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Corrosivity in A West Java Reservoir Correlated with Fish Farms and Watershed Runoff

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Abstract. Cirata Reservoir, which has multiple uses including hydroelectric power for Java and Bali, is subject to environmental pressure from fish farms in its waters and human activities upstream. Corrosivity expressed as an index, LSI, was assessed four times yearly in 2013–2017 in the reservoir and in seven tributaries. Fish cages were also counted in the reservoir in 2007, 2011, 2014, 2016, and 2018. In the reservoir, yearly mean LSI in a fish farm area declined overall from -0.83 to -1.96 in 2013–2017, but quarterly values in 2015–2016 ranged from -2.6 to -0.31. Similarly upstream in the reservoir's watershed, the yearly mean LSI of seven tributary rivers declined unsteadily in 2013–2017 from -0.77 to -1.55, but quarterly LSI during 2015–2016 in the Citarum River, largest tributary, ranged from -2.4 to +0.68. Although watershed runoff may thus account for the reservoir's corrosivity, several findings implicate fish farming increase the corrosivity even more. The number of floating net cages for fish culture nearly doubled in the past decade, from 53,031 plots in 2011, through 68,461 plots in 2014 and 77,195 plots in 2017, to 98,397 in 2018. The reservoir was previously estimated to have an environmental carrying capacity of 12,000 plots. Biological oxygen demand tends to increase in the vicinity of floating net cages.

1. Introduction

Saguling, Cirata, and Jatiluhur reservoirs successively impound the Citarum River in West Java, Indonesia. Cirata Reservoir, the main focus of this report, receives about 70% of its water from the Citarum River and most of the rest from the Cikundul, Cibalagung, Cilaku, Cisokan, Cicendo, and Cilangkap Rivers. The reservoir has a maximum area 65.6 km² and a water capacity of 2 billion m³. Its most important function is to provide hydroelectric power to Java and Bali with an installed capacity of 1008 megawatts [1]. In addition, the reservoir also functions as a place of aquaculture, agriculture, controlling water discharge, water transportation, tourism and other functions.

Since its completion in 1988, Cirata Reservoir has experienced environmental pressure from human activities and their effects. These include land use changes around reservoirs and watersheds, various economic activities of communities in the watershed, and global climate change and associated extremes in weather. Together these effects threaten the reservoir's reliability as a source of hydroelectric power. Power generation and its safety will be compromised by decreased storage capacity related to sedimentation, damage to hydromechanical-electrical equipment, and weathering of concrete caused by degradation of water quality.



In addition to domestic and industrial wastes and agricultural waste from the watershed, Cirata Reservoir has also been affected by expansion of fish farming in floating net cages. The organic matter from the farms is capable of lowering the pH of reservoir waters, leading to corrosiveness that threatens the sustainability of electricity generation and increasing maintenance operational costs. To assess this internal threat, we studied the corrosivity of the reservoir and its tributaries, in relation to the recent growth of fish farming.

2. Methods

Calculation of the number of floating net cages in the Cirata Reservoir was carried out by means of a census in all waters of the Cirata Reservoir. The census included parts of three entities: Purwakarta Regency, West Bandung Regency, and Cianjur Regency. The census was carried out in 2007, 2011, 2014 and 2017 by means of data collection on owner's identity and calculation of floating net cages plot numbers. In addition, to update the floating net cages census to 2018, secondary data was traced from the existing literature.

To assess corrosivity we measured acidity, pH, and biological oxygen demand, BOD. We calculated the Langelier Saturation Index, or LSI, as $\text{pH} - \text{pH}_s$, where pH is the acidity measured and pH_s is pH saturation, that is, if there is an equilibrium of salt of CaCO_3 with Ca^{2+} ions and HCO_3^- ions [2]. We measured BOD because it is a pollution indicator, as determined by [3].

Measurement and sampling were carried out for a period of 5 years, from 2013 to 2017. The data were obtained quarterly, at intervals of 3 months. For watershed data we measured samples from each of seven river mouths just outside the reservoir—the mouths of the Cikundul, Cibalagung, Cisokan, Citarum, Cicendo, Cilangkap and Cilaku Rivers (figure 1). For the reservoir itself, we measured water samples in two places: the center of the reservoir among floating net cages, and an area close to the power intake (figure 1). The degree of corrosivity is categorized as in table 1.

Table 1. LSI indication based on improved Langelier by Carrier (1965) [4].

LSI	Indication
-2.0<-0.5	Serious corrosion
-0.5<0	Slightly corrosion but non-scale forming
LSI = 0.0	Balanced but pitting corrosion possible
0.0<0.5	Slightly scale forming and corrosive
0.5<2	Scale forming but non corrosive

3. Floating Net Cages Fish Farming and Biological Oxygen Demand

Freshwater fish farming in the floating net cages in Cirata Reservoir began in 1988 with a total of 78 plots. A typical floating net cage has a surface area of 7 x 7 square meters (m^2) and a depth of 3–4 meters. Common fish seeds planted in this farming include Carp (*Cyprinus carpio*) and Tilapia (*Oreochromis niloticus*).

With a high level of production and very cheap rent cost and sufficient security, the use of floating net cages in Cirata Reservoir has grown rapidly (figures 2, 3), far beyond the reservoir's reported carrying capacity. From the census carried out, during the last 4 periods, the number of floating net cages increased as follows: 2007, 51,418 plots; 2011, 53,031 plots; 2014, 68,461 plots; 2017, 77,195 plots; and June 2018, 98,397 plots [5]. The carrying capacity Cirata Reservoir has been estimated as 12,000 plots [6].

Although fish farming in the Cirata Reservoir benefits the local economy by providing food and jobs, the floating net cages can cause environmental harm. Most of their impacts can be mitigated by applying appropriate policies that limit the water area allocated for floating net cages [7]. However, the fishery has now gone so far beyond the reservoir's estimated carrying capacity that adverse effects can be expected. These include sedimentation of organic matter that increases BOD and consequently makes the waters more acidic. Excessive fish farming may thus contribute to corrosion to the hydropower plant equipment and to the concrete of the reservoir dam.

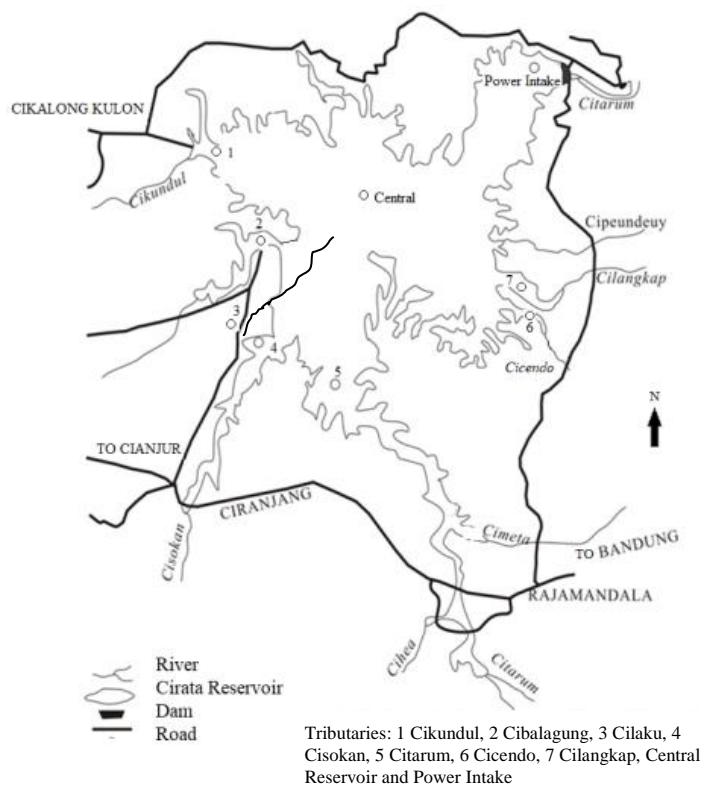


Figure 1. Sampling locality for water analyses.



Figure 2. Floating net cages fish farming in Cirata Reservoir.

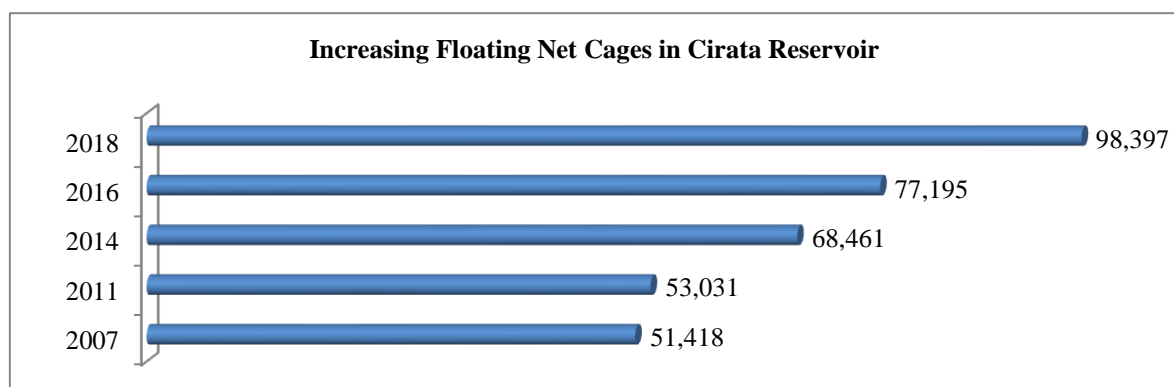


Figure 3. Significant increase of floating net cages in Cirata Reservoir from 2007 to 2018.

BOD data from 2013–2017 are available from three sites: the mouth of the Citarum River, the central part of the reservoir (floating net cages area), and power intakes. The results show that BOD has increased through time, and that greatest increase occurred at the floating net cages area. BOD in this central part of the reservoir, measured in the third and fourth quarters of 2017, reached 10.78 mg/l and 7.5 mg/l. According to PP No. 82 of 2001 [8], the quality standard set for fisheries is a maximum of 6 mg/l, meaning that the value is above the quality standard. Such high values of BOD, as an indication of oxygen demand, are consistent with the presence of organic matter from the floating net cages. High BOD values are typically associated with unpleasant odors and unhealthy waters. BOD tends to rise with environmental conditions that are favorable for microbiological activity in warm

water. BOD is directly related to the decomposition of dead organic matter in lakes, hence higher BOD values can be directly correlated with pollution status and have an inverse relationship with dissolved oxygen (DO) concentrations [9]. In low DO conditions, the activity of anaerobic decomposers bacteria is more intensive, so the concentration of NH_3 , H_2S and aggressive CO_2 in the reservoir is higher. The high concentration of H_2S and CO_2 in water will increase the acidity of the water (the pH value becomes low) and cause the corrosive water to rise [10, 11].

High BOD in Cirata Reservoir can be linked to the corrosivity data considered next. In brief, this data shows overall decreases in pH between 2013 and 2018 at the Citarum River mouth, in the central part of the reservoir, and at the power intake. High BOD and falling pH are common in the floating net cages area, as well as in the power intake. These findings associate floating net cages fish farming activities with potential for corrosion of dam equipment.

4. Corrosivity

4.1. Corrosivity of Tributary Rivers

The LSI data from the mouths of the seven sampled tributaries the Cikundul, Cibalagung, Cilaku, Cisokan, Citarum, Cicendo, and Cilangkap Rivers show an overall decline in 2013–2017. During these 5 years, the seven rivers showed a trend of decline in LSI. The LSI of the annual average of 7 rivers during the period of 2013 to 2017 is -0.77, -0.52, -1.16, -0.56, -1.55 respectively which indicate a serious level of corrosion. The average 5-year LSI value is 0.91 or is at a serious level of corrosion. These increases in corrosivity of water correlate with the human activities the reservoir's watershed.

The LSI data is particularly important from the Citarum River as the reservoir's main tributary. The annual average from 2013 to 2017 LSI values at the Citarum River mouth, at its entrance into Cirata Reservoir, shows a continuing downward trend, which are -0.65, -0.4, -1.07, -0.5 and -1.54 respectively with an average 5 years of -0.83. This value also indicates a serious level of corrosion. However, quarterly LSI during 2015–2016 in the Citarum River, largest tributary, ranged from -2.4 to +0.68.

Because the Citarum's inflow to the Cirata Reservoir consists of outflow from Saguling Reservoir, water quality in the Cirata Reservoir depends largely on the conditions in Saguling Reservoir. Saguling Reservoir receives water from surrounding watersheds, especially from the Citarum River, that has been polluted by domestic waste and industrial waste. This waste has exceeded the carrying capacity of Saguling Reservoir [12].

4.2. Corrosivity of Cirata Reservoir

Increasing corrosivity in Cirata Reservoir between 2013 and 2017 is further evidenced by a downward LSI trend in the central part of the reservoir waters around the floating net cages activities. Annual average LSI in this location from 2013 to 2017 is -0.83, -0.55, -2.13, -1.16, -1.96 with a five-year average of -1.32, but quarterly values in 2015–2016 ranged from -2.6 to -0.31. This LSI value is much lower than the average value of 7 rivers including the Citarum River and can be stated to have a serious corrosive. This serious corrosive condition has a profound effect on the damage to hydromechanical-electric devices and concrete dam. In the power intake area, the corrosive conditions are similar to those in the central part of floating net cages area. The annual corrosivity average values from 2013 to 2017 are -0.86, -0.57, -1.90, -1.06, -1.88 respectively with an average 5 years of -1.26 or a serious corrosive level.

To observe the corrosive conditions in Cirata Reservoir more clearly, a cross section of the corrosive value of three observation sites was made, namely the Citarum River mouth, the central part of the reservoir (floating net cages area) and the power intake area where the power plant equipment and concrete buildings were located. The results are shown in figure 4. The figure shows that LSI fluctuates but declines overall at each of the three observation sites. From the figure it can be seen that the water input from the Citarum River, already weakly corrosive in 2013, reached a serious level of corrosiveness in the 5 years from 2013 to 2017. At the same time, due to activity and rapid increase in

the number of floating net cages in the reservoir, corrosivity in the central part of the reservoir shows a serious corrosive level since 2013, with LSI declining overall into 2017. In the power intake area, the water corrosion condition is similar to that of the central part of the reservoir. Overall, these conditions indicate that the increase in the number of floating net cages and the effects of other human activities has significantly increased the water corrosion of the Cirata Reservoir. The LSI value even in 2015 reached -2.4 in the Citarum River inflow and in the central part of the reservoir and even the LSI value in the power intake area extended to -2.9 which indicate that the corrosion of reservoir water has a very serious corrosive level.

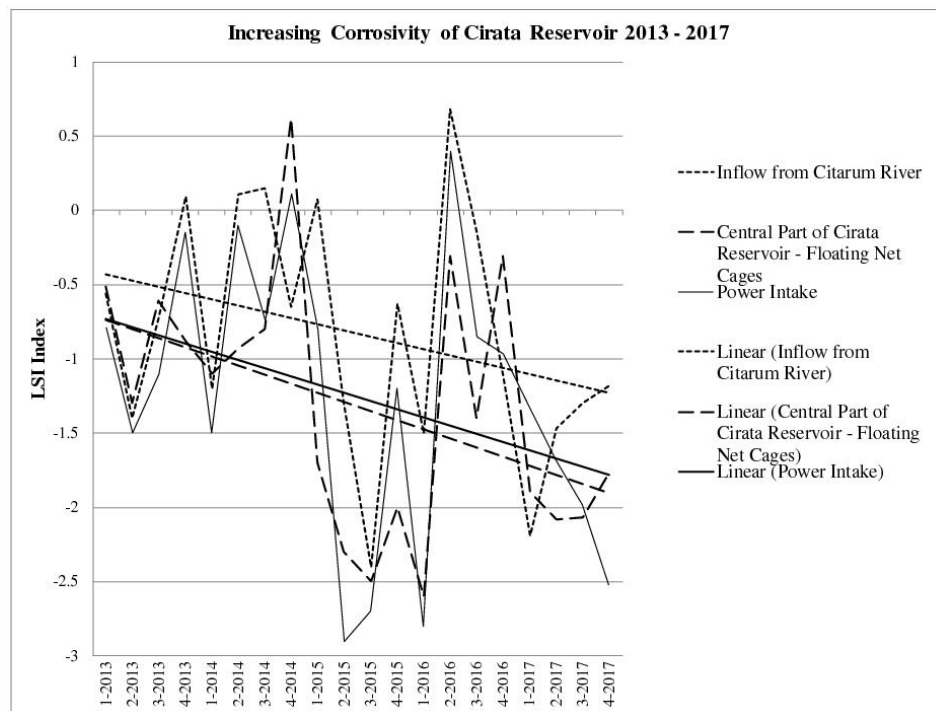


Figure 4. Quarterly fluctuations of LSI and the downtrend LSI value or increasing corrosivity of Cirata Reservoir from 2013 to 2017.

Detrimental effects on power production can be anticipated from these and other findings. In Jatiluhur Reservoir, a reservoir downstream from Cirata Reservoir, it was found that the lower the LSI value, the greater the level of corrosion that occurs in the heat exchanger pipe and utility material in the reservoir [13]. In addition to corrosion caused by water, corrosion also occurs due to atmospheric conditions. Based on research conducted in the power intake area and its surroundings by [14], it is known that atmospheric corrosion also occurs with low to moderate levels. The biggest corrosion occurs in the tailrace area or power plant outlet. Corrosion from the atmosphere is likely because domestic waste and floating net cages activities produce organic material that will react to produce H_2S gas which is then released into the air, where it reacts with metals and causes corrosion. The sustainability of the Cirata Reservoir is thus influenced by the floating net cages fish farming, and it is recommended to limit the number of floating net cages, improve the structure of the selling price, law enforcement and increase the firmness of the officer against violations [15].

5. Conclusions

The corrosivity of water of the Cirata Reservoir continues increased overall in 2013–2017. This increase threatens the sustainability of the reservoir as a supplier of hydroelectric power in Java and Bali. Much of the increased corrosivity appears to be derived from the reservoir's largest tributary. However, increased corrosivity in the reservoir water correlates also with an increase in fish farming.

To reduce the reservoir water corrosion, a reduction of the number of floating net cages in the waters of Cirata Reservoir is needed. In addition, recovery and pollution reduction efforts must also be made to watersheds that are directly related to reservoirs and even in watersheds that are far from the Cirata Reservoir, namely in the watershed of the Saguling Dam and in the upstream of Citarum River. Integrated, regional efforts and their consistent implementation are thus needed to improve water quality and reduce water corrosivity in Cirata Reservoir.

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