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Health and ecological risk assessment of heavy metals in water and sediments within a data scarce urban catchment in Tanzania – A case of Ngerengere River, Morogoro Municipality

Abstract

Low-, middle- and high-income countries, exhibit indications of risks associated with water quality. The study investigated heavy metal concentrations in surface water and sediments within the Ngerengere River and its tributaries (Kikundi, Bigwa, and Morogoro) drain within in the Morogoro Municipality of Tanzania, an Urban Catchment Area (UCA) with limited available data mainly because of inadequate monitoring and reporting capabilities. Analysis of health and ecological risks associated with heavy metal pollution was also carried out using health risk assessments models, pollution indices, and multivariate analysis techniques. Between the dry and wet seasons of 2023, water and sediment samples from (13) sampling stations strategically established along the Ngerengere river and its tributaries were analyzed for six heavy metals (Pb, Cr, Ni, Cd, Cu and Zn) using the Atomic Absorption Spectrophotometer Model Perking Elmer 850 Graphite Furnace and Perking Elmer AS 800 Auto-sampler coupled with a computer interface for operational, displaying and reading the results. The calculated degree of water contamination (Cd) values in river water in both dry and wet seasons ranged from 0 to 6.803 indicating low and high degrees of contamination respectively. Heavy metal concentration in sediment decreases in the order of Zn>Ni>Cr>Cu>Cd>Pb. The non-cancer risk index (HI) via ingestion and dermal pathways in dry and wet seasons for both children and adult groups was <1 hence no non-cancer risk, However, cumulative dermal and ingestion exposure in both children and adults indicated potential cancer risk in dry and wet season. The analysis of ecological risks associated with heavy metal enrichment in the sediment indicated high enrichment of sediments with Cd, Ni and Zn. Conclusively, in wet months, risk indices tend to be low, while in dry months, they typically remain high.

Keywords: heavy metal, sediment, health risk, ecological risk, Ngerengere river, tributaries

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Silaji S Mbonaga,[1] Amina A Hamad,[1] Stelyus L Mkoma[2]

[1]Department of Geography and Environmental Studies, College of Natural and Applied Sciences, Sokoine University of Agriculture, Tanzania

[2]Department of Chemistry and Physics, College of Natural and Applied Sciences, Sokoine University of Agriculture, Tanzania

Correspondence: Silaji S Mbonaga, Department of Geography and Environmental Studies, College of Natural and Applied Sciences, Sokoine University of Agriculture, P.O. Box. 3000, Morogoro, Tanzania, Tel +255752800080, Email silaji.mbonaga@sua.ac.tz

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Abbreviations: CFs, contamination factors; Cd, degree of water contamination; EDI, estimated daily intake; EFs, enrichment factors; ERI, ecological risk index; HCA, hierarchical cluster analysis; Igeo, geoaccumulation index; NI, nemerow index; PCA, principal component analysis; PLIs, pollution load indices; THQ, target hazard quotient; UCA, urban catchment area; USEPA, the United States environmental protection agency; WHO, World Health Organization

Introduction

Life relies on water, an indispensable element. Of the Earth's overall water content, only 3% is freshwater.[1] A mere 0.01% of this freshwater is accessible for human consumption. Freshwater sources such as rivers play a crucial role in the terrestrial ecosystem, offering abundant water resources essential for the sustainable development of human society and ecological environments.[2,3] Ensuring access to safe and sufficient drinking water stands as a focal point in the development objectives of any nation, however, the acceleration of industrialization and urbanization, driven by human activities that disregard natural sources have resulted in pollution of rivers marked by elevated levels of potential toxic elements such as heavy metals.[4] Pollution of heavy metals in river systems poses a significant threat to both aquatic ecosystems and human communities. This is primarily due to the prevalence, long-lasting nature, inherent toxicity, inability to degrade, widespread distribution, accumulation in organisms, and amplification through the food chain.[5–7]

In the field of environmental studies, the term "heavy metals" refers to metals and metalloids characterized by a high atomic weight and a specific gravity five times greater than that of water at 4 °C. Hence, heavy metals are categorized into essential ones such as Zinc (Zn), Copper (Cu), Iron (Fe), Manganese (Mn), etc., and non-essential or toxic heavy metals including Arsenic (As), Cadmium (Cd), Lead (Pb), Mercury (Hg), etc. The toxic heavy metals pose significant harm even at low concentrations when consumed over an extended period.[8] The increased contamination of water from heavy metals directly jeopardizes human health.[9,10] Previous research indicates that individuals, both adults and children, exposed to heavy metals (such as Cu, Zn, Cd, Pb, and Cr) through direct ingestion and dermal absorption, often face health risks, including but not limited to cancerous and non-cancerous, neurological disorders, and intellectual disability.[11]

While natural sources like rock weathering, soil erosion, atmospheric deposition, and microbial degradation contribute less to heavy metals in rivers, anthropogenic sources, including municipal discharge, agricultural fertilizer, and industrial pollution, are recognized as the primary sources for heavy metal pollution in rivers.[12] In recent decades, heavy metal pollution in rivers has been a prominent focus of research globally, with extensive work conducted on aspects such as the form distribution, migration, release and enrichment, pollution, and risk assessments of heavy metals in river sediments.[13–15] The insights from these studies hold theoretical value

in understanding the geochemical cycle of heavy metals in rivers and practical significance in guiding efforts for river pollution control.

On the other hand, the sediment, as a natural component of the aquatic ecosystem, functions as a reservoir for various pollutants.[16] Therefore, the anthropogenic impact leading to an excessive presence of heavy metal loads in the sediment can pose a threat to water supplies and induce changes in environmental conditions. This consideration is crucial, especially since most rivers in developing countries serve as the primary water source. Furthermore, heavy metal contamination in sediments has noteworthy implications for benthic organisms, biota, and water quality, particularly for numerous invertebrates that rely on sediments as a food source. Given the potential bioaccumulation of heavy metals in invertebrate organisms, there is a risk of these metals subsequently entering other components of the trophic chain.[17] Other studies have also established the ecological risks associated with heavy metals in sediment.[18,19] Sediment serves as a suitable indicator of the health of riverine ecosystems because of its crucial function in transporting and storing pollutants, as well as its ability to release them into the water.[18]

The Ngerengere River drains within the Morogoro Municipality in Tanzania serves as a crucial freshwater source for urban areas in Morogoro. In this particular area, there's only one dam, the Mindu dam, which plays a vital role as a primary freshwater reservoir for urban regions in Morogoro. It sustains a range of activities including farming and fishing.[20] Flowing through a network of main streams and tributaries, known as the Ngerengere-Morogoro River, it traverses diverse landscapes including forest lands, urban residential areas, and farmlands. As it progresses downstream, the Morogoro River, the principal tributary, courses through densely populated residential areas.[21] The primary contributors to heavy metal pollution in the Ngerengere River are traced back to municipal waste, sewage discharge, pesticide and fertilizer usage, the combustion of fossil fuels, artisanal and small-scale mining, as well as industrial effluents.[22]

To date, numerous approaches have been devised for evaluating the health and ecological dangers posed by heavy metals in water bodies.[23,24] The most common approach that has been used recently to assess the health and ecological risks of heavy metals in water and sediments is the use of pollution indices.[25–28] Health Risk Assessment (HRA) indices have been used instead of clinical and epidemiological studies due to economic implications and their ability to estimate and quantify the risk of human exposure to certain pollutants by both deterministic and probabilistic methods.[29] The use of sediment pollution indices against the traditional method of comparing the concentrations of heavy metals against the maximum allowable concentration[30] was due to their ability to combine pollution risk to ecological systems[27,31] and accounting the influence of anthropogenic activities in sediment pollution.[32]

Despite the wide application of pollution indices to study the health and ecological toxicity of heavy metal contamination in the river water and sediment across the globe, there are scarce studies that have been done in Tanzania particularly the Urban catchment of Ngerengere River characterized by an array of point and non-point sources of pollution. Before this study, previous studies in the Ngerengere River catchment have been undertaken to identify heavy metal concentrations present in the waters, sediment and aquatic organisms,[22,33] however, these studies did not establish health and ecological risk assessments associated with heavy metals pollution in the river water and sediment; Furthermore the studies did not adequately take into consideration the influence of tributaries (Kikundi, Bigwa and Morogoro) to the transportation and deposition of heavy metals in the Ngerengere River water and sediments.

This paper offers scientific novelty by concentrating on an area where quality indices for heavy metal pollution have not been previously calculated, despite the presence of numerous pollution sources. The study utilized pollution indices to assess the human health and ecological risks associated with heavy metal (Pb, Cr, Ni, Cd, Cu and Zn) in the water and sediment of Ngerengere River and its tributaries drains within the Morogoro Municipality. To achieve this goal, various specific pollution indices crucial for evaluating the quality of river water and sediments were employed and tested, namely the degree of water contamination (Cd), geo–accumulation index (Igeo), contamination factor (CF), Pollution Load Index (PLI), Nemerow Index, Enrichment Factor and the Potential Ecological Risk Index (RI). The scientific novelty of this paper lies in its focus on the study area, where these quality indices have not been previously calculated, despite the presence of numerous sources of heavy metal pollution.

Therefore, the objectives of this study were (1) To assess and quantify the extent of heavy metal pollution in both the river water and surface sediments of the Ngerengere River in dry and wet seasons, influenced by both point and non-point sources. (2) To evaluate the potential health and ecological risks associated with heavy metal pollution. The study hypothesized that the levels of heavy metal contamination in the river water and surface sediments of the Ngerengere are influenced by both point and non-point sources with significant variability in dry and wet seasons. It further hypothesized that heavy metals contamination in River water and sediment poses potential health and ecological risks to human and aquatic organisms. The findings of this study offer a valuable understanding of the levels of human health and ecological risks associated with heavy metal pollution in the Urban catchment of Ngerengere River. Findings and recommendations from this study provided baseline information regarding health and ecological risk management aimed at mitigating anthropogenic pollution of urban rivers and safeguarding public health and the life aquatic organisms.

Material and methods

Description of the Study area

The Ngerengere River Catchment (NRC) area is positioned centrally within the Wami-Ruvu sub-basin, located between approximately 6° 30′ 00″ and 7° 10′ 00″ South latitude, and 37° 58′ 26″ and 38° 31′ 30″ East longitude, covering an area of approximately 2780 square kilometers. Originating from the Uluguru mountains, this river extends across a significant portion of the Morogoro region, encompassing both the Morogoro Urban District and parts of the Morogoro Rural District.[34] Within this catchment, the Mindu dam stands as the sole dam, playing a critical role in providing freshwater to urban areas in Morogoro, supporting various activities such as agriculture and fishing. Eventually, it merges with the lower Ruvu River, contributing to its flow towards the Indian Ocean. This study focuses on the segment of the Ngerengere River and its three tributaries—Bigwa, Kikundi, and Morogoro—within Morogoro Municipality, aligning with specific research objectives. The urban center of Morogoro Municipality, inhabited by over 471,409 individuals, is the point where the Ngerengere River drains.

The current state of these water sources is characterized by heightened levels of pollution, originating from household waste, sewage, industrial effluents, agricultural practices, and fishing activities.[35] Additionally, the Ngerengere River has been integrated into the urbanized area due to rapid urban expansion witnessed in recent decades. Furthermore, the depletion of vegetation along the riverbanks is emerging as a pressing issue, disrupting the river's

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ecological balance.[36] Nevertheless, inhabitants, particularly those residing in the Morogoro Municipality communities along the river, depend on the river water and nearby natural wells for their daily necessities.

Situated within the tropical climate belt, the catchment experiences two primary rainy seasons. Annual precipitation across much of the catchment ranges from 800 to 1,000 mm per year, while in the Uluguru Mountains, it exceeds 1,500 mm per year.[37] During sampling periods, the average monthly temperature, rainfall and evaporation in the dry and wet seasons were 24.75^{0}C, 2.3 mm, 161. 1 mm and 27.1^{0}C, 117.3, 158.1mm respectively. These climatic fluctuations potentially affecting water quality particularly transport and deposition of heavy metals in water and sediment. The local geology of Morogoro town comprises the Usagaran unit, a Precambrian basement complex featuring high-grade metamorphic rocks like amphibolite, gneiss, and granulites. Furthermore, the area is characterized by Neogene formation containing a substantial accumulation of red soil which is also known as "mbuga" soil, and alluvium, dominant soil textural classes are silt clay and loamy sand.[38]

Sampling and analysis

A total of thirteen (13) water and sediment samples from the main river (Ngerengere) and three tributaries namely (Morogoro, Bigwa and Kikundi) were collected in the dry and wet periods of the months of September and December 2023, respectively. Locations of sample collection (Figure 1 and Table 1) were geo-referenced through a handheld global GPS unit (Map 62, Garmin), and relevant observations to describe sampling location characteristics were recorded onsite.

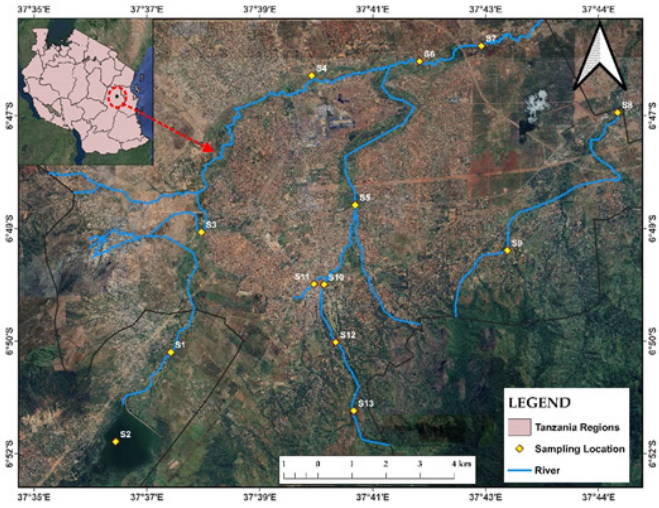

Figure 1 A map of Ngerengere River and its three tributaries flowing within the Morogoro Municipality showing sampling locations for heavy metal analysis.

Table 1 Description of the sampling stations selected within Ngerengere River and its three tributaries in Morogoro Municipality

Sample ID	Coordinates		Elevation	Location characteristics
S1	37M 0348197	UTM 9243391	487	The Kasanga area is located near the Tanzam highway. Characterized by residential and agricultural, activities.
S2	37M 0346587	UTM 9240756	510	Mindu Dam. The station comprises diverse activities (fishing, agriculture and water transportation). It was considered as the upstream of the Ngerengere River in this study.
S3	37M 0349091	UTM 9246929	485	Chamwino area, is dominated by extensive residential and agricultural activities.
S4	37M 0352313	UTM 9251550	474	Kihonda VETA, 10km from Chamwino (S3). Dominated by agricultural, residential and some areas of bare land.
S5	37M 0353601	UTM 9247741	491	Approximately 400m from the Msamvu area. This station covers a wide range of potential pollution sources, including car washes, petrol stations, and residential areas.
S6	37M 0355481	UTM 9251973	462	Represent the downstream zone of the river. Approximately 1 km from Industrial areas such as textile industries. The Confluence of the Morogoro tributary and Ngerengere River drains to Ngerengere. Extensive agricultural, residential, and livestock activities at this confluence point make it critical to assess the combined impact of these activities on water quality.
S7	37M 0357295	UTM 9252433	460	The downstream station represents the boundary of the Urban area of Morogoro Municipality. Extensive agricultural, fishing, and domestic activities such as washing near rivers and livestock activities.
S8	37M 0361296	UTM 9250483	519	Approximately 10 km from Uluguru mountains (the water source) Locally known as the Kitungwa area. Characterized by agricultural residential activities.
S9	37M 0358071	UTM 9246415	519	Locally known as Bigwa Stream. Characterized by a mixture of residential, and car washes and about 10m from Matombo – Morogoro road
S10	37M 0352693	UTM 9245397	517	The Midstream of the Morogoro River (Mwele) area represents a location with car washes, residential businesses, and a school, all of which can contribute to water pollution. Monitoring here helps assess the influence of these urban activities on water quality.
S11	37M 0352398	UTM 9245413	522	The station is referred to as Kikundi Stream which drains to Morogoro tributary. Extensive informal business, roads, residential neighbourhoods, and commercial activities. It provided a broad view of urban impacts on the river.
S12	37M 0353041	UTM 9243699	544	2 km from Choma waterfalls in Uluguru mountains which is the headwater. The station is characterized by a forest canopy and a few residential areas.
S13	37M 0353576	UTM 9241683	702	The station is headwater and upstream (Uluguru Mountains). Located in forested areas, is selected to represent a relatively pristine or less human-impacted location. It serves as a reference point for understanding natural background water quality conditions and the potential influence of nearby forests on water quality.

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Collected samples of water were sampled in 1000 ml polyethylene bottles previously rinsed with water from the river followed by acidification with nitric acid before being stored at 4°C cooling temperature for the subsequent laboratory analysis. The goal of acidification is to avoid complexation processes between certain ions and adsorption/desorption from colloids or other biochemical reactions. The detailed description of this method has been also reported in other previous studies.[13,39] Sediment samples were collected by stainless scoops at 0-10 cm depth and stored in polyethylene bags while hand-operated manual augers were used in high-velocity areas, The collected samples were collected into polyethylene bags and kept in ice-cooled container maintained at 4°C to avoid cross-contamination. No further chemical pretreatments were done rather than laboratory digestion of sediment samples using standardized procedures.[40]

All the samples were analyzed for the contents of Fe, Cu, Zn, Cr, Cd, Pb and Ni using Atomic Absorption Spectrophotometry (AAS) at the Chemistry laboratory in Sokoine University of Agriculture and Ardhi University - environmental engineering laboratory, the AAS model Perking Elmer 850 Graphite Furnace and Perking Elmer AS 800 Auto-sampler with a computer interface for operational, reading and displaying the results. The reagents used included distilled water, aqua regia 1:3 by volume (1 concentrated HCl: 3 concentrated HNO_3 (65-68%) and Sulphuric Acid (H_2SO_4) for digestion and extraction. The detection limit of the instrument was set to 0.01 mg/l, while the accuracy for each experimental run was above 98%.

The concentrations of heavy metals in water were expressed in mg/L while in the sediment the heavy metal concentrations were exposed in mg/kg and compared against the acceptable thresholds for heavy metals in drinking water established by various organizations such as the Tanzania Bureau of Standards, United States Environmental Protection Agency (USEPA), World Health Organization, WHO (Table 2). The use of these standards to benchmark the comparison of water quality with international and national standards was also observed in the previous study.[41] To date, there are no Tanzania standards on the sediment quality hence literature sources were consulted for benchmarking the discussion and comparing the obtained sediment quality with previous studies.[42]

Table 2 Acceptable thresholds for heavy metal concentrations (expressed in mg/L) in drinking water as set by various international agencies

Agency	Limit values (mg/L)						
	Cd	Cr	Cu	Fe	Ni	Pb	Zn
TZS 789;2008	0.05	0.05	3	1	-	0.1	15
US EPA, 2009	0.005	0.1	1	0.3	0.1	0.015	5
WHO, 2008	0.003	0.05	2	0.3	0.07	0.01	3

Health risk assessment and study area population

According to the Tanzania census of 2022, the population of Morogoro Municipality was 471,409 residents translates to a population density of approximately 1,814.65 persons per square kilometre. The total number of households in the study area is 133,809 while the average household size of 3 individuals.

Health risk assessment was based on the carcinogenic and non-carcinogenic heavy metals. The Reference Doses (RfD) and slope factors (SF) values for non-carcinogens and carcinogens respectively have been obtained from various sources including the US EPA toxicological database. For risk assessment purposes Reference Dose (RfD) and Reference Concentration (RfC) which are protective even for the most sensitive groups of the population were determined.

Non-carcinogenic risks of exposure to heavy metals

The risks of non-cancer related to heavy metals exposure were estimated by calculating the risk quotient adopted from US EPA. Heavy metal concentrations inform exposure models for calculating ingestion and dermal pathways. An additional non-carcinogenic hazard index, dividing calculated lifetime daily exposure by reference dose, was derived. Health risk assessments employed parameters recommended by the US EPA, including estimated daily intake (EDI) and target hazard quotient (THQ). A hazard index below 1 indicates no health risk. For carcinogenic risks, daily intake (mg/kg/day) multiplied by the slope factor determines risk levels, with distinctions between adults and children due to children's higher sensitivity to heavy metals. These two indices have been also used in previous studies[24,29,43,44] to assess the impact of heavy metals on the health of populations.

$$HQ\,ing\,/\,derm = \frac{\mathrm{D}\,ing\,/\,derm}{\mathrm{RfD}\,ing\,/\,derm} \quad (1)$$

Where $HQ\,ing\,/\,derm$ the risk quotient per ingestion or dermal contact. $\mathrm{RfD}\,ing\,/\,derm$ represents the reference dose by ingestion or dermal contact and is expressed in mg/kg/d and $\mathrm{D}\,ing\,/\,derm$ is the exposure dose by ingestion or dermal contact expressed in mg/kg/d and calculated according to equations 2 and 3 adopted from US EPA and in other scientific research.[30] An HQ below 1 is deemed safe and denotes significant non-carcinogenicity. However, if the HQ exceeds 1, it suggests a potential health hazard for individuals exposed to the contaminant at those levels.

$$\mathrm{D}\,ing = \frac{Cw \times IR \times EF \times ED}{Bw \times AT} \quad (2)$$

$$\mathrm{D}derm = \frac{Cw \times SA \times KP \times EF \times ED \times ET}{BW \times AT} \quad (3)$$

$$\mathrm{HI} = \Sigma HQ \quad (4)$$

In this context, D*ing* represents the intake dosage via water consumption (in µg/kg/day), D*derm* signifies the intake dosage through skin absorption (in µg/kg/day), and *Cw* denotes the recorded metal concentration in water (in µg/L). *IR* stands for the rate of water intake per unit time (in L/day), estimated at 2.2 L/day for adults and 1.8 L/day for children. *EF* refers to the frequency of exposure (350 days/year), while ED represents the duration of exposure (70 years for adults and 6 years for children). *BW* signifies the average body weight (70 kg for adults and 15 kg for children). *AT* represents the average lifespan, calculated as 66 years multiplied by 365 days, resulting in 25,550 days for children, and for adults, the average exposure duration is 24,090 days. *SA* stands for the area of exposed skin (18,000 cm²), *ET* is the duration of exposure (0.58 hours/day), *CF* represents the conversion factor (0.001 L/cm³), and *Kp* indicates the coefficient of dermal permeability (in cm/h). Table 3 and Table 4 visualize in summary, the input parameters used in this study.

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Table 3 Input parameters for exposure dose calculation.[43,24]

Parameters	Symbols	Units	Value	
			Adult	Children
Rate of direct ingestion	IR	L/day	2.2	1.8
Exposure frequency for dermal	EF	Days/year	365	365
Exposure Frequency for Oral	EF	Days/year	350	350
Exposure duration	ED	Years	70	6
The exposure time of bathing	ET	Hrs/day	0.58	1
Conversion Factor for Dermal Exposure	CF		0.001	0.001
Body weight	BW	Kg	70	15
Average time	AT	Days	24,090	25,550
Exposed skin area	SA	Cm^2	18000	6600

Table 4 Reference doses for oral and dermal exposure pathways, the dermal permeability coefficients of the Heavy metals used in this study.[45,46]

Element	Rfdoral	Rfddermal	CSF (kg/day/mg)	Permeability coefficient (Kp) cm/hr
Pb	1.4	0.42	8.5	0.001
Cr	3	0.015	41	0.002
Cd	0.5	0.005	6.1	0.001
Ni	20	5.4	0.84	0.0002
Zn	300	60	NA	0.006
Cu	40	12	NA	0.001

Carcinogenic risks of exposure

The risks of cancer are estimated from the Excess Life Cancer Risks (ELCR) and the risk index (RI) according to equations 5 and 6.

$$\mathrm{ELCR} = D \times SF \tag{5}$$

Where SF represents the slope factor of each selected pollutant.

$$\mathrm{RI} = \Sigma ELCR \tag{6}$$

To avoid overestimating risk, the analysis did not rely solely on the maximum concentration, which might occur only once. Instead, it considered mean and minimum concentrations, which are potentially more representative, alongside the maximum concentration in risk assessment.[47]

Water quality based on the degree of contamination (Cd)

The degree of contamination of water by heavy metals is given by the following formula.[15]

$$\mathrm{Cd} = \sum_{i}^{N} \mathrm{FCi} \tag{7}$$

$$\mathrm{FCi} = C_{Ai} / C_{Ni} \tag{8}$$

Cd represents the degree of metallic contamination. FC, the contamination factor and i the parameter considered (heavy metal). C_{Ai} and C_{Ni} are the field measured value and the limit value respectively. Depending on the Cd value the waters can be slightly polluted, moderately polluted and highly polluted (Table 5).[48]

Table 5 Degree of pollution based on Cd value

Cd values	Degree of pollution
<1	Low
1–3	Medium
> 3	High

Sediment pollution assessment indices

Potential ecological risk index due to heavy metal pollution of the sediment

The study used Lars Hakanson's potential ecological risk index (RI) method to evaluate the potential ecological risk of heavy metals in sediments (equation 9)

$$\mathrm{C_f^i} = \frac{\mathrm{C_D^i}}{\mathrm{C_R^i}} \tag{9}$$

$$\mathrm{E_r^i} = \mathrm{T_r^i} \times \mathrm{C_f^i} \tag{10}$$

$$\mathrm{RI} = \sum_{i=1}^{n} \mathrm{E_r^i} \tag{11}$$

Where is the pollution index for a given heavy metal, $\mathrm{C_R^i}$ is the reference value of the heavy metal in the sediment, $\mathrm{C_D^i}$ is the present concentration of heavy metal, $\mathrm{E_r^i}$ is heavy metal potential ecological risk factor, $\mathrm{T_r^i}$ is the toxic response factor for a single heavy metal contamination, and RI is the total potential ecological risk index for heavy metals. The background values were obtained from the world surface rock average during the pre-industrial era.[49] In this study the background values were 127, 49, 16, 32, 0.2, 71 and 35,900 mg/kg for Zn, Ni, Pb, Cu, Cd, Cr and Fe respectively. When RI < 150, the risk level is low ; when 150 ≤ RI < 300, the risk level is medium ; when 300 ≤ RI < 600, the risk level is high ; and when RI ≥ 600, the risk level is very high. The toxic response factor for Cu, Zn, Cr, Ni, Pb and Cd is 5, 1, 2, 5,5 and 30 respectively.[19]

The geoaccumulation index

The geoaccumulation index (I_{geo}) method was used to evaluate the pollution level of heavy metals in sediments in the study area. This method eliminated the influence of natural geological accumulation.

$$\mathrm{I_{geo}} = \log 2 \frac{Ci}{1.5Bi} \tag{12}$$

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Where *Ci* is the heavy metal real concentration in the studied site; and *Bi* would be the reference sample background value. Generally, the Igeo consists of 7 grades in the range of $5 < Igeo \leq 0$ in which minimum values indicate the soil has not been contaminated, while maximum values show it has been extremely contaminated. $Igeo \leq 0$ means that the soil is not contaminated ; $0 < Igeo \leq 1$ indicates uncontaminated up to moderately contaminated degrees ; $1 < Igeo \leq 2$ presents a moderately contaminated degree ; $2 < Igeo \leq 3$ means moderately up to strongly contaminated degrees ; $3 < Igeo \leq 4$ indicates a strongly contaminated degree; $4 < Igeo \leq 5$ presents strongly up to extremely contaminated degrees, and lastly $Igeo > 5$ shows that the soil has been extremely contaminated.[26]

Nemerow index

The Nemerow index (PN) can take into account the contents of all heavy metals and make a comprehensive evaluation of the pollution level of heavy metals in sediments.[11]

$$P_N = \sqrt{\mathrm{Avg}P_i^2 + \mathrm{Max}P_i^2 / 2} \quad (13)$$

Where Pi is a single pollution index, $Pi = Ci/Si$. *Ci* is the measured concentration and *Si* is the pollutant concentration standard value. *MaxPi* and *AvgPi* are the maximum and average values of all index Pi, respectively. The method divides pollution into five levels : $PN \leq 0.7$, safety domain ; $0.7 < PN \leq 1.0$, precaution domain; $1.0 < PN \leq 2.0$, slightly polluted domain; $2.0 < PN \leq 3.0$, moderately polluted domain; $PN > 3$, seriously polluted domain.[19]

Contamination factor (Cf)

The contamination factor (CF) was employed for assessing the contamination level of sediments, calculated by dividing the concentration of each heavy metal in the sediment (*Cm)* by its background concentration (*Bm*) as depicted in equation 14.

$$Cf = \frac{\mathrm{Cm}}{\mathrm{Bm}} \quad (14)$$

C_m is metal concentration in samples ; Bm represents background metal concentration ; Contamination factor (CF) $CF < 1$ ... low degree $1 \leq CF < 3$ ... moderate degree $3 \leq CF < 6$ ... considerable degree $CF > 6$ ... very high degree.[50]

Enrichment Factor (EF)

Enrichment factors (EF) were utilized to assess potential anthropogenic contributions to the observed metal content in sediments and were computed following the method described:

$$\frac{Cm}{Fe} sample / \frac{Cm}{Fe} background \quad (15)$$

Where; Fe is iron concentration because of its abundance**,** *Cm* heavy metal concentration in the sediment sample; Enrichment factor (EF) $EF \leq 2$ ... minimal enrichment $2<EF<5$... moderate enrichment $5 < EF < 20$ ... significant enrichment $20 < EF \leq 40$ ... very high enrichment $EF > 40$ ... extremely high enrichment.

Pollution load index

The PLI serves as a method for evaluating the overall extent of sediment pollution worldwide, factoring in the levels of various heavy metals. It is determined by considering the contamination factors (CF) of each metal as outlined in Equation (14). When computing the PLI for each sampling site, all heavy metal pollutants are considered.[51]

$$PLI = \left(CF_1 \times CF_2 \times CF_3 \times CF_4 \ldots \times CF_n\right)^{1/n} \quad (16)$$

Where CF refers to the contamination factor for each pollutant; PLI<1 (indicates the uncontaminated degree of the sediments) and PLI>1 (indicates the contaminated degree of the sediments).

Statistical analysis

The Geoaccumulation Index (Igeo), Enrichment Factors (EFs), Contamination Factors (CFs), Pollution Load Indices (PLIs), Ecological Risk Index, Nemerow Index and Degree of Water Contamination were computed. Statistical analysis was conducted on the data. Pearson correlation analyses were utilized to discern relationships among the concentrations of various heavy metals, while Principal Component Analysis (PCA) and Hierarchical Cluster Analysis (HCA) were carried out to pinpoint potential sources of heavy metals across the Ngerengere River and its tributaries. All statistical procedures were executed using the OriginPro 2024 software. Key findings were presented in tables and figures.

Results and discussion

Heavy metal concentration in surface water in the dry season

The study revealed that the order of magnitude of the recorded concentrations of heavy metals is Cu > Cr > Ni > Pb > Zn > Cd. The level of Pb concentrations ranged from >0.01 mg/L (which was below the detection limit) to 0.04±0.01 mg/L to 0.09±0.01 mg/L which exceeds the maximum permissible limits established by Tanzania Standards, WHO and US EPA. Higher concentrations of Chromium ranging from 0.02±0.01 mg/L to 0.25±0.01 mg/L exceed Tanzania, WHO and US EPA standards. The aforementioned levels of heavy metals were higher compared to the maximum allowable limits set by TBS, WHO and US EPA. The midstream and downstream areas of the Ngerengere River in Morogoro municipality showed higher heavy metal pollution compared to the upstream sections. This stems from industrial operations, agricultural runoff, the discharge of household sewage, and insufficient waste management practices, notably at the Mafisa dumpsite, which lacks proper containment facilities for leachate. Other studies have also reported the influence of human activities on heavy metal pollution in surface water.[45,52,53] The study revealed that the highest concentrations of Cd, Cu, Zn and Ni were 0.03±0.02 mg/L, 0.73±0.04 mg/L, 0.03±0.02 mg/L and 0.19±0.02 mg/L respectively. These findings are quite similar to other studies that reported the same concentrations ranges of heavy metals.[41,44,54] The recorded concentrations values are not in agreement with the recorded higher heavy metal concentrations in the Mara River in the same sampling campaigns.[55] This disagreement is attirbuted to the effect of mining activities ranging from artisanal to large-scale mining operations in the Mara area. Metals like Lead (Pb) and Cadmium (Cd) exhibit toxicity even at low concentrations and lack essential functions in the human body.[56] Consequently, they are categorized as non-essential or toxic metals. In the wet season the order of magnitude for heavy metals concentrations in river water was Zn> Ni>Cr>Pb>Cu >Cd with the concentrations of 4.07±0.081, 3.07±0.04, 0.053±0.04, 0.01±0.001, 0.007±0.001 and 0.002±0.001 for Zn, Ni, Cr, Pb, Cu and Cd respectively. The decrease in the concentration of Pb, Cr, Cd and Cu in the wet season accounts for the effect of dilution.[57] The increase in Zn and Ni concentration in the wet season is associated with an increase in sediment due to water erosion.[58]

The findings on heavy metals concentration in the river water sampled during the dry season and wet season have been presented in Figure 2.

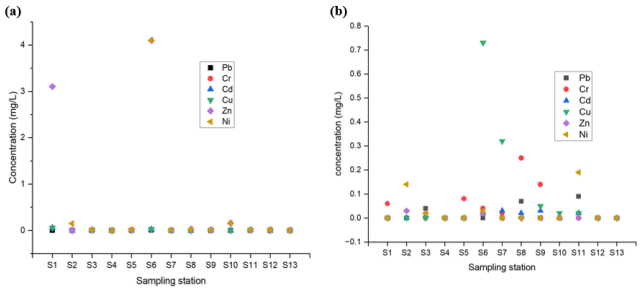

Figure 2 Heavy metals concentration in the river water sampled during wet season (a) and dry season (b).

Degree of water contamination

The index for metallic water contamination revealed the low and high degree of contamination. The calculated Cd values in river water samples in both dry and wet seasons ranged from 0 to 6.803 indicating low and high degrees of Contamination respectively (Table 6). The findings indicated that the highest heavy metal contamination was experienced during the dry season compared to the wet season. In Mara River, similar results were reported with a Cd value of less than 1.5 for all sampling locations.[48]

Health risk assessment

Noncarcinogenic risk assessment

The estimated daily intake for children and adults via ingestion and dermal exposure in dry and wet seasons and its associated non-carcinogenic health risks related to the studied heavy metals are shown in the Table 7. The HI through ingestion and dermal exposure in dry and wet seasons for both children and adult groups was less than 1 in all sampling points. Hence, the study did not find evidence for potential noncarcinogenic risk related to heavy metals (Pb, Cd, Cr, Ni, Cu and Zn) within the urban catchment of Ngerengere River in Morogoro Municipality. The total HI for both exposure pathways across all sampling seasons for children and adults were 1.37×10^{-1} and 4.70×10^{-1} respectively (Table 7). Similar results were obtained in the previous study,[10] that reported a total HI of 3.31×10^{-3}, 2.15×10^{-6}, and 3.32×10^{-3} for ingestion and dermal exposure in the adult population in Iran. In Great Ruaha River low HI for dermal exposure but higher HI for ingestion exposure for the exposed groups were recorded.[46] Furthermore similar HI was obtained in the assessment of non-cancer risks associated with an exposure to fish cultured in selected private fishponds in Dar es Salaam, Tanzania.[24] In this study the contribution of six heavy metals to non-carcinogenic risk for children and adults via both ingestion and dermal exposure was in the order of Ni>Cr>Cd>Pb>Zn>Cu. Despite of lower HI for the population exposed to river water further investigation should be done to assess the non-cancer risks related to exposure from vegetables irrigated by river water. This is due to the phytoaccumulation potential of heavy metals.[6] Furthermore other health implications that are not related to cancer might be attributed to other parameters such as pathogenic microorganisms.[59]

Table 6 Calculated Cd values for water samples in wet and dry season

Sampling station	Cd Wet season	Pollution		Cd Wet season	Pollution
1	6.803	Low		0.06	Low
2	0.2818	Low		0.286	Low
3	0.008	Low		0.144	Low
4	0	Low		0	Low
5	0.0064	Low		0.08	Low
6	0.9525	Low		0.669	Low
7	0.0009	Low		0.48	Low
8	0.005	Low		0.45	Low
9	0.006	Low		0.465	Low
10	0.0316	Low		0.01	Low
11	0.007	Low		0.59	Low
12	0.0028	Low		0	Low
13	0.001	Low		0	Low
Mean	**0.623538**	**Low**	**Mean**	**0.248769**	**Low**
Standard deviation	**1.875595**		**Standard deviation**	**0.250483**	

Table 7 Calculated CDI, HI and ELCR for ingestion and dermal exposure in exposed groups for dry and wet season

Heavy metals	Sampling station	CDI (Ing) children		CDI (Derm) children		CDI (Ing) adult		CDI (Derm) adult	
		Dry season	Wet season	Dry season	Wet season	Dry season	Wet season	Dry season	Wet season
Pb	S3	4.1×10^{-4}	-	2.3×10^{-6}	-	1.3×10^{-3}	-	2.6×10^{-6}	
	S6	-	1×10^{-3}	-	5.7×10^{-7}	-	3×10^{-4}	-	6.5×10^{-7}
	S8	7.2×10^{-5}	-	4×10^{-6}	-	2.1×10^{-3}	-	4.6×10^{-6}	
	S11	9.3×10^{-4}	-	5.2×10^{-6}	-	3×10^{-3}	-	5.9×10^{-6}	
HI = CDI/RfD		1×10^{-3}	7.1×10^{-4}	2.7×10^{-5}	1.4×10^{-6}	4.6×10^{-3}	2.1×10^{-4}	3.1×10^{-5}	1.5×10^{-6}

Table 7 Continued...

Heavy metals	Sampling station	CDI (Ing) children		CDI (Derm) children		CDI (Ing) adult		CDI (Derm) adult	
		Dry season	Wet season	Dry season	Wet season	Dry season	Wet season	Dry season	Wet season
ELCR =CDI × SF		1.2×10^{-2}	8.5×10^{-3}	9.8×10^{-5}	4.9×10^{-6}	5.4×10^{-2}	2.6×10^{-3}	1.1×10^{-4}	5.5×10^{-6}
Cr	S1	6.2×10^{-4}	5.5×10^{-3}	6.9×10^{-6}	6.1×10^{-6}	2×10^{-3}	1.8×10^{-3}	7.8×10^{-6}	6.9×10^{-6}
	S3	-	8.2×10^{-5}	-	6.6×10^{-6}	-	2.7×10^{-4}	-	1×10^{-6}
	S5	8.2×10^{-4}	5.1×10^{-5}	9.2×10^{-6}	5.7×10^{-7}	2.7×10^{-3}	1.7×10^{-4}	1×10^{-5}	6.5×10^{-7}
	S6	4.1×10^{-4}	9.3×10^{-5}	4.6×10^{-6}	1×10^{-6}	1.3×10^{-3}	3×10^{-4}	5.2×10^{-6}	5.9×10^{-3}
	S7	2.1×10^{-4}	-	2.3×10^{-6}	-	6.7×10^{-4}	-	2.6×10^{-6}	-
	S8	2.6×10^{-3}	-	2.9×10^{-5}	-	8.3×10^{-3}	-	3.3×10^{-5}	-
	S9	1.4×10^{-3}	6.2×10^{-5}	1.6×10^{-5}	6.9×10^{-7}	4.7×10^{-3}	2×10^{-4}	1.8×10^{-5}	9×10^{-6}
	S11	-	7.2×10^{-5}	-	8×10^{-7}	-	2.3×10^{-4}	-	9.1×10^{-7}
HI = CDI/RfD		2×10^{-3}	4.7×10^{-3}	4.5×10^{-3}	1.1×10^{-3}	3.9×10^{-2}	5.9×10^{-3}	5.1×10^{-3}	4×10^{-1}
ELCR =CDI × SF		2.9×10^{-1}	5.7×10^{-1}	2.8×10^{-3}	6.4×10^{-4}	8.1×10^{-1}	1.2×10^{-1}	3.1×10^{-3}	2.4×10^{-1}
Cd	S3	1×10^{-4}	-	5.7×10^{-6}	-	3.3×10^{-4}	-	6.5×10^{-7}	-
	S6	2.1×10^{-4}	2.1×10^{-4}	1.1×10^{-6}	4×10^{-7}	6.6×10^{-4}	6.7×10^{-5}	1.3×10^{-6}	1.3×10^{-7}
	S7	3.1×10^{-4}	-	2.9×10^{-4}	-	1×10^{-3}	-	2×10^{-6}	-
	S8	2.1×10^{-4}	-	1.1×10^{-6}	-	6.7×10^{-4}	-	1.3×10^{-6}	-
	S9	3.1×10^{-4}	-	2.9×10^{-4}	-	1×10^{-3}	-	2×10^{-6}	-
	S11	2.1×10^{-4}	-	1.1×10^{-6}	-	6.7×10^{-4}	-	1×10^{-6}	-
HI = CDI/RfD		2.7×10^{-3}	4.2×10^{-4}	1.2×10^{-1}	8×10^{-5}	8.7×10^{-3}	1.3×10^{-4}	1.7×10^{-3}	2.6×10^{-5}
ELCR =CDI × SF		8.2×10^{-3}	1.3×10^{-3}	3.6×10^{-3}	2.4×10^{-6}	2.6×10^{-2}	4.09×10^{-4}	5×10^{-5}	7.9×10^{-7}
Cu	S6	7.5×10^{-3}	7.2×10^{-5}	4.2×10^{-5}	4×10^{-7}	0.02433	2.3×10^{-4}	4.8×10^{-5}	4.6×10^{-4}
	S7	3.3×10^{-3}	1×10^{-5}	1.8×10^{-5}	5.7×10^{-8}	0.01067	3.3×10^{-5}	2.1×10^{-5}	6.5×10^{-8}
	S9	5.1×10^{-4}	-	2.9×10^{-6}	-	1.7×10^{-3}	-	3.3×10^{-6}	-
	S10	2.1×10^{-4}	-	1.1×10^{-6}	-	6.7×10^{-4}	-	1.3×10^{-6}	-
	S11	2.1×10^{-4}	-	1.1×10^{-6}	-	6.7×10^{-4}	-	1.3×10^{-6}	-
HI = CDI/RfD		5.9×10^{-4}	4.1×10^{-6}	1.2×10^{-5}	8.5×10^{-8}	1.9×10^{-3}	1.32×10^{-5}	1.4×10^{-5}	8.5×10^{-5}
ELCR =CDI × SF		-	-	-	-	-	-	-	-
Zn	S1	-	3.1×10^{-2}	-	1.1×10^{-3}	-	0.1017	-	1.2×10^{-3}
	S2	3.1×10^{-4}	9.3×10^{-5}	1×10^{-5}	9.3×10^{-5}	1×10^{-3}	3×10^{-4}	1.2×10^{-5}	3.5×10^{-6}
	S3	2.1×10^{-4}	-	6.9×10^{-6}	-	6.7×10^{-4}	-	7.8×10^{-6}	-
	S5	-	7.2×10^{-5}	-	2.4×10^{-6}	-	2.3×10^{-4}	-	2.7×10^{-6}
	S6	2.1×10^{-4}	4.2×10^{-2}	6.9×10^{-6}	1.4×10^{-3}	6.7×10^{-4}	0.1357	7.8×10^{-6}	1.6×10^{-3}
	S7	-	2.1×10^{-5}	-	6.9×10^{-7}	-	6.7×10^{-5}	-	7.8×10^{-7}
	S8	-	2.6×10^{-4}	-	8.6×10^{-6}	-	8.3×10^{-4}	-	9.8×10^{-6}
	S10	-	1.6×10^{-3}	-	5.4×10^{-5}	-	5.3×10^{-3}	-	6.2×10^{-5}
	S12	-	1.4×10^{-4}	-	4.8×10^{-6}	-	4.7×10^{-4}	-	5.5×10^{-6}
	S13	-	5.1×10^{-5}	-	3×10^{-5}	-	1.7×10^{-4}	-	2×10^{-6}
HI = CDI/RfD		2.4×10^{-6}	2.5×10^{-4}	4×10^{-7}	4.5×10^{-5}	7.8×10^{-6}	4.1×10^{-3}	6.6×10^{-5}	4.7×10^{-5}
ELCR =CDI × SF		-	-	-	-	-		-	-
Ni	S1	-	3.2×10^{-2}	-	3.5×10^{-5}	-	0.1023	-	4×10^{-5}
	S2	1.4×10^{-3}	1.4×10^{-3}	1.4×10^{-6}	1.6×10^{-6}	4.7×10^{-3}	4.7×10^{-3}	1.8×10^{-6}	1.8×10^{-6}
	S3	2.1×10^{-4}	-	2.3×10^{-7}	-	6.7×10^{-4}	-	2.6×10^{-7}	-
	S6	3.1×10^{-4}	3.1×10^{-5}	3.4×10^{-7}	3.4×10^{-8}	1×10^{-3}	1×10^{-4}	3.9×10^{-7}	3.9×10^{-6}
	S11	1.9×10^{-4}	-	2.2×10^{-6}	-	6.3×10^{-3}	-	2.5×10^{-6}	-
HI = CDI/RfD		5.3×10^{-5}	8.4×10^{-4}	3.5×10^{-7}	3.1×10^{-6}	3.2×10^{-4}	2.7×10^{-3}	4.1×10^{-7}	3.8×10^{-6}
ELCR =CDI × SF		1.8×10^{-3}	2.8×10^{-2}	3.5×10^{-6}	3.1×10^{-5}	1.1×10^{-2}	9×10^{-2}	4.2×10^{-6}	3.8×10^{-5}
HI total		6.4×10^{-3}	6.9×10^{-3}	1.2×10^{-1}	1.2×10^{-3}	5.5×10^{-2}	1.3×10^{-2}	6.9×10^{-3}	4×10^{-1}
HI total dermal + Ingestion		Children 1.37×10^{-1}				Adult 4.70×10^{-1}			
ELCR total		1.5×10^{-1}	1.4×10^{-2}	2.5×10^{-1}	2.4×10^{-3}	5.8×10^{-1}	2.6×10^{-2}	1.4×10^{-2}	7.9×10^{-1}
ELCR total dermal + Ingestion		Children 4.1×10^{-1}				Adult 1.41			

(-) indicated that the level of heavy metal concentration was below the detection limit.

Cancer risk assessment

Cancer risk assessment was conducted for metals Pb, Cr, Ni and Cd which are carcinogenic in nature only.[5] For a particular heavy metal, an Individual Lifetime Cancer Risk (ILCR) below 1×10-6 is considered as insignificant, indicating negligible cancer risk. Conversely, an ILCR exceeding 1×10-4 is regarded as harmful, signifying significant cancer risk. As for the cumulative exposure to all heavy metals across various routes, the tolerable threshold is 1×10-5.[60,61] This study revealed that cancer risk via cumulative dermal and ingestion exposure in both children and adults was high in both wet and dry seasons. The potential cancer risks for children ranged from 2.4×10^{-3} to 2.5×10^{-1} for the dermal pathway and 1.4×10^{-2} to 1.5×10^{-1} for the ingestion pathway, while for the adult group cancer risk ranged from 1.4×10^{-2} to 7.9×10^{-1} for dermal pathway and 2.6×10^{-2} to 5.8×10^{-1} for ingestion pathway. Overall, the calculated cancer risk for children and adults through dermal and ingestion exposure were $4.14.1\times10^{-1}$ and 1.41 respectively. The study revealed that Cr had the highest average contribution of ILCR with its highest individual ILCR values of 8.1×10^{-1} and 5.7×10^{-1} recorded for adults and children respectively via ingestion exposure while Cd has the lowest cancer risk of 1.3×10^{-7}. The health implications of the studied heavy metals including Lead (Pb), for example, possess carcinogenic properties and can negatively affect the respiratory and digestive systems, as well as suppress the immune system. It is particularly harmful to children, impacting their intelligence and nervous systems.[62] Cadmium (Cd) tends to accumulate in the circulatory system, kidneys (especially the renal cortex), lungs, and heart, posing toxicity to bones and gonads. These risks are acknowledged by the International Agency for Research on Cancer and the National Toxicology Program,[63] with Cd classified as a Group 1 carcinogen. Chromium (Cr) can take on various oxidation states, with hexavalent chromium (VI) being highly soluble and mobile, causing harm to the skin, liver, kidneys, and respiratory organs. It leads to ailments such as dermatitis, renal tubular necrosis, nasal septum perforation, and lung cancer.[64] Nickel (Ni) tends to accumulate primarily in the spinal cord, brain, and organs due to its mutagenic and carcinogenic properties.[65] These results clearly show that adults are more vulnerable to health risks associated with drinking water than children. In Great Ruaha River, Tanzania health risk assessment reported that adults were most vulnerable to health risks due to exposure to heavy metals contamination.[46] These findings signified the contamination of the Ngerengere Urban River water and justified the need for prior treatment of river water for healthy human consumption. The use of water with Pb, Cr, Ni and Cd levels higher than the permissible limit can also be of health risk to the aquatic organisms that live in the water.[43]

Uncertainty analysis

In health risk assessment, errors may arise due to various factors. Future exposure assessment relies on factors such as the fate and transport of heavy metals, estimations, remedial options, land use projections, and assumptions about the frequency and duration of exposure, all of which can introduce uncertainties. In our study, we made the assumption that water for domestic use is consumed every day of the year, and cancer risk was assessed over a span of 70 years of exposure. However, it's important to note that individuals may not necessarily reside in Morogoro Municipality for the entirety of those years.

Sediment ecological risk assessment

Heavy metals in sediments

The results of heavy metal concentration in the sediments are shown in Figure 3. In the wet season the highest mean concentration was 0.117 mg/kg, 0.98 mg/kg, 6.238 mg/kg, 0.041 mg/kg and 12.755 mg/kg for Pb, Cr, Ni, Cu and Zn respectively. Cd concentration was below the detection limit in the wet season. In dry season highest mean concentrations were 4.11 mg/kg, 1.078 mg/kg, 1.312 mg/kg, 0.814, 2.533 mg/kg and 0.639 for Zn, Cu, Ni, Cd, Cr and Pb respectively. The higher concentrations of heavy metals in sediment are due to the deposition of heavy metals in river water and the adsorption process in riverbed sediments.[26] While river sediments can absorb certain heavy metals, thus mitigating water pollution to some extent, they can also leach these metals back into the water, resulting in secondary pollution that proves challenging to manage.[66] Furthermore, these results are not consistent with other studies that reported the elevated concentrations of heavy metals in areas surrounded by mining activities.[15,67] There is no specified sediment quality guideline, therefore the findings from this study were compared with US EPA sediment quality guideline. Based on the US EPA guidelines the maximum concentration of the heavy metals in the sediment should be <40 mg/kg, <25 mg/kg, <25 mg/kg and <90 mg/kg for Pb, Cr, Cu and Zn respectively. The obtained concentrations of heavy metals in sediment were within the US EPA guidelines. Physical parameters of the sediments were analyzed for soil moisture, total carbon and textural classes. Moisture percentage in the soil sample ranged from 9.187±0.314% to 41.455±0.598% while total carbon ranged from 1.03±0.241% to 5.231±0.158% in the dry season. For the wet season moisture percentage in the sediment samples ranged from 11.612±0.013% to 41.419±0.036%, and total carbon ranged from 0.259±0.023% to 3.375±0.032%. Textural classification revealed that the dominant texture properties of the collected sediments were composed of loamy sand and silt clay. Other study, indicated that a notable section of Morogoro Municipality, particularly its central regions, is defined by silty clay soil, while loamy sand predominates in the peripheral areas.[38]

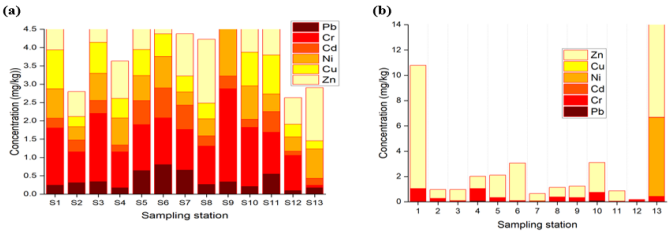

Figure 3 Heavy metal concentrations (mg/kg) in dry (a) and wet season (b) for the selected sediments sample.

Multivariate analytical tests for heavy metal loading in the sediment

It's crucial to pinpoint the sources of this pollution to establish an efficient action plan. Multivariate analyses have proven successful in numerous studies[8,68] serving as effective tools for identifying the sources of heavy metal pollution in sediment.[69,70] A Pearson correlation test was conducted to explore the connections between the concentrations of various heavy metals (Table 8). In the dry season strong positive correlations were found between Cr and Cu (with a correlation coefficient (of 0.78224, $p<0.01$), Cu and Zn (0.76809, $p<0.01$). Moderate positive correlation between Cr and Ni (0.59746, $p<0.01$), Ni and Cu (0.55327, $p<0.01$), and low positive correlation for Pb and Cd (0.44617, $p<0.01$), Cr and Zinc (0.36139, $p<0.01$), Pb and Zinc (0.3273, $p<0.01$), Pb and Cr (0.30172, $p<0.01$), Pb and Cu (0.28838, $p<0.01$), Ni and Zn (0.20374, $p<0.01$), Cd and Zn (0.18603, $p<0.01$) , Cd and Cu (0.17202, $p<0.01$) Pb and Ni, (0.01617, $p<0.01$), Cr and Cd (0.13303, $p<0.01$) Pb and Cr (0.30172, $p<0.01$). A negative correlation was also recorded between Cd and Ni (-0.05191, $p<0.01$). Therefore, based on these findings it can be concluded that in the dry season there was a positive correlation of heavy metals concentrations across the sampling stations except for Cd and Ni.

Citation: Mbonaga SS, Hamad AA, Mkoma SL. Health and ecological risk assessment of heavy metals in water and sediments within a data scarce urban catchment in Tanzania – A case of Ngerengere River, Morogoro Municipality. *MOJ Eco Environ Sci.* 2024;9(2):72–87. DOI: 10.15406/mojes.2024.09.00309

Table 8 Correlation of heavy metal in sediment during the dry season

Heavy metals	Pb	Cr	Cd	Ni	Cu	Zn
Pb	1	0.30172	0.44617	0.01617	0.28838	0.3273
Cr		1	0.13303	0.59746	0.78224	0.36139
Cd			1	-0.05191	0.17202	0.18603
Ni				1	0.55327	0.20374
Cu					1	0.76809
Zn						1

The sources of the heavy metals found in the sediments in the Ngerengere River and its tributaries were analyzed using PCA and HCA. Both PCA and HCA were used to determine whether the heavy metals (Pb, Cr, Cd, Ni, Cu and Zn) had a common source. The PCA results for the heavy metal concentrations in dry season are shown in Table and HCA is presented in Figure 4. Principal Component Analysis (PCA) was conducted utilizing Varimax rotation and Kaiser Normalization. The outcomes of the PCA suggest that the variables can be categorized into two principal components, PC1 and PC2.

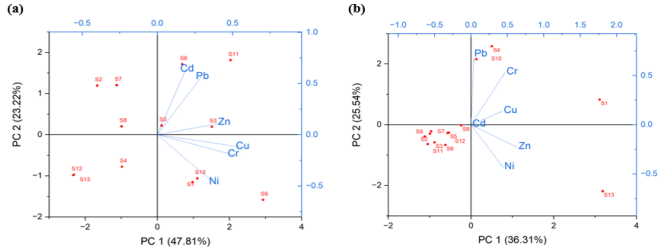

Figure 4 PCA Bi-plot for heavy metal variance in sediment during dry season (a) and wet season (b).

Component 1 (PC1) is positively loaded with the Pb, Cr, Ni, Cd, Cu and Zn concentrations. Component 2 (PC2) is associated with the Pb, Cd and Zn concentrations. PC1 and PC2 explain 47.81% and 23.22%, respectively, of the total variance. Pb, Cd and Ni have a positive loading for both PC1 and PC2 (Table 9).

Table 9 Coefficients of PCA

Heavy metals	Coefficients of PC1	Coefficients of PC2
Pb	0.29038	0.56195
Cr	0.49528	-0.19273
Cd	0.18893	0.63564
Ni	0.36797	-0.46386
Cu	0.55714	-0.12068
Zn	0.4346	0.11531
Cumulative Percentage %	47.81%	23.22%

Hierarchical Cluster Analysis (HCA) was conducted on standardized data employing Z-scores, utilizing Ward's method and the Euclidean distance metric. The analyzed parameters were initially divided into two major clusters (Figure 5). Cluster 1 consists of twelve sampling stations. Cluster 2 consists of only one sampling station. C1 and C2 include the sampling points of the upstream to downstream and midstream reaches, respectively. The heavy metal concentration value of C2 was roughly twice as much as that of C1, indicating that there were significant impacts of human activities in the dry season. In the wet season the study observed a positive high correlation between Ni and Zn (0.76995, $p<0.01$), a moderate positive correlation between Pb and Cr (0.52943, $p<0.01$), a weak positive correlation between Cr and Cu, Cr and Ni, Cr and Zn, Cu and Zn. A negative correlation was observed for Pb and Ni, Pb and Cu as well as Ni and Cu (Table 10).

Table 10 Correlation Coefficients of heavy metal in sediment during the wet season

	Pb	Cr	Cd	Ni	Cu	Zn
Pb	1	0.52943	0	-0.14362	-0.11003	-0.14084
Cr		1	0	0.08291	0.47147	0.45837
Cd			1	0	0	0
Ni				1	-0.0096	0.76995
Cu					1	0.46639
Zn						1

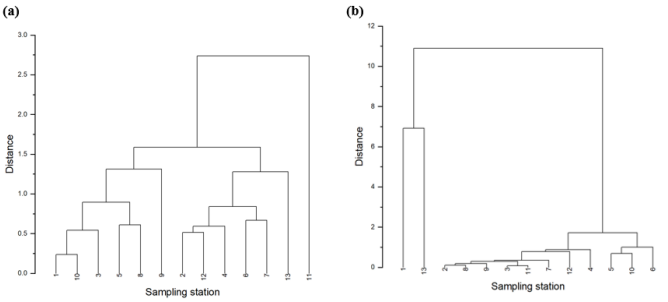

Figure 5 HCA dendrogram for clustered pollution sources in dry season (a) and wet season (b).

Furthermore, the PCA yielded two significant components of pollution with eigenvalues >1.00, accounting for a total of 61.85% of the variation in heavy metal concentration (Table 11). The first principal component (PC1), 36.31% of the calculated variance, exhibited a high positive load for Zn, but a low positive load for Cu, Ni and Cr. Chromium and Nickel are commonly found together in various types of rocks and consequently can be present in soils derived from these rock formations and their concentration can be elevated by an influence of anthropogenic activities.[71] This was confirmed by our study, obtaining a positive correlation coefficient between them in both dry and wet seasons. The second principal component, which explained 25.54% of the total variance, showed a strongly positive load of Pb, a moderate positive loading for Cr but a low positive loading of Cu. Cu is an abundant metal in nature and it has wide application in industrial activities.[72] The two elements (Pb and Cr) recorded a high and moderate positive loading are associated with close geo-chemical dependence as the iron family in the natural soils,[73] which is presented again in the current results with a positive correlation coefficient of r = 0.52943 and 0.30172 in both wet and dry season respectively. A negative load was recorded for Ni and Zn.

Table 11 Coefficients of PCA in the wet season

	Coefficients of PC1	Coefficients of PC2
Pb	0.04079	0.67731
Cr	0.46788	0.53091
Cd	0	0
Ni	0.43848	-0.43369
Cu	0.43057	0.13753
Zn	0.63386	-0.22889
Cumulative percentage %	36.31	25.54

In the wet season, the spatial cluster analysis CA generated a dendrogram (Figure 5), where all thirteen sampling sites were divided into two statistically significant clusters. Cluster 1 comprised two sampling sites (S-1 and site-13), while Cluster 2 comprised the remaining eleven sampling sites (site-2, site-3, site-4, site-5, site-6, site-7, site-8, site-9, site-10, site-11, and site-12). The classification of clusters varied depending on the significance level due to the similarity

in characteristic features and anthropogenic or natural background source types among the sites. Cluster 1 represented low-contaminated sites (upstream reaches of the Ngerengere River and its tributaries, whereas Cluster 2 represented highly contaminated sites (midstream and downstream reaches of the Ngerengere River and its tributaries). These observations are similar to a previous study.[50]

Indices for sediment pollution assessment

Pollution load index

The classifications for PLI classes are as follows: PLI < 1 indicates sediments in excellent condition; PLI = 1 suggests sediments are at a baseline quality level; and PLI > 1 indicates a progressive deterioration of the site.[51] In this study, data from the dry period showed higher PLI levels compared to those from the dry period (Figure 7a). Moreover, neither the dry nor the wet period had PLI values ≥ 1, indicating that the PLI values reflected sites in good ecological health. Generally, the individual PLIs for Cd for all sampling stations were > 1, indicating that the sediment at those sampling stations was contaminated with Cd, especially from anthropogenic activities.[74]

Enrichment factor

Human activities' impact on heavy metal concentrations in shallow sediments of the Ngerengere River and its tributaries in Morogoro Municipality was studied by assessing anthropogenic sources via EF calculations. Iron (Fe) was used as a reference element to differentiate between anthropogenic and natural sources and has been previously employed for this purpose.[70] EF values below 2 indicate minimal enrichment of a heavy metal or metalloid, while values between 2 and 5 suggest moderate enrichment. A value exceeding 5 but below 20 signifies significant enrichment, and values surpassing 20 indicate very high enrichment. EF values beyond 40 indicate extremely high enrichment. The order of EF in the dry season and wet season were Cd>Pb>Cu>Zn>Cr>Ni with EF values of 341, 5, 3, 2.9, 2.8 and 2 respectively. In this study, during the dry season there was extremely high enrichment for Cd. These similar findings indicated extremely heavy metal enrichment in Mara River sediments were also reported in other research.[15] EF values for Cd during the dry season across all sampling stations were considerably above 40. For Pb in the dry season, moderate sediment enrichment was observed at sampling stations S2, S6, S8, S9, S10 and S11, with EF values of 5, 3, 2, 2, 2 and 3, respectively. The study findings revealed that EF values for Cr, Ni, Cu, and Zn for the most of sampling stations were well below 2 (Figure 6), indicating minimal enrichment of these two toxic heavy metals during the dry month. In the wet season the order of EF values was in the order of Ni>Zn>Cr>Pb>Cu>Cd with EF values of 93, 73, 4, 3, 0.5, and 0 respectively. The study revealed that extremely high enrichment was recorded for Ni and Zn with EF values of 93 and 73 respectively. Moderate enrichment was observed for Pb and Cr while EF values for Cd and Cu in wet seasons were below, which suggests minimum enrichment of C and Cu in Ngerengere river sediment within Morogoro Municipality in wet season attributed to dilution due to flooding. Extremely heavy metals enrichment across the sampling station in both dry and wet seasons indicated the influence of anthropogenic activities such as agriculture activities, industrial and domestic sewage[75] and vehicles and spillage particularly from Tanzam highway Municipality.[22,76]

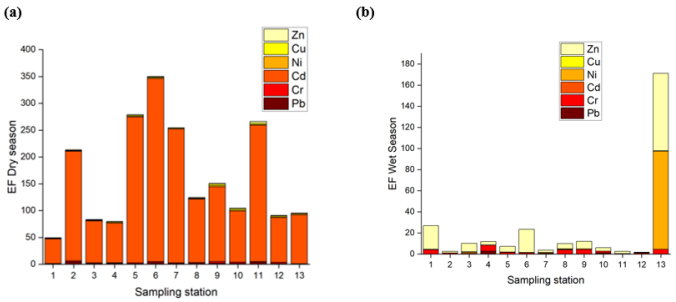

Figure 6 EF values in the wet (a) and dry season (b).

Geoaccumulation index

The mean Igeos for the sampling points are shown in Table 12. The mean I_{geos} indicate that sediment at most of the sampling points was uncontaminated (Igeo≤0) with heavy metals but that sediment at some sampling points during the dry was contaminated with Cd. Sediment at Sediment at S5, S6, S7 and S11 was moderately contaminated with Cd (1≤Igeo≤2). The mean Igeos for both dry and wet seasons decreased in the order Cd (0.382) >Pb (0.0048) >Zn (0.0043) >Cu (0.0041) > Cr (0.0035) > Ni (0.0027).

Table 12 Mean Igeos in the sediment sample during the dry and wet season

Sampling station	Mean Igeo					
	Pb	Cr	Cd	Ni	Cu	Zn
Wet season	0.000237351	0.000958643	0	0.00206263	7.77E-05	0.004275076
Dry season	0.004803937	0.00351256	0.381999351	0.002798902	0.004136268	0.002767555

Contamination factor

During the wet season, all the heavy metal CFs were below 1, indicating a low level of contamination. In the dry season the CFs for Pb, Ni, Cr, Cu and Zn for all the sampling points indicate moderate contamination (1<CF< 6). The mean CFs decreased in the order Ni (2.287) >Cd (2.194) >Co (0.794) >Cr (0.793) > Pb (0.609)>Fe (0.552)>Mn (0.517)>Cu (0.503)>Zn (0.355). In contrast, during the dry season, CF values for Cd and across all sites ranged between 1 and 3, suggesting a moderate degree of contamination (Figure 7). There was a considerable degree of contamination to pose ecological implications [19] due to high CFs for Cd at sampling stations S6, S7, and S8 which represent the midstream and downstream reaches of the Ngerengere River and tributaries It is recognized that seasonal changes in temperature and rainfall can impact the levels and distribution of specific heavy metals in aquatic environments. These climatic variations demonstrate specificity in their effects on different heavy metals.[77]

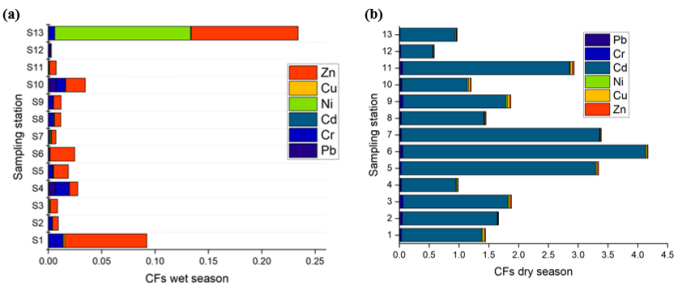

Figure 7 CF values for sediment samples collected from the Ngerengere River and its tributaries in the dry (a) and wet seasons (b).

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Ecological risk index

The risk index (RI) classes are categorized as follows: typically, RI values below 150 indicate a low potential for ecological risk; 150 ≤ RI < 300 suggest a moderate potential ecological risk; RI values when 300 ≤ RI < 600, indicate a considerable ecological risk; and RI values exceeding 600 indicate sediment quality posing a significant environmental health risk. Findings from the current study indicate that, in both dry and wet seasons all sampling sites for the main river and its tributaries had RI values below 150 (Table 13), suggesting that the sites studied were at a low potential for ecological risk. Generally, across all sampling stations, the RI values were higher for samples collected during the dry period compared to those from the wet period.

Table 13 Ecological Risk Index in the dry and wet season

Sampling station	Ecological Risk Index Dry season							Ecological Risk Index Wet season						
	Pb	Cr	Cd	Ni	Cu	Zn	RI	Pb	Cr	Cd	Ni	Cu	Zn	RI
S1	0.079	0.044	40.35	0.081	0.166	0.016	40.736	0	1.96	0	0.155	0.205	9.736	12.056
S2	0.185	0.024	47.85	0.037	0.0446	0.005	48.1456	0	0.492	0	0.135	0	0.695	1.322
S3	0.173	0.052	52.8	0.075	0.132	0.019	53.251	0	0.074	0	0.235	0.06	0.877	1.246
S4	0.104	0.027	27.45	0.076	0.083	0.008	27.748	0.52	1.858	0	0	0.06	0.971	3.409
S5	0.066	0.035	97.8	0.07	0.112	0.015	98.098	0	0.594	0	0.14	0.04	1.779	2.553
S6	0.2	0.036	122.1	0.088	0.097	0.009	122.53	0	0.16	0	0.065	0.045	2.95	3.22
S7	0.098	0.031	99.75	0.036	0.068	0.009	99.992	0.13	0	0	0.245	0.06	0.558	0.993
S8	0.117	0.029	41.4	0.047	0.0675	0.014	41.6745	0	0.654	0	0.18	0.09	0.763	1.687
S9	0.131	0.071	51.9	0.134	0.168	0.017	52.421	0	0.624	0	0.135	0	0.906	1.665
S10	0.116	0.045	32.85	0.093	0.144	0.017	33.265	0.59	1.238	0	0	0.04	2.367	4.235
S11	0.193	0.032	84.15	0.049	0.167	0.032	84.623	0	0.042	0	0.115	0.045	0.813	1.015
S12	0.046	0.027	16.2	0.04	0.055	0.006	16.374	0	0.254	0	0.14	0.1	0	0.494
S13	0.048	0.002	27.75	0.082	0.035	0.011	27.928	0	0.868	0	31.19	0.06	12.755	44.873

Nemerow Index of Heavy Metals contamination in the sediments

The analysis of Nemerow's synthetic contamination index (PN), derived from the single pollution index (Pi), indicated the safety domain group of sediment contamination status for the Ngerengere River and its tributaries with PN values ≤ 0.7 in both wet and dry season. PN values obtained from this study were 0.541465 and 0.520241 for the wet and dry seasons.

Broad health and ecological implications of heavy metal pollution

This study examined six harmful substances (Pb, Cr, Ni, Cd, Cu, and Zn) in the Urban catchment of the Ngerengere River, Tanzania. Research has shown heavy metals severely affect human health, impacting systems like hematopoietic, nervous, endocrine, and cardiovascular.[5] Heavy metals concentrations, were found to be higher in both sediment and water samples around the midstream and downstream reaches of the Ngerengere river and its tributaries, likely due to the presence of point and non-point sources of pollution.[7] Generally, for water samples, the highest heavy metal concentrations were in dry season where the recorded concentrations were 0.09±0.01 mg/L, 0.25±0.01 mg/L, 0.03±0.02 mg/L, 0.73±0.04 mg/L, 0.03±0.02 mg/L and 0.19±0.02 mg/L for Pb, Cr, Cd, Cu, Zn and Ni respectively. The observed results poses serious health risks to humans and has toxic effects on fish and other aquatic organisms.[78]

Noncarcinogenic risk assessments found that daily intake (EDI) for children and adults, via ingestion and dermal exposure in both dry and wet seasons, never exceeded a hazard index (HI) of 1 at any sampling point. This suggests no evidence of potential noncarcinogenic risks from heavy metals (Pb, Cd, Cr, Ni, Cu, and Zn) in the studied area. These findings align with other previous studies that reported the same EDI values.[10,46] Despite the low hazard indices for populations exposed to river water, further investigation is needed to assess the noncancer risks associated with exposure from vegetables irrigated by river water, considering the potential phytoaccumulation of heavy metals. The cancer risk assessment, the study focused on metals Pb, Cr, Ni, and Cd, known for their carcinogenic properties.[79] The individual lifetime cancer risk (ILCR) values for these metals were found to be high, exceeding the threshold of significance (1×10^{-6}) across various exposure pathways for both children and adults in both wet and dry seasons. Particularly high ILCR values were observed for Cr, with the highest individual values recorded for adults and children via ingestion exposure.

The highest metal concentrations in the sediment during wet season were 0.117 mg/kg, 0.98 mg/kg, 6.238 mg/kg, 0.041 mg/kg and 12.755 mg/kg for Pb, Cr, Ni, Cu and Zn respectively. Cd were not detected in all samples during the wet season due to its known mobility properties in aquatic environment.[80] During the dry season, the maximum average concentrations were 4.11 mg/kg for Zinc (Zn), 1.078 mg/kg for Copper (Cu), 1.312 mg/kg for Nickel (Ni), 0.814 mg/kg for Cadmium (Cd), 2.533 mg/kg for Chromium (Cr), and 0.639 mg/kg for Lead (Pb). Across all sampling seasons strong positive correlations of heavy metals in the sediment were found between Cr and Cu; Cu and Zn, suggesting co-occurrence properties of these metals.[40]

The PLI values provide insights into the overall pollution status of sediments. In our study, PLI values were consistently below 1 during both the dry and wet seasons, indicating good ecological health of the sites. This suggests that the sediments are relatively unpolluted and maintain a baseline quality level. However, individual PLIs for Cd exceeded 1 at all sampling stations, indicating Cd contamination likely originating from anthropogenic activities.[81] The EF values offer a deeper understanding of the influence of human activities on heavy metal concentrations in sediments. During the dry season, extremely high enrichment for Cd was observed across all sampling stations, indicating significant anthropogenic contributions. Moderate enrichment of Lead (Pb) was also observed at several sampling stations, this has been also reported in Msimbazi river, which is one among the large Urban Rivers in Tanzania.[82] In

the wet season, Ni and Zn showed extremely high enrichment, contrasting with the dry season. These results highlight the influence of human activities like agriculture, industry, and vehicular emissions on heavy metal contamination. Most sediment samples were uncontaminated according to the Geoaccumulation Index, except for Cd contamination at some points during the dry season. This suggests localized contamination possibly due to anthropogenic inputs.[81] The CF values indicate the degree of sediment contamination with heavy metals. During the dry season, moderate contamination was observed for Pb, Ni, Cr, Cu, and Zn across all sampling points, highlighting the influence of anthropogenic activities. Cd contamination was particularly significant at certain sampling stations, indicating ecological implications for the affected areas. In contrast, the wet season showed lower CF values, suggesting reduced contamination levels attributed to dilution effects from flooding. The RI values assess the potential ecological risk posed by sediment contamination. All sampling sites during both dry and wet seasons had RI values below 150, indicating a low potential for ecological risk, these results are slightly coincide with other study reported low RI of Cr, Cu and Pb.[83] However, RI values were generally higher during the dry season compared to the wet season, reflecting seasonal variations in heavy metal distribution and contamination levels. The PN values indicate the overall contamination status of sediments. In our study, PN values ≤ 0.7 were obtained for both wet and dry seasons, suggesting that sediments in the Ngerengere River and its tributaries fall within the safety domain group of contamination status.

Conclusion

Heavy metal concentrations in the water and sediment of the Ngerengere River and its tributaries were assessed to evaluate health and ecological risks associated with heavy metal contamination in the surface water and sediment. The study focused on the urban catchment of the Ngerengere River, including urban centers in Morogoro Municipality, where the river and its tributaries drain. Various pollution indices, such as Igeo, EFs, CFs, PLIs, Ecological Risk Index, Nemerow Index, and Degree of Water Contamination, were computed to analyze water and sediment pollution and associated ecological risks. The contamination level of river water by degree of water contamination was assessed based on observed concentration levels. During both dry and wet seasons, measured degree of water contamination values ranged from 0 to 6.803, showing contamination variability, with highest concentrations in the dry season. The study found varying potential cancer risks from dermal and ingestion exposure among children and adults. Children had slightly higher ingestion risks, while adults had higher dermal risks, though lower overall than children. Cancer risks from cumulative exposure were elevated in both groups in both seasons. Noncancer risks were >1, indicating lower risk via dermal and ingestion exposure. Mean sediment heavy metal concentrations in decreasing order for dry and wet seasons were Zn>Ni>Cr>Cu>Pb>Cd, with highest Zn and Ni concentrations in dry season and Pb, Cr, Cd, and Cu in wet season, indicating seasonal variation. Lowest Pb, Cd, and Cu concentrations in wet season suggested heavy rainfall effects during sampling, increasing river hydrodynamics and sediment transport, signifying higher heavy metal pollution input.

Pollution indices and statistical analysis supported observed variability and ecological implications. The mean Igeos for both dry and wet seasons decreased in the order of Cd>Pb>Zn >Cu>Cr> Ni. The order of EF in the dry season and wet season were Cd>Pb>Cu>Zn>Cr>Ni with high EF values of Cd. The mean CF values for all heavy metals in the wet season were <1, while the highest CF was 3.325 for Cd at sampling station S7. The PLIs indicate that in the wet season all the sampling points were uncontaminated. However, in the dry season sediments were contaminated with Cd in most of the sampling stations. The results of the present study reveal that during both the dry and wet seasons, all sampling sites along the main river and its tributaries exhibited Ecological Risk index (RI) values below 150. The examination of Nemerow's synthetic contamination index (PN), which is derived from the single pollution index (Pi), revealed a category of sediment contamination considered within the safety domain for the Ngerengere River and its tributaries.

These findings build on previous Ngerengere River studies, using health risk and sediment pollution indices to assess heavy metal impacts. Cd and Pb present risks to the river ecosystem, likely from agricultural pesticide and fertilizer use in Kichangani and Chamwino areas, fuel use, corrosion-resistant paint on fishing boats, untreated aquaculture wastewater, and settlement runoff. The urban river serves over 471,409 residents and faces risks to human health, aquatic organisms, and ecosystem services from these toxic metals. Short-term measures should include regular water quality monitoring and treatment, while long-term efforts should focus on river rehabilitation and restoration. Authorities need robust measures to prevent heavy metal pollution, particularly Cd, Pb, Cr, and Ni. Further research should be done to investigate ecotoxicity on Ngerengere River biota.

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Author's contribution

S.S.M designed the study, conducted data collection and analysis, interpretation of findings, S.L.M, and A.A.M provide technical inputs and review of the manuscript, supported the final write up of the manuscript.

Availability of data and material

The data sets used and analyzed during the study are available and still under analysis for subsequent publications but will be available upon request from authors

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Conflicts of interest

The authors declare that they have no competing interests.

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