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Metal Content of the Yellowtail Fish (*Caesio cuning*) Consumed by the Community in Boedingi, North Konawe, Indonesia: An Environmental Health Risk Assessment in the Mining Area

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Abstract: The rapid development of mining activities, the shipping industry, and public transportation across the land and water areas of Boedingi Village can have both positive and negative impacts on the water quality of this area. This study aimed to determine the heavy metal content in yellowtail fish (*Caesio cuning*), a type of fish that is generally consumed by Boedingi villagers in North Konawe, Indonesia. A descriptive method with an environmental health risk assessment (EHRA) was employed to measure metal profiles (Pb, Cd, and Hg). The results showed that the metal levels in the water exceeded the thresholds, indicating significant heavy metal pollution. In addition, the Cd levels of the fish surpassed the food safety standard according to the USA Food and Drug Administration (FDA). Since Indonesia began its large-scale shift from conventional to electrical transportation, global and government collaboration have become critical in managing the environmental and health impacts of the related industries. This is especially important because this area is one of the largest nickel producers (the raw material of electrical transportation) both nationally and globally.

Keywords: biomonitoring; metal; environmental health risk assessment; mining

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1. Introduction

Boedingi Village in North Konawe District, Southeast Sulawesi Province, Indonesia, is an area rich in natural resources, both biological and non-biological. The biological natural resources include coral reefs, fish, mollusks, and various types of animals. In comparison, the non-biological natural resources include minerals such as nickel. To date, these natural resources have been mined on a large scale. Based on the 2022 records of the Southeast Sulawesi Central Statistics Agency (BPS), there are 50 mining companies operating in the North Konawe District, some of which are located in Boedingi Village and its surrounding areas [1]. The village is also directly adjacent to various water areas that are home to various marine biota and is also a place for the living and livelihood of the local community, most of whom work as fishermen.

The rapid development of the mining, shipping, and public transportation industries across the land and water areas of Boedingi Village have had both positive and negative impacts on the local waters. One of the positive impacts is boosting the economy and accommodation in the region, while one of the negative impacts is an increase in pollution due to improperly treated waste. Waste products like nickel slag, fly ash, steel slag, used bleaching earths, ship welding debris, and fuel leaks from ships can all contribute to heavy metal pollution in the environment [2]. In addition to these industrial activities, village community activities also add to the pollution burden. Household waste from bathrooms, kitchens, and laundry, as well as agricultural activities (pesticide fertilizers) and small-scale industrial operations, can introduce heavy metals into the water. As a result, this area's water quality can affect the aquatic biota, and poor water quality can increase the toxicity of heavy metal pollutants to these organisms [3].

Pollution burdens, whether solid or liquid, organic or inorganic, that are continuously and directly disposed of can contaminate both land and water. Heavy metals are an example of such pollutants. In brief, heavy metals can be defined as the elements with the atomic numbers 22–92, located in periods 4–7 in the Mendeleev periodic table [4]. Since there are many community and industrial activities around Boedingi Village, this increases the burden of heavy metal pollution around the village's waters. Heavy metals are hazardous pollutants if they are present in excess, as they can cause severe health problems. Therefore, their presence in aquatic environments needs careful monitoring.

Heavy metals that accumulate in water can enter the human body through the food chain. Organisms generally need heavy metals at low levels, but prolonged accumulation can be toxic and disrupt health by causing sore throats, headaches, dermatitis, allergies, anemia, kidney failure, pneumonia, and so on [5]. When heavy metal concentrations exceed safe limits, they can bind to sulfhydryl groups (-SH) on protein molecules and inhibit enzyme activity. This disruption affects metabolic processes, as pollutants combined with the enzyme's active site can render it inactive [6].

The hierarchical nature of the food chain allows heavy metals to move from the environment to organisms and ultimately from one organism to another. Fish, as aquatic organisms, are especially vulnerable to heavy metal exposure in waters [7]. Heavy metals can be absorbed by a fish's body in two ways: food channel (diet exposure) and gill surface (water exposure) [8]. Some heavy metals can cause liver and gill damage and, in some cases, death. If humans consume aquatic organisms containing heavy metals above the threshold limit, it will have a detrimental impact on human health [9].

The yellowtail fish (*Caesio cuning*) is an endemic organism found in Indonesian and Southeast Asian waters [10], including in Boedingi Village, North Konawe, Indonesia. This fish is carnivorous and is a common food source for local communities [11]. *Euterpina sp.* is the primary zooplankton consumed by yellowtail fish during all phases of gonad maturity [12]. This type of fish can also be found on coral reefs and only migrates when necessary, depending on the conditions of the ecosystem [13].

Based on preliminary studies of the local respondents, this fish has the highest economic value and is not only consumed by nearby communities but also sold to both local and regional markets [14]. Additionally, the demand for this fish species has increased from year to year [15]. Therefore, it is necessary to measure the heavy metal content in the yellowtail fish (*Caesio cuning*) consumed by the Boedingi villagers. This study aimed to determine the heavy metal content in the yellowtail fish (*Caesio cuning*) consumed by the residents of Boedingi Village, North Konawe, Indonesia. Since Indonesia has begun to make a large-scale substitution from conventional to electrical transportation, this study is expected to have significant implications for measuring the environmental health risk in the region, which is the largest nickel mining area (raw material of electrical transportation) in both Indonesia and the world.

2. Materials and Methods

2.1. Study Setting and Design

This study was conducted in Boedingi Village, North Konawe District, Southeast Sulawesi Province. The fish samples were tested for heavy metal content at the Biomolecular and Environmental Laboratory, Faculty of Mathematics and Natural Sciences, Halu Oleo University (Figure 1). All laboratory activities regarding equipment and measurements were regularly audited and monitored per ISO 17025 for the gold standard of laboratory quality assurance and control (QA-QC). Descriptive quantitative research using exploratory methods was employed to determine the content of heavy metals, including Lead (Pb), Copper (Cu), Cadmium (Cd), Iron (Fe), Nickel (Ni), and Mercury (Hg), in the selected yellowtail fish.

Figure 1. The morphology of the yellowtail fish (*Caesio cuning*) [16]: kingdom: *Animalia*; phylum: *Chordata*; class: *Actinopterygii*; order: *Perciformes*; family: *Caesionidae*; genus: *Caesio*; species: *Caesio cuning*.

2.2. Instrument

Table 1, below, shows the instruments utilized in this study.

Table 1. Instruments.

Name of Instruments	Functions
AAS (Atomic Absorption Spectrophotometer)	To read heavy metal content concentration
Clear plastic bag	Sample container
Cool boxes	To contain the samples
Labeling paper	To label the samples
Analytical balance	To weigh the test materials
Measuring cup	Suspension container
Chemistry glass	Suspension container
Watch glass	To cover the measuring cup
Global Positioning System (GPS)	To define coordinates
Water quality meter	To measure the water's physical and chemical parameters
pH meter	To measure the water's pH
Salinity meter	To measure the water's salinity
Thermometer	To measure the water's temperature
Turbidity meter	To measure the water's turbidity
Biological Oxygen Demand (BOD) meter	To measure the water's BOD
Bubu (fishing traps)	To catch fish
Gill net	To catch fish
A set of surgical instruments	To dissect the samples
Surgical board	To dissect the samples
Camera	For documenting

2.3. Sampling

Fish sampling was conducted at three station points: Station I, near the pier of a private mining area; Station II, near the Boedingi Village pier; and Station III, in the waters around the settlement. Each location was represented by one fish sample, measuring 15–20 cm, selected as the optimal size for analyzing metal content biomarkers [17]. The sampling stations were chosen based on the intensity of activities that could contribute to water pollution. A purposive sampling method was applied to ensure that the selected fish samples reflected the conditions of the fish population in all observation locations. The process was critical to provide a comprehensive overview of the heavy metal content in the yellowtail fish (*Caesio cuning*) from each area.

The fish samples were caught using traps and gill nets, locally known as trawls, with canoes serving as transportation. Both *Bubu* (fishing traps) and gill nets were deemed effective fishing tools commonly used by local fishermen to capture fish.

2.4. Metal Assessment Procedure (Environmental Health Risk Assessment—EHRA)

The steps for assessing the heavy metals in the yellowtail fish (*Caesio cuning*) included the detection of Pb, Cd, and Hg. According to Aeni (2017) [17], the analysis began with washing the fish sample, weighing the total weight (kg), and measuring the length and width. Then, the fish meat was separated from the fish bones, mashed, and weighed to be as much as 0.5 g. After that, the meat was put into a volumetric flask, and 5 mL of concentrated nitric acid solution (HNO_3 65%) was added before it was left for 15 min in the acid room. Later, the sample was analyzed using an Atomic Absorption Spectrophotometer (AAS).

Before the AAS assessment, sample solutions, standards, and blanks were prepared. The standard series was prepared by diluting 1000 mg/L of each heavy metal into a concentration series in a 100 mL volumetric flask. Six standard solution concentrations were prepared for each heavy metal: 0, 0.2, 0.4, 0.6, 0.8, and 1 mg/L. The initial stage in the reading process was to turn the AAS device on and adjust the position of the cathode lamp, absorbent cell, and wavelength to test each heavy metal. The standard solution was then connected to a small hose that fed into a tube in the AAS system, where the reducing agent ($SnCl_2$) was introduced. The absorbance levels were automatically displayed on the monitor. After the standard solution was read, a linear curve of the standard solution was formed, namely the relationship between the absorbance value (y) of the standard solution and the concentration of heavy metals in the standard solution (ug/l) (x). The absorbance values of the blank and the yellowtail fish (*Caesio cuning*) samples were then measured following the same procedure. Then, the concentration value of each heavy metal was calculated so that a linear curve of the sample solution could be formed. Finally, the heavy metal content in the sample was calculated, and the results were tabulated.

The metal contents in the fish's environment and meat were assessed using Indonesian regulations, which align with international thresholds for maximum allowable concentrations (MACs). These parameters follow both international and national standards, such as Indonesian Government Regulation Number 22 of 2021, which incorporates and adjusts parameters based on guidelines from organizations like the United States Environmental Protection Agency (EPA) and the World Health Organization (WHO) [18,19]. Additionally, the limits for metal concentrations in fish meat were guided by the National Agency for Drug and Food Control, which also follows WHO/FAO recommendations [20].

3. Results

3.1. General Description of the Research Station

This study was performed in the local waters of Boedingi Village, Lasolo Islands, which administratively belongs to the North Konawe District, Southeast Sulawesi Province, Indonesia. The waters of Boedingi Village feature a pier used for fishing boats and transport ships as well as a separate pier for a mining company, which is used for loading and unloading mining products. Additionally, there are residential areas located along the coastal waters.

Station I is located at coordinates 03°26′57.9″ S and 122°23′02.1″ E in the waters surrounding the pier of a mining company. This area serves as a route and anchorage for barges transporting mining products. Station II, located at 03°26′55.4″ S and 122°22′55.9″ E, is near the Boedingi Village pier, while Station III, at 03°26′52.9″ S and 122°22′53.9″ E, is situated near a residential area (Figure 2).

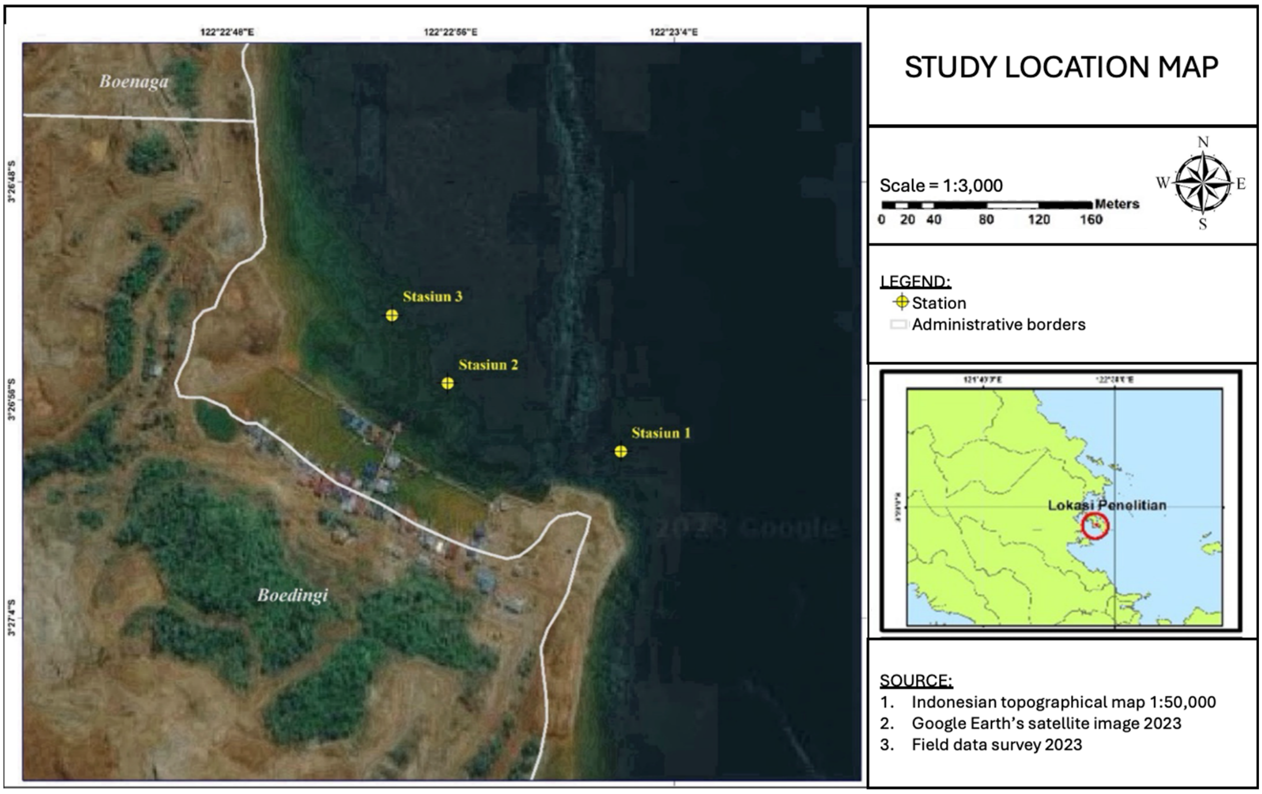

Figure 2. Study setting location.

3.2. Environmental Parameters at the Research Location

The results of the measurements for both the physical and chemical parameters of the waters at each research station are presented below.

Table 2 shows the measurements of the environmental parameters in the waters of Boedingi Village. There are six parameters, which are physical (temperature and turbidity) and chemical (DO, pH, salinity, and BOD), that were measured at each station. The environmental parameters were measured twice, and then, the results of each parameter were averaged. The aim of measuring the environmental factors was to examine the influence of water conditions on the heavy metal levels in the yellowtail fish (*Caesio cuning*). The results of measuring the physical and chemical factors of river waters were compared with the gold standards according to Indonesian Government Regulation Number 22 of 2021. The following is an explanation of the physical and chemical parameters studied.

Table 2. Physical and chemical parameter values of Boedingi Village water at each station.

Environmental Parameter	Time	Station			Standard [1]
		I	II	III	
Physical					
Water Temperature (C)	Morning	30.0	29.8	30.0	28–30
	Afternoon	29.5	29.5	29.3	
	Evening	28.5	28.2	28.3	
Water Turbidity (NTUs)	Morning	5.80 *	5.79 *	5.88 *	5
	Afternoon	6.23 *	6.21 *	6.26 *	
	Evening	5.35 *	5.33 *	5.30 *	
Chemical					
Dissolved Oxygen (DO) (mg/L)	Morning	5.5 *	6.1 *	6.2 *	>5
	Afternoon	5.3 *	6.2 *	6.1 *	
	Evening	5.8 *	6.3 *	6.0 *	

Table 2. *Cont.*

Environmental Parameter	Time	Station			Standard [1]
		I	II	III	
pH	Morning	7.15	7.11	7.17	7–8.5
	Afternoon	7.17	7.25	7.20	
	Evening	7.14	7.25	7.28	
Salinity (‰)	Morning	31 *	32 *	32 *	33–34
	Afternoon	31 *	30 *	31 *	
	Evening	25 *	30 *	32 *	
Biological Oxygen Demand (BOD) (mg/L)	Morning	11.49	13.75	10.62	20
	Afternoon	11.27	13.72	10.56	
	Evening	11.70	13.90	10.60	

* Exceeds the threshold; [1] Indonesian Government Regulation Number 22 of 2021.

3.2.1. Physical Parameters

1. Water Temperature

Based on the measurement results, the water temperature obtained at Station I had a value of 28.5 °C, Station II had a temperature value of 28.2 °C, and Station III had a temperature value of 28.3 °C. Based on Indonesian Government Regulation Number 22 of 2021, the value obtained is considered good and within the threshold for the water gold standards of 28–30 °C. The increase in temperature at each station was caused by the reasonably high intensity of solar radiation. This water temperature can be said to be good for the life of aquatic biota.

2. Water Turbidity

The water turbidity at Station I had a value of 5.35 NTUs, Station II had a value of 5.33 NTUs, and Station III had a value of 5.31 NTUs. Based on Indonesian Government Regulation Number 22 of 2021, the value obtained was classified as exceeding the specified threshold, namely 5 NTUs. This elevated turbidity is likely due to soil particles entering the water during the loading and unloading of mining products.

3.2.2. Chemical Parameters

1. Dissolved Oxygen (DO)

The results of the DO measurements were 5.8 mg/L at Station I, 6.3 mg/L at Station II, and 6.0 mg/L at Station III. For the data collected at each station, the DO values pass the seawater gold standards according to Indonesian Government Regulation Number 22 of 2021 for marine biota, with a standard DO value of >5 mg/L.

2. Potential of Hydrogen (pH)

The pH values from each station had relatively small differences in value, in which the pH measured at Station I was 7.14, it was 7.25 at Station II, and it was 7.28 at Station III.

3. Salinity

Station I had a salinity value of 25.1‰; Station II had a value of 30.7‰; and Station III had a value of 32.2‰. Based on Indonesian Government Regulation Number 22 of 2021, the values obtained do not meet the water gold standards in the range of 33–34‰.

4. Biological Oxygen Demand (BOD)

Station I had a BOD value of 11.70 mg/L, 13.90 mg/L was measured for Station II, and 10.60 mg/L was measured for Station III. The BOD values obtained are below the maximum recommended standard for marine biota, which is set at 20 mg/L, according to Indonesian Government Regulation Number 22 of 2021.

3.3. Heavy Metal Contents

3.3.1. Heavy Metal Contents in Water Samples at Each Station

The following table presents the results of an analysis of Pb, Cd, and Hg in the waters of Boedingi Village at three stations: Station I, near the pier of one of the mining companies; Station II, in the area near the Boedingi Village pier; and Station III, near the settlement.

Based on Table 3, the heavy metals in the Boedingi Village waters have exceeded the threshold for the gold standards set out in Indonesian Government Regulation Number 22 of 2021. As a result, these waters are categorized as highly contaminated. This implies that heavy metals have severely polluted the village waters.

Table 3. Metal contents of lead (Pb), cadmium (Cd), and mercury (Hg) in Boedingi Village waters.

Sample Source	Type of Analysis	Metal Content (mg/L)	MAC (mg/L) [1]
Station 1	Lead (Pb)	0.0319 *	0.008
	Cadmium (Cd)	0.0128 *	0.001
	Mercury (Hg)	0.0061 *	0.001
Station 2	Lead (Pb)	0.0279 *	0.008
	Cadmium (Cd)	0.0093 *	0.001
	Mercury (Hg)	0.0032 *	0.001
Station 3	Lead (Pb)	0.0299 *	0.008
	Cadmium (Cd)	0.0124 *	0.001
	Mercury (Hg)	0.0059 *	0.001

* Exceeds the threshold; [1] Indonesian Government Regulation Number 22 of 2021.

Table 2 shows that the levels of the heavy metals, including Pb, Cd, and Hg, at Station 1 were higher than those at the other two stations. This is likely because Station 1 is located near the pier, where fuel spills from barges and material spills occur during the loading and unloading of mining products. These spills could also have contributed to the elevated levels of heavy metals at Stations 2 and 3, as currents can carry the spilled materials and fuel. In contrast, the relatively high levels of heavy metals at Station 2 are likely due to fuel spills from fishing boats, while the elevated levels at Station 3 may be attributed to household waste, including bathroom waste, kitchen activities, and laundry effluents.

3.3.2. Heavy Metal Contents in Fish Samples at Each Station

Based on the results of the analysis in Table 4, the average levels of Pb, Cd, and Hg in the yellowtail fish meat (*Caesio cuning*) found in the Boedingi Village waters are still below both Russian [21] and Indonesian standards (according to Regulation of the National Agency for Drug and Food Control Number 9 of 2022, concerning Requirements for Heavy Metal Contamination in Processed Food). However, the Cd level in the studied fish exceeded the MACs, according to the US Food and Drug Administration (FDA).

Table 4. Metal contents of lead (Pb), cadmium (Cd), and mercury (Hg) in yellowtail fish (*Caesio cuning*) meat in Boedingi Village waters.

Sample Source	Type of Analysis	Metal Content (ppm)					MAC (ppm)		
		Fish 1	Fish 2	Fish 3	Average	Std. Dev.	Indonesian [1]	Russian [2]	US [3]
Station 1	Lead (Pb)	0.172	0.133	0.120	0.140	0.027	0.30	1.0	0.05
	Cadmium (Cd)	0.061 *3	0.039 *3	0.050 *3	0.050 *3	0.011	0.30	0.2	0.005
	Mercury (Hg)	0.014	0.014	0.018	0.015	0.002	0.50	0.6	ne
Station 2	Lead (Pb)	0.123	0.159	0.162	0.148	0.022	0.30	1.0	0.05
	Cadmium (Cd)	0.017 *3	0.032 *3	0.080 *3	0.043 *3	0.033	0.30	0.2	0.005
	Mercury (Hg)	0.016	0.017	0.013	0.015	0.002	0.50	0.6	ne
Station 3	Lead (Pb)	0.117	0.125	0.170	0.137	0.029	0.30	1.0	0.05
	Cadmium (Cd)	0.082 *3	0.036 *3	0.046 *3	0.054 *3	0.024	0.30	0.2	0.005
	Mercury (Hg)	0.015	0.015	0.010	0.013	0.003	0.50	0.6	ne

* Exceeds the threshold; [1] Indonesian BPOM No. 9 of 2022; [2] Dudarev et al., 2019 [21]; [3] US FDA.

4. Discussion

4.1. Environmental Parameters at the Research Location

Water temperature is crucial for the survival of aquatic organisms, as well as for various chemical and biological activities. These processes typically function optimally within a permissible temperature range of 26 °C to 32 °C. Both high and low water temperatures can impact the toxicity and solubility of heavy metals; specifically, higher water temperatures increase the toxicity and solubility of heavy metals, while lower temperatures decrease them [22].

Turbidity generally indicates the clarity of the water or the level of suspended sediment, which can be either mineral or organic in nature. In addition, water turbidity could also indicate the water's ability to transmit light. The lower the level of turbidity in a body of water, the greater the opportunity for aquatic vegetation to carry out photosynthesis and the greater the supply of oxygen in the water [23].

Dissolved oxygen (DO) is a chemical variable that plays a crucial role in the life of aquatic biota. DO concentration is influenced by the respiration process of aquatic biota and the decomposition process of organic material by microbes. Another ecological influence that causes decreases in DO concentration is the addition of organic substances (organic waste) and minerals [24].

Changes in the Potential of Hydrogen (pH) in the water system will affect the life of the surrounding organisms. Water containing heavy metals tends to be acidic compared with water that is free of heavy metals. An increase in water pH reduces the solubility of metals because it shifts the stability of the metals from their carbonate forms to their hydroxide forms [4].

The optimum salinity required by living creatures ranges from 33 to 34‰ [4]. The low salinity at each station is due to the influx of freshwater from the settlement and low rainfall. Tanjung et al. (2019) stated that salinity values are influenced by several factors: freshwater input, evaporation, rainfall, and the presence of estuaries and currents. The salinity of a body of water affects the bioaccumulation of heavy metals [4]. Yudiati et al. (2009) highlighted that a decrease in salinity will cause an increase in the toxic power of heavy metals and the level of bioaccumulation of heavy metals will be greater [24].

BOD is needed by microorganisms to break down or decompose organic materials under aerobic conditions. This parameter is an index number for measuring pollution from waste in waters. A higher BOD concentration in a body of water indicates a high concentration of organic matter. The BOD parameter is a general parameter that can be used to determine the water pollution level from a particular source of pollution. The level of pollution is considered low if the BOD value is 0–10 mg/L, medium if the BOD value is 10–20 mg/L, and high if the BOD value exceeds 20 mg/L [25].

4.2. Metal Content in Water Samples at Each Station

The major causes of increasing lead concentrations in water are domestic waste, industrial activities, the use of paint containing lead, ship welding, and fuel leaks from ships [9]. Cd can enter water through various human activities such as industrial, agricultural, and domestic activities. Hg, a highly toxic heavy metal, can enter water through mining activities, coal burning residue, factory waste, fungicides, pesticides, household waste, etc.

These data show that the input of heavy metals, both the natural decomposition of metal minerals from geological processes in waters and from waste from various activities at sea and on land, greatly influences fluctuations in heavy metal levels. In principle, two efforts can be made to overcome pollution, which are non-technical and technical countermeasures. Non-technical countermeasures mean efforts to establish laws and regulations that can be used to plan, regulate, and supervise all types of industrial and technological activities to prevent pollution. Meanwhile, countermeasures can be taken through the engineering of waste disposal: for example, by modifying the waste disposal process or adding tools to reduce pollution [8].

Variations in the toxicity of heavy metals to marine organisms are caused by the absorption, storage, detoxification, and removal of the heavy metals between different marine organisms. The influential intrinsic factors include nutrient conditions, water flow by osmotic flux and surface impermeability, while the extrinsic factors include temperature, salinity, and dissolved metal concentration [26].

4.3. Metal Content in Yellowtail Fish (Caesio cuning) Meat Samples at Each Station

The input of the heavy metal Pb comes from household waste (bathroom waste, kitchen activities, washing clothes) and industrial activities (material and fuel spills). The major causes of increasing Pb levels in waters are household waste, industrial activities, the use of paint containing lead, ship welding, and fuel leaking from ships. Pb concentrations above the recommended threshold can disrupt the survival of aquatic organisms and humans. In particular, Pb can inhibit the growth rate of fish, and if the lead concentration in human blood is greater than 20 μg/dL, it can reduce hemoglobin and increase the risk of anemia [9].

Aside from those that originate from nature, Cd input also comes from high population activity and industrial activity around the waters of Boedingi Village. This heavy metal can enter waters through various human activities, such as industrial, agricultural, and household activities [9]. Cd is very toxic to humans because it can cause kidney and lung function disorders, increase blood pressure, and cause infertility in adult men [27]. Similarly, the input of Hg comes from industrial activities and residents' activities around the village waters. Hg is a very toxic heavy metal that can enter water due to mining activities, coal burning residue, factory waste, fungicides, pesticides, household waste, etc.

The concentration of Hg in the yellowtail fish (*Caesio cuning*) obtained from the waters of Lae-Lae Island in Makassar, South Sulawesi, Indonesia, was determined to be below the permissible tolerance threshold by regulations [17,28]. The influential factors on the Hg content in the fish meat samples were the low concentration of Hg in the waters of Lae-Lae Island, the physical and chemical conditions of the waters, food, fish size, and the ability of the yellowtail fish (*Caesio cuning*) to neutralize heavy metals.

Based on the analysis of the heavy metal content in the samples of yellowtail fish meat (*Caesio cuning*) and water from Boedingi Village, the water conditions in the village were found to have high levels of Pb, Cd, and Hg. However, these metals had not accumulated in excessive amounts in the yellowtail fish meat. The physiological abilities of different fish, as well as the effects of exposure to heavy metals, will affect the levels of these metals in a fish's body [29]. The *Caesionidae* family has distinctive characteristics, such as living in groups (schooling), swimming quickly (fast swimming), and eating zooplankton [17]. Although yellowtail fish (*Caesio cuning*) can swim quickly [30] and are tolerant of various environmental conditions [16], it still cannot be guaranteed that metal contents will not accumulate in excessive amounts in their meat.

Meanwhile, all types of fish, including the yellowtail fish (*Caesio cuning*), contain a compound called Metallothionein (MT), which plays a role in neutralizing heavy metals. MT has been proven in some vertebrate animals, including fish, to have the capacity to absorb heavy metals in a fish's body and reduce their toxicity. Apart from that, MT also plays a role in maintaining electrolyte balance and strengthening the fish's immune system [31]. The yellowtail fish (*Caesio cuning*) could neutralize heavy metals, including Hg, by utilizing the capabilities of its enzymatic and non-enzymatic systems [31]. However, the accumulation of heavy metals in fish meat still largely depends on the fish's diet, which is related to the water's condition.

Water management in industrial areas must be carried out to minimize the impact of pollution, especially when it relates to heavy metals [32]. Household waste management can be improved by arranging septic tanks and sewer lines, reducing the burden of industrial pollutants by building integrated installations and utilizing waste as compost and biogas [17]. Management of mining activity waste is also required to manage the resulting waste in accordance with Indonesian Government Regulation Number 101 of 2014 Article

3 paragraph (1) concerning the Waste Management of Toxic and Hazardous Materials. This includes reducing, storing, collecting, transporting, utilizing, processing, and/or landfilling hazardous waste [33].

5. Conclusions

As the first study to report on the environmental health impacts of one of the largest nickel mining activities in the world by examining the condition of the surrounding waters and biomarkers, this study concludes that the heavy metal contents in the yellowtail fish (*Caesio cuning*) meat are lower than the Indonesian and Russian standards. However, the Cd level in the fish exceeds the MAC according to the USA standard (FDA). In addition, the heavy metals present in the Boedingi Village waters have exceeded the thresholds established by Indonesian Government Regulation Number 22 of 2021. Thus, the concentration of heavy metals in the studied waters is categorized as high. This implies that the studied waters have been polluted by Pb, Cd, and Hg. Despite this finding, the community still consumes yellowtail fish (*Caesio cuning*), and this situation may affect public health in the near future.

The suggestions put forward in this study are as follows: (1) a further study to estimate, using forecasting analysis, the heavy metal content in the yellowtail fish (*Caesio cuning*) in Boedingi Village, North Konawe District, needs to be carried out in the future; (2) it is necessary to conduct further research on the influence of heavy metals in the Boedingi Village waters polluted by the heavy metals Pb, Cd, and Hg on the fish cultivation cages of residents around the village waters; and (3) the government should impose strict control and sanctions over activities in Boedingi Village.

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References

1. Christiawan, Y.A. Pengaruh Morfologi Dan Batuan Dasar terhadap Proses Laterisasi Endapan Nikel Laterit PT. Daka Group Site Boedingi Kecamatan Lasolo Kepulauan Kabupaten Konawe Utara Provinsi Sulawesi Tenggara. Skripsi. Surabaya. 2020. Available online: https://library.itats.ac.id/index.php?p=show_detail&id=28640 (accessed on 15 July 2024).
2. Lestari, P.; Trihadiningrum, Y. The impact of improper solid waste management to plastic pollution in Indonesian coast and marine environment. *Mar. Pollut. Bull.* **2019**, *149*, 110505. [CrossRef] [PubMed]
3. Mardani, N.P.S.; Restu, I.W.; dan Sari, A.H.W. Kandungan Logam Berat Timbal (Pb) dan Kadmium (Cd) pada Badan Air dan Ikan di Perairan Teluk Benoa, Bali. *Curr. Trends Aquat. Sci.* **2018**, *1*, 106. [CrossRef]
4. Tanjung, R.H.R.; Suwito, S.; Purnamasari, V.; dan Suharno, S. Analisis Kandungan Logam Berat pada Ikan Kakap Putih (Lates calcarifer Bloch) di Perairan Mimika Papua. *J. Ilmu Lingkung.* **2019**, *17*, 256. [CrossRef]
5. Ahmad, F. Dampak Aktivitas Perkotaan dan Penambangan Nikel Terhadap Tingkat Kontaminasi Logam Berat dalam Air Laut dan Sedimen. *MAKARA Sci. Ser.* **2013**, *18*, 71–78.

6. Yulaipi, S.; Aunurohim, A. Bioakumulasi Pb dan Hubungannya dengan Laju Pertumbuhan Ikan Munjair. *J. Sains Dan Seni Pomits* **2013**, *2*, E166–E170.
7. Puspasari, R. Logam dalam Ekosistem Perairan. *BAWAL Widya Ris. Perikan. Tangkap* **2017**, *1*, 43. [CrossRef]
8. Rosihan, A.; Husaini, H. *Logam Berat Sekitar Manusia*; Pustaka Buana: Bogor, Indonesia, 2017; ISBN 978-602-6483-47-8.
9. Pratiwi, D.Y. Dampak Pencemaran Logam Berat (Timbal, Tembaga, Merkuri, Kadmium, Krom) terhadap Organisme Perairan dan Kesehatan Manusia. *J. Akuatek* **2020**, *1*, 59–65.
10. Burhani, S.; Fadillah, Y. Studi Manajemen Model Rantai Pasok Hasil Tangkapan di Pangkalan Pendaratan Ikan (PPI) Paotere Kota Makassar. *J. Inf. Sains Dan Teknol.* **2022**, *5*, 150–166.
11. Mohamad, A.; Mile, L.; Naiu, A.S. Evaluasi Kandungan Merkuri (Hg) Pada Beberapa Ikan Ekonomis Penting di Desa Mopuya Kabupaten Bonebolango. *NIKe J.* **2021**, *9*, 093–098.
12. Tiara, L. Kebiasaan Makan dan Hubungan Panjang Berat Ikan Ekor Kuning (*Caesio cuning*) Yang Didaratkan di Pelabuhan Perikanan Nusantara Sungailiat Kabupaten Bangka. Ph.D. Thesis, Universitas Bangka Belitung, Kepulauan Bangka Belitung, Indonesia, 2020.
13. Ferlin, F.; T Almuarifah, T.; Mazrianti, M.; Uzdah Sari Ramadhani Wahyuningrat, U. *Bunga Rampai EKONOMI MARITIM Sulawesi Tenggara*; AADZ Grafika: Kendari, Indonesia, 2022.
14. Sari, N.; Supratman, O.; Utami, E. Aspek Reproduksi dan Umur Ikan Ekor kuning (*Caesio cuning*) Yang di Daratkan di Pelabuhan Perikanan Nusantara Sungailiat Kabupaten Bangka. *J. Enggano* **2019**, *4*, 193–207. [CrossRef]
15. Yu, M.; Herrmann, B.; Liu, C.; Zhang, L.; Tang, Y. Effect of Codend Design and Mesh Size on the Size Selectivity and Exploitation Pattern of Three Commercial Fish in Stow Net Fishery of the Yellow Sea, China. *Sustainability* **2023**, *15*, 6583. [CrossRef]
16. Zuhdi, M.F.; Madduppa, H. Identifikasi *Caesio cuning* Berdasarkan Karakterisasi Morfometrik dan DNA Barcoding yang Didaratkan di Pasar Ikan Muara Baru, Jakarta. *J. Kelaut. Trop.* **2020**, *23*, 199–206. [CrossRef]
17. Nur Aeni, A. Bioakumulasi Logam Berat Merkuri (Hg) pada Ikan Ekor Kuning (Caesio cuning) di Perairan Pulau Lae-lae Makassar. Undergraduate (S1) Thesis, Universitas Islam Negeri Alauddin Makassar, Sulawesi Selatan, Indonesia, 2017. Available online: http://repositori.uin-alauddin.ac.id/7998/ (accessed on 13 August 2023).
18. Astuti, R.D.P.; Mallongi, A.; Amiruddin, R.; Hatta, M.; Rauf, A.U. Risk identification of heavy metals in well water surrounds watershed area of Pangkajene, Indonesia. *Gac. Sanit.* **2021**, *35*, S33–S37. [CrossRef]
19. Sahide, M.A.K.; Fisher, M.R.; Hasfi, N.; Masâ, E.I.; Yunus, A.; Faturachmat, F.; Larekeng, S.H.; Maryudi, A. Navigating the Hidden Politics of Water Resource Bureaucracies in Indonesia: Mapping Issue-Elements and Alliances. *Hasanuddin Law Rev.* **2023**, *9*, 57–87. [CrossRef]
20. Sartika, R.D.; Atmarita, A.; Duki, M.; Bardosono, S.; Wibowo, L.; Lukito, W. Consumption of Sugar-Sweetened Beverages and Its Potential Health Implications in Indonesia. *Kesmas.* **2022**, *17*, 1–9. [CrossRef]
21. Dudarev, A.A.; Chupakhin, V.S.; Vlasov, S.V.; Yamin-Pasternak, S. Traditional Diet and Environmental Contaminants in Coastal Chukotka III: Metals. *Int. J. Environ. Res. Public Health* **2019**, *16*, 699. [CrossRef] [PubMed]
22. Nurbarasamuma, N.; Chaerul, M. Pencemaran Logam Berat Hg, As, Cd Di Sedimen Sungai Langkowala Akibat Aktivitas Penambangan Kabupaten Bombana Sulawesi Tenggara. *J. Lingkung. Almuslim* **2022**, *1*, 1–7. [CrossRef]
23. Ratih, R.D.; Handayani, W.; Oktavianawati, I. Karakterisasi dan Penentuan Komposisi Asam Lemak dari Hasil Pemurnian Limbah Pengalengan Ikan dengan Variasi Alkali pada Proses Netralisasi. *Berk. Sainstek* **2016**, *4*, 19–23.
24. Siburian, R.; Simatupang, L.; Bukit, M. Analisis kualitas perairan laut terhadap aktivitas di lingkungan pelabuhan Waingapu-Alor Sumba Timur. *J. Pengabdi. Kpd. Masy.* **2017**, *23*, 225–232. [CrossRef]
25. Yudiati, E.; Sedjati, S.; Enggar, I.; Hasibuan, I. Dampak pemaparan logam berat kadmium pada salinitas yang berbeda terhadap mortalitas dan kerusakan jaringan insang juvenile udang Vaname (*Litopeneus vannamei*). *Ilmu Kelaut. Indones. J. Mar. Sci.* **2009**, *14*, 29–35.
26. Isangedighi, I.A.; David, G.S. Heavy metals contamination in fish: Effects on human health. *J. Aquat. Sci. Mar. Biol.* **2019**, *2*, 7–12. [CrossRef]
27. Azizah, A.; Birawida, A.B.; Daud, A.; Sila, N. Health Risk Impact of Cadmium Exposure on Public Drinking Water Sources in Kodingareng and Barrang Lompo Islands Sangkarrang District Makassar City. *NeuroQuantology* **2022**, *20*, 387. [CrossRef]
28. *SNI 7387:2009*; Batas Maksimum Cemaran Logam Berat Dalam Pangan. SNI: Jakarta Pusat, Indonesia, 2009; pp. 15–17. Available online: https://standarpangan.pom.go.id/dokumen/peraturan/2018/0._salinan_PerBPOM_5_Tahun_2018_Cemaran_Logam_Berat_join__4_.pdf (accessed on 13 August 2023).
29. Hardinawati, H. Analisis Kandungan Logam Berat Timbal (Pb) pada Hati, Daging dan Kulit Ikan Baronang (Siganus gutattus) di Pulau Lae-lae. Undergraduate (S1) Thesis, Universitas Islam Negeri Alauddin Makassar, Sulawesi Selatan, Indonesia, 2017. Available online: http://repositori.uin-alauddin.ac.id/4107/ (accessed on 13 August 2023).
30. Haryanti, E.T.; Martuti, N.K.T. Analisis Cemaran Logam Berat Timbal (Pb) dan Kadmium (Cd) Dalam Daging Ikan Kakap Merah (*Lutjanus* sp.) Di TPI Kluwut Brebes. *Life Sci.* **2016**, *9*, 18–24. Available online: http://journal.unnes.ac.id/sju/index.php/LifeSci (accessed on 13 August 2023).
31. Wang, L.; Liang, Q.; Chen, T.; Wang, Z.; Xu, J.; Ma, H. Characterization of collagen from the skin of Amur sturgeon (*Acipenser schrenckii*). *Food Hydrocoll.* **2014**, *38*, 104–109. [CrossRef]

32. Utomo, S.W.; Rahmadina, F.; Wispriyono, B.; Kusnoputranto, H.; Asyary, A. Metal Contents of Lake Fish in Area Close to Disposal of Industrial Waste. *J. Environ. Public Health* **2021**, *2021*, 6675374. [CrossRef]
33. Widiyanto, A.F.; Suratman, S.; Alifah, N.; Murniati, T.; Pratiwi, O.C. Knowledge and Practice in Household Waste Management. *Kesmas* **2019**, *13*, 112–116. [CrossRef]