the Environment. Vol. 60 p. 165–176.

Government Regulation of the Republic of Indonesia Number 82 Year 2001 regarding Management of Water Quality and Control of Water Pollution.

HART B.T. VAN DOK W., DJUANGSIH N. 2002. Nutrient budget for Saguling Reservoir, West Java, Indonesia. Water Research. Vol. 36 p. 2152–2160.

KAZI T.G., ARAIN M.B., JAMALI M.K., JALBANI N., SARFRAZ R.A., BAIG J.A., SHAH A.Q. 2009. Assessment of water quality of polluted lake using multivariate statistical technique: A case study. Ecotoxicology and Environmental Safety. Vol. 72. Iss. 2 p. 301–309.

LAI Y.C., TU Y.T., YANG C.P., SURAMPALLI R.Y., KAO C.M. 2013. Development of a water quality modeling system for river pollution index and suspended solid loading evaluation. Journal of Hydrology. Vol. 478 p. 89–101.

MARGANINGRUM D. 2013. Manajemen Sumberdaya Air Terpadu Waduk Saguling dalam Rangka Pengembangan SPAM Regional KSN Cekungan Bandung. PhD Thesis. Bandung. Institut Teknologi.

MARSELINA M., SALAMI I.R.S.S., MARGANINGRUM D. 2017. Primary pollutant selection and determination of water quality index in class discharge division based on three class Markov model. International Journal of Geomate. Vol. 13. Iss. 38 p. 89–96.

NASTITI A.S., KRISMONO KARTAMIHARJA E.S. 2001. Impact of fish cultivation floating net cages of increament N and P elements in Saguling, Cirata and Jatiluhur Reservoir. Journal of Indonesian Fisheries Research. Vol. 7. Iss. 2 p. 22–30.

Peraturan Menteri Negara Lingkungan Hidupnomor 28 Tahun 2009 tentang Daya Tampung Beban Pencemaran Air Danau dan/atau Wadukmenteri Negara Lingkungan Hidup [Regulation of the Ministry of Environment Indonesia Number 28 of 2009 about pollution lake or reservoir] [online]. [Access 31.07.2017]. Available at: http://komara.weebly.com/peraturan-lingkungan/permen-lh-no-28-tahun-2009-tentang-daya-tampung-beban-pencemaran-air-danau-danatau-waduk

SINGH K.P., MALIK A., MOHAN D., SINHA S. 2004. Multivariate statistical techniques for the evaluation of spatial and temporal variations in water quality of Gomti River (India): Water Research. Vol. 38 p. 3980–3992.

Mariana MARSELINA, Muhamad BURHANUDIN

Ładunek fosforu i zdolność do samooczyszczania zbiorników wodnych w warunkach tropikalnych według klas ilości wody

STRESZCZENIE

Zbiornik Saguling z wielkością odpływu sięgającą 1622 $dm^3 \cdot s^{-1}$ może być źródłem wody dla zespołu miejskiego Bandung. Niezbędne są jednak badania, by stwierdzić, czy jakość wody spełnia krajowe normy. W przedstawionych badaniach wykazano, że średnie stężenie fosforu w latach 1999–2013 wynosiło 315,0 $mg \cdot m^{-3}$. Ta wielkość mieści się w III klasie rządowych norm i jest odpowiednia do chowu i hodowli ryb, pojenia zwierząt i nawadniania. Nie spełnia jednak norm I klasy (200 $mg \cdot m^{-3}$) dla wody pitnej. Stężenie całkowitego fosforu w latach wilgotnych, normalnych i suchych wynosiło odpowiednio 796,3, 643,8, i 674,8 $mg \cdot m^{-3}$. Ładunek zanieczyszczeń był najwyższy w latach wilgotnych z powodu dużej ilości osadów dennych. Ładunek zanieczyszczeń doprowadzanych do zbiornika nie przekraczał normy dla III klasy równej 29 405,01 $kg \cdot rok^{-1}$.W latach wilgotnych, normalnych i suchych ładunki te wynosiły odpowiednio 38 790,1, 25 991,9 i 23 929.0 $kg \cdot rok^{-1}$. Zanieczyszczenie fosforem spowodowane jest używaniem pływających sadzów na ryby, co utrudnia osiągnięcie norm jakościowych. Ładunek fosforu mógł być wyższy w deszczowej porze roku z powodu dużej ilości wody, co prawdopodobnie było przyczyną mniejszego stężenia zanieczyszczeń w zbiorniku.

Słowa kluczowe: *jakość wody, ładunek zanieczyszczeń, zanieczyszczenie fosforem, zbiornik*