

Article

An Assessment of Heavy Metal Contamination in the Nakdong River Around the Weir

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Abstract: In this study, the concentrations and characteristics of copper (Cu), zinc (Zn), and lead (Pb) contamination in sediment samples were investigated using aqua regia extraction and Tessier's five-step sequential extraction. Based on the concentration of metals, the influence of the Hapcheon-Changnyeong weir on sediments in the Nakdong River was assessed. The origins of the contaminants, their bioavailability, and their mobility were determined using sequential extraction. Greater concentrations of heavy metals were found in samples collected closer to the weir. The largest proportion of Cu was identified in the residual fraction based on sequential extraction, whereas Zn was predominantly found in the reducible fraction. Iron-manganese in the reducible fraction of Zn has the potential to leach back to the water body. In addition, the combined concentration of fractions 1 and 2 of Cu comprised more than 20% of total amount that still has potential to affect the water quality. The results of this study were compared with existing sediment standards set out by the NIER (National Institute of Environmental Research), Canada, and US EPA (United States Environmental Protection Agency) guidelines, as well as the risk assessment code (RAC). The concentrations of heavy metals exceeded the standards set by the Canadian guideline by up to four times in particular samples, highlighting the need for continual monitoring.



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Keywords: heavy metal; surface water quality; aqua regia extraction; sequential extraction; monitoring; water contaminants

1. Introduction

Chemical contaminants, such as metals, herbicides, and toxic organic compounds may enter rivers from numerous sources [1]. In contrast to organic pollutants, heavy metals are problematic since they do not biodegrade, threatening the aquatic ecosystem and eventually human health through bioaccumulation [2–5]. In particular, river flow may stagnate around weirs, leading to increased sedimentation of heavy metals. Such heavy metals may subsequently re-enter the water through diffusion and re-suspension, deteriorating the water quality [6]. Therefore, it is necessary to continuously monitor the chemical and physical changes of heavy metals in sediments around weirs [6].

Aqua regia extraction is frequently employed to monitor the concentration of heavy metals in river sediments. However, heavy metals are likely to be released into the water under different environmental conditions, depending on their chemical nature and have varying effects on sediment and water quality. Therefore, the metals must be further partitioned through sequential extraction according to their chemical form [7,8]. While sequential extractions are time-consuming, they enhance the understanding of the bioavailability and origins of heavy metals and are often used during water quality management [9]. Among the various sequential extraction techniques, Tessier's method is one of the most well-known methods and enables sediments to be subdivided into five fractions [10]. This method's main advantage is that heavy metal concentrations may be measured after partitioning based on their chemical forms [11]. Originally, Tessier's sequential method was

developed to examine the concentrations of heavy metals in aquatic sediments. However, its application has been gradually extended to the classification of heavy metals in soil [12].

The Nakdong River is a major river in South Korea that requires continuous monitoring for heavy metals while also differentiating between their chemical forms. Weirs are employed along the Nakdong River to provide both drinking water and water for agricultural and industrial processes in the local region. However, a previous study reported that the concentrations of copper (Cu), zinc (Zn), and lead (Pb) of sediments in the Nakdong River were expected to exceed sediment heavy metal standards due to the presence of several industrial complexes further downstream [13]. Since heavy metals in water tend to remediate quicker than that of sediment, and sediment is one of the ultimate sink of metals even with extremely low concentration, we focused on investigating the heavy metal concentrations of sediments [14,15]. For these reasons, monitoring the concentrations of such metals in the Nakdong River is crucial, particularly in regions of the river with weirs where the water flow is expected to stagnate.

This paper investigates the quantities of Cu, Zn, and Pb in sediments retrieved from the Hapcheon-Changnyeong weir (HCW). Their concentrations were measured through the aqua regia extraction method and compared with values obtained from Tessier's five-step sequential method to study correlations and recovery. Furthermore, the origins, bioavailability, and mobility of each metal were studied based on their proportions in each fraction during sequential extraction. The extent of metal contamination in the sediment was evaluated by comparing the obtained concentrations with the standard levels for heavy metals published by the National Institute of Environmental Research (NIER), Canada, and the United States Environmental Protection Agency (US EPA) [16–18] as well as the risk assessment code (RAC). This study's conclusions will be used to monitor the heavy metal contamination in sediment in the HCW and predict their impact on the water and the surrounding ecosystem.

2. Materials and Methods

2.1. Study Area

This study focused on the sediment found in the HCW on the Nakdong River (South Korea). The HCW, constructed to retain water resources for the Changnyeong and Hapcheon areas, has a total length of 328 m and a height of 11.5 m. The movable portion of the weir has a length of 138 m, while the fixed portion measures 190 m. The accumulative precipitation of 2019 was 959.8 mm, while the accumulative precipitation from July to September 2019 was 444.6 mm [19].

2.2. Sampling Method

Sediment samples were collected from two locations that were 1 and 5 km north of the weir, labeled ND1 and ND2, respectively, and shown in Figure 1. These samples were collected in 2019, on 23rd July, 13th August, and 19th September. Since the flow rate of the river affects transportation and accumulation of sediment [20], we sampled from July to September to investigate the effect of flow rate and retention time changed by the precipitation on the sediment.

The sediment was sampled by an experienced diver using an acrylic core (diameter 5 cm, height 22 cm) ensuring that the surrounding sediment was not disturbed and carried to the laboratory in an icebox held at 4 °C. Heavy metals were extracted by first drying the upper 2 cm of the sediment until it reached a constant weight and then sieving the sediment with a 0.5 mm sieve [21–23].

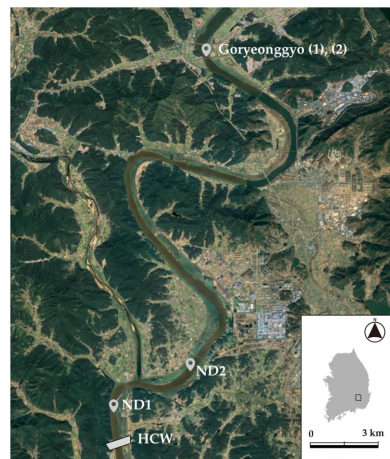


Figure 1. Sampling site (ND1 and ND2), and the locations of previous research (Goryeonggyo (1), (2)) of heavy metals in the Nakdong River.

2.3. Physical and Chemical Characteristics of the Study Area

The in situ pH and Dissolved Oxygen (DO) concentration of water body were measured using a multiparameter instrument (professional plus, YSI, USA). To measure total organic carbon (TOC), the sediment samples were freeze-dried and crushed in an agate mortar, and measured with elemental analyzer (EA 1110, FV instruments, UK) after removing inorganic carbonates with 1.0N hydrochloric acid. The particle size was measured by a particle size analyzer (Mastersizer 2000, Malvan, UK) after removing organics and carbonates using 10% hydro peroxide and 0.1 N hydrochloric acid [24].

2.4. Aqua Regia Extraction

Aqua regia extraction was used to find the total amount of heavy metal in the sediment. Each sample was duplicated for precise result. Aqua regia extraction is used in Germany, the Netherlands, and many other European countries to evaluate sediment contamination [25]. Aqua regia consists of 35–37% hydrochloric acid and 60% nitric acid in a 3:1 ratio [26,27]. A total of 1 g of dried sediment was stirred with 10 mL aqua regia, first at 40 °C for 1 h and subsequently at 140 °C for 4 h, per previously reported methods [28]. The solution was then vacuum filtered, and the filtrate was diluted with distilled water to 100 mL. The concentrations of Cu, Zn, and Pb were measured using inductively coupled plasma atomic emission spectroscopy (ICP-OES) (ICP-5800, Agilent, USA). Analysis was performed by the National Instrumentation Center for Environmental Management (NICEM) at Seoul National University, South Korea (<https://nicem.snu.ac.kr>, accessed on 19 February 2021). The calibration was done with reference solution produced by Inorganic Ventures (<https://www.inorganicventures.com>, accessed on 19 February 2021), and the R^2 values were 0.999 for Cu, Pb, and Zn. The detection limit is 0.001 mg/L, 0.003 mg/L, and 0.001 mg/L for Cu, Pb, and Zn, respectively.

2.5. Sequential Extraction

To study each chemical fraction of heavy metal, we employed the five-step sequential method devised by Tessier and later modified by Yong [8,11,29,30]. In the fifth step, aqua regia was used rather than perchloric acid or hydrofluoric acid to verify the result of aqua regia extraction and sequential extraction. Samples were duplicated. The five steps involve sequentially combining the heavy metals with (1) exchangeable ions, (2) carbonates, (3) iron-manganese oxides, (4) sulfides and organics, and (5) residual metals, which are bound to lithogenic minerals, to achieve extraction and quantification [31,32]. Exchangeable ions, carbonates, and iron-manganese oxides usually represent heavy metals that are derived from anthropogenic sources. Anthropogenic sources typically exhibit high bioavailability

and readily leach into the water [33]. On the other hand, residuals consist of heavy metals with low bioavailability and mobility [9,32].

Each of the five extraction steps is detailed below. Note that the effluent leached from each step was filtered using Whatman 40 filter paper, made up to 100 mL diluted with distilled water, and then was processed in the next extraction step. (1) Exchangeable ions were extracted from 1 g of dried sample in 8 mL of 1 M $MgCl_2$ adjusted to pH 7 with CH_3COOH for one hour at room temperature. (2) Carbonates were extracted in 8 mL of 1 M CH_3COOH adjusted to pH 5 with CH_3COOH and stirred for 5 h at room temperature. (3) Iron–manganese oxides were extracted in 20 mL of 0.04 M $NH_2OH \cdot HCl$ diluted with 25% CH_3COOH at 95 °C. (4) Sulfides and organics were extracted in 3 mL of 0.02 M HNO_3 and 2 mL of 30% H_2O_2 and held at 85 °C for 2 h. An additional 3 mL of 30% H_2O_2 was subsequently added, and the solution was stirred for a further 3 h. Finally, 7 mL of distilled water and 5 mL of 3.2 M CH_3COONH_4 diluted with 20% HNO_3 , which was diluted with distilled water, were added and stirred for 30 min at room temperature. (5) Residuals were extracted using 10 mL of aqua regia for one hour at 40 °C and four hours at 140 °C (Figure 2). The concentrations of extracted metals were measured using ICPOES (ICP-5800, Agilent) with the same method mentioned in 2.4 Aqua Regia Extraction.

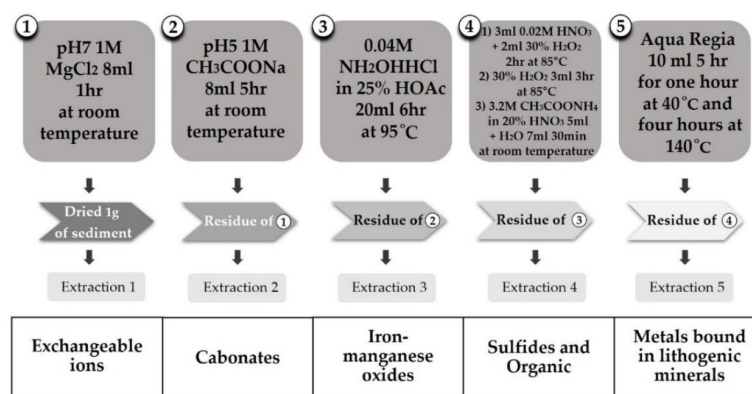


Figure 2. Tessier's five-step extraction flow chart.

2.6. Risk Assessment Code

The RAC is a widely applied to evaluation of heavy metal mobility and bioavailability. Since heavy metals with high bioavailability might enter aquatic animals and plants, they are considered as an important environmental issue [33]. The RAC is calculated by the ratio of the exchangeable fraction and carbonate fraction to the sum of all fractions, and is expressed as a percentage [34,35]. Since the exchangeable fraction and carbonate fraction of heavy metal are easily leached to the water body, the RAC evaluates the mobility and bioavailability of heavy metals [34]. The code is categorized into five classes (Table 1).

Table 1. Risk Assessment Code Categorization.

Class	Risk Assessment Code (%)	Degree of Risk
I	$RAC \leq 1$	No risk
II	$1 < RAC \leq 10$	Light risk
III	$10 < RAC \leq 30$	Medium risk
IV	$30 < RAC \leq 50$	High risk
V	$RAC > 50$	Very high risk

3. Results

3.1. Environmental Characteristics of the Study Area

The particle size of sediment influences the concentration of heavy metals [36] and was measured at locations ND1 and ND2. Hydrological factors such as water depth, precipitation, and retention time can affect sediment formation and were also measured.

The water depths were found to be independent of the sampling date and measured to be 4.0–6.0 m at ND1 and 6.7–6.8 m at ND2, as shown in Table 2.

Table 2. Environmental Characteristics of the Study Area.

Point	Month	Depth(m)	Sand(%)	Silt(%)	Clay(%)	TOC(%)
ND1	July	4.0	92.40	6.12	1.48	2.80
	August	6.0	68.21	26.76	5.03	0.23
	September	5.1	17.86	63.67	18.47	3.57
ND2	July	6.8	94.09	4.69	1.22	0.11
	August	6.7	95.79	3.72	0.49	0.19
	September	6.8	92.58	6	1.42	0.15

Due to the monsoon climate in South Korea, most rainfall is concentrated between July and August, while it is not expected to have high volume of precipitation during September. The precipitation and outflow of the weir during these months are shown in Figure 3. Significant volumes of precipitation and outflow had occurred immediately before our first sample collection in July. In contrast, inflow and outflow volumes were comparatively lower during August. The flow rate of the river influences on transportation and accumulation of sediment [20]. Thus, the flow rate and retention time are considered as important environmental factors, which affect the quality of the sediment. The retention time is calculated by dividing the volume of the waterbody by the volume of inflow. The data used for calculating the retention time were collected over 28 days before the sampling, provided by Korea Water Resource Corporation [19]. The average retention times during July, August, and September were found to be 2.25, 2.31, and 2.75 days, respectively. According to previous research, the retention time of the HCW increased 2 to 12-fold compared with the retention time before the HCW construction, which shows the possible flow rate decrease around the HCW [37]. The pH remained vertically constant in the water body, which ranged from 7.32–9.01, and the DO of overlying water remained oxidic, over 6 mg/L, at both locations (ND1, ND2) during the sampling period. The TOC and particle size composition are also presented in Table 2. For the case of ND1, the TOC concentrations in July and September were 2.80% and 3.57%, respectively. However, TOC concentration in August was 0.23%. For the case of ND2, the TOC concentration difference from July to September was negligible.

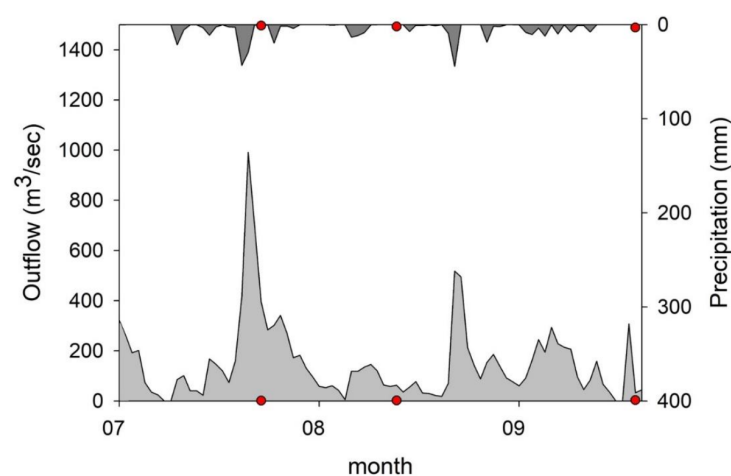


Figure 3. The amounts of outflow and precipitation. The red points indicate the dates on when samples were collected.

The particle sizes changed drastically at ND1. The amount of silt and clay had increased at ND1, while sand composition decreased. The sudden increase in TOC concentration in September at ND1 could be explained with the significant increase in silt and

clay composition. However, at ND2, the change of particle size distribution was negligible, which corresponds with the TOC concentration.

3.2. Aqua Regia Extraction

The total concentration of Cu, Zn, and Pb in the sediment samples through aqua regia extraction are shown in Figure 4. Zn exhibited the highest average concentration over the three months of observation, while Pb demonstrated the lowest. Furthermore, the concentrations of each metal were found to be higher at location ND1 than at ND2. Cu concentrations at ND2 were calculated to be 43.71%, 88.32%, and 38.97% of the values obtained at ND1 during July, August, and September, respectively (Figure 4a). The corresponding percentages for Zn concentrations were 17.70%, 97.27%, and 15.74% (Figure 4b), while they were 19.93%, 95.83%, and 14.37% for Pb (Figure 4c). The differences in concentration between ND1 and ND2 were especially significant in July and September. These results can be attributed to ND1's closer proximity to the weir than ND2, where the water flow is expected to slow to a greater extent. In turn, this is likely to increase the accumulation of heavy metals in the sediment around the weir [6].

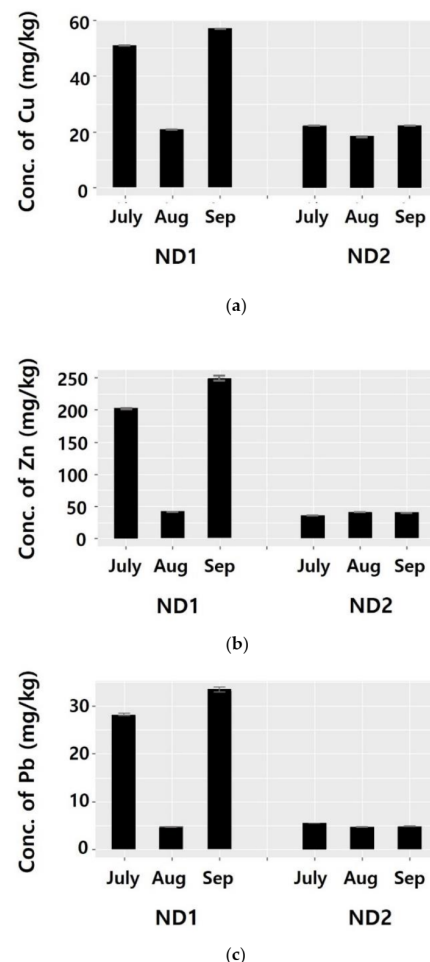


Figure 4. Concentration of (a) Cu, (b) Zn, and (c) Pb in sediment samples from the HCW, analyzed by aqua regia extraction.

Previous studies that have reported Cu, Zn, and Pb concentrations in the Nakdong River before the construction of the HCW are summarized in Table 3. The locations of two of the studies are marked in Figure 1, according to the numbering in Table 3. The heavy metal concentrations reported in these studies were lower than our values, as shown in Table 3. Therefore, this further suggests that the weir impacts the water flow and worsens the content of heavy metals in the sedimentation.

Table 3. Concentration of the heavy Metals before the dam construction.

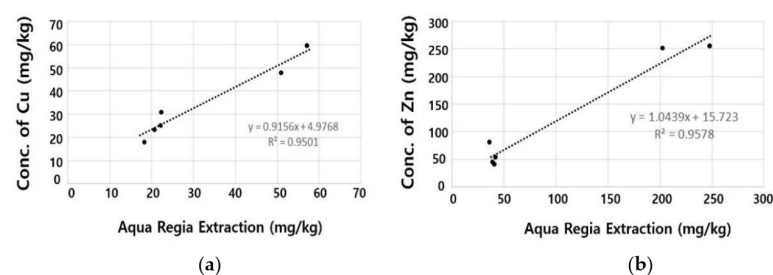
Characteristic		Concentration of Heavy Metals (mg/kg)		Reference
(1)	Stagnant flow Sampled in 2005	Cu	15.24	[32]
		Zn	80.44	
		Pb	33.47	
(2)	Sampled before 2000	Cu	6.42	[38]
		Zn	34.77	
		Pd	9.87	
(3)	Sampled in 1997	Cu	19.38	[39]
		Zn	-	
		Pb	22.50	

3.3. Sequential Extraction

Sequential extraction was performed on each sediment sample obtained from ND1 and ND2 between July and September to investigate the concentrations of heavy metals in each chemical form. The results of Pb are not presented since the measured concentrations in some fractions were below the detection limit. The total Cu and Zn concentrations across the five extraction steps were evaluated to be 17.90–59.83 and 40.50–251.90 mg/kg. The concentrations of Cu and Zn obtained through sequential extraction were 110.35% and 133.12% of the values obtained using aqua regia extraction, respectively.

Sequential extraction showed similar trends regarding the total concentration of Cu and Pb with aqua regia extraction. Their concentrations were found to be higher during July and September than during August. Since the 10-day accumulative inflow of August was approximately 50% and 75% of July and September, it is expected that less amount of heavy metals flowed into the river [40]. For the case of ND1, the August Cu concentration corresponds to 49% and 39% of the July and September Cu concentrations, respectively. Similarly, at ND2, the August Cu concentration corresponded to 58% and 71% of the July and September Cu concentrations, respectively. In addition, the Zn concentrations measured at ND1 and ND2 during August were 22% (21%) and 50% (90%) of the values measured in July (September), respectively. This results corresponded with the results of TOC. For the case of ND1, TOC in August was lower than that of July and September. The results of TOC and metal concentration of ND1 is similar with previous research [41,42]. This indicates the possible impact of weir to the sedimentation of pollutants especially when the accumulative inflow volume is significant.

To ensure that the sequential extraction results were valid, the total concentrations of heavy metal obtained from the aqua regia extraction and Tessier's sequential extraction were correlated through linear regression, as shown in Figure 5. The gradients obtained for Cu (Figure 5a) and Zn (Figure 5b) concentrations were 0.92 and 1.04, respectively, with corresponding R^2 values of 0.95 and 0.96. The fact that the R^2 values approach unity for both metals indicates that the relationship between the two techniques is statistically significant. Furthermore, gradients of approximately 1 indicate that the results from sequential extraction are comparable to those from aqua regia extraction.

**Figure 5.** Correlation between aqua regia and sequential extraction for (a) Cu and (b) Zn.

Between July and September, the minimum and maximum average Cu concentrations were obtained from steps 1 and 5 of the sequential extraction method, respectively (Figure 6). Cu residuals extracted from step 5 amounted to 7.93 to 26.1 mg/kg, (Figure 6a) corresponding to between 33.6% and 63.5% (Figure 6c) of the total Cu concentration. Larger percentages of Cu residual were obtained from ND2 during July and August (63.53% and 51.40%) than from ND1 (49.79% and 33.62%). In contrast, this was reversed during September, where the percentage of Cu residual was higher at ND1 (43.63%) than at ND2 (39.84%). A large amount of Cu residual corresponds to low bioavailability and mobility of Cu. Since the background concentration of Cu in river sediments in South Korea is 43.9 mg/kg [16,43], Cu residuals in the present sediment samples were likely derived from natural origins. Moreover, the Cu concentration bound to organic matters is much higher than that of other heavy metal bound to organics. This is because, particulate organic matter is one of the main ligands attachable to Cu [28,44–46]. This also explains the significant concentrations of Cu extracted from fraction 4.

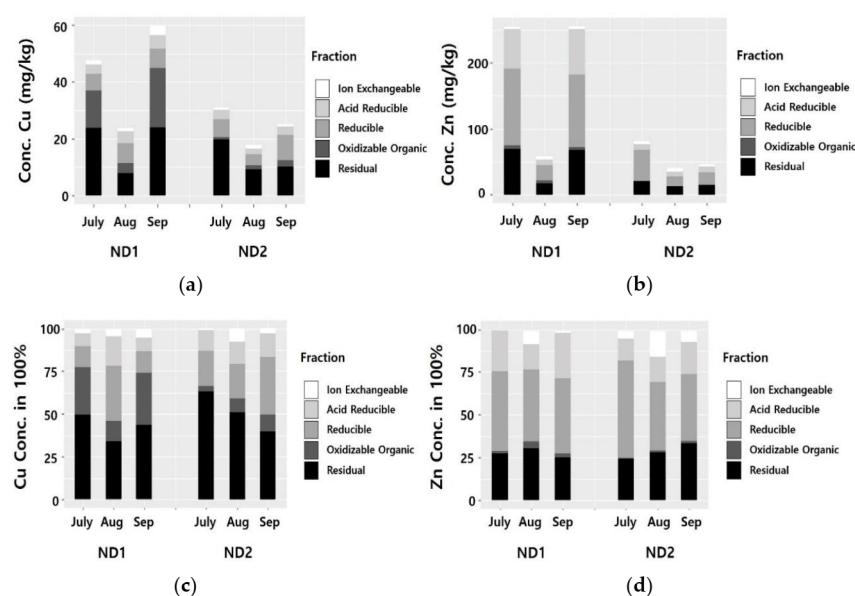


Figure 6. Results of sequential extraction: (1) Concentration of each fraction of sequential extraction for (a) Cu and (b) Zn, (2) Concentration in each fraction of sequential extraction expressed as a percentage of the total concentration for (c) Cu and (d) Zn.

The exchangeable fraction has the highest chance to leach back into water, which constitute the smallest portion of total Cu. Ion exchangeable forms alone accounted for only 1.46 to 8.10% of the total concentration of Cu. Therefore, it may not impact the water quality significantly. However, heavy metals bound to carbonates also have high bioavailability and impact the water body. These chemical forms typically arise due to anthropogenic input and are commonly referred to as nonresistant phases [28]. We note that the combination of exchangeable and carbonate forms represents 10.65 to 22.16% of the total Cu concentration. Together, these two forms may affect the water quality, despite the majority of the Cu concentration existing as residual Cu.

The average concentration of leached Zn was greatest during its extraction in fraction 3, bound to iron and manganese, as shown in Figure 6, while the smallest amount of Zn was extracted in fraction 4, bound to organic matters. Fraction 3 ranged between 16.10 and 117.05 mg/kg (Figure 6b), corresponding to between 38.9% and 56.4% of the total Zn concentration (Figure 6d). In July, the percentage of this fraction was higher at ND2 (56.37%) than at ND1 (46.47%). Conversely, the percentages were higher at ND1 during August and September (46.47% and 42.57%) than at ND2 (39.75% and 38.90%). Heavy metals bound to iron-manganese oxides along with metals bound to organics and residuals, are classified as resistant forms since they are readily incorporated into the sediment [28,31].

However, iron and manganese oxides may leach back into the water provided that specific circumstances are achieved, such as anaerobic conditions [47]. Therefore, Zn bound to iron-manganese oxides may leach and be taken up by aquatic animals during dry seasons with a stagnant overlying water body, which could represent a potential threat to the water body and aquatic ecosystem.

In contrast, the smallest fraction was comprised of Zn bound to organics including sulfides and organics that were extracted during fraction 4. Along with the organic matter's preference toward Cu, Zn adsorbed onto sulfides and organics are stable under anaerobic conditions but may dissolve under aerobic conditions [47]. Since high volumes of precipitation were recorded between July and September 2019, no thermocline was likely formed at the water body near the HCW [48]. In turn, this could have enabled the water at lower depths to maintain aerobic conditions. Under these circumstances, Zn adsorbed onto sulfides and organics may have leached back into the water, while iron-manganese oxides would have remained in the sediment.

The exchangeable fraction of Zn consisted of 0.62 to 16.30% of total Zn. However, we note that the summed concentration of Zn bound to exchangeable and carbonates accounted for 18.44 to 30.99% of the total concentration of Zn, indicating that Zn could affect the water quality.

3.4. Risk Assessment Code

The RAC is applied to assess the potential threats of heavy metals by evaluating heavy metal mobility and bioavailability [34,35]. Therefore, explaining the results using the RAC will provide a clearer evaluation regarding the concentrations of heavy metals extracted. The result of the RAC is shown in Figure 7. According to the RAC, Cu concentrations around the HCW has medium risk. On the other hand, Zn sample of August at ND2 poses a high risk to aquatic animals. Except for the August ND2 sample, Zn samples indicate that Zn poses a medium risk to aquatic animals. This shows that the Cu and Zn concentrations are not negligible, which indicates that both Cu and Zn have potential to deteriorate the quality of the water body. This suggests the necessity of continuous monitoring.

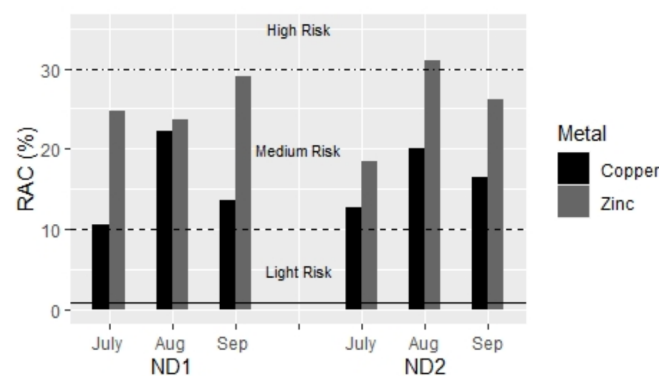


Figure 7. Risk Assessment Code (RAC) for Cu and Zinc in sediment samples from the HCW, analyzed by sequential extraction.

3.5. Assessment of the Sediment Quality

The heavy metal extraction results were compared with the standards published by NIER, Canada, and US EPA to assess the quality of our sediments. The sediment concentrations of Cu, Zn, and Pb were found to be 19.90–59.84 mg/kg, 35.85–255.6 mg/kg, and 4.6–33.05 mg/kg, respectively. According to the NIER's sediment quality standard, our Zn and Pb concentrations may be classified as grade 1, while the Cu concentrations may be classified between grades 1 and 2 (Figure 8a). Although the Cu concentrations reached grade 2 in samples obtained during July and September at ND1, all other samples maintained a grade 1 classification. Therefore, Cu contamination is not expected to affect the river's benthos [16].

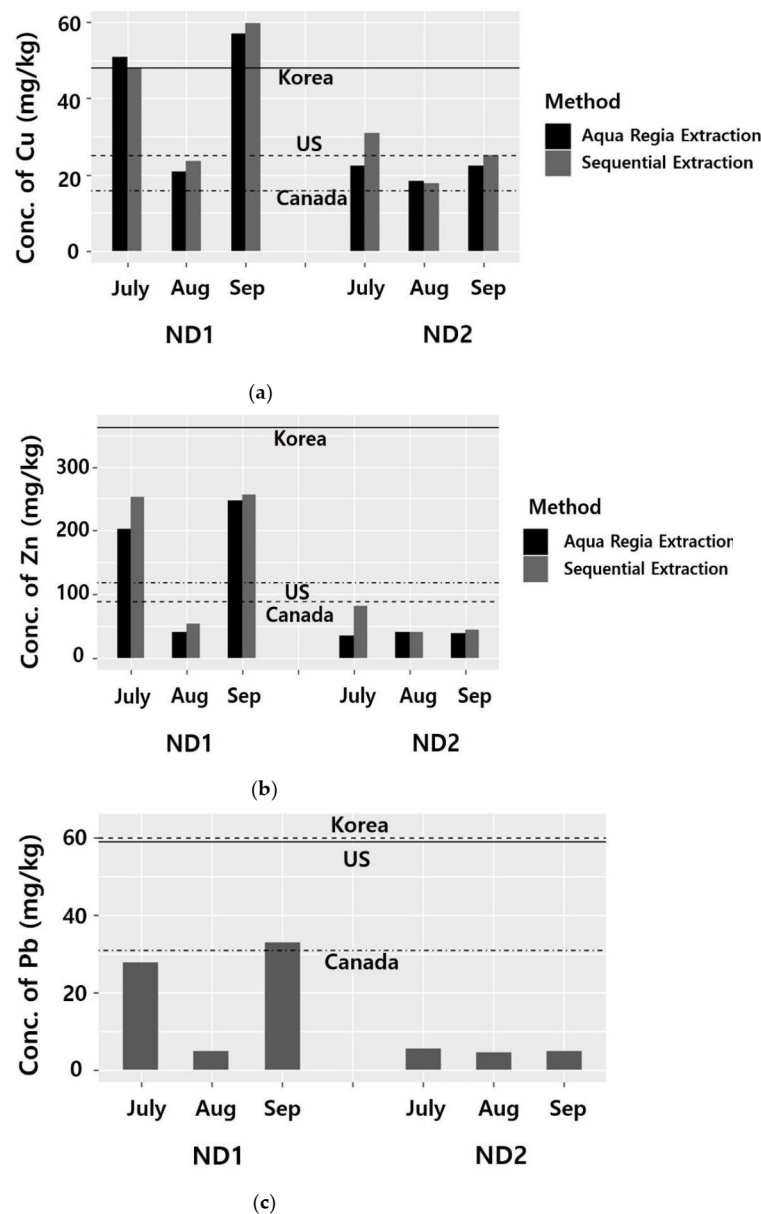


Figure 8. Sediment heavy metal standard of (a) Korea NIER, (b) Canada, and (c) US EPA.

Our data were further assessed according to the international standards for sediment quality as set by the Canada and US EPA. According to the former, all Cu concentrations, as well as the Zn concentrations in July and September (sampled at ND1), and the Pb concentrations in September (sampled at ND1) exceeded the "Lowest Effect Level" (LEL) standard, as shown in Figure 8b [17]. Metals concentrations that exceed LEL values risk impacting the aquatic ecosystem. Similarly, Cu and Pb concentrations from several samples exceeded the non-polluting standards set by the US EPA [18], as shown in Figure 8c, which indicates potential threats to the aquatic ecosystem.

4. Conclusions

In this study, aqua regia extraction and sequential extraction were employed to quantify the heavy metal contamination in sediments from the HCW of the Nakdong River and evaluate possible contamination sources. The weir's impact on heavy metal sedimentation was studied, and the sediment quality was assessed through comparisons with heavy metal standards published by the NIER, Canada, and US EPA. Our experimental results demonstrated higher concentrations of Cu, Zn, and Pb in the sediment during July

and September than in August. Furthermore, higher metal concentrations were found in samples collected closer to the weir, ND1. There was no difference between heavy metal concentrations measured by aqua regia extraction and sequential extraction, as supported by correlation analysis. Since the concentration of heavy metals was higher at ND1 than at ND2, the result indicates that the weir decreases the water velocity and promotes metal sedimentation. The correlation between TOC concentration and heavy metal concentrations also suggests the reliability of the experiment. Sequential extraction showed that naturally occurring Cu residuals comprised the most considerable fraction of total Cu contamination. In contrast, iron-manganese oxides comprised the most considerable portion of Zn contamination, which is assumed to be formed through human activity. Similarly, the result of RAC indicated that both Cu and Zn might cause medium risk on water body and aquatic ecosystem. Additionally, the sediment quality was assessed according to the NEIR, Canadian, and US EPA guidelines. Based on the NIER criteria, only the Cu contamination in samples taken from location ND1 during July and September was expected to impact the aquatic ecosystem. The other metals were not expected to affect the aquatic ecosystem of the river. However, the application of the Canadian, and US EPA standards found that the Cu concentrations in all samples were expected to impact the aquatic ecosystem. Furthermore, Zn concentrations in July and September (sampled at ND1) and the Pb concentrations in September (sampled at ND1) were also sufficient to potentially impact the aquatic ecosystem. Heavy metal contamination in the sediments has a negative impact on the aquatic ecosystem which might be enhanced by the installation of a weir through river flow stagnation. Based on the results of this study, with respect to water quality management, it is necessary to continue monitoring the levels of heavy metal contamination to manage the sediment quality around the weir.

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Informed Consent Statement: Not applicable.

Data Availability Statement: Data available on request due to the restriction of privacy. The data presented in this study are available on request from the corresponding author. The data are not publicly available due to we also need to use these data for further research, involving privacy.

Conflicts of Interest: The authors declare no conflict of interest.

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