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Metal Concentrations and Bio-Concentration Factor (BCF) in Surface Water and Economical Fish Species from Wadaslintang Multipurpose Dam, Wonosobo, Indonesia

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Abstract. Changes in land use and increasing anthropogenic activities in the catchment area of the Wadaslintang Reservoir have the potential to pollute the water. One of the pollutants that have an impact on human health is heavy metals. This study aimed to analyze the concentrations of heavy metals cadmium (Cd), lead (Pb), copper (Cu), and zinc (Zn) in surface water and some economical fish, and to calculate bioconcentration factors. The samples were taken by a purposive random sampling method at the research station that represents the area of floating net cages, dam inlets, and outlets. Fish samples were obtained from fishers and floating net cage farmers. The analysis showed that the average concentration of heavy metals in fish was relatively higher than the concentration in water. The range and average concentrations of Pb, Cd, and Cu in water have exceeded the second class quality standards of the Government Regulation of the Republic of Indonesia Number 82 of 2001. The concentration of heavy metals and cadmium in fish samples has exceeded the maximum limit of heavy metal contamination based on SNI 7387: 2009. Based on the bioconcentration factor (BCFo-w) value, and the concentration of heavy metals in the fish showed the ability of fish to accumulate heavy metals in water in the order of Zn> Cd> Cu> Pb.

1. Introduction

The Wadaslintang Dam is open water with a coverage area of 14.6 Km2 located in Wonosobo Regency, Central Java Province, Indonesia. This dam has possibly exposed by pollution due to anthropogenic activities from the catchment area and reservoir bodies [1]. Heavy metal pollution was reported in the Wadaslintang dam that would impact the organisms and people who consume fish from these waters. Some heavy metals such as Lead (Pb), Cadmium (Cd), Copper (Cu), and Zinc (Zn) are a significant concern in most countries [2]. The Bioconcentration Factor (BCF) can be used to calculate the ratio of the pollutant concentration to an organism in its environment [2]. Bioconcentration and biomagnification processes can cause adverse effects in fish, even at low exposure because metals integrate into important protein synthesis reactions and result in disruption of vital processes [3].

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The Wadaslintang Dam is a water resource that is used by some local people for drinking, income for fishers, and fish cultivation using a floating net cage. This study aimed to determine the concentration of heavy metal lead (Pb), zinc (Zn), copper (Cu), and cadmium (Cd) in surface water, and fish in the Wadaslintang Reservoir as well as to calculate the metal bioconcentration factor in fish.

2. Methods

2.1. Sampling and Sample Collection

The samples were collected by mean of a purposive sampling method taken at one-meter depth. Fish samples were collected using nets (mesh size > 3 inches) in the fishing areas, then placed them in a sterile polyethylene bag, and stored in an icebox. Heavy metal concentrations were analyzed using the Atomic Absorption Spectrophotometer (AAS).

Table 1. The stations of water sampling

No	Station		Geographical positions
1	Reservoir inlet (estuary of four major rivers that enter the reservoir)	(Inlet)	E 109⁰47’15.2” – S 07⁰34’14.8”
2	The floating net cage area belongs to the community	(FNC)	E 109⁰47’18.0” – S 07⁰35’19.5”
3	The floating net cage area owned by a private company	(FNPC)	E 109⁰47’04.2” – S 07⁰36’32.5”
4	The central area of the reservoir	(CR)	E 109⁰46’47.5” – S 07⁰34’58.2”
5	Reservoir outlet (near Spillway)	(Outlet)	E 109°46’58.0” – S 07°36’32.0”

2.2. Data Analysis

The data were analyzed based on the quality standards of the Republic of Indonesia Government Regulation Number 82 of 2001 [4] and WHO [5]. The bioconcentration factor was calculated using the following formula.

$$BCF = \frac{Corg}{Cwater}$$

Corg : concentration of heavy metals in organisms
Cwater : concentration of heavy metals in water
BCF < 100 = low accumulation
100 < BCF < 1000 = medium/moderate accumulation
BCF > 1000 = high accumulation [6]

The contamination factor (CF) was calculated using a formula as follows [7]:

$$C_f^i = \frac{C_{0-1}^i}{C_n^i}$$

C_{0-1}^i = average concentration of heavy metals from each sampling station
C_n^i = the maximum permitted limit according to [5]

$C_f^i < 1$ = low contamination factor
$1 \leq C_f^i < 3$ = moderate contamination factor
$3 \leq C_f^i < 6$ = considerable contamination factor
$6 \leq C_f^i$ = very high contamination factor [7]

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3. Results

3.1. Concentrations of metals in surface water

The concentration of heavy metals in surface water varies significantly at each station (Figure 1), Cd was 20.00% (0.019 ppm), Zn 24.21% (0.023 ppm), Cu 23.16% (0.022 ppm) and Pb 32.63% (0.031 ppm). The concentration of heavy metal copper (Cu) in surface water in Wadaslintang Reservoir ranged from 0.014 to 0.036 ppm, with an average concentration of 0.022 ppm.

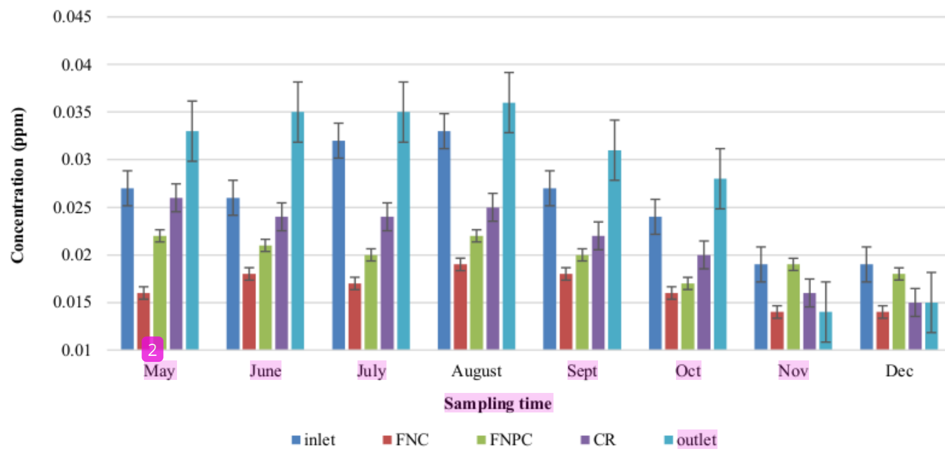

Figure 1. Cu concentration in surface water in Wadaslintang Reservoir

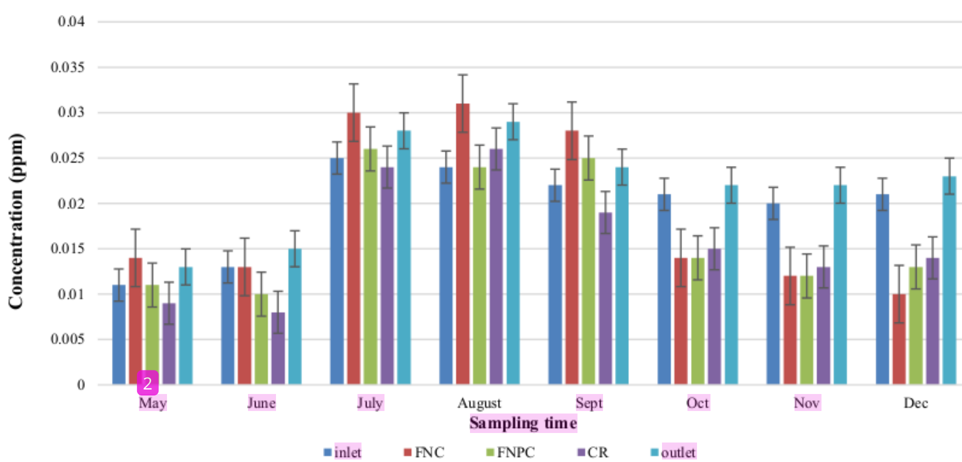

Figure 2. Cd concentration in surface water in Wadaslintang Reservoir

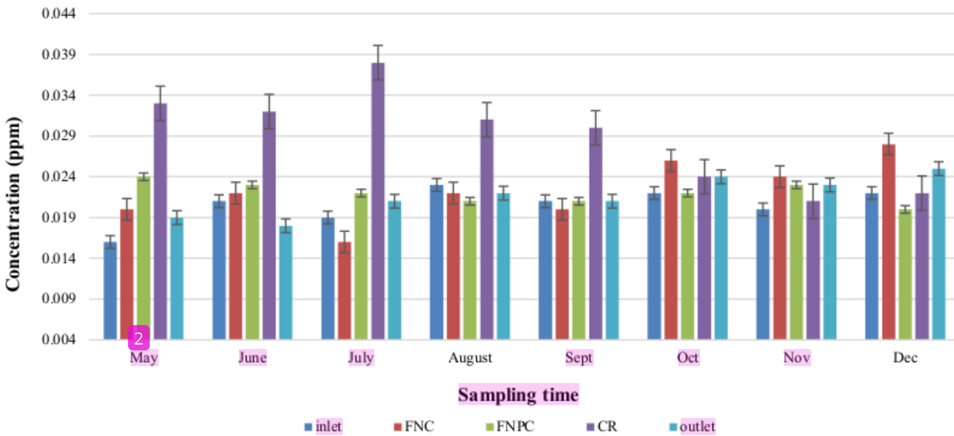

Figure 3. Zn concentration in surface water in Wadaslintang Reservoir

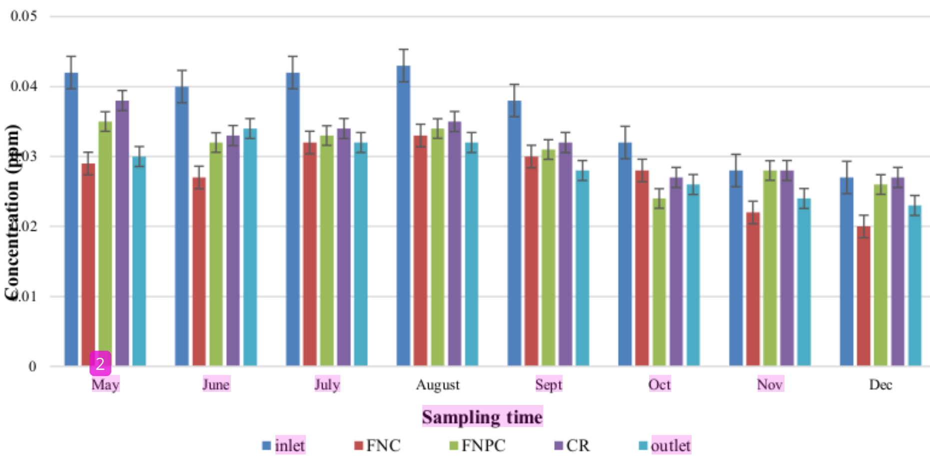

Figure 4. Pb concentration in surface water in Wadaslintang Reservoir

The results show the concentration of Cd in the Wadaslintang Reservoir ranges from 0.008 - 0.029 ppm, with an average concentration of 0.019 ppm. This concentration has exceeded the second-class quality standard Government Regulation of the Republic of Indonesia Number 82 of 2001 [4] at 0.01 ppm and WHO [5] at 0.003 ppm.

3.2. Metals concentrations of in fish

Heavy metal concentrations in fish are presented in Table 2. It showed the following order in nila fish, Zinc > Pb > Cu > Cd. The same order of heavy metal concentration, also, occurred in cultivated tilapia (*Oreochromis* sp) in floating net cages and tilapia (*Oreochromis niloticus*) from the reservoir. The order of concentration of heavy metals in betutu fish (*O. marmorata*) and catfish (*Pangasius pangasius*) was Zn > Pb > Cd > Cu. The highest concentration of heavy metal Zn was found in wild tilapia from the reservoir at 2.70 ppm, and the lowest concentration was in betutu fish (1.56 ppm). The highest Pb concentration was found in betutu fish (0.53 ppm), and the lowest was in wild tilapia from the reservoir (0.43 ppm). The highest Cd concentration was in betutu fish (0.38 ppm), and the lowest concentration in river tilapia was 0.18 ppm. The highest Cu concentration was found in tilapia from floating net cages (0.42 ppm), and the lowest concentration was found in catfish by 0.19 ppm.

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Table 2. The concentration of heavy metals in fish caught in the Wadaslintang Dam

Fish	Cu	Cd	Pb	Zn
Nila (*Oreochromis* sp) from the river mouth	0.25	0.18 [a)]	0.46 [a)]	2.33
Nila (*Oreochromis* sp) from FNPC	0.40	0.23 [a)]	0.44 [a)]	2.12
Nila (*Oreochromis* sp) from FNC	0.42	0.25 [a)]	0.46 [a)]	2.09
Nila (*Oreochromis* sp) wild from reservoir	0.37	0.36 [a)]	0.43 [a)]	2.70
Marble goby (*Oxyeleotris marmorata*) wild from reservoir	0.21	0.38 [a)]	0.53 [a)]	1.56
Catfish (*Pangasius pangasius*) wild from reservoir	0.19	0.22 [a)]	0.46 [a)]	1.67
SNI 7387:2009	-	0.1	0.3	-
BPOM No. 03725/B/SK/VII/89	20	1	2	2 - 100

Source: Primary data (2017)
[a)] : exceed the threshold Indonesian National Standard [8]
[b)] : exceed the threshold Indonesian Food and Drug Control Agency [9]

3.3. Contamination factor in surface water

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Contamination factors of heavy metal in surface water are available in Table 5. Contamination factors value of the heavy metals were as follows Cd > Pb > Cu and Zn. The most significant contamination factor of Cd was observed in the river mouth of Kemejing (8.46), classifying as very high contamination. In contrast, the lowest Cd metal contamination factor (5.29) was at the river mouth of Cengis. The contamination factor of heavy metals Cu and Zn was in the low contamination category.

Tabel 3. Contamination Factor of Heavy methal in Surface water

No	Station	Contamination factor (CF)			
		Cu	Cd	Pb	Zn
1	inlet	0.013 [a)]	6.54 [d)]	3.65 [c)]	0.007 [a)]
2	FNC	0.010 [a)]	5.63 [c)]	3.04 [c)]	0.007 [a)]
3	FNPC	0.008 [a)]	6.33 [d)]	3.01 [c)]	0.007 [a)]
4	CR	0.011 [a)]	5.33 [c)]	3.18 [c)]	0.010 [a)]
5	outlet	0.014 [a)]	7.33 [d)]	2.86 [b)]	0.007 [a)]

Source: Primary data (2017)
[a)] low contamination; [b)] moderate contamination; [c)] considerable contamination; [d)]very hight contamination

3.4. Bioconcentration factor (BCFo-w)

The bioconcentration factor is the ability of an organism to accumulate heavy metals. The higher the BCF value of certain metals is in the organism, the higher the organism in accumulating these heavy metals. Provisions for the accumulation of heavy metals are grouped into three, according to Van Esch [6], low, medium, and high. Table 4 presents the value of the organism's bioconcentration factor for water. The results of calculating BCF values, as presented in Table 4 showed that almost all fish have low accumulation, except wild tilapia caught in river mouths and wild tilapia from reservoirs for the heavy metal content of Zn which is the medium accumulation category. The highest BCF organism-water value of 16,201 in Cu was found in tilapia while the lowest values were in wild catfish (*P. pangasius*) caught from reservoirs (8,320). The highest BCF organism-water value for Cd was *betutu* fish (*O. marmorata*) (19,856), while the lowest value was in wild tilapia originating from rivers (9,406).

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Table 4. BCF organism-water in fish caught in the Wadaslintang Dam

Componen	**BCF (o-w)** Cu	**BCF (o-w)** Cd	**BCF (o-w)** Pb	**BCF (o-w)** Zn
Nila (*Oreochromis niloticus*) from floating net cage belongs to the community (FNC)	18.391	13.063	15.215	93.760
Nila (*Oreochromis niloticus*) from floating net cage owned by a private company (FNPC)	24.71	13.158	20.91	74.64
Wild Nila (*Oreochromis niloticus*) from the river	10.947	9.406	15.215	104.526
Wild Nila (*Oreochromis niloticus*) from a reservoir	16.201	18.811	14.222	121.125
Wild Marble goby (*Oxyeleotris marmorata*) from a reservoir	9.195	19.856	17.530	69.983
Wild Catfish (*Pangasius pangasius*) from a reservoir	8.320	11.496	15.215	74.918

Source: primary data (2017)

The BCF value calculation, as presented in Table 4 revealed that almost all fish have low accumulation, except for wild tilapia caught in river mouths and reservoir bodies, specifically for Zn content classifying as the medium accumulation. The highest BCF value for Cu (24.71) was in nila (*Oreochromis niloticus*) from a floating net cage owned by a private company (FNPC). The highest BCF value for Cd was in Wild Marble Goby (*O. marmorata*) from the reservoir, and for Pb was found in Nila (*Oreochromis niloticus*) from a floating net cage owned by a private company (FNPC). The fish can provide information about the condition of metal pollution in waters [10].

4. Discussion

Based on the Government of the Republic of Indonesia Regulation No. 82 of 2001 (class 2, by allotment for fisheries and irrigation activities), almost research stations showed that the concentration of heavy metals had exceeded the specified quality standards. Similarly, Cd and Pb concentrations of all stations have exceeded the quality standard except Cu and Zn [5]. It suggested that heavy metals have contaminated the Wadaslintang Reservoir. The presence of heavy metals in waters can threaten the survival of aquatic organisms even in humans who consume these organisms [11]. Cd and Pb are high-risk impacts on human health; at high concentrations, they can cause death, while at low concentrations, they tend to accumulate [12]. The difference in the concentration of heavy metals in surface water from all research stations is influenced by various factors, including the origin of pollutant sources, the level of pollutant concentration, water flow, mixing of water masses, and the nature of pollutants. The solubility of heavy metals in water also depends on water quality. In waters rich in organic matter, the concentration of heavy metals in water is generally lower because of the low dissolved oxygen content.

It showed that the concentration of Cu in the Wadaslintang Reservoir was still below WHO provisions [5], which is 2 ppm. However, based on the provisions of PPRI No. 82 of 2001, almost all research stations showed the concentration of Cu had exceeded the second-class quality standard, except for the floating net cage cultivation area, which was managed by the community. The highest Cu concentration of 0.036 ppm was found in the outlet area, while the lowest concentration of 0.014 ppm was found in the area of floating net cage cultivation that was managed by the community. The high concentration of Cu in the outlet area is due to the flow of water that tends to lead to the outlet that brings with it dissolved Cu. In November and December, Cu concentrations in all sampling stations were below the quality standard, due to the increase in reservoir water volume, resulting in dilution of the heavy metal concentrations.

The highest Cd concentration range was at the outlet. Zn concentrations in the Wadaslintang Reservoir ranged from 0.016 to 0.036 ppm, with an average concentration of 0.023 ppm. The highest concentration was in the center of the reservoir, while the lowest concentration was in the inlet. The results showed that the concentration of Zn in most sampling stations had exceeded the second-class quality standard Government Regulation of the Republic of Indonesia Number 82 Year 20011 of 0.02 ppm. The maximum limit of Zn concentration based on WHO [5] is 3 ppm; thus, the Zn concentration in the Wadaslintang Reservoir was still in the safe category. The lead concentration (Pb) in all sampling stations in the Wadaslintang Reservoir was above WHO [5], which was 0.01 ppm. However, based on the provisions of the Government of the Republic of Indonesia, namely Government Regulation No. 82 of 2001, of the five research stations, only three showed an average concentration above the quality standard (0.03 ppm). The analysis showed that the highest Pb concentration of 0.043 ppm was found in the reservoir inlet, while the lowest concentration of 0.020 ppm was found in the community-owned Karamba area. The high concentration of Pb in the inlet area came from community activity waste in the DTA and watershed, including from domestic waste, agricultural waste (insecticides, pesticides), detergents, industrial waste, and fuel.

The presence of heavy metals in water will affect the concentration of heavy metals in aquatic organisms because of the process of biomagnification and the biological accumulation process (bioaccumulation). The biomagnification process occurs through food chain activities that occur between organisms, while the accumulation process can occur directly through the absorption process in these aquatic organisms. The concentration of heavy metals in aquatic organisms varies greatly depending on the concentration of heavy metals in the habitat of the organism, life cycle, eating habits, age, and growth rate of the organism.

Based on [8] the Indonesian National Standard (SNI: 7387; 2009), the maximum concentration of heavy metals in fish and its processed products for Cd is 0.1 ppm, and Pb is 0.3 ppm. It shows that all fish samples caught by fishermen in the Wadaslintang Dam have concentrations of Cd heavy metals and Pb above the applicable provisions. Whereas, based on the provisions of BPOM No. 03725 / B / SK / VII / 89, all fish samples caught by fishermen in the Wadaslintang Dam are still below the applicable provisions. According to [13], the maximum concentration for fish consumption per day is 0.05 - 0.15 mg / day for Cd and 0.2 - 0.3 mg / day for Pb.

Zinc is an essential element for organisms because it is needed in enzymatic activity. The concentration of Zn in the body can reduce the adverse effects of the presence of lead in the body, however, if the concentration exceeds provisions, Zn can harm the function of organs where heavy metals accumulate. In Wadaslintang Reservoir, zinc concentration in water has exceeded the minimum class II criteria for quality standards, according to Government Regulation No. 82 of 2001. The concentration of zinc in tilapia has exceeded the minimum requirements based on the Food and Drug Supervisory Agency Number 03725 / B / SK / VII / 89. It is because several factors are affecting heavy metal concentration in fish, including fish exposure time, the concentration of heavy metals in the environment/fish habitat, fish size, eating habits, eating habits, and location/distance of pollutant sources. The accumulation of biological heavy metals into fish bodies, among others, depends on the physiological conditions of each fish species, type and source of feed, and the specifications of the toxicological properties of each heavy metal [13].

5. Conclusion

The average concentration of heavy metals in fish was relatively higher than the concentration in water. The concentrations of Pb, Cd, and Cu in water have exceeded the second class quality standards of the Government Regulation of the Republic of Indonesia Number 82 of 2001. The concentration of heavy metals and cadmium in fish samples has exceeded the maximum limit of heavy metal contamination based on SNI 7387: 2009. Based on the bioconcentration factor (BCFo-w) and the concentration of heavy metals in the fish shows the ability of fish to accumulate heavy metals are Zn> Cd> Cu> Pb, respectively.

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