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Evaluating Water Quality and Health Risks: A Study of Aisin River and Sediment Contamination in Eripa, Osun State, Nigeria

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ABSTRACT

This study assessed water quality and potential health risks from heavy metal contamination in the Aisin River, a key surface water source in Eripa, Osun State, Nigeria. Water and sediment samples were collected from five strategic locations and analysed for physicochemical parameters and heavy metal concentrations. Sample digestion followed the United States Environmental Protection Agency (EPA) method, and metals were quantified using Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES). The weighted arithmetic water quality index (WAWQI) was used to evaluate water quality, while human health risks were assessed using hazard quotient (HQ) and carcinogenic risk (CR) models for ingestion, dermal, and inhalation pathways in adults and children. WQI values ranged from 51.94 to 77.95, classifying the water as “poor” to “very poor.” Concentrations of Pb, Cd, Cr, and As in water exceeded the WHO permissible limits. Cr levels in water at L1 were significantly lower ($p < 0.05$) than at other sites, while Zn at L1 was significantly higher ($p < 0.05$). In sediments, Pb, Cd, Cr, and As were significantly elevated at L1 ($p < 0.05$), suggesting localised contamination. Overall, sediments showed higher metal concentrations than water ($p < 0.05$). Ingestion was the dominant route of exposure, with children more vulnerable than adults. HQ values for children via sediment ingestion exceeded 1 at several sites. Although carcinogenic risks remained within acceptable limits (10^6 – 10^4), they were highest through ingestion. These findings underscore the urgent need for targeted pollution control, sustainable land-use practices, and continuous environmental monitoring to protect public health and the aquatic ecosystem.

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Introduction

One of the most essential components for a healthy life is water, supporting hydration, metabolism, temperature regulation, and waste elimination (1,2). Beyond its physiological roles such as temperature regulation, digestion, waste excretion through urine and sweat, muscle and nerve function, organ protection, and detoxification, it underpins national development, public health, and socio-

economic well-being (3). In Nigeria, many rural communities depend heavily on surface water for daily use. Unfortunately, poor water quality and limited availability contribute to the spread of infectious diseases and increased mortality rates in these regions.

Surface water environments are increasingly degraded by mining, urbanisation, construction, agricultural development, and industrial activities

(4,5). Heavy metal pollution/contamination is a major concern in water bodies today due to the persistence, toxicity, bioaccumulation, and biomagnification of these metals (6). Undisputably, essential metals are beneficial to daily living; however, economic development is directly responsible for both purposeful and unintentional releases of these metals into the environment (3). Common exposure pathways to heavy metals include ingestion, dermal contact, and inhalation with metals such as lead (Pb), Cadmium (Cd), Chromium (Cr), Arsenic (As), and Nickel (Ni) linked to kidney, respiratory disorders, congenital anomalies, and cancers (7–10).

A scientific approach for evaluating the relationship between environmental contaminants and their associated health risks is the health risk assessment (HRA). HRA involves many components, including but not limited to hazard identification, dose-response assessment, exposure evaluation, and risk characterisation. All of these elements are used collectively to quantify the risk posed by contaminants and to guide the general public in critical decision-making. Standard indices such as hazard quotients (HQ), hazard index (HI), and lifetime cancer risk (LCR) are most commonly used to assess both carcinogenic and non-carcinogenic risks. (4,8).

The Aisin River, which sustains domestic, agricultural, and industrial activities in Eripa, is threatened by waste disposal, runoff, and informal discharges. Despite its importance, little scientific information exists on its contamination status. This study, therefore, aims to conduct a comprehensive health risk assessment of heavy metals in the river, with a particular focus on their concentrations and potential implications for human health. Specifically, it (i) quantifies the concentration levels of selected heavy metals (e.g., Pb, Cd, Cr, Ni, As) in the river; (ii) estimates the non-carcinogenic and carcinogenic health risks associated with exposure to these metals across exposure pathways; and (iii) generates baseline data to guide the formulation of effective water quality management strategies. The novelty of this research lies in providing the first comprehensive risk characterisation for the Aisin River, thereby supporting evidence-based water governance and public health protection.

Materials and methods

Site description

The Aisin River flows from the neighbouring town of Otan-Ayegbaju in the Boluwaduro Local

Government Area through several rocky valleys and thick forests to Eripa and flows across different quarters of Eripa to Iree, then flows through Iba to the Otin River. It is one of the tributaries of the Ojutu River, which flows through various towns and villages in Osun State, and was dammed in Ede town to provide water to Ede Okinni, Ilobu, Osogbo, and many other places. Aisin River serves as a water source for cattle, and Many people in Eripa and Iree use its water for laundry, bathing, fishing, irrigation, and spiritual cleansing. This river has historically been heavily contaminated by waste from residential, commercial, and industrial areas, as well as overuse of pesticides and fertilisers from farms.

Sample collection and storage

Samples were collected at five key locations along the river's course to capture the range of anthropogenic activities. The several locations where samples were taken are depicted in Figure 1. Samples of water were gathered and stored in sterile containers. Using a sterile plastic scoop, samples of sediment were taken from the top sediment (0-20 cm) and placed into polyethene bags. After that, the samples were placed in a cooler box and brought to the Chemistry lab at the Federal University of Health Sciences in Ila-Orangun for further processing prior to analysis.

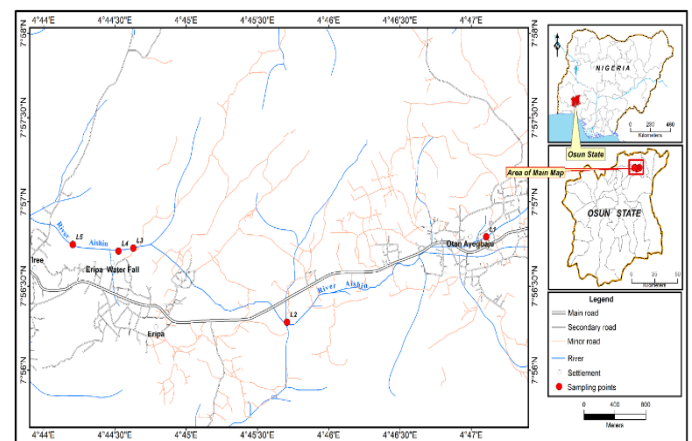


Figure 1: Map of Otan Ayegbaju, Eripa and Iree showing sampling points

Measurement of physicochemical parameters

The on-site multiparameter (HANNA Instrument Inc., HI 9828 pH/ORP/EC/DO, Woonsocket, RI, USA) was used to test the water's physicochemical parameters, including pH, temperature, electrical conductivity, total dissolved solids (TDS), and dissolved oxygen (DO). Prior to usage, the equipment

was calibrated in accordance with the manufacturer's instructions.

Water and sediment sample digestion

Following three days of air drying, the sediments were broken up with a mortar and pestle, and the fine grains were collected by passing them through a 100 µm sieve. After being weighed, the sieved samples were transferred into a Teflon tube. After adding nitric acid to the tubes, they were digested at 150±20°C. A 0.45 µm syringe filter was then used to filter the samples after decanting them into a 50 mL volumetric container. ICP-OES was used to analyse the samples.

Weighted arithmetic water quality index

The weighted arithmetic water quality index (WAWQI) method was used. The model consists of four ordered sequential steps (1). The first, second, and third steps involve identifying and selecting the parameters, scaling the quality rating for each selected parameter, and determining the unit weight (Wi) for each parameter, respectively. The final step involves summing the values of all sub-indices for all parameters. The following equations were used when calculating the WQI.

Using equation 1, the unit weight (Wi) for each parameter was calculated (11):

$$W_i = \frac{K}{S_i} \tag{1}$$

where all parameters connote their usual meaning. Wi is the unit weight of the ith parameter, K is a proportionality constant, and Si denotes the standard value for the parameter (12).

Equation 2 defines the magnitude of K.

$$K = \frac{1}{\sum(\frac{1}{S_i})} \tag{2}$$

Equation 3 was used to determine the quality rating, Qi, for each parameter.

$$Q_i = \left(\frac{V_i - V_0}{S_i - V_0}\right) \tag{3}$$

Where Vi and V0 are the observed concentration value and the ideal value of the parameter, respectively. For pH, the quality rating was calculated using a modified version (Equation 4):

$$Q_i = \left(\frac{V_i - 7}{S_i - 7}\right) \tag{4}$$

Here, the ideal pH value was set to 7, while all other parameters were set to 0.

The subindex for each parameter (Si) and the overall WQI were calculated using Equation (5):

$$S_i = \frac{\sum W_i Q_i}{\sum W_i} \tag{5a}$$

$$WQI = \sum S_i \tag{5b}$$

Here, Si represents the subindex for the ith parameter, and i corresponds to the total number of parameters considered in the analysis.

Human health risk assessment

Contaminants of concern (COCs) in Aisin river water and sediment, primarily metals including lead (Pb), cadmium (Cd), chromium (Cr), arsenic (As), cobalt (Co), zinc (Zn), copper (Cu), selenium (Se), nickel (Ni) and manganese (Mn). Inductively Coupled Plasma Mass Spectrometry (ICP-MS) was used to determine the concentrations of these pollutants. The exposure assessment followed, involving calculation of chronic daily intake (CDI) and evaluation of the extent and frequency of human exposure to contaminants via three primary pathways: ingestion, inhalation, and dermal contact.

Ingestion includes consumption of river water (direct) or sediment (incidental ingestion during recreational activities). The ingestion pathway CDI_{ingest} is calculated using equation 6.

$$CDI_{ingest(water)} = \frac{C_w \times IR \times EF \times ED}{BW \times AT} \tag{6a}$$

$$CDI_{ingest(sediment)} = \frac{C_w \times IRS \times CF \times EF \times ED}{BW \times AT} \tag{6b}$$

Cw is the contaminant concentration in water or sediment (mg/L or mg/kg), IR is the ingestion rate (L/day), IRS = 100 mg/kg/day for adults (13) EF is exposure frequency (days/year), ED is exposure duration (years), CF is the conversion factor (cm3), BW is the body weight (kg), and AT is the average time (days).

Inhalation involves exposure to contaminants by breathing in resuspended sediment particles, while dermal contact involves direct contact with water and sediment during bathing, swimming, or occupational activities. The dermal pathway CDI_{dermal} and the inhalation pathway CDI_{inhalation} are calculated using equation 7.

$$CDI_{dermal(water)} = \frac{C_w \times K_p \times SA \times EF \times ED \times ET \times CF}{BW \times AT} \tag{7a}$$

$$CDI_{dermal(sediment)} = \frac{C_w \times SA \times AF \times ABS \times EF \times ED \times CF}{BW \times AT} \tag{7b}$$

$$CDI_{inhalation(sediment)} = \frac{C_w \times EF \times ED \times ET}{PEF \times 24 \times AT} \tag{7c}$$

Cw is the contaminant concentration in water or sediment (mg/L or mg/kg), Kp is dermal permeability coefficient (cm/hr), SA is exposed skin area (cm²), EF is exposure frequency (days/year), ED is exposure duration (years), ET is exposure time (hours/day), CF is

Conversion factor (mg/cm³), AF is adherence factor (0.7 mg/cm²), ABS denotes dermal absorption fraction (0.0001 for all metals except As with 0.03), BW is the body weight (kg), AT is the average time (days) and PEF represents the particle emission factor of 1.36 × 10⁹

To determine the toxicity assessment, the following health risk indices were used. They include the reference dose (R_fD) for non-carcinogenic effects and slope factor (SF) for carcinogenic effects, based on established guidelines (12). Risk characterisation was conducted through non-carcinogenic and carcinogenic risk assessments.

Non-carcinogenic risk assessment

Non-carcinogenic risks were evaluated using hazard quotient (HQ) and CDI values. The HQ was calculated as

$$HQ_{\text{ingest/dermal(water/sediment)}} = \frac{CDI_{\text{ingest/dermal}}}{R_fD} \quad (9)$$

An HQ > 1 indicates potential adverse health effects (14). The hazard index (HI) representing the cumulative non-carcinogenic risk from multiple contaminants was determined as:

$$HI_{\text{ingest/dermal(water/sediment)}} = \sum HQ_{(Pb,Cd,Cr,As,Co,Zn,Cu,Se,Ni,Mn)} \quad (10)$$

Carcinogenic risk assessment

Carcinogenic risk (CR) via ingestion, dermal and inhalation was estimated using the chronic daily intake and the slope factor (SF) as:

$$CR = CDI_{\text{ingest/dermal/inhalation(water/sediment)}} \times SF \quad (11)$$

Acceptable CR values range between 10⁻⁶ and 10⁻⁴ (15). This threshold ensures minimal risk of cancer over a lifetime.

Statistical analyses

The concentration of heavy metals was reported in the form of mean±standard deviation. Significant differences in heavy metal concentrations among the sample sites were assessed using one-way Analysis of Variance (ANOVA), followed by Duncan's test for pairwise comparisons. Data analysis was performed using the Statistical Package for the Social Sciences (SPSS, version 27.0), and p < .05 was considered statistically significant.

Results and discussion

Physicochemical parameters and water quality assessment of the Aisin River

The water quality index of the Aisin River ranged from 51.94 to 77.95 across the five sampling points (Table 1), classifying the water as “poor” to “very poor”. The pH ranges from 6.99 to 7.34, indicating neutral to slightly alkaline conditions, which are suitable for aquatic life and limit the solubility of toxic metals, thereby reducing contamination risks. Alkalinity values range from 23.33 – 36.67 mg/L, providing a buffer against pH fluctuations. TDS values range between 25.03 and 36.02, and salinity levels from 0.48 – 1.04 mg/L reflect the presence of dissolved ions from natural weathering or runoff. Slightly elevated chloride (5.88 – 8.88 mg/L) and sulphate (2.59 – 3.25 mg/L) levels in certain locations suggest potential contributions from fertilisers or soil erosion.

Table 1: Computed water quality values for the Aisin River

Parameter	L1	L2	L3	L4	L5
pH	6.99	7.34	7.24	7.30	7.32
EC (µscm)	60.07	70.02	50.03	50.02	64.02
TDS(ppm)	30.01	36.02	25.03	25.03	32.03
Turbidity (NTU)	1.77	1.93	1.91	1.86	1.82
Salinity (mg/L)	0.48	0.75	0.87	0.75	1.04
Alkalinity (mg/L)	33.33	30.00	23.33	36.67	30.00
Chloride (mg/L)	6.51	5.88	7.69	8.88	6.51
Sulphate (mg/L)	3.03	2.59	3.03	3.25	2.81
TSS (mg/L)	0.16	0.28	0.17	0.14	0.14
TS (mg/L)	30.17	36.30	25.20	25.17	32.16
WQI	51.94	77.95	60.88	71.88	74.15

Specifically, the water quality category in L1 is poor. Parameters including moderate TDS (30.01 ppm), normal pH (6.99) and elevated chloride levels (6.51 mg/L) contribute to this classification. L1 could have been exposed to some anthropogenic activities, or it is a result of natural geological factors (16). L2 exhibits the highest WQI among the sampling points, classifying it as “very poor”. This could be attributed to agricultural runoff or localised point-source pollution. The WQI classifies the water at L3 as poor. At this point, the high sulphate and chloride levels may indicate contributions from diffuse pollution sources. At L4, the WQI classification is also poor. This could, however, be attributed to salinity and TDS levels. At L5, the classification is also poor, with slightly higher salinity and TDS levels. These results suggest potential contamination from agricultural activities, given the elevated ionic concentrations compared to upstream locations.

The results obtained in this research align with previous studies of river systems in regions with mixed anthropogenic and natural influences. Rivers impacted by agricultural runoff often exhibit high WQI values, with key parameters like salinity, TDS and chloride influencing water quality (17). An earlier study by (18) on the Ogun and Ona River basins, also (19) reported similar trends in the Eleyele catchment area, Ibadan, south-western Nigeria, where agricultural and urban runoff contributed to poor water quality classification. In contrast, rivers with significant industrial pollution often have WQI values exceeding 100, rendering the water unsuitable for drinking. The Aisin River, with WQI values ranging from 51.94 to 77.95, suggests moderate anthropogenic pressure but not significant industrial contamination.

Concentration of heavy metals in water samples

Analysis (Table 2) revealed that Pb, Cd, Cr, and As exceed WHO limits in water, raising ecological and health concerns (20). Pb concentrations ranged from 0.05 to 0.08 mg/L, likely due to industrial runoff, vehicular emissions, and improper waste disposal. Cd levels, at 0.40 to 0.44 mg/L, exceeded standards by over 100 times, attributed to industrial discharges and agricultural runoff. Cr concentrations, ranging from 0.66 to 0.74 mg/L, far exceeded the 0.05 mg/L limit, likely due to activities such as animal skin tanning, with the carcinogenic Cr⁶⁺ form of particular concern. The levels ranged from 0.05 to 0.06 mg/L, above the 0.01 mg/L limit, indicating contamination from geological sources or pesticide use. While Co lacks a

specific WHO limit, its concentrations (0.16–0.21 mg/L) suggest potential environmental toxicity. Zn, Cu, and Se levels were within safe limits, suggesting minimal contamination, while Ni levels (0.05–0.06 mg/L) approached the 0.07 mg/L limit but did not exceed it. The Mn concentration ranges from 0.03–0.09 mg/L, slightly exceeding the 0.04 mg/L limit at some locations, possibly due to leaching. These findings highlight the urgent need for pollution control and improved water treatment to safeguard health and the ecosystems. Statistical analysis showed no significant difference ($p > 0.05$) in the concentrations of Pb, Cd, As, Co, Cu, Se, Ni and Mn across the five sampling locations. However, Cr concentration in L1 was significantly lower than in other locations ($p < 0.05$), while Zn concentration was significantly highest in L1. The Zn concentrations in L2, L3, and L5 did not differ significantly from each other ($p > 0.05$), but the Zn concentration in L4 was significantly lower than all other locations ($p < 0.05$). These intra-location variations, though limited for most metals, highlight localised sources of contamination, particularly for Cr and Zn.

Health implications include neurological risks from Pb (21,22), kidney and bone damage from Cd (23), carcinogenic potential of Cr⁶⁺ (24), and cardiovascular/dermal impacts of As (25). These findings emphasise the urgent need for interventions to mitigate human exposure to these contaminants. The contamination may also threaten the aquatic ecosystems, as toxic metals in aquatic organisms can disrupt the food chain and biodiversity. Higher levels of Co, Mn, and Ni, although not exceeding critical limits in most cases, can still impact aquatic organisms and soil quality. Low levels of Zn, Cu, and Se suggest minimal contamination for these elements, which is a positive aspect of the water quality.

Concentration of heavy metals in sediment samples

The sediment concentrations analysis of the Aisin River (Table 2) reveals significant contamination by toxic metals, particularly Pb (0.08 mg/Kg to 0.11 mg/Kg), Cd (0.51 mg/Kg to 0.61 mg/Kg), Cr (0.71 mg/Kg to 0.85 mg/Kg), and As (0.08 mg/Kg to 0.12 mg/Kg), which exceed natural background levels. The result shows that L1 consistently has a higher heavy metal concentration than the other locations ($p < .05$). This indicates that L1 is more affected by heavy metal contamination. Elevated Pb levels indicate industrial effluents and vehicular emissions, while high Cd

concentrations suggest agricultural runoff and industrial discharges as primary sources. Cr contamination linked to industrial activities, and pollution from pesticide use and geological leaching, further highlight anthropogenic impacts. In contrast, metals such as Co, Zn, Cu, Se, Ni, and Mn were found at relatively low concentrations, suggesting limited pollution or natural origins. The findings underscore the ecological and health risks posed by heavy metal contamination, necessitating urgent measures, including stricter pollution controls, sustainable agricultural practices, and sediment remediation strategies, to safeguard the river's ecosystem and prevent further environmental degradation.

The comparison of the concentration of heavy metals in water and sediment in the different locations shows that Pb concentrations were found to be consistently higher in sediment than in water across most of these locations ($p < .05$). For Cr, it was significantly higher in most of the location in water than sediment while the concentration of Co and Cu in location 1 were not significantly different but significantly different in other locations ($p > .05$). The concentration of Se was not significantly different in L2, L3, L4 and L5 ($p > .05$) while in L1, it was significantly higher in sediment and sand than water sample ($p < .05$). Result shows higher concentration of heavy metals in sediment than water.

Non-carcinogenic health risk assessment posed by HM in water and sediment via different pathways

Hazard Quotient (HQ) indicated ingestion as the dominant pathway, especially for children (Table 3). Water ingestion HQs were 0.1829 – 0.2119 for adults and 0.6816 – 0.7894 for children, below the safe limit of 1. However, sediment ingestion HQs exceeded 1 in children (1.0046–1.4398), indicating potential health risks. Dermal exposure contributed minimally. Children show higher susceptibility due to their lower body weight and higher ingestion rates (26).

Carcinogenic health risk assessment in water and sediment posed by HM via different pathways.

Carcinogenic risk from Pb, Cd, Cr, As, and Ni remained within the acceptable range of 10^{-6} to 10^{-4} for both adults and children (Table 4). Ingestion was the main pathway, particularly in children ($5.5E-04$ – $6.3E-04$), though still within regulatory thresholds. Dermal exposure to heavy metals from water presented very low risks for both adults and children. For adults, the risk ranged from $5.85516E-07$ to

$6.36498E-07$, and for children, it ranged from $9.82482E-06$ to $1.068E-05$. These values are significantly lower than ingestion risks, indicating that dermal exposure poses a minimal carcinogenic risk. Dermal exposure risks are slightly higher for children than adults, but still, the values remain exceedingly low and well below typical carcinogenic risk thresholds. Inhalation exposure for both adults and children was negligible. The inhalation risk values ranged from $3.07E-09$ to $5.56E-06$ for adults and from $1.54E-08$ to $1.57E-08$ for children. These values are far below the acceptable risk limit, confirming that inhalation is not a significant pathway for carcinogenic risk from waterborne heavy metals.

Ingestion of sediment posed a slightly higher risk for both adults and children than ingestion of water. For adults, the risk ranged from 0.000104 to 0.000107; for children, it ranged from 0.000104 to 0.000107 as well. These values, while still low, indicate a higher carcinogenic risk from sediment than from water, though they remain well below the regulatory threshold. Dermal exposure to sediment for both adults and children was also relatively low. For adults, the risk ranged from $4.28E-06$ to $5E-06$, and for children, it ranged from $4.28E-06$ to $5E-06$. Similar to water exposure, dermal contact with sediment poses a minimal carcinogenic risk. Inhalation risk from sediment was extremely low, with values ranging from $1.54E-08$ to $1.57E-08$ for both adults and children. This suggests that inhalation is an insignificant exposure route for carcinogenic risks from sediment contaminants.

The overall carcinogenic risk posed by heavy metals in water and sediment is very low, with ingestion identified as the most significant exposure pathway. While children have slightly higher ingestion risks than adults, the risks remain within safe limits, well below regulatory thresholds for carcinogenic risk. Dermal and inhalation exposures present negligible risks. These findings suggest that heavy metal contamination in the study area poses minimal carcinogenic risks to both adults and children through the evaluated exposure pathways. Nonetheless, continued monitoring and potential mitigation strategies for environmental contamination are recommended, particularly in areas with elevated ingestion risk.

Conclusion

The Comprehensive evaluation of the Aisin River's Physiochemical characteristics and heavy

Table 2: Comparison of the heavy metals in the water and sediment in the different locations

Sample	Groups	Pb	Cd	Cr	AS	Co	Zn	Cu	Se	Ni	Mn
L1	Water	0.05±0.01 ^a	0.44±0.04 ^a	0.70±0.01 ^b	0.05±0.02 ^a	0.20±0.01 ^a	0.09±0.01 ^a	0.06±0.01 ^a	0.02±0.01 ^a	0.06±0.01 ^a	0.04±0.02 ^a
	Sediment	0.09±0.01 ^b	0.88±0.03 ^c	0.56±0.03 ^a	0.08±0.01 ^a	0.21±0.02 ^a	0.12±0.01 ^b	0.08±0.02 ^a	0.05±0.01 ^b	0.08±0.02 ^b	0.10±0.01 ^b
L2	Water	0.08±0.01 ^b	0.42±0.02 ^a	0.66±0.02 ^b	0.05±0.01 ^a	0.21±0.01 ^c	0.06±0.01 ^b	0.04±0.02 ^a	0.02±0.01 ^a	0.05±0.02 ^b	0.03±0.02 ^a
	Sediment	0.03±0.01 ^a	0.37±0.02 ^a	0.50±0.01 ^a	0.03±0.01 ^a	0.14±0.01 ^a	0.03±0.01 ^a	0.04±0.01 ^a	0.02±0.01 ^a	0.03±0.01 ^a	0.02±0.01 ^a
L3	Water	0.06±0.01 ^b	0.43±0.02 ^b	0.72±0.03 ^b	0.05±0.01 ^a	0.19±0.02 ^b	0.07±0.01 ^b	0.04±0.01 ^a	0.03±0.01 ^a	0.06±0.01 ^b	0.03±0.01 ^a
	Sediment	0.03±0.00 ^a	0.34±0.01 ^a	0.43±0.02 ^a	0.04±0.01 ^a	0.12±0.01 ^a	0.02±0.01 ^a	0.04±0.01 ^a	0.02±0.01 ^a	0.04±0.01 ^a	0.02±0.01 ^a
L4	Water	0.06±0.02 ^a	0.40±0.03 ^b	0.71±0.03 ^b	0.06±0.01 ^b	0.16±0.02	0.04±0.01 ^a	0.02±0.01 ^a	0.02±0.01 ^a	0.06±0.01 ^b	0.09±0.10 ^a
	Sediment	0.03±0.02 ^a	0.33±0.01 ^a	0.44±0.02 ^a	0.03±0.01 ^a	0.11±0.01	0.03±0.01 ^a	0.04±0.01 ^a	0.02±0.01 ^a	0.03±0.01 ^c	0.02±0.00 ^a
L5	Water	0.07±0.01 ^b	0.44±0.01 ^b	0.74±0.02 ^b	0.06±0.00 ^b	0.20±0.01 ^b	0.05±0.01 ^a	0.03±0.01 ^a	0.03±0.01 ^a	0.05±0.02 ^b	0.06±0.01 ^b
	Sediment	0.04±0.01 ^a	0.32±0.01 ^a	0.43±0.02 ^a	0.03±0.01 ^a	0.12±0.01 ^a	0.03±0.02 ^a	0.03±0.02 ^a	0.01±0.01 ^a	0.02±0.01 ^a	0.02±0.01 ^a

Similar superscript letter means not significantly different at 5 % (p<.05), and different superscripts are significantly different at 5 % (p<.05).

Table 3: Non-carcinogenic health risk assessment posed by HM in water and sediment via different pathways

Source	Water				Sediment			
	Adult		Children		Adult		Children	
	Ingestion	Dermal	Ingestion	Dermal	Ingestion	Dermal	Ingestion	Dermal
L 1	0.1919	0.0059	0.7152	0.0982	0.3010	0.6048	1.1216	0.1396
L 2	0.1829	0.0055	0.6816	0.0922	0.3390	0.6474	1.2635	0.1424
L 3	0.1908	0.0058	0.7108	0.0974	0.3863	0.4960	1.4398	0.1573
L 4	0.1979	0.0058	0.7373	0.0969	0.2695	0.4702	1.0046	0.1298
L 5	0.2119	0.0062	0.7894	0.1037	0.3483	0.5318	1.2979	0.1510

Table 4: Carcinogenic health risk assessment in Water posed by HM via different pathways

Sample ID	Water				Sediment					
	Adult		Children		Adult		Inhalation	Children		Inhalation
	Ingestion	Dermal	Ingestion	Dermal	Ingestion	Dermal		Ingestion	Dermal	
L 1	0.00016	5.85516E-07	0.000597	9.82482E-06	5.97E-06	2.44E-07	3.07E-09	0.000104	4.28E-06	1.54E-08
L 2	0.00015	5.4918E-07	0.000560	9.21462E-06	5.64E-06	2.76E-07	2.9E-09	9.88E-05	4.83E-06	1.45E-08
L 3	0.00016	5.81704E-07	0.000589	9.76061E-06	5.91E-06	3.18E-07	3.04E-09	0.000104	5.56E-06	1.52E-08
L 4	0.00016	5.9673E-07	0.000586	1.00128E-05	5.64E-06	2.19E-07	2.9E-09	9.87E-05	3.83E-06	1.45E-08
L 5	0.00017	6.36498E-07	0.000629	1.068E-05	6.1E-06	2.86E-07	3.14E-09	0.000107	5E-06	1.57E-08

metal concentrations in water and sediment samples across five strategic locations (L1, L2, L3, L4, and L5) provides critical insight into the river's environmental status. The findings of this research demonstrate a disturbing trend of declining water quality, underscoring significant environmental pressures that threaten both aquatic ecosystems and human health. The WAWQI values ranging from 51.94 to 77.95 across the study area. These values fall within the categories of "poor" to "very poor" water quality, indicating that the river is not suitable for direct consumption and may pose a significant health risk if used without adequate treatment. Among all sampling locations, L5 recorded the highest WQI, suggesting that water quality deteriorates downstream, likely due to cumulative pollution loads from upstream agricultural, domestic and possibly industrial activities. While parameters like pH remained within WHO-acceptable ranges, elevated values for TDS, salinity, chloride, and sulphate indicate ionic enrichment of the water. These elevated levels point toward excessive nutrient loading, likely resulting from fertiliser runoff, erosion, and improper waste disposal practices. High chloride concentrations suggest possible sewage intrusion or mixing with saline water, while elevated sulphate levels may be linked to industrial effluents or natural leaching from geological formations.

Heavy metal analysis presented a more serious concern. The concentrations of toxic metals such as Pb, Cd, Cr and As in the water are consistently above the WHO permissible limits at all sampling points. Cadmium levels were particularly alarming, with mean concentrations exceeding the WHO guideline value by more than 100-fold, posing a significant risk to human and ecological health. Site L1 consistently recorded the highest metal load, potentially due to its location near agricultural activity or as a confluence point for upstream discharges. Statistical analyses (mean comparisons) confirmed significant differences ($p < 0.05$) in heavy metal concentrations among sites, particularly for Pb, Cd, Cr, and As. These metals, once settled in sediment, can become re-mobilised due to changes in redox potential, pH, or microbial activity.

On a more positive note, concentrations of other metals such as zinc (Zn), copper (Cu), selenium (Se), and nickel (Ni) remained within WHO safe limits, and parameters such as turbidity and alkalinity, though elevated at some sites, were generally within acceptable bounds. Nevertheless, the presence of high WQI values, elevated TDS and salinity, and toxic

heavy metals points to a river system under considerable ecological duress. In conclusion, the Aisin River is facing significant environmental degradation. The combination of poor water quality, widespread heavy metal pollution, and sediment contamination signals an urgent need for intervention. Without immediate and sustained remediation efforts, the river may continue to deteriorate, with potentially irreversible consequences for biodiversity, agriculture, and public health.

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Ethical approval

This study does not require ethical approval

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