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Derivation of Human Health Ambient Water Quality Criteria for Heavy Metals and Health Risk Assessment in Ntawogba Creek

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ABSTRACT

In recent times, heavy metals pollution is a public health concern due to their toxic, bioaccumulative nature and their tendency to persist in aquatic environment for extended periods. Human health ambient water quality criteria (AWQC) are defined as the safe concentration levels of chemicals in water that do not pose a risk to human health and very significant in accurate estimation of health risk of pollutants. Currently, the impact of aquatic vegetables is often overlooked in the formulation of these criteria in most countries. Consequently, this study incorporated the consumption of aquatic vegetables (*Brasenia schreberi*) into the derivation of AWQC and conducted a health risk assessment for five heavy metals present in Ntawogba Creek. The toxicological data for cadmium (Cd), lead (Pb), chromium (Cr), arsenic (As) and zinc (Zn) were collected from different databases, screened, and used to develop AWQC for these heavy metals. The result revealed that the heavy metal concentration in water was in the order of Zn(30.95mgL^{-1}) > Cr(2.72mgL^{-1}) > Cd(1.84mgL^{-1}) > Pb(0.66mgL^{-1}) > As(0.005mgL^{-1}). Furthermore, the AWQC (consumption of water, fish and aquatic vegetables) value of the 5 heavy metals with respect to human health was in the order of As (0.73µg/L) < Cd (8.68µg/L) < Cr(19.1µg/L) < Cd(225.35µg/L) < Zn(2093.37µg/L). The hazard quotients of Pb, Cr, Cd, As and Zn were higher than the safe level (HQ=1), indicating that Pb, Cr, Cd, As and Zn in Ntawogba Creek posed a significant health risk. Therefore, greater attention should be given to the health risks posed by these metals from dietary intake related to surface water.

Keywords: Heavy Metals, Ambient Water Quality Criteria, Health Risk Assessment, Aquatic Vegetable, Hazard Quotient.

Introduction

Enormous amounts of industrial chemicals are produced and afterward released into aquatic environments through point and non-point emissions, leading to the deterioration of water quality (Venier *et al*., 2014, 2015; Liu *et al*., 2016). This decline in water quality poses serious threats to ecosystem functions and human health, becoming a major obstacle to the sustainable development of social economy (Cui *et al*., 2020). Heavy metals, defined as metals or metalloids with a specific density greater than 5g/cm3 (Monisha *et al*., 2014), have attracted global attention due to their toxicities, persistence, resistance to degradation, and their bioaccumulation in aquatic organisms such as fish, shrimp, crab, and mollusks (Zhong *et al*., 2018a). These heavy metals pose significant health risks to humans consuming these aquatic organisms (Chen *et al*., 2020a, b; Khan *et al*., 2010; Long *et al*., 2020). Even at low levels, arsenic (As), cadmium (Cd), chromium (VI) (Cr (VI)), and lead (Pb) have been reported to adversely affect human health (Ahmed *et al*., 2015; Makedonski *et al*., 2017). Additionally, essential metals like zinc (Zn) can be harmful to human health if dietary intake exceeds safe levels (ATSDR, 2005; WHO, 2011). Consequently, the USEPA (2002) has established human health ambient water quality criteria for 8 toxic metals to protect the general population from the consumption of contaminated water and aquatic organisms.

Human health ambient water quality criteria (AWQC) refer to the maximum pollutant concentrations that do not cause toxic or harmful effects in humans or ecosystems (Cui *et al*., 2020).

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The establishment of AWQC and their application in revising water quality standards (WQS) for toxic metals are urgently required for environmental risk assessment and management in Nigeria. Ambient water quality criteria (AWQC) values are formulated to account for the long-term consumption of aquatic organisms and water. While some studies have provided aquatic life criteria (ALC) for heavy metals (Hong *et al*., 2020), few have derived AWQC values with a focus on human health. Given the significant risks that heavy metals in water environments pose, it is essential to develop ambient water quality criteria for heavy metals that prioritize human health.

Risk assessment is a technique used to evaluate the effects of pollutants (Wang *et al*., 2020a). It can be categorized into human health risk assessment and ecological risk assessment based on the specific protection targets (Wang *et al*., 2021). This study, however, focuses on risk assessment concerning human health. To assess the potential risks posed by pollutants in surface water, which serves as a source of drinking water and aquatic products, pollutant concentrations in surface water can be compared to human health AWQC (Chen *et al*., 2020a, b).

In this study, the Ntawogba Creek was chosen as the research area to analyze the concentrations of five toxic heavy metals: arsenic (As), cadmium (Cd), chromium (Cr), lead (Pb) and zinc (Zn) in the water. The AWQC values for these heavy metals concerning human health will be derived based on measured bioaccumulation factors (BAFs) and USEPA population exposure parameters. The specific objectives of this study are: (1) to analyze the pollution levels of the selected heavy metals in the surface water of Ntawogba Creek; (2) to provide the corresponding AWQC values concerning human health; and (3) to evaluate the human health risks associated with these heavy metals in Ntawogba Creek. This study serves as a reference and basis for environmental management and risk assessments of heavy metals in aquatic environments.

Materials and Methods

Study area and sample collection

The study area, Ntawogba Creek, is situated on the western border of the city of Port Harcourt, Rivers State, Nigeria.

The water course can be found flanked at latitudes of 4^0 47’ and 4^0 49’N and longitudes of 6^0 59’ and 7^0 00’E. The area has a climate likened to that of the tropical equatorial latitude, with an average precipitation of 2719mm and a temperature that fluctuates between 22ºC and 32ºC all through the year (Gobo *et al.*, 1998; Gobo *et al.*, 2008). The Ntawogba Creek is a stream that originates in the northern area of Orazi Forest and flows southward into the Bonny Sea. The creek is a major water resource used for drinking, other domestic, commercial and industrial activities in Port Harcourt metropolis. Over time, these activities have deteriorated the water quality of the creek.

Twenty (20) surface water samples were obtained from Ntawogba creek. A volume of 1 litre of water samples were collected below the surface of each sample station and placed into sterile polypropylene containers. Toxicity data for aquatic organisms were mainly obtained from the Ecotox database (https://cfpub.epa.gov/ecotox) and published literature. The water samples were acidified using 1% Nitric acid (HNO_3) and placed in an ice chest at 4ºC till it was conveyed to the lab for further analysis (APHA, 2012; Pandiyan *et al*., 2021). A Map of the sampling stations of surface water in Ntawogba Creek is presented in Figure 1.

Sample analysis and quality control

In analyzing the water sample, 100ml of water sample was measured into a 250ml beaker; about 10ml of sulfuric acid (H_2SO_4), 10ml of nitric acid (HNO_3) and 5ml of perchloric acid ($HCLO_4$) were added in a ratio of 2:2:1 respectively. The mixture was heated in a water bath for about 2 hours at 105ºC till it reduced to 20 ml. It was allowed to cool for 10-20mins; the sample was filtered using a filter paper into a 100ml volumetric flask. The sample was falsified with distilled water to 100ml; put the sample into a 120ml white plastic container. The atomic absorption spectrophotometer Raleigh WFF 320 model was used to estimate the concentration of Cd, Pb, Cr, As, and Zn in the samples. During the analysis of samples, procedural blanks, sample duplicate entries, and recovery rate testing were conducted for quality control and quality assurance (QA/ QC). The comparative nonconformity of the replica samples was 5%, and the recovery rate for the five (5) heavy metals ranged from 86.3 percent to 107.8 percent (APHA, 2017).

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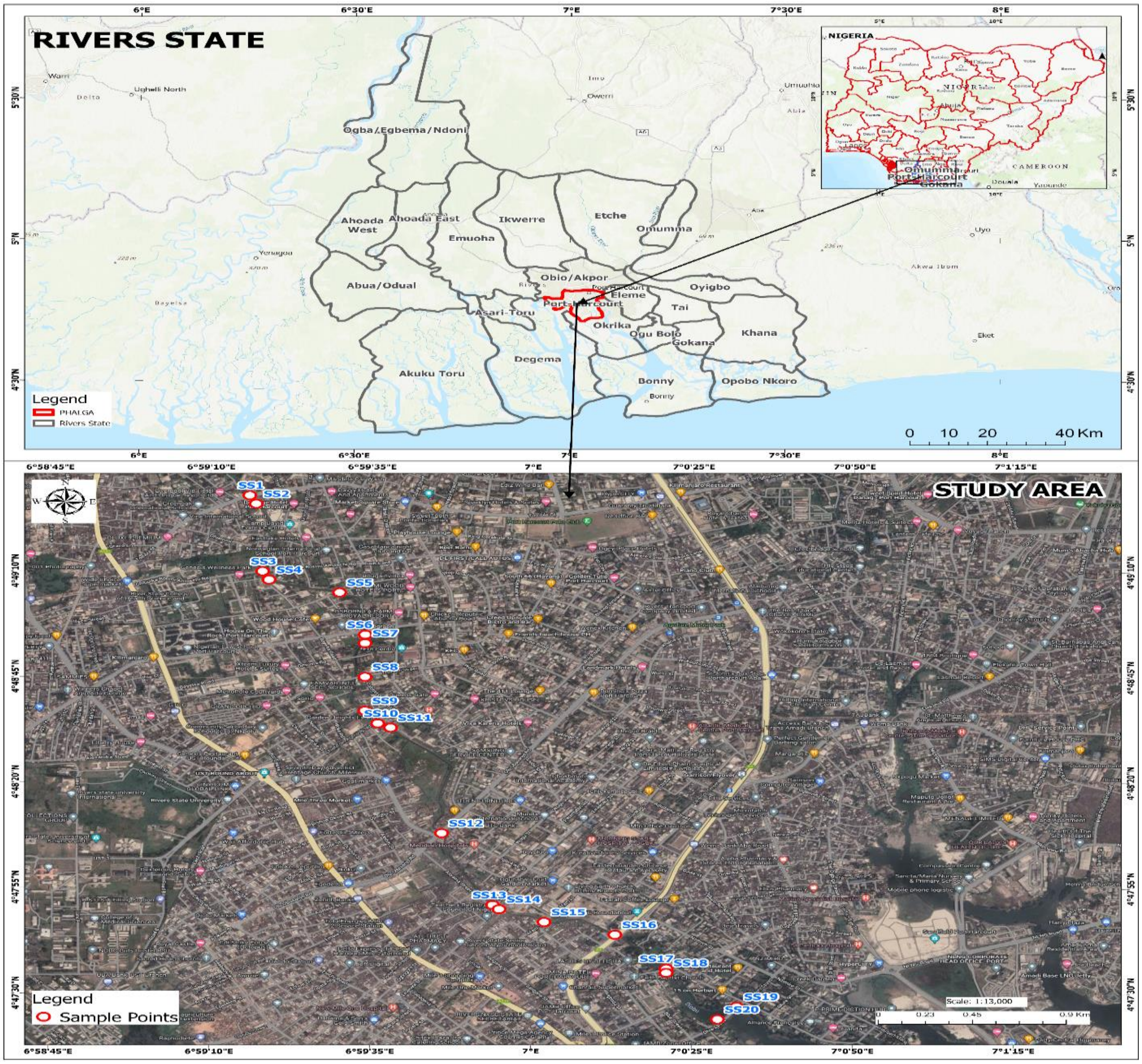

Figure: 1. Map showing surface water sampling stations in Ntawogba Creek

Ambient water quality criteria (AWQC) derivation

The Ambient Water Quality Criteria (AWQC) for human health represents specific chemical concentrations that can be present in ambient water without posing risks to human health (Wang et al., 2020b). The intake of trophic level 1 was considered using the methodology recommended by the USEPA (USEPA, 2002) (Eqn. (1). *B. schreberi* was selected as the representative species for trophic level 1. Toxicity data from published studies were utilized to derive the Human Health Ambient Water Quality Criteria (HHAWQC) and to perform a health risk assessment (Cui *et al.*, 2021; Yi *et al*., 2011; Fan *et al*., 2021). Eqn (1) was used in deriving AWQC.

$$\mathrm{AWQC} = \frac{\mathrm{RfD}\,.\,\mathrm{RSC}\,.\,\mathrm{BW}}{\mathrm{DI} + \sum_{i=2}^{4}(\mathrm{FI_i}\,.\,\mathrm{BAF_i}) + (\mathrm{VI}\,.\,\mathrm{BAF_i})} \qquad (1)$$

Where:
AWQC = ambient water quality criteria (mgL^{-1}); RfD = reference Dose ($mgkd^{-1}d^{-1}$); RSC = relative source contribution; BW = bodyweight (70kg); DI = drinking water intake ($2Ld^{-1}$); FI_i = fish intake at trophic level $_i$ (i = 2, 3 and 4) were 0.0038, 0.0080 and 0.0057 kgd^{-1} respectively, FI_i and other parameters were based on USEPA (2002) recommended parameters stated in SS5 (USEPA, 2002). VI = vegetable intake ($0.1544kgd^{-1}$) were obtained from published literature (Cui *et al*., 2021).

BAF_i = bioaccumulation factor at trophic level i (I = 1, 2, 3, and 4) ($mgkg^{-1}$) calculated using eqn. (8).

$$BAF_i = \frac{C_{if}}{C_w} \quad (2)$$

Where: C_{if} = the concentration of HMs in aquatic organism at trophic I (I = 1, 2, 3, and 4) ($mgkg^{-1}$) and C_w = the concentration of HMs in water (mgL^{-1}).

Human health risk assessment

Risk assessment serves as a crucial foundation for environmental management, aiding decision-makers in identifying, evaluating, and subsequently controlling high-risk areas (Bakhtavar *et al*., 2021). Human health risk assessment is a methodological approach used to estimate the likelihood of potential adverse health effects occurring within a specified time frame (Wang *et al*., 2021). The Hazard Quotient (HQ), developed by the United States Environmental Protection Agency (USEPA, 1989), is frequently employed in risk assessments, while the Hazard Index (HI) is used to assess the cumulative risk associated with a particular type of pollutant. In this study, the HQ for human exposure to heavy metals via fish consumption, aquatic vegetable consumption, and water consumption pathways was calculated using two approaches: one by dividing the exposure concentration by the human health Ambient Water Quality Criteria (AWQC) values, and the other through specific formulas (Eqs. (3), (4), (5), and (6). The HI [Eq. (7)] was utilized to estimate the total health risk from exposure to multiple heavy metals in water (Chen et al., 2017).

$$HQ_w = \frac{C_w\, .\, DI\, .\, EF\, .\, ED}{BW\, .\, AT\, .\, RFD} \quad (3)$$

$$HQ_f = \frac{C_f\, .\, FI\, .\, EF\, .\, ED}{BW\, .\, AT\, .\, RFD} \quad (4)$$

$$HQ_v = \frac{C_v\, .\, VI\, .\, EF\, .\, ED}{BW\, .\, AT\, .\, RFD} \quad (5)$$

$$HQ = HQ_w + HQ_f + HQ_v \quad (6)$$

$$HI \sum HQ \quad (7)$$

Where:

$HQ_w/HQ_f/HQ_v$ = hazard quotient for water, fish and aquatic vegetable ($mgkg^{-1}d^{-1}$); $C_w/C_f/C_v$ = concentration of HMs in water(mgL^{-1}), fish($mgkg^{-1}$), and aquatic vegetable ($mgkg^{-1}$); DI/FI/VI = ingestion rate of water ($2Ld^{-1}$), fish ($0.0175kgd^{-1}$) and aquatic vegetable ($0.5581kgd^{-1}$); EF = exposure frequency (365days); ED = exposure duration (70years); BW = bodyweight (70kg); AT = average time (EF x ED) (25550d); RfD = reference dose for specific heavy metal. VI was based on Cui *et al.* (2021), and other parameters where based on USEPA (2002).

Results

The results in Table 1 shows the parameters of AWQC and the comparison between the AWQC developed in this study and USEPA. The Reference Dose (RfD) values indicate the maximum safe daily exposure. Lead (Pb) has an RfD of 0.0035 mg/kg-d, chromium (Cr) 0.0003 mg/kg-d, cadmium (Cd) 0.006 mg/kg-d, arsenic (As) 0.0003 mg/kg-d, and zinc (Zn) 0.30 mg/kg-d.

Table 1: Parameters of AWQC and the comparison between the AWQC developed in this study and USEPA

Parameters/AWQC	Heavy Metals				
	Pb	Cr	Cd	As	Zn
Reference Dose (mg/kg^{-d})	0.0035	0.0003	0.006	0.0003	0.300
Relative Source Contribution (RSC)	0.2000	0.2000	0.250	0.2000	0.200
BAF T_1 (L/kg)	0.0560	0.0250	0.001	0.0400	0.105
BAF T_2 (L/kg)	1.3030	0.7620	0.183	18.8260	0.434
BAF T_3 (L/kg)	11.4390	6.4710	1.946	313.2000	0.420
BAF T_4 (L/kg)	12.1210	25.3680	0.010	216.0000	0.233
AWQC (water + fish) (µg/L)	226.2800	19.1000	8.680	0.7300	2093.370
AWQC (water + fish + vegetable) (µg/L)	225.3800	19.0600	8.680	0.7300	2076.590
USEPA (water + fish) (µg/L)	-	-	-	0.01800	7400.000

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The Relative Source Contribution (RSC) values show the proportion of total exposure attributed to water and food. The values are 0.20 for Pb, Cr, As, and Zn, while Cd has the highest RSC at 0.25. This suggests that 25% of total cadmium exposure is expected to come from dietary sources, while the other metals contribute 20%. The Bioaccumulation Factors (BAFs) show how much these metals accumulate in organisms from water. At the lowest trophic level (T1), the BAF values are 0.056 L/kg for Pb, 0.025 L/kg for Cr, 0.001 L/kg for Cd, 0.040 L/kg for As, and 0.105 L/kg for Zn. However, at the highest trophic level (T4), the bioaccumulation increases significantly for Pb (12.121 L/kg), Cr (25.368 L/kg), Cd (0.010 L/kg), As (216.00 L/kg), and Zn (0.233 L/kg). The exceptionally high values for arsenic at T3 (313.20 L/kg) and T4 (216.00 L/kg) indicate a strong potential for bioaccumulation and biomagnification in aquatic food chains. The AWQC (water + fish) values in this study differ significantly from those set by the USEPA. The study-derived AWQC values (µg/L) are 226.28 for Pb, 19.10 for Cr, 8.68 for Cd, 0.73 for As, and 2093.37 for Zn. In comparison, the USEPA values are available only for arsenic (0.018 µg/L) and zinc (7400 µg/L). Notably, the USEPA sets a much lower limit for arsenic (0.018 µg/L) compared to this study (0.73 µg/L), indicating a stricter regulation. Meanwhile, zinc has a much higher permissible limit in USEPA guidelines (7400 µg/L) compared to this study's 2093.37 µg/L. When vegetable consumption is included in the AWQC calculation, the values slightly decrease: Pb from 226.28 to 225.38 µg/L, Cr from 19.10 to 19.06 µg/L, Cd remains at 8.68 µg/L, As remains at 0.73 µg/L, and Zn from 2093.37 to 2076.59 µg/L.

Table 2 presents results of heavy metal concentrations in Ntawogba Creek which reveals significant contamination by cadmium (Cd), lead (Pb), chromium (Cr), arsenic (As), and zinc (Zn) across the 20 sampled locations. The mean concentrations recorded for these metals are 0.66 mg/L for Cd, 2.72 mg/L for Pb, 1.84 mg/L for Cr, 0.05 mg/L for As, and 30.95 mg/L for Zn, with varying levels of deviation from sample to sample.

Among the samples, cadmium concentrations range from 0.16 mg/L (SS1) to 0.92 mg/L (SS6), indicating moderate pollution, while lead levels vary from 1.79 mg/L (SS11) to 3.73 mg/L (SS5), suggesting a widespread presence of lead contamination. Chromium concentrations fluctuate between 1.09mg/L (SS11) and 2.84 mg/L (SS19), arsenic between 0.017 mg/L (SS15) and 0.084 mg/L (SS13), and zinc between 23.12 mg/L (SS1) and 44.57 mg/L (SS9). When compared to the Aquatic Water Quality Criteria (AWQC) developed in this study, it is evident that the concentrations of cadmium, lead, chromium, and arsenic all exceed their respective AWQC limits of 8.68 µg/L, 226.28 µg/L, 19.10 µg/L, and 0.73 µg/L, respectively. Similarly, zinc levels in the creek surpass the AWQC limit of 2093.37 µg/L (2.09 mg/L), confirming significant contamination. The highest lead concentration (3.73 mg/L) observed in SS5 and the highest chromium concentration (2.84 mg/L) in SS19 suggest specific pollution sources at these locations. Additionally, the extremely high zinc levels in SS9 (44.57 mg/L) and SS13 (38.63 mg/L) indicate possible industrial or municipal waste discharge into the creek.

Table 3 presents results of the human health risk assessment of lead (Pb), chromium (Cr), cadmium (Cd), arsenic (As), and zinc (Zn) through exposure to drinking water, edible fish, and aquatic vegetables. For non-carcinogenic risk, the Hazard Quotient (HQ) values calculated using the AWQC method show that cadmium presents the highest risk (HQ = 211.98), followed by chromium (HQ = 118.85) and arsenic (HQ = 68.49). Lead and zinc have lower HQ values of 2.92 and 14.78, respectively, but they still contribute to the overall risk. When aquatic vegetables are included, HQ values remain almost unchanged, with only minor increases. The total Hazard Index (HI) for Water + Organism is 417.02, while the HI for Water + Organism + Vegetable is 417.38, far exceeding the safe threshold of 1, indicating an extremely high non-carcinogenic health risk. Similarly, the HQ-formula method confirms the presence of high non-carcinogenic risks, though at lower levels. The HI values of 102.9 (Water + Organism) and 103.04 (Water + Organism + Vegetable) still indicate severe potential health effects.

For carcinogenic risk, the Lifetime Cancer Risk (LCR) values show that chromium (LCR = 0.039) and cadmium (LCR = 0.034) contribute the highest cancer risks, followed by arsenic (LCR = 0.0063). Lead presents a lower cancer risk (LCR = 0.00018), but it remains a concern due to its cumulative toxic effects over time. The Total Lifetime Cancer Risk (TLCR) is 0.0795, which is nearly 800 times higher than the acceptable threshold (0.0001).

Table 2: Heavy metal concentration (mg L^{-1}) of five representative pollutants in Ntawogba Creek

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Water Sample Code	Heavy metal concentration (mg L^{-1}) Cd	Pb	Cr	As	Zn
SS1	0.16	2.15	1.26	0.078	23.12
SS2	0.88	2.79	1.68	0.035	26.32
SS3	0.52	3.53	1.40	0.031	24.66
SS4	0.50	3.42	1.11	0.056	28.35
SS5	0.72	3.73	1.47	0.072	27.29
SS6	0.92	2.54	1.87	0.067	27.40
SS7	0.76	2.66	1.35	0.057	27.35
SS8	0.60	2.79	1.24	0.051	31.90
SS9	0.64	2.37	1.34	0.065	44.57
SS10	0.80	3.11	2.55	0.057	37.04
SS11	0.71	1.79	1.09	0.036	32.46
SS12	0.85	2.59	2.32	0.055	32.43
SS13	0.66	3.11	1.88	0.084	38.63
SS14	0.74	2.45	2.12	0.052	27.95
SS15	0.40	2.69	2.65	0.017	29.90
SS16	0.80	2.61	2.27	0.038	31.26
SS17	0.68	2.35	2.19	0.062	29.62
SS18	0.72	2.10	1.41	0.066	30.62
SS19	0.55	2.77	2.84	0.070	35.47
SS20	0.65	2.80	2.68	0.020	32.58
Mean	0.66	2.72	1.84	0.05	30.95
SD	0.18	0.48	0.58	0.02	5.08

Table 3: Human health risk assessment of heavy metals through drinking water, edible consuming fish and aquatic vegetable assessed by AWQC methods

Method	Exposure Route	Heavy metal concentration (mg L^{-1})					
		Pb	**Cr**	**Cd**	**As**	**Zn**	**HI**
HQ-AWQC	Water + Organism	2.92	118.85	211.98	68.49	14.78	417.02
	Water + Organism + Vegetable	2.93	119.10	211.98	68.49	14.90	417.38
HQ-formula							
Non-Carcinogenic	Water + Organism	0.74	26.09	53.89	13.97	2.94	102.9
Risk	Water + Organism + Vegetable	0.75	26.15	53.89	13.97	2.96	103.04
Carcinogenic		**LCR**	**LCR**	**LCR**	**LCR**	**LCR**	**TLCR**
Risk	Water + Organism	0.00018	0.039	0.034	0.0063	-	0.0795
	Water + Organism + Vegetable	0.00018	0.039	0.034	0.0063	-	0.0795

Figure 1 presents the correlation between Hazard Quotient (HQ) values derived from the AWQC method and the formula method provides insight into the consistency and reliability of risk assessment approaches. Figure 1 illustrates how closely the two methods align in estimating human health risks associated with heavy metal exposure.

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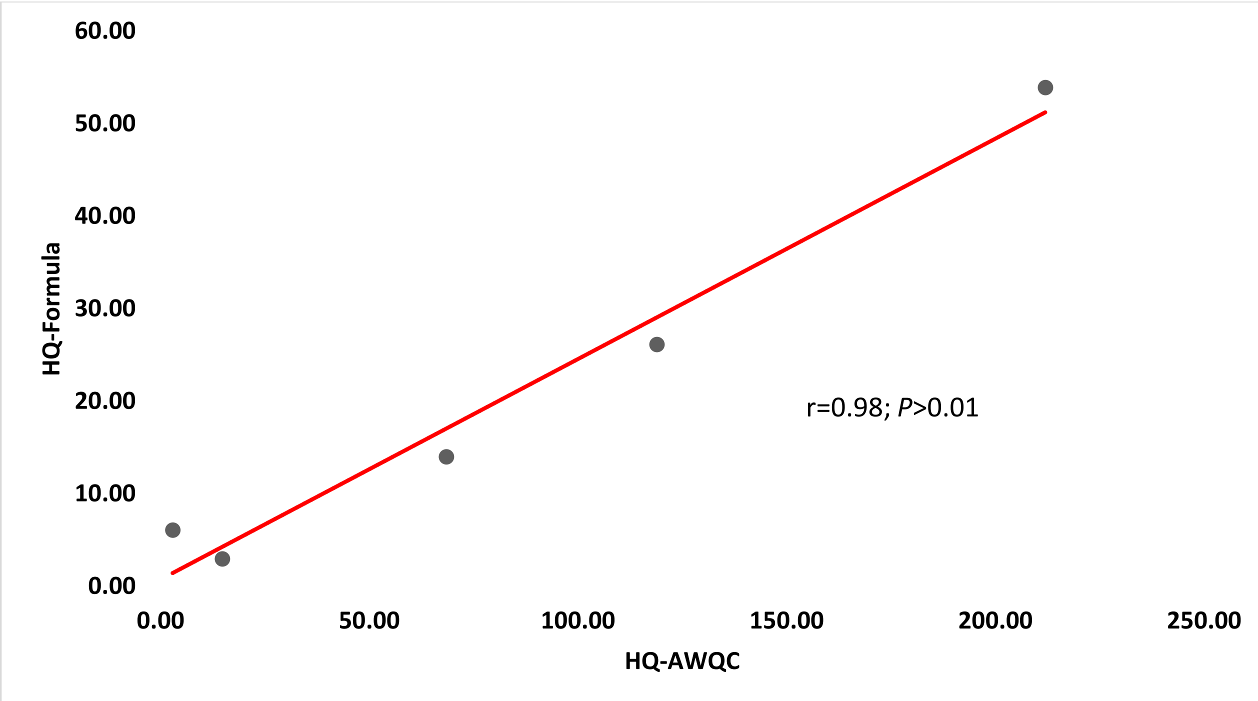

Figure 1: The correlation of HQ derived based on AWQC and formula methods

Discussion

Heavy metal contamination in aquatic ecosystems poses significant environmental and human health risks. This study evaluates the Aquatic Water Quality Criteria (AWQC) and human health risk assessment of heavy metals in Ntawogba Creek, comparing findings with global standards such as those of the USEPA and WHO. The study investigates bioaccumulation patterns, hazard indices, and carcinogenic risks associated with cadmium (Cd), lead (Pb), chromium (Cr), arsenic (As), and zinc (Zn).

The RfD values reported align with existing risk assessments, with cadmium (0.006 mg/kg-d) and arsenic (0.0003 mg/kg-d) consistent with USEPA and WHO guidelines. However, the chromium RfD (0.0003 mg/kg-d) is lower than in studies differentiating Cr (III) and Cr (VI), where Cr (VI) exhibits a lower RfD due to higher toxicity.

The RSC values (0.20 for Pb, Cr, As, and Zn; 0.25 for Cd) highlight dietary contributions to metal exposure. Studies by Cui et al. (2016) and Khan *et al*. (2020) report higher dietary cadmium contributions due to contamination in crops and seafood, corroborating the elevated RSC (0.25) in this study.

Arsenic exhibited the highest bioaccumulation, with a BAF of 313.20 L/kg at T3 and 216.00 L/kg at T4, indicating a strong potential for biomagnification. This is consistent with Rahman et al. (2019), who found significant arsenic accumulation in fish and aquatic organisms. Lead (Pb: 12.121 L/kg at T4) and chromium (Cr: 25.368 L/kg at T4) bioaccumulation values align with findings from Wang *et al*. (2018), who observed lead accumulation in fish bones and chromium in muscle tissues. Conversely, cadmium BAF values (0.001 L/kg at T1 and 0.010 L/kg at T4) were lower than expected. Zhang et al. (2021) reported cadmium bioaccumulation exceeding 1.0 L/kg in polluted water bodies, suggesting potential regional contamination differences in this study.

The AWQC values for Pb (226.28 µg/L), Cr (19.10 µg/L), Cd (8.68 µg/L), As (0.73 µg/L), and Zn (2093.37 µg/L) showed significant deviations from USEPA criteria. Notably, the USEPA limit for arsenic (0.018 µg/L) is far stricter than this study's value (0.73 µg/L), likely due to differences in regional exposure models and risk assumptions (Li *et al.*, 2020). Conversely, the USEPA permissible zinc limit (7400 µg/L) is much higher than this study's finding (2093.37 µg/L), consistent with Chen et al. (2017) and Alam et al. (2021), who noted zinc's lower toxicity.

Mean concentrations of Cd, Pb, Cr, As, and Zn exceeded AWQC limits, making the creek unsuitable for aquatic life and human consumption. Cadmium levels (0.16–0.92 mg/L) surpass the WHO limit (0.003 mg/L) and align with Akinbile *et al*. (2016), who reported high Cd levels in Ogun River, Nigeria, due to industrial discharge.

Lead concentrations peaked at 3.73 mg/L, exceeding the WHO guideline (0.01 mg/L). Similar contamination levels were reported in Nigeria's Warri River (Ogbeibu et al., 2019) and China's Yellow River (Zhang *et al.*, 2020), linking Pb pollution to vehicular emissions and industrial waste. Chromium levels (up to 2.84 mg/L) exceeded the WHO limit (0.05 mg/L), consistent with Elechi Creek studies by Nwankwoala & Chukwu (2019), attributing pollution to tannery and textile effluents.

The Hazard Index (HI) for water + organism (102.9) and water + organism + vegetable (103.04) far exceeded the USEPA safety threshold of 1.0, indicating chronic toxicity risks. Ogunfowokan *et al.* (2019) found comparable HI values in the Osun River, Nigeria, emphasizing lead and cadmium toxicity concerns.

Total Lifetime Cancer Risk (TLCR) of 0.0795 surpasses the USEPA threshold (1×10^{-4}), indicating severe long-term carcinogenic potential. Chromium (LCR = 0.039) and cadmium (LCR = 0.034) were the highest contributors, consistent with Zhang *et al.* (2020), who linked cadmium pollution in the Yellow River to mining effluents. Arsenic (LCR = 0.0063) remains a significant carcinogen, associated with skin, bladder, and lung cancers (Haque *et al.*, 2018).

High Pb, Cr, and Zn concentrations in SS5, SS9, and SS19 suggest contamination from electroplating, battery manufacturing, and metal processing industries (Adebayo *et al*., 2020). Cadmium and arsenic were likely introduced via agricultural runoff and municipal waste, similar to findings from Ghana's Pra River (Bempah et al., 2019).

Heavy metal bioaccumulation in fish and plants threatens aquatic biodiversity and ecosystem stability (Ali *et al.,* 2019). Chromium toxicity in aquatic organisms, as reported by Otieno et al. (2021) in Kenya's Lake Naivasha, can lead to oxidative stress and DNA damage.

Conclusion

The study confirms significant heavy metal contamination in Ntawogba Creek, with Cd, Pb, Cr, As, and Zn exceeding WHO and USEPA limits. Industrial effluents, urban runoff, and agriculture contribute to this pollution. Arsenic shows the highest bioaccumulation, indicating biomagnification potential. Risk assessment reveals severe non-carcinogenic and carcinogenic health risks, with HI values exceeding safe thresholds and Total Lifetime Cancer Risk (TLCR) for Cr, Cd, and As above acceptable limits. Therefore, immediate regulatory enforcement, remediation, and public health interventions are necessary to mitigate risks and protect both ecosystems and human health.

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