Bioaccumulation of chromium in the cultivation of *Oreochromis niloticus* and *Clarias gariepinus* in Bantul District, Yogyakarta, Indonesia

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Abstract. This study aims to determine the concentration of chromium contaminants in water and sediment and the accumulation level in *Oreochromis niloticus* and *Clarias gariepinus* cultivated in ponds downstream of Opak River, Indonesia. The observational method was used by measuring the bioaccumulation level in fish from different locations. Water, sediment, and fish samples were collected monthly from April to June 2022 to coincide with the dry season. The samples were collected randomly from cultivation ponds that received the Opak River flow in Banguntapan, Piyungan, Jetis, Pundong, and Kretek Sub-districts. Sampling and preparation of water, sediment, and fish samples were carried out. Cr concentration measurement in samples was performed using atomic absorption (AAS). The results showed that the *O. niloticus* and *C. gariepinus* cultivation ponds in the four study areas were contaminated with Cr, with the levels of 0.05 mg L^{-1}. The average concentration of Cr contaminants was consistently higher in pond sediment (1.084 mg kg^{-1} in O. niloticus ponds and 0.873 mg kg^{-1} in C. gariepinus ponds) than in pond water (0.207 mg L^{-1} in *O. niloticus* ponds and 0.132 mg L^{-1} in *C. gariepinus* ponds). *O. niloticus* and *C. gariepinus* samples from the four study areas were contaminated and accumulated Cr contaminants with a range and mean of 0.188-0.330 and 0.257 for *O. niloticus* and 0.191-0.516 and 0.278 for *C. gariepinus*. Compared to *O. niloticus, C. gariepinus* had a higher accumulation, but the levels in both species were below the safe limit for food, namely 2.5 mg kg^{-1}. The concentration of Cr contaminants in water samples was not significantly different between the control and treatment ponds ($p<0.05$). However, there was a significant difference between the Cr levels in the sediment and fish samples ($p>0.05$). The range of Cr bioaccumulation factor (BAF) in *C. gariepinus* was higher (0.251-0.411) compared to *O. niloticus* (0.184-0.388).

Key Words: contamination, fishes, Opak River sediment, water.

Introduction. Freshwater ecosystems, such as rivers, lakes, swamps, ponds, and others, are vital components of human life on Earth (Biggs et al 2017). Furthermore, they play a significant ecological role in maintaining ecosystem health, supporting the economy, and providing habitats for biota. They also support the way of life of various human populations worldwide (UNEP 2016). Rivers, in particular, are open and complex ecosystems vulnerable to contamination. The close relationship between these waterbodies and human activities affects them due to excessive exploitation and increased population growth. Since the beginning of the industrial revolution, river contamination through various untreated wastewater disposal activities has disrupted the economy (Hostetter 2006). Data from UNEP (2016) and WWDR (2017) also showed that in some developing countries in Asia, only 8% and 28% of wastewater was treated before being discharged.

Without good environmental management, the Piyungan Industrial Area may increase environmental and public health risks. The liquid waste disposal activities from this area, specifically tanning industries, have been proven to distribute heavy metals, such as chromium (Cr), widely across various environmental components, including river water, sediment, soil, well water, and various aquatic plants and animals (Rahardjo & Prasetyaningsih 2017). Previous studies reported that continuous waste disposal significantly contributes to the increase in Cr concentration in river water, sediment, fish, and rice in the downstream area of Opak River (Rahardjo et al 2021a; Rahardjo et al 2021b). Although the accumulation level of this metal in fish was below the toxicity threshold for biota and the environment, long-term consumption of Cr-contaminated fishery products can potentially cause health problems (Rahardjo et al 2021a). Furthermore, Cr contaminants have been widely distributed in river water, irrigation channels, and rice fields in the downstream areas of the Opak River (Rahardjo et al 2021b). The high concentration of this metal was reported in rice plants (1.0105-6.2870 mg kg^{-1}), paddy soil (1.2062 mg kg^{-1}), river sediment (0.7126 mg kg^{-1}), irrigation water (0.2393 mg L^{-1}), and river water (0.0188 mg L^{-1}).

The widespread distribution of Cr and its increasing concentration and accumulation in various environmental components downstream of Opak River pose a potential threat to the environment, fisheries, and public health. It indicates that using the river and its contaminated irrigation channels for fishery can cause complex problems related to product quality, food security, and public health. Fish are important components in the food chain of aquatic ecosystems and can accumulate large amounts of contaminants from contaminated water (Sonone et al 2021). Although several studies have been conducted on heavy metal contamination and its effects on river ecosystems and fish, only a few have focused on ponds. Therefore, this study aims to determine the level of Cr contamination in water, sediment, tilapia, and catfish, as well as the bioconcentration and bioaccumulation factors of the metal in fish.

Material and Method

Description of the study sites. The study measured the level of Cr contamination in water, sediment, and fish carcass. The fish samples were randomly collected from each breeding group selected as a representation from the sub-districts that received the Opak River flow, namely Piyungan, Jetis, Pundong, and Kretek. There were two species selected, namely *C. gariepenus* and *O. niloticus*, these having the highest production in Bantul Regency (Department of Marine and Fisheries 2021). A sampling of water, sediment in aquaculture ponds, and fish at each research station was conducted every month from April to June 2022.

The control in this study was represented by the fish cultivation ponds from the Piyungan Sub-district. Although these areas received water flow from the Opak River, they were not affected by liquid waste discharge from the Piyungan industrial area. Meanwhile, fish cultivation ponds in Jetis, Pundong, and Kretek sub-districts received contaminated liquid waste. The location of the control ponds was only 1-2 km away from the industrial area. Sampling stations were located in the sub-districts of Piyungan, Jetis, Pundong, and Kretek (Figure 1).

Preparation, extraction, and analysis of samples. Water, sediment, and fish samples were collected monthly from April to June to coincide with the dry season. Sediment samples were cleaned with water and separated from other impurities. The clean samples were filtered, and 2 g were weighed for extraction. In the fish preparation process, the muscle tissue was used because it serves as the primary site for metal storage and is often consumed. The muscle tissue was cut using a stainless-steel knife and separated from the skin and bones. Subsequently, the samples were oven-dried at 60°C until they had a water content of approximately 10% and pulverized with a mortar. 100 mL of water samples were prepared, and 10 mL of concentrated HNO_3 was added for extraction. The mixture was heated on a stove to a volume of 20 mL, and the process was repeated twice to obtain the maximum extract. The extraction results were then filtered with a filter paper into a 50 mL volumetric flask, and distilled water was added to get a final volume of 50 mL, followed by homogenization. The solid samples (sediment and fish) were extracted using the acid method by measuring 2 g of sediment (US EPA 1994). Each sample was placed in an Erlenmeyer, followed by adding Aqua Regia (1-part HNO_3 + 3 parts HCl) and heated on a stove to a volume of 10 mL. The process was repeated twice, and the extract obtained was transferred into a 10 mL volumetric flask. Distilled water was added to extracts with a volume of less than 10 mL and then filtered using filter paper. Cr content in the sample extract was measured using the Atomic Absorption Spectrophotometry (AAS) method based on SNI 06-6989.17-2004 (Indonesian National Standardization Agency 2004). The analysis process was carried out with the PerkinElmer Pin AAcle 900T Atomic Absorption Spectrometer.

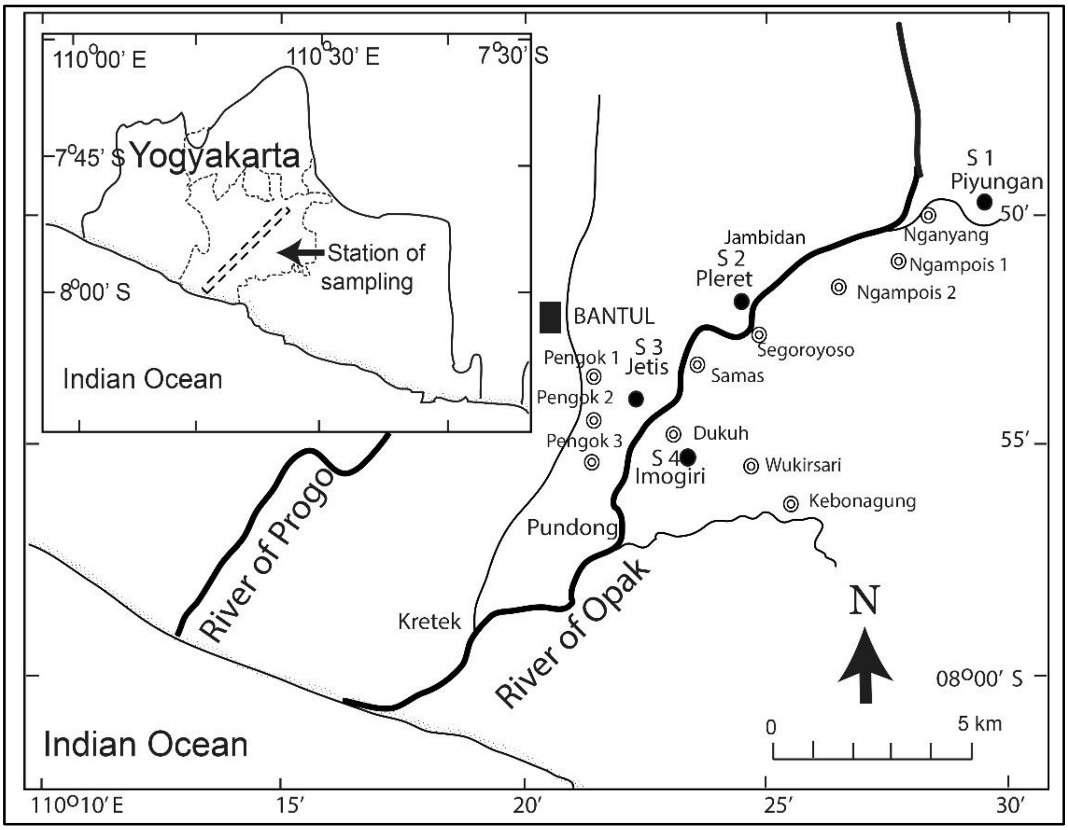

Figure 1. Map of water, sediment, and fish sampling locations in sub-districts Piyungan (S1), Pleret (S2), Jetis (S3) and Imogiri (S4); the hollow circle represents catfish (*Clarias gariepinus*) and tilapia (*Oreochromis niloticus*) aquaculture ponds that receive Opak river flow.

Calculation of the bioconcentration factor. Bioconcentration factors (BCF) involve the measurement of the ability to accumulate heavy metals in the contaminated aquatic environment (Van der Oost et al 2003). The BCF value was measured in mg L^{-1} and can be obtained using the following formula:

BCF Cr = Cr concentration in fish carcass/Cr concentration in water

BCF values higher than 1000 mg L^{-1}, between 100 and 1000 mg L^{-1}, and lower than 100 mg L^{-1} in an aquatic organism indicate high, moderate, and low accumulative properties, respectively (Amriani et al 2011).

Calculation of bioaccumulation factor. Bioaccumulation factors (BAF) were calculated to determine the metal concentration in fish and sediment. BAF was obtained using the following formula (Abel 1989):

BAF Cr = Cr (fish sample)/Cr (sediment)

Where: Cr (fish sample) is the Cr concentration measured in the fish (mg kg^{-1} dry weight); Cr (sediment) is the Cr concentration measured in the sediment (mg kg^{-1} dry weight). BAF was calculated using the mean concentration value of each element present in the fish sample and sediment. BAF higher than 1 indicate that Cr experiences bioaccumulation or biomagnification (Ibhadon et al 2014).

Statistical analysis. The data obtained from the calculation of Cr concentration in water, sediment, and fish, as well as the bioaccumulation level in fish were analyzed descriptively. Analysis was also carried out quantitatively using One-Way ANOVA to determine the differences in mean values of Cr concentration in water, sediment, and fish among the sub-districts. To determine differences in Cr accumulation levels between species of fish, the t test was used.

Cr contamination levels in fishponds. Based on the water and sediment samples analysis, all tilapia and catfish ponds in the four sub-districts were contaminated by Cr. Furthermore, the metal concentration in tilapia ponds had a higher range and mean (0.126-0.283 mg L^{-1} and 0.207±0.057 mg L^{-1}) compared to catfish ponds (0.108-0.148 mg L^{-1} and 0.132±0.013 mg L^{-1}). Similar results were also obtained in the sediment samples of the ponds, where the mean Cr concentration in tilapia ponds (1.084±0.549 mg kg^{-1}) was higher compared to the catfish (0.873±0.573 mg kg^{-1}). Based on the sampling locations, the highest level in the water was found in the tilapia ponds in Imogiri Sub-district with mean of 0.251±0.037 mg L^{-1}. For the sediment sample, the highest concentration was obtained in catfish ponds in Piyungan Sub-district with a mean of 1.282±0.244 mg kg^{-1} (Table 1).

Table 1

The concentration of Cr contaminants in the water (mg L^{-1}) and the sediment (mg kg^{-1}) of studied fishponds

Sampling station	*Oreochromis niloticus* Range	*Oreochromis niloticus* Mean ± SD	*Clarias gariepinus* Range	*Clarias gariepinus* mean± SD
		Pond water		
Control	0.108-0.126	0.114±0.010	0.108-0.138	0.118±0.017
Piyungan	0.126-0.171	0.147±0.022	0.108-0.124	0.113±0.009
Pleret	0.166-0.215	0.194±0.025	0.126-0.146	0.134±0.010
Jetis	0.216-0.270	0.235±0.030	0.126-0.146	0.136±0.010
Imogiri	0.230-0.283	0.251±0.037	0.139-0.148	0.144±0.004
Total	0.126-0.283	0.207±0.057	0.108-0.148	0.132±0.013
		Sediment		
Control	0.126-0.148	0.137±0.011	0.148-0.212	0.171±0.038
Piyungan	0.725-1.013	0.915±0.164	1.057-1.542	1.282±0.244
Pleret	0.491-0.819	0.630±0.169	0.595-0.725	0.667±0.066
Jetis	1.345-1.840	1.566±0.251	0.923-1.155	0.689±0.119
Imogiri	1.005-1.661	1.227±0.375	0.518-1.269	0.856±0.380
Total	0.491-1.840	1.084±0.549	0.518-1.542	0.873±0.573

Statistical analysis using ANOVA showed that there was no significant difference in the concentration of Cr contaminants in water samples between control and treatment ponds ($p>0.05$). However, for concentrations in sediment and fish samples, there were significant differences at all stations ($p>0.05$).

Accumulation of Cr contaminants in cultivated fish. The results showed that the tilapia and catfish samples from the study areas had been contaminated with Cr, and accumulated Cr contaminants with a mean concentration of 0.257 mg kg^{-1} and 0.278 mg kg^{-1}, respectively. Furthermore, the accumulation of Cr in catfish tended to be higher than in tilapia. The highest level of the contaminants in tilapia was found in Jetis, followed by Imogiri, Pleret, and Piyungan. For the accumulation in catfish, the highest level was observed in Piyungan, followed by Jetis, Pleret, and Imogiri, as presented in Table 2.

Table 2

Accumulation of Cr contaminants in fish (mg kg^{-1})

Sampling station	*Oreochromis niloticus*		*Clarias gariepinus*	
	Range	*Mean± SD*	*Range*	*Mean± SD*
Control	0.108-0.147	0.127±0.019	0.118-0.162	0.145±0.023
Piyungan	0.188-0.268	0.231±0.040	0.270-0.516	0.358±0.137
Pleret	0.216-0.288	0.245±0.037	0.228-0.302	0.258±0.038
Jetis	0.245-0.330	0.287±0.042	0.208-0.412	0.283±0.112
Imogiri	0.260-0.272	0.283±0.006	0.191-0.240	0.215±0.024
Total	0.188-0.330	0.257±0.061	0.191-0.516	0.278±0.079

BCF and BAF values of Cr in fish. The BCF value in *O. niloticus* fish cultivation ponds ranges from 1.12 to 1.57, while in *C. gariepinus* fish cultivation ponds it ranges from 1.22 to 3.168. The highest BCF values in the two cultivation ponds were found near the liquid waste disposal point from the leather tanning industrial complex in the Piyungan industrial area. The highest BCF of Cr in tilapia was found in Piyungan ponds (1.571), followed by Pleret (1.263), Imogiri (1.127), and Jetis (1.221). The highest BCF of Cr in catfish was obtained in Piyungan (3.168), followed by Jetis (2.081), Pleret (1.925), and Imogiri (1.493) areas (Table 3). BCF values at all research locations were above 1000 mg L^{-1}, indicating high accumulative properties.

Table 3

BCF and BAF values of chromium pollutants in sediment and fishes

Sampling station	*Oreochromis niloticus*		*Clarias gariepinus*	
	BCF Value	*BAF Value*	*BCF Value*	*BAF Value*
Control	1.120	0.970	1.220	0.850
Piyungan	1.571	0.252	3.168	0.279
Pleret	1.263	0.388	1.925	0.387
Jetis	1.221	0.184	2.081	0.411
Imogiri	1.127	0.231	1.493	0.251
Range	1.120-1.571	0.184-0.97	1.22-3.168	0.251-0.85
Mean	1.798	0.405	1.977	0.436

Note: BCF - bioconcentration factor; BAF - bioaccumulation factor.

The BCF value of *C. gariepinus* tends to be higher than that of *O. niloticus* at all locations. The same results were also seen in the BAF value. The BAF value of Cr pollution in *O. niloticus* ranges from 0.184 to 0.97, while in *C. gariepinus* it ranges from 0.251 to 0.85. The BAF value in *C. gariepinus* with an average of 0.436 is slightly higher when compared to the BAF value in *O. niloticus* with an average of 0.405.

Cr contamination level in ponds. The research results show that the use of Opak river water which has been contaminated with leather tannery industry wastewater from the Piyungan Industrial Area is a contributing factor to the discovery of Cr in water, sediment and fish samples. Even in control areas, Cr contaminants were still found in water, sediment and fish samples. The discovery of Cr pollutants in the control pool was due to the proximity of the control pool to industrial areas, causing exposure to contaminants from the air (Graney & Eriksen 2004). Based on information from fish farmers at the control location, it was reported that there were several small-scale leather tanning industries outside the Piyungan industrial area that discharged their liquid waste into the Opak River. The use of Opak River water which has been contaminated by Cr pollutants, even in the river mouth area (Rahardjo & Prasetyaningsih 2017), is the main factor in the contamination of fish farming ponds in the four research areas. The continuous discharge of tannery industry wastewater into the Opak River is a factor causing the increase in Cr concentrations in river water, sediment, fish and rice fields downstream of the Opak River (Rahardjo et al 2021a; Rahardjo et al 2021b).

The concentration of Cr pollutant in water samples was found in smaller concentrations than in sediment samples, both in *O. niloticus* and *C. gariepinus* fish pond samples. The results of this study also show that there is no difference in the concentration of Cr in the water media at all research locations. The low concentration of metals in water samples is thought to be caused by Cr easily binding to organic matter and being quickly deposited into sediment or soil (Weber et al 2013; Alinnor & Alagoa 2014; Chimela et al 2016; Ehiemere et al 2022). Heavy metals such as Cr will interact more easily with sediment, causing sequestration (Brady et al 2015). The process of heavy metals entering into sediment increases the concentration of pollutants in sediment, decreasing it in the water (Nurkhasanah 2015). So sediment can act as a natural absorber of heavy metals in aquatic ecosystems, thereby reducing the bioavailable fraction in water (Gilbert & Avenant-Oldewage 2014; Udosen et al 2016). Therefore, higher concentrations of these heavy metal pollutants are found in sediments that function as metal reservoirs compared to receiving water media (Brady et al 2015; Bai et al 2018). So monitoring river and pond pollution based only on measuring pollutant concentrations in water media is inaccurate and inadequate for identifying metal inputs in water systems (Ismail et al 2016). Metal concentrations in sediments are also an indispensable tool in water quality evaluation (Abdel-Khalek et al 2016). River pollution by heavy metals is one of the problems of ecological systems because of its ability to accumulate and biomagnify along the water, sediment and aquatic food chain, resulting in sub-lethal effects or death in local fish populations (McGeer et al 2000; Xu et al 2004).

The normal Cr concentration in water media is 0.01 mg L^{-1} (Ahmad 2009), and excessive amounts of Cr can affect water bodies and surrounding organisms. In this research, it was proven that water media is the environmental component with the lowest concentration of Cr pollutant, namely in the range of 0.132-0.207 mg L^{-1}. However, the average concentration of Cr pollutants in *O. niloticus* fishponds (0.207±0.057 mg L^{-1}), and in *C. gariepinus* ponds (0.132±0.013 mg L^{-1}), has exceeded the water quality standards for aquaculture based on Government Regulation Number 82 of 2002, namely 0.05 mg L^{-1}. The same concentration is also set by UNEP/WHO for the criteria for protecting aquatic ecosystems with a maximum allowable concentration (MAC) Cr value of 0.05 mg L^{-1} (UNEP 2008). The prevalence of heavy metal pollutants, including Cr, has had a major impact on fish health and diversity. Therefore, business organizations can focus on improving their waste disposal practices and implementing sustainability approaches to improve waste properties and reduce hazardous waste. Implementing these practices can help improve water quality by reducing the entry of pollutants into waters while also improving the quality and health of fish (Manalo & Hemavathy 2023).

Accumulation of Cr contaminants in cultivated fish. Cr pollutant accumulated in all samples of *O. niloticus* and *C. gariepinus* with varying concentrations. This can be an indicator that the water source for fish cultivation has been contaminated by Cr. This condition has been predicted in research by Rahardjo et al (2021b) that Cr pollution in the Opak River has the potential to pose a threat to the environment, fishing businesses and public health downstream of the Opak River. Heavy metals accumulate by aquatic organisms such as fish, through food, water, and sediment (Ahmad & Sarah 2014). So heavy metal pollution in waters can cause migration of heavy metals into fish bodies through bioconcentration and bioaccumulation (Baki et al 2018; Korkmaz et al 2019; Arisekar et al 2020). High levels of heavy metal accumulation in fish indicate high levels of pollutant concentrations in the aquatic environment (Zhao et al 2012).

Accumulation levels of heavy metals in commercial fish species have received significant attention and increasing interest in their use as bioindicators for assessing the integrity of aquatic environmental systems (Jiang et al 2005; Chi et al 2007; US EPA 2011). Fish absorb and build up heavy metals in their tissues from the surrounding water, as it is the primary route for ingesting waterborne contaminants. Fish have long been used to assess water pollution and are therefore known as biological indicators of aquatic ecosystems (Zaidi & Pal 2017).

Exposure to Cr pollutants in fish can cause various behavioral modifications such as delayed feeding behavior, uneven swimming, and accelerated operculum (Aslam &

Yousafzai 2017). Heavy metal contaminants can cause respiratory damage, gill damage, neurotoxin effects, damage to the blood and circulatory systems, psychological effects and other impacts of heavy metals in fish (Sonone et al 2021). Exposure to heavy metals in fish triggers structural changes such as hypertrophy and paraplegia in the gill epithelium and weakens the immune system (Aslam & Yousafzai 2017). Javed & Usmani (2019) said that heavy metal contaminants can cause accumulation in tissues such as muscle, gills, kidneys, liver and integument of fish, which increases genotoxicity and oxidative stress in fish. Furthermore, fish function abnormalities can be used as biomarkers from environments that have been contaminated with heavy metals (Ali et al 2019). Further effects of exposure to heavy metals include disrupting growth and development and having a negative impact on the fish reproductive system (Sonone et al 2021).

The range and mean concentration of Cr in *C. gariepinus* tended to be higher (0.191-0.516 and 0.278 mg kg^{-1}) than in *O. niloticus* fish (0.188-0.33 and 0.257 mg kg^{-1}). However, statistical analysis (t test) showed that there was no significant difference in the accumulation of Cr pollutant between the two types of fish ($p>0.05$). This proves that the accumulation of Cr pollutants in fish bodies is not only caused by differences in species, but is caused by many factors such as invasion routes, metabolic characteristics of sample tissue, and environmental conditions in which the species live (Ozmen et al 2008). Zhao et al (2012) and Rajeshkumar & Li (2018) stated that the accumulation of heavy metals is also influenced by uncontrolled environmental variables, such as water current, temperature, pH, electroconductivity, etc.

Based on its habitat, *C. gariepinus* is dominant at the bottom of ponds and prefers muddy river substrates. It becomes easier for them to find food and camouflage. Direct and continuous contact between these fish and sediments that collect Cr also impacts these organisms. Another factor that increases the possibility of Cr concentration in *C. gariepinus* is the position of the gills close to the ventral part of the head, often in contact with muddy substrates. The high concentration in the gills occurs because the gills are a place for the exchange of metal ions from water and have a large surface area, making it easier for rapid diffusion of contaminants. In addition, their gills are capable of accumulating heavy metals in high concentrations. El-Moselhy et al (2014) observed that the distribution of Cr in the fish body was higher in the organs and lower in the liver and muscles.

The Cr concentration in fish obtained in this study is classified as safe and the fish can be consumed based on standards set by the Director General of the Food and Drug Supervisory Agency, with a maximum limit of 2.5 mg kg^{-1} (Director General of POM 1989), and is lower than the limit set by US FDA (2017) for consumed fish, namely 12-13 mg kg^{-1}. Although heavy metal concentrations in fish are usually below the maximum limit (Velusamy et al 2014; Rahman et al 2019), heavy metals are not the only source of contaminants in the food chain. The diversity of food sources in humans can cause the accumulation of heavy metals in the body, which will ultimately reach detrimental levels, causing serious health risks, such as cancer (Badamasi et al 2019; Yu et al 2020) and neurodegenerative diseases (Cicero et al 2017; Chen et al 2019). Sriuttha et al (2017) observed that aquatic animals such as fish, can accumulate Cr from water, sediment and food. Usually, sources of Cr in fish ponds include plant residues, road dust containing Cr from tire wear and brake linings, textile waste, and leather tanneries (Gangwar 2010; Sanyal et al 2017).

Bioconcentration and bioaccumulation factor of Cr in fishes. The BCF of Cr in *O. niloticus* ranges from 1.12 to 1.571 mg kg^{-1}, while in *C. gariepinus* it ranges from 1.22 to 3.168 mg kg^{-1}. The BCF in both types of fish in all locations is relatively low, namely <100. Even though the BCF is low, it can prove that there has been a transfer of Cr from the water to the fish. This means that Opak River water contaminated by Cr and used as a water source for fish farming can be a source of Cr contamination in fish. This is confirmed by Yasmeen et al (2016) and Mensoor & Said (2018) that contaminated water can increase the heavy metal content in fish muscles.

Relative BCF varies based on the type and location of cultivation ponds. Variations in BCF values can be caused by differences in water Cr concentrations and organism characteristics such as body weight, age and metabolism (Haryanti & Martuti 2020).

Awaliyah et al (2021) reported that the age and weight of fish influence heavy metal concentrations. Arkianti et al (2019) revealed that the BCF value is influenced by the type of heavy metal, organism, length of exposure, and water environmental conditions. BCF in both species of fish tends to be higher in cultivation ponds in Piyungan sub-district, close to industrial waste disposal points for leather tanneries. This shows that the potential for exposure to Cr through water media at this location is higher compared to other locations.

BAF in this study fluctuated, indicating there was no relationship between the proximity of the cultivation location and the source of contaminants. However, this value could be influenced by the large concentration of Cr, sediment, and intrinsic factors in the fish. Eneji et al (2011) observed that the rate of bioaccumulation of heavy metals in fish depends on the concentration of these metals in the surrounding water body or sediment, their feeding habits, and their ability to digest contaminants. Sediment functions as a natural absorber of heavy metals in aquatic ecosystems, thereby reducing the bioavailable fraction in water (Gilbert & Avenant-Oldewage 2014). *C. gariepenus* has a higher BAF value than *O. niloticus* because it is a benthic and omnivorous species. According to Madu et al (2017), *C. gariepenus* tends to bioconcentrate contaminants from bottom sediments because of its habitat and food preferences. The BAF Cr value in *O. niloticus* and *C. gariepenus* is below 1. Previous research revealed that values above 1 indicate that Cr has been biologically accumulated or biologically enlarged (Ibhadon et al 2014).

The research results show that the sediment contains higher levels of heavy metals than water. This difference can be explained by the tendency of metals to accumulate in sediments and biomagnify along the aquatic food chain (Kouakou et al 2016). The high concentration of Cr in the sediment is a determining factor in the value of the BAF. The BAF in *O. niloticus* and *C. gariepinus* at all research locations had a value of less than 1 (BAF<1). The low value of the BAF is caused by the low concentration of Cr in sediment, which is below the threshold for the ability of organisms to accumulate metal in their bodies (Abdallah & Abdallah 2008; Zhao et al 2012). The Cr concentration in the sediment is far below the threshold value set by US EPA (1991), of <25 mg kg^{-1}. In this study, the concentration of Cr in *O. niloticus* fish pond sediments ranged from 0.491 to 1.84 mg kg^{-1} with a mean of 1.084±0.549 mg kg^{-1}, while in *C. gariepinus* pond sediments it was 0.518-1.542 mg kg^{-1} and 0.873±0.573 mg kg^{-1}. The bioaccumulation process will occur in the body if the BAF value is under 1, its uptake being influenced by many factors such as sex, size, age, reproductive cycle, movement pattern, eating habit and environment (Zhao et al 2012).

Conclusions. Water, sediment, tilapia, and catfish in the aquaculture ponds in the four study areas contained Cr with concentrations exceeding the tolerance threshold based on the Indonesian Government Regulation 82 of 2001 and UNEP/WHO. Furthermore, the mean concentration of Cr in sediment was higher than in *O. niloticus* or *C. gariepinus* rearing ponds. The contaminants accumulated in the carcasses of both species, but their levels were still within the tolerance limits for food ingredients.

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Conflict of Interest. The authors declare that there is no conflict of interest.

References

Abdallah M. A. M., Abdallah A. M. A., 2008 Biomonitoring study of heavy metals in biota and sediments in the south eastern coast of Mediterranean Sea, Egypt. Environmental Monitoring and Assessment 146:139-145.

Abdel-Khalek A. A., Elhaddad E., Mamdouh S., Marie M. A. S., 2016 Assessment of metal pollution around Sabal drainage in River Nile and its impacts on bioaccumulation level, metals correlation and human risk hazard using *Oreochromis niloticus* as a bioindicator. Turkish Journal of Fisheries and Aquatic Sciences 16(2):227-239.

Abel P. D., 1989 Pollutant toxicity to aquatic animals - methods of study and their applications. Reviews on Environmental Health 8(1-4):119-155.

Ahmad A., Sarah A., 2014 Assessment of abandoned mine impacts on concentrations and distribution of heavy metals in surface sediments of catchments around Sungai Lembing abandoned tin mine. Iranica Journal of Energy & Environment 5(4):453-460.

Ahmad F., 2009 [The degree of heavy metals pollution in seawater and sediment in the waters of Muna, Kabaena and Buton Island, Northeast of Sulawesi]. Makara Sains 13(2):117-124. [In Indonesian].

Ali H., Khan E., Ilahi I., 2019 Environmental chemistry and ecotoxicology of hazardous heavy metals: Environmental persistence, toxicity, and bioaccumulation. Journal of Chemistry 2019:6730305.

Alinnor I. J., Alagoa A. F., 2014 Trace metal distribution in fish, sediment and water samples from Nkisa River, Nigeria. British Journal of Applied Science & Technology 4(20):2901-2913.

Amriani, Hendrarto B., Hadiyarto A., 2011 [Bioaccumulation of heavy metals lead (Pb) and zinc (Zn) in blood clams (*Anadara granosa* L.) and mangrove clams (*Polymesoda bengalensis* L.) in Kendari Bay Waters]. Journal of Environmental Science 9(2):45-50. [In Indonesian].

Arisekar U., Shakila R. J., Shalini R., Jeyasekaran G., 2020 Human health risk assessment of heavy metals in aquatic sediments and freshwater fish caught from Thamirabarani River, the Western Ghats of South Tamil Nadu. Marine Pollution Bulletin 159:111496.

Arkianti N., Dewi N. K., Martuti N. K. T., 2019 [Content of the heavy metal lead (Pb) in fish in the Lamat River, Magelang Regency]. Life Science 8(1):54-63. [In Indonesian].

Aslam S., Yousafzai A. M., 2017 Chromium toxicity in fish: A review article. Journal of Entomology and Zoology Studies 5(3):1483-1488.

Awaliyah V. I., Hudha A. M., Miharja F. J., 2021 [Cadmium heavy metal bioaccumulation in mujair fish (*Oreochromis mossambicus*) in Ngipik Gresik Lake]. Proceedings of the VI National Seminar, Biology Education Study Program, Faculty of Teacher Training and Education, Universitas Muhammadiyah Malang, Malang, Indonesia, pp. 283-287. [In Indonesian].

Badamasi I., Odong R., Masembe C., 2019 Implications of increasing pollution levels on commercially important fishes in Lake Victoria. Journal of Great Lakes Research 45(6):1274-1289.

Bai L., Liu X. L., Hu J., Li J., Wang Z. L., Han G., Li S. L., Liu C. Q., 2018 Heavy metal accumulation in common aquatic plants in rivers and lakes in the Taihu Basin. International Journal of Environmental Research and Public Health 15:2857.

Baki M. A., Hossain M. M., Akter J. Quraishi S. B., Shojib M. F. H., Ullah A. K. M. A., Khan M. F., 2018 Concentration of heavy metals in seafood (fishes, shrimp, lobster and crabs) and human health assessment in Saint Martin Island, Bangladesh. Ecotoxicology and Environmental Safety 159:153-163.

Biggs J., von Fumetti S., Kelly-Quinn M., 2017 The importance of small waterbodies for biodiversity and ecosystem services: implications for policy makers. Hydrobiologia 793:33-39.

Brady J. P., Ayoko G. A., Martens W. N., Goonetillek A., 2015 Development of a hybrid pollution index for heavy metals in marine and estuarine sediments. Environmental Monitoring and Assessment 187(5):306.

Chen Q. Y., DesMarais T., Costa M., 2019 Metals and mechanisms of carcinogenesis. Annual Review of Pharmacology Toxicology 59:537-554.
Chi Q. Q., Zhu G. W., Langdon A., 2007 Bioaccumulation of heavy metals in fishes from Taihu Lake, China. Journal of Environmental Sciences 19(12):1500-1504.
Chimela W., Hart A. I., Babatunde B. I., Zabbey N., 2016 Assessment of human health risk from heavy metal loads in freshwater clam, *Ergeria radiata*, from the Nun River, Niger Delta, Nigeria. Journal of Environment and Earth Science 6(9):10-20.
Cicero C. E., Mostile G., Vasta R., Rapisarda V., Signorelli S. S., Ferrante M., Zappia M., Nicoletti A., 2017 Metals and neurodegenerative diseases. A systematic review. Environmental Research 159:82-94.
Ehiemere V. C., Ihedioha J. N., Ekere N. R., Ibeto C. N., Abugu H. O., 2022 Pollution and risk assessment of heavy metals in water, sediment and fish (*Clarias gariepinus*) in a fish farm cluster in Niger Delta region, Nigeria. Journal of Water and Health 20(6):927-945.
El-Moselhy K., Othman A. I., El-Azem H. A., El-Metwally M. E. A., 2014 Bioaccumulation of heavy metals in some tissues of fish in the Red Sea, Egypt. Egyptian Journal of Basic and Applied Sciences 1(2):97-105.
Eneji I. S., Ato R. S., Annune P. A., 2011 Bioaccumulation of heavy metals in fish (*Tilapia zilli* and C*larias gariepinus*) organs from River Benue, North–Central Nigeria. Pakistan Journal of Analytical and Environmental Chemistry 12(1-2):25-31.
Gangwar D. K. K., 2010 Metals concentration in textile and tannery effluents, associated soils and ground water. New York Science Journal 3(4):82-89.
Gilbert B. M., Avenant-Oldewage A., 2014 Arsenic, chromium, copper, iron, manganese, lead, selenium, and zinc in the tissues of the largemouth yellowfish, *Labeobarbus kimberleyensis* (Gilchrist and Thompson, 1913) from the Vaal Dam, South Africa, and associated consumption risks. Water SA 40(4):739-748.
Graney J. R., Eriksen T. M., 2004 Metals in pond sediments as archives of anthropogenic activities: a study in response to health concerns. Applied Geochemistry 19(7):1177-1188.
Haryanti E. T., Martuti N. K. T., 2020 [Analysis of heavy metal contamination with lead (Pb) and cadmium (Cd) in red snapper (*Lutjanus* sp.) meat at TPI Kluwut Brebes]. Life Science 9(2):1-12. [In Indonesian].
Hostetter M. K., 2006 The great stink of Paris and the nineteenth-century struggle against filth and germs. The Journal of Clinical Investigation 116(11):2835.
Ibhadon S., Emere M. C., Abdulsalami M. S., Yilwa V., 2014 Bioaccumulation of some trace metals in wild and farm raised African catfish *Clarias gariepinus* in Kaduna, Nigeria. Pakistan Journal of Nutrition 13(12):686-691.
Ismail A., Toriman M. E., Juahir H., Zain S. M., Habir N. L. A., Retnam A., Kamaruddin M. K. A., Umar R., Azid A., 2016 Spatial assessment and source identification of heavy metals pollution in surface water using several chemometric techniques. Marine Pollution Bulletin 106(1-2):292-300.
Javed M., Usmani N., 2019 An overview of the adverse effects of heavy metal contamination on fish health. Proceedings of the National Academy of Sciences, India Section B: Biological Sciences 89:389-403.
Jiang Q., Lee T., Chen K., Wong H., Zheng J., Giesy J., Lo K., Yamashita N., Lam P., 2005 Human health risk assessment of organochlorines associated with fish consumption in a coastal city in China. Environmental Pollution 136:155-165.
Korkmaz C., Ay Ö., Ersoysal Y., Köroğlu M. A., Erdem C., 2019 Heavy metal levels in muscle tissues of some fish species caught from north-east Mediterranean: evaluation of their effects on human health. Journal of Food Composition and Analysis 81:1-9.
Kouakou A. R., N`Guessan L. B. K., Yao K. B., Trokourey A., Adouby K., 2016 Heavy metals in sediments and their transfer to edible mollusc. Journal of Applied Sciences 16(11):534-541.
Madu J. C., Odo G. E., Asogwa C. N., Nwani C. D., 2017 Heavy metal concentrations in, and human health risk assessment of, three commercially valuable fish species in the lower Niger River, Nigeria. African Journal of Aquatic Science 42(4):341-349.

Manalo J. V. I., Hemavathy R. V., 2023 Effects of water pollution on the quality of fish. Journal of Survey in Fisheries Sciences 10(1S):6029-6035.
McGeer J. C., Szebedinszky C., McDonald D. G., Wood C. M., 2000 Effect of chronic sublethal exposure to waterborne Cu, Cd, or Zn in rainbow trout 2: tissue specific metal accumulation. Aquatic Toxicology 50(3):245-256.
Mensoor M., Said A., 2018 Determination of heavy metals in freshwater fishes of the Tigris River in Baghdad. Fishes 3(2):23.
Nurkhasanah S., 2015 [Content of the heavy metal chromium (Cr) in water, sediment, and tilapia (*Oreochromis niloticus*) as well as biometric characteristics and histological conditions in the Cimanuk Lama River, Indramayu Regency]. Thesis, Postgraduate Faculty, Bogor Agricultural Institute, Bogor, Indonesia, 52 p. [In Indonesian].
Ozmen M., Ayas Z., Güngördü A., Ekmekci G. F., Yerli S., 2008 Ecotoxicological assessment of water pollution in Sariyar Dam Lake, Turkey. Ecotoxicology and Environmental Safety 70(1):163-173.
Rahardjo D., Djumanto, Manusiwa W. S., Prasetyaningsih A., 2021a The chromium concentration downstream of the Opak River, Yogyakarta, Indonesia. AACL Bioflux 14(1):596-602.
Rahardjo D., Djumanto, Prasetyaningsih A., Laoli B., Manusiwa W. S., 2021b Chromium content in fish and rice and its effect on public health along the downstream Opak River, Bantul District, Indonesia. International Journal of Bonorowo Wetlands 11(2):69-74.
Rahardjo, Prastyaningsih, 2017 [Distribution and accumulation of chromium in the leather industrial area of Banyakan Village]. Proceedings of the National Seminar III 2017, University of Muhammadiyah Malang, Indonesia, pp. 330-338. [In Indonesian].
Rahman M. S., Hossain M. S., Ahmed M. K., Akhter S., Jolly Y. N., Akhter S., Kabir M. J., Choudhury T. R., 2019 Assessment of heavy metals contamination in selected tropical marine fish species in Bangladesh and their impact on human health. Environmental Nanotechnology, Monitoring & Management 11:100210.
Rajeshkumar S., Li X., 2018 Bioaccumulation of heavy metals in fish species from the Meiliang Bay, Taihu Lake, China. Toxicology Reports 5:288-295.
Sanyal A. T., Kaviraj S. S., Saha S., 2017 Toxicity and bioaccumulation of chromium in some freshwater fish. Human and Ecological Risk Assessment: An International Journal 23(7):1655-1667.
Sonone S. S., Jadhav S., Sankhla M. S., Kumar R., 2021 Water contamination by heavy metals and their toxic effect on aquaculture and human health through food Chain. Letters in Applied Nano BioScience 10(2):2148-2166.
Sriuttha M., Tengjaroenkul B., Intamat S., Phoonaploy U., Thanomsangad P., Neeratanaphan L., 2017 Cadmium, chromium, and lead accumulation in aquatic plants and animals near a municipal landfill. Human and Ecological Risk Assessment 23(2):350-363.
Udosen E. D., Offiong N. A. O., Edem S., Edet J. B., 2016 Distribution of trace metals in surface water and sediments of Imo River Estuary (Nigeria): health risk assessment, seasonal and physicochemical variability. Journal of Environmental Chemistry and Ecotoxicology 8(1):1-8.
Van der Oost R., Beyer J., Vermeulen N. P. E., 2003 Fish bioaccumulation and biomarkers in environmental risk assessment: a review. Environmental Toxicology and Pharmacology 13(2):57-149.
Velusamy A., Kumar P. S., Ram A., Chinnadurai S., 2014 Bioaccumulation of heavy metals in commercially important marine fishes from Mumbai Harbor, India. Marine Pollution Bulletin 81(1):218-224.
Weber P., Behr E. R., Knorr C. D. L., Vendruscolo D. S., Flores E. M. M., Dressler V. L., Baldisserotto B., 2013 Metals in the water, sediment, and tissues of two fish species from different trophic levels in a subtropical Brazilian river. Microchemical Journal 106:61-66.
Xu Y. J., Liu X. Z., Ma A. J., 2004 Current research on toxicity effect and molecular mechanism of heavy metals on fish. Marine Science 28(10):67-70.

Yasmeen K., Mirza M. A., Khan N. A., Kausar N., Rehman A. U., Hanif M., 2016 Trace metals health risk appraisal in fish species of Arabian Sea. Springerplus 5(1):859.
Yu B., Wang X., Dong K. F., Xiao G., Ma D., 2020 Heavy metal concentrations in aquatic organisms (fishes, shrimp and crabs) and health risk assessment in China. Marine Pollution Bulletin 159:111505.
Zaidi J., Pal A., 2017 Review on heavy metal pollution in major lakes of India: Remediation through plants. African Journal of Environmental Science and Technology 11(6):255-265.
Zhao S., Feng C., Quan W., Chen X., Niu J., Shen Z., 2012 Role of living environments in the accumulation characteristics of heavy metals in fishes and crabs in the Yangtze River estuary, China. Marine Pollution Bulletin 64(6):1163-1171.
*** Decree of the Director General of Drug and Food Control Republic of Indonesia Number: 0375/B/SK/VII/89 concerning Maximum Limits of Heavy Metal Contamination in Food.
*** Department of Marine and Fisheries, 2021 [Monograph book 2020 Yogyakarta special region of marine and fisheries service 2021].141 p. [In Indonesian].
*** Government Regulation of the Republic of Indonesia Number 82 of 2002
*** Indonesian National Standardization Agency, 2004 [SNI 06-6989.17-2004 Water and wastewater - Part 17: How to test total chrome (Cr-T) using the atomic absorption spectrophotometry (SSA) method-flame]. Jakarta. [In Indonesian].
*** UNEP, 2008 Water quality for ecosystem and human health. UNEP GEMS/Water Programme, 130 p.
*** UNEP, 2016 A Snapshot of the World's Water Quality: Towards a Global Assessment. United Nations Environment Programme (UNEP), Nairobi, Kenya, 162 p.
*** US EPA, 1991 Sediment quality guidelines. Draft report, EPA Region V, Chicago, USA.
*** US EPA, 1994 Method 200.2 Sample preparation procedure for spectrochemical determination of total recoverable elements. Environmental Monitoring Systems Laboratory Office of Research and Development, Ohio, USA.
*** US EPA, 2011 US EPA regional screening level (RSL) summary table: November 2011. United States Environmental Protection Agency, Washington D. C., USA.
*** US FDA, 2017 Recommendations of the United States Public Health Service, Food and Drug Administration.
*** WWDR, 2017 2017 UN world water development report, wastewater: The untapped resource. UNESCO, Paris.

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