PRINT ISSN 1119-8362
Electronic ISSN 2659-1499

Full-text Available Online at
https://www.ajol.info/index.php/jasem
https://www.bioline.org.br/ja

J. Appl. Sci. Environ. Manage.
Vol. 28 (6) 1745-1755 June 2024

Pollution Level of Heavy Metals and Risk Implications from the Lower Omo River: East African Fresh Water in the Semiarid Region of Southern Ethiopia

***[1,2]ABIY, AK; [3]GIRMA, TY;[4]SOLOMON, SS; [5]YOHANNES, SB**

*[*1]Sheka Zone, Department of Water, Mines and Energy, Masha, Ethiopia*
[2]Environmental Toxicology Program, Department of Biology, College of Natural and Computational Sciences, Hawassa University, Ethiopia
[3]Department of Aquatic Sciences, Fishery and Aquaculture, College of Natural and Computational Sciences, Hawassa University, Ethiopia
[4]Department of Biology, College of Natural and Computational Sciences, Hawassa University, Ethiopia
[5]Department of Environmental Health, College of Medicine and Health Sciences, Hawassa University Hawassa City, 1409, State, Ethiopia.

**Corresponding Author Email:* andemoabiy@yahoo.com
**ORCID: https://orcid.org/*0009-0009-5303-0645
**Tel: +251912686422*

Co-Authors Email: girmati@yahoo.com; sorsasota@yahoo.com;*johnseifu80@gmail.com; yohannesseifu@hu.edu.et*

ABSTRACT: TheOmo River passes through Omorate town, where domestic, municipal, and industrial waste from the town and its vicinities, including agrochemicals, flows into the river.Hence, this research aims to assess heavy metal contamination levels and associated risks in the Lower Omo River, located in the semiarid region of Southern Africa. The mean concentrations of the detected heavy metals in the river water were 0.439mg/L for (Mn), 0.1 (Zn), 0.168 (Cu), 0.393 (Cr), 0.318 (Pb), 0.007 (Ni), 8.926 (Fe), and0.06 (Co).The order for the mean concentrations of the heavy metals in the water was Fe >Mn > Cr > Pb > Cu > Zn > Cu > Co > Ni. The mean levels of lead (Pb), manganese (Mn), and chromium (Cr) were above the acceptable limits for water set by WHO. The HPI value indicates that all water sample sites were heavily polluted. The HQs through oral ingestion and dermal for both children and adults were in the order of Cr >Pb> Mn > Fe >Cu > Co > Ni > Zn. The HQ value greater than 1 was examined for Cr, Pb, and Mn both in children and adults through ingestion and dermal route from the River water.The CRs for both children and adults via ingestion of the River water followed the order Cr > Pb. According to CRI value, the River water could be classified as very high environmental risk.

DOI: https://dx.doi.org/10.4314/jasem.v28i6.13

Cite this Article as: ABIY, A. K; GIRMA, T. Y; SOLOMON, S. S; YOHANNES, S. B (2024). Pollution Level of Heavy Metals and Risk Implications from the Lower Omo River: East African Fresh Water in the Semiarid Region of Southern Ethiopia. *J. Appl. Sci. Environ. Manage.* 28 (6) 1745-1755

Dates: Received: 15 March 2024; Revised: 28 May 2024; Accepted: 16 June 2024 Published: 11 June 2024

Keywords: Ecological risk; human health risk; heavy metals; Omo River

Fresh water is a vital resource for all life forms (Abdullah and Ahmad, 2016). Heavy metal pollution in surface water is currently a global environmental and public health concern. The riverine ecosystem is the most important factor for sustaining human life (Divya *et al*., 2016). The water quality of rivers is highly important because rivers are generally used for domestic water supplies, agriculture (irrigation, and other human purposes (Andreea, 2018). However, its quality is threatened by ecological degradation and pollution (Mehjbeen and Nazura, 2017).Different organic and inorganic pollutants are released from natural and anthropogenic sources in aquatic systems (Pramita *et al*., 2021). Pollution of river water bodies may occur due to the discharge of domestic and industrial wastewater, chemicals used for agriculture, solid waste and drainage from the land surface (Mekonnen and Amsalu, 2018).The mobilization of these pollutants could alter the physicochemical properties of water, which may be toxic to aquatic life

**Corresponding Author Email:* andemoabiy@yahoo.com
**ORCID: https://orcid.org/*0009-0009-5303-0645
**Tel: +251912686422*

and humans through the food chain (Pramita *et al*., 2021). Among these pollutants, heavy metals play a major role in environmental pollution due to their toxic nature, bioaccumulation and biomagnificationsin the food chain (Samuel *et al*., 2020; Pramita *et al*., 2021).In developing countries, clean and safe water is a vital concern (Asrafuzzaman *et al*.,2011).Despite the importance of ensuring the quality of drinking water, less attention has been given to water quality monitoring in developing countries such as Ethiopia (Mekonnen and Amsalu, 2018**).** The Omo River Basin is a vital resource for the people of southern Ethiopia (Wakjira and Getahun, 2017). Although the quality and pollution level of this freshwater caused by heavy metals has notbeen yet reported, it is a major source of water for domestic use, agriculture (irrigation), and lives tock. Recently, the Omo River has experienced rapid development of industry and intensive agriculture along the river and its catchments, especially on the upstream side of the Omo Delta (Wakjira and Getahun, 2017). Large-scale irrigation development, industry and land use changes in the upper and middle Omo Basin in recent years have already resulted in changes in the environment of the lower Omo River basin ecosystem (Ojwang *et al*., 2010). It has been inevitably altered by the rapid development of industry and agriculture in its catchment (Ojwang *et al*., 2010).The developments of irrigation and agriculture in general in the Omo River basin have led to increased use of fertilizers and pesticides. Over 30% of the Upper Omo upstream inflow will be abstracted for irrigation (Avery, 2012).According to the results gained from other irrigation projects, large-scale irrigation development in the Lower Omo could have a significant effect on aquatic resources and water chemistry due to agrochemicals and increased nutrient levels, leading to the destruction of aquatic biota (Avery, 2012).Experience with similar projects has also indicated that proper amounts of fertilizers and pesticides are not being used, and as a result, excessive chemical runoff can occur (Gure *et al*., 2019). This improper use of agrochemicals may cause potential adverse impacts, including depreciation of downstream water quality, increased vulnerability of the ecosystem and harm to humans and livestock (Ojwang *et al*., 2010). Chemical contamination of the lower Omo could arise from human activities. These include chemicals from large-scale irrigation projects, from construction projects (hydroelectric dams), waste discharges from sugar factories and from oil spillage (Avery, 2012; Gure *et al*., 2019). Thus, the purpose of this research was to ascertain the degree of heavy metal pollution and the potential risks associated with the Lower Omo River, an East African freshwater located in the semiarid region of southern Ethiopia.

MATERIALS AND METHODS

Description of the study area: The lower Omo River basin is located in the southern part of Ethiopia. It passes through Omorate town, where domestic, municipal, and industrial waste from the town and its vicinities, including agrochemicals, flows into the river. It drains south from Ethiopia's humid highlands to arid lowlands terminating in the Omo delta on Lake Turkana, where its lower portion is found in the eastern arm of the East African Great Rift Valley. The study was carried out at the lower reaches of the Omo River in the vicinity of Omorate town. It receives an annual precipitation of up to 2,000 mm (UNEP, 2010), although the mean annual rainfall could reach 350 mm in the lower Omo River Valley near the lake (Wakjira and Getahun, 2017).The geographic coordinates of the sampling points are presented in Figure 1.

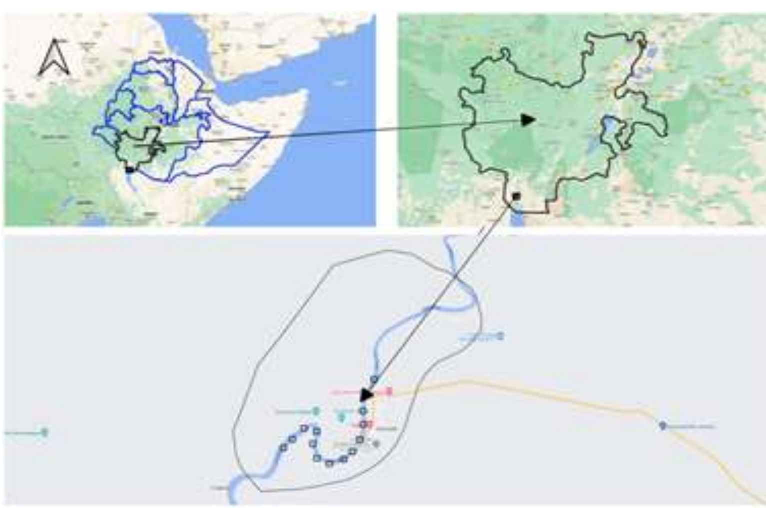

Fig1: Geographic coordinates of the sampling points in the Omo River

Sampling and Sample Collection: Water samples were collected from different river locations of fifteen sub sample sites with three sampling points on each subsite were taken, yielding a total of 45 samples from the River. The water samples were collected in high-quality, screw capped, highdensity; pre sterilized polypropylene bottles, each with 2 litter capacities. The water samples were acidified with 5% HNO_3 to keep the metals dissolved in solution orto prevent the water's heavy metals from decaying (Kang *et al*., 2020) and then placed in an ice box. On the same day, the collected samples were transported and stored in the Research Laboratory of Chemistry, Water Supply and Environmental Engineering, Arba Minch University of Water Technology Institute, Arba Minch, Ethiopia.

*Sample preparation:*The water samples were digested with a concentrated acid mixture of 65% HNO_3 (1 ml) and 35% HCl (0.5 ml) on a thermostatic hot plate. According to the methods developed by the United States Environmental Protection Agency (USEPA) 3005, a 50 ml aliquot of wellmixed water samples was digested in a beaker covered with a watch glass by adding 1 ml of concentrated (65%) HNO3 and 0.5 ml of concentrated (35%) HCl and heated on a hot plate boiled until a clear solution was formed. The beaker was subsequently removed and cooled. After digestion and cooling**,** the samples were diluted with distilled water and filtered through Whatman filter paper for analysis (Dugasa and Endale, 2018).

Sample analysis: The absorbance of heavy metals was analysed using a flame atomic absorption spectrometer (GFAAS- novAA400p; Germany), and the concentrations of the heavy metals in the water samples were determined from a standard calibration curve.Analytical grade standards of each target heavy metal were used to construct calibration curves. Before real sample analysis, the instrument was calibrated by preparing a series of concentrations of the standard solutions for each analyte. Analysis of each heavy metal was carried out in triplicate. Values below the detection limits were reported as 'ND' (not detected). Analysis was carried out according to APHA protocol (APHA, 2017).

*Water quality evaluation based on water quality indices:*The assessment of heavy metals pollution was an important aspect of water quality assessment programs. The Global Environment Monitoring System (GEMS) program includes metals such as Al, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb, and Zn as a high priority metals (Alma *et al*., 2022).In the present study, the nine heavy metals including Cd, Cr, Cu, Fe, Mn, Ni, Co, Pb and Zn were investigated.

*Heavy metal pollution index (HPI):*The heavy metal pollution index (HPI) is used as an indicator of the overall water quality related to heavy metal content (Mohan *et al*., 1996; Alma *et al*., 2022). Multiple heavy metals in water and their collective impact on water qualitywere comprehensively evaluated using HPI (Taygi *et al*., 2013)andis calculated according to the following equation [1] (Mohan *et al*., 1996; Ahmed *et al*., 2023)

$$\text{HPI} = \frac{\sum_{i=1}^{n} WiQi}{\sum_{i=1}^{n} Wi} \quad (1)$$

$$\text{Wi} = \frac{K}{Si} \quad (2)$$

$$\boldsymbol{K} = \frac{\mathbf{1}}{\sum\left(\frac{\mathbf{1}}{\mathbf{Vstandard}}\right)} \quad (\mathbf{3})$$

$$\mathbf{Qi} = \frac{\boldsymbol{Mi - Ii}}{(\boldsymbol{Si - Ii})}\ \boldsymbol{x}\ \mathbf{100} \quad (\mathbf{4})$$

Where HPI is the metal pollution index (Equations 1), Wi is the unit weighting of the i^{th} heavy metal (Equation 2),K is the proportionality constant which is inversely proportional to the maximum permissible value (Si) of the heavy metals for drinking, livestock and irrigation use that is calculated as presented in Equation (3), and Qi is the sub-index for the i^{th} heavy metal (the individual quality rating for the i^{th} heavy metal) calculated using Equations (4). Mi and Ii represent the monitored and ideal values of the i^{th} parameter, respectively for heavy metals (µg/L). A value of HPI < 100 represents low pollution of heavy metals, HPI value > 100 indicates the water is unsuitable for consumption and HPI = 100 is the threshold value at which harmful health consequences are probable (Mohan *et al*., 1996; Elsiddig*et al*., 2020; Tala*et al*., 2023).

*Metal index (MI):*The MI is a water quality indicator that assesses the overall pollution level derived from the concentrations of heavy metals when compared to their respective maximum allowable concentration (MAC). It is used for estimating the quality of water for different utilizations (Josephine *et al*., 2021). According to this index, water samples may be divided into three groups as: potable (MI <1), on the threshold of risk of drinking (MI = 1) and non-potable (MI> 1) table 7 and calculated according to equation (4) (Jafarabadi *et al*., 2017; Goher *et al*., 2020; Ahmad *et al*., 2023).

$$\text{MI} = \sum_{i=1}^{n} \frac{\boldsymbol{Ci}}{\boldsymbol{MAC}} \quad (5)$$

Where MI is the metal index, Ci is the mean concentration of each heavy metal in the water sample, and MAC is the maximum allowable concentration for each heavy metal in the water sample. An MI < 1 indicates that the water is suitable for consumption. An MI >1 indicates that the water is unsuitable for domestic use (EdetandOffiong 2002; Alma *et al*., 2022).According to Caerio *et al* (2005), it was also classified as presented in Table 1(Caerio *et al*,.2005).

Table1. Water Quality Classification using MI

MI	description
< 0.3	Very pure
0.3-1	pure
1-2.2	Slightly affected
2-4	Moderately affected
4-6	Strongly affected
6	Seriously affected

Exposure assessment: The health risks for the heavy metals from water through oral ingestion and dermal absorption were estimated according United States Environmental Protection Agency (USEPA) risk assessment guideline (USEPA, 2005).To assess non cancer and cancer risks for humans (children and adults), the chronic daily intake (CDI) of HMs, which represents the lifetime average daily dose (LADD) of exposure to a contaminantwas used (USEPA, 2005; Bamuwuwamye et al., 2017). The CDI of the HMs in water via oral ingestion and dermal absorption was calculated by using the following equations 7 and 8 (Govind*et al.*, 2022; Ugwu *et al.*, 2022):

$$\text{CDI ingestion} = (\text{C x IR x EF x ED}) \Big/ (\text{BW x AT}) \quad (7)$$

$$CDI\ dermal = \frac{(\text{C x EF x ED} \times \text{ET} \times \text{SA} \times \text{KP} \times \text{CF})}{(\text{BW x AT})} \quad (8)$$

Where: CDI is the chronic daily intake (mg/kg/day); C is mean concentration of heavy metal in the water (mg/L); IR is the ingestion rate per day (1 L/day for a child and 2.2 L/day for adult) (Bamuwuwamye *et al*., 2017; Ugwu *et al*., 2022); ED is the exposure duration (6 years for a child and 65 years for an adult) (WHO, 2015; Ahmad *et al*., 2023); EF is the exposure frequency (365 days/year);*ET* is exposure time (0.58 h/day for adults; 1 h/day for children (UNEPA, 2005); BW is average body weight (15 kg for a child and 60 kg for adult) (WHO, 2012) over the exposure period; *AT* is the average time representing the period over which exposure is averaged [(for carcinogens, AT=65×365=23725 days for both children and adults; for non-carcinogens, AT=ED×365 which equals 2190 days and 10950 days for children and adults, respectively) (USEPA, 1989; USEPA, 2004)];*SA* is exposed skin area available for contact (18000 cm^2 for adults; 6600 cm^2 for children) (USEPA, 2004); KP is dermal permeability coefficient of heavy metal in water (cm/h)[Pb (0.004), Ni (0.001), Co (0.001), Cu (0.001), Zn (0.006), Mn (0.001), Fe (0.001), and Cr (0.001)] (USEPA, 2004); CF is unit conversion factor (0.001L/cm3) (USEPA, 2004;Bamuwuwamye *et al*., 2017; Govind*et al*., 20222).

Noncarcinogenic risk assessment (HQ and HI): The noncancer risks of HMs in water were determined by using the hazard quotient (HQ) and hazard index (HI) according to equation 2. The hazard index (*HI*) is the overall potential for noncarcinogenic effects posed by multiple pollutants via ingestion or dermal pathways.

$$\text{HQ Ingestion} = {CDIingestion}\big/_{RfDingestion} \quad (9)$$

$$\text{HQ dermal} = {CDIdermal}\big/_{RfDdermal} \quad (10)$$

$$\text{HI} = \sum \text{HQ} \quad (5)$$

Where*HI*represents the overall potential for noncarcinogenic effects posed by more than one pollutant via ingestion or dermal pathway; HQ is the noncancer hazard quotient; CDI is the chronic daily intake (mg metal/kg/day); and RfDrepresents the chronic oral reference dose which is probably without a significant risk of harmful effects throughout life (Bamuwamye *et al*., 2015).The oral reference doses ($RfD_{ingestion}$) of Pb, Ni, Co, Cu, Zn, Mn, Fe, and Cr are 0.0035, 0.02,0.03, 0.04, 0.3 , 0.014 , 0.7, and 0.003 mg/kg/day (USEPA, 2004; USEPA, 2005; USEPA, 2016).The dermal reference doses (RfD_{dermal}) of Pb, Ni, Cu, Zn, Co, Mn, Fe, and Cr are 0.000525, 0.0054, 0.012, 0.06, 0.016, 0.00005, 0.14 and 0.000075 (USEPA, 2002; USEPA, 2005; USEPA, 1995; Akaninyen *et al*., 2022) mg/kg/day, respectively.The potential risk to human health posed by exposure to multiple HMs was measured by the hazard index (HI), which is the sum of all HQs calculated for each heavy metal. A value of HQ or HI < 1 indicates no significant no cancer risk; a value > 1 indicates significant no cancer risk, which increases with increasing HQ or HI (Govind*et al*., 20222; Ugwu *et al*., 2022).

*Carcinogenic risk assessment (CR):*Cancer risk was calculated as the quotientof the CDI (mg/kg/day) and cancer slope factor (CSF) measured in $mg/kg/day)^{-1}$.In the present study, the *CR* was assessed for elements that are considered to be toxic to humans, Cr, Pb, and Ni.

The carcinogenic risk (*CR*) associated with the ingestion pathway can be estimated using the following formula:

$$CR_{ingestion} = CDI_{ingestion} \times CSF_{ingestion} \quad (11)$$

$$CR_{\ dermal} = CDI_{\ dermal} \times CSF_{\ derma} \quad (12)$$

where $CR_{\ ingestion}$ = carcinogenic risk (*CR*) associated with ingestion; CDI = chronic intake (mg/kg/BW/day); and $CSF_{ingestion}$ = the oral carcinogenic slope factor (mg/kg/day), which is 0.0085 for Pb, 0.5 for Cr and 1.7 for Ni.The total cancer risk as a result of exposure to multiple contaminants due to consumption of a particular type of water was assumed to be the sum of each metal cancer risk (∑CR). The United States Environmental

Protection Agency (USEPA) suggested that a$CR < 10^{-6}$ indicates no carcinogenic risk to human health; a $CR > 1 \times 10^{-4}$ indicates a high risk of developing cancer; and a risk ranging from 1×10^{-6} to 1×10^{-4} represents an acceptable risk to human health(USEPA, 1989).2.7 Estimation of ecological risks from water

Estimation of environmental risks using the risk index factor (RI): The risk index factor (RI) resulting from the ingestion of heavy metals from Lower Omo River water was used to estimate potential environmental risk. A risk index factor related to the presence of toxic heavy metals in water was proposed by Hakanson and was calculated according to Hakanson (1980).

$$RI = \frac{Ti \times OC}{NOEC} \quad (13)$$

Where Ri is the risk index factor; Ti is the toxicity coefficient of the metal; OC is the mean concentration of the metal; and NOEC is the maximum allowable concentration. The toxicity coefficients of the metals were 5 for Pb= Ni=Cu=Co, 1 for Zn =Mn, 10 for Fe, and 2 for Cr (Hakanson, 1980, Collins *et al*., 2019).

Comprehensive risk index (CRI) of water: The comprehensive risk index (CRI), which is the summation of the risk index factor (Ri), was calculated according to the following equation(Hakanson, 1980).

$$CRI = \sum RI \quad (14)$$

Where RI is the risk index factor for each metal

The Ri and CRI are classified as no potential environmental danger (RI<1), Low possible environmental danger ($1 \leq RI < 40$), Modest possible environmental danger ($40 \leq RI < 80$), Considerable possible environmental danger ($80 \leq RI < 160$), Severe possible environmental danger($160 \leq RI < 320$), Very severe potential environmental danger ($RI \geq 320$) and for CRI; Low ($CRI < 60$), Moderate ($60 \leq CRI < 120$), high ($120 \leq CRI < 240$), Very high ($CRI \geq 240$)(Hakanson, 1980).

RESULTS AND DISCUSSION

*Concentration of heavy metals from the River water:*The mean concentrations of heavy metals in the river water samples are presented in Table 1 The mean concentrations of the heavy metals in the water samples followed the order Fe (8.926 mg/L) > Mn (0.439 mg/L**)** **>**Cr **(**0.393 mg/L)**>**Pb **(**0.318 mg/L**)** **>**Cu **(**0.168 mg/L) > Zn (0.1 mg/L) > Co (0.06 mg/L) > Ni (0.007 mg/L). Cadmiumwas not detected in any of the water samples which might be due to lack of significant level of Cadmium containing pollution sources in the nearby catchment draining into the river water. The maximum concentration of heavy metals detected in the river water was Fe (12.85mg/L) with min level (8.926mg/L), and the minimum mean concentration was Ni (0.007 mg/L). The mean concentration of Fe in the River water of the present study was larger than that inthe study by Gabriela et al. (2019) from Atoyac River(0.209mg/L) in MexicoandRofhiwaet al. (2021) fromMutangwi River (0.24mg/L) in South Africa. The Fe levels in the River water was above theWHO (2012) and USEPA (2011) permissible limits for drinking. This could be due to the urban wastes and use of steel pipes for irrigation in the River system. The concentration of manganese (Mn) ranged from 0.41 to 0.51 mg/L with mean level of 0.439mg/L.The Mn level of the waterinthe present study was larger than that inthe study by Emily et al., (2023) in Kenya from Sosian River. However, lower mean level of Mn was recorded in this study than in the study byTengku et al. (2020)from Malaysia (0.497mg/L) andYasemin and Fusun (2021) from Akcay River of Turkey (6.48mg/L). The mean concentration of Mn in the present study was above theWHO (2012) and USEPA (2011) permissible limits for drinking.The different agricultural activities and pollution from cities and villages in the basin may have contributed the rise of Mn level in the water.The zinc level ranged from 0.04 to 0.17 mg/L with mean value of 0.1 mg/L. The mean Zn level in the present study was greater than that in the study by Azlini*et al*. (2018) from Highland River (0.033mg/L) in Malaysia However, the Zn level of the River water in this study was lower than that in earlier study byFlipos*et al*. (2021) from Megech River **(**0.13mg/L) in Ethiopia and Mariusz and Joanna (2023) from Muchawka River (176mg/L) in Poland. Its mean concentration in the present study was below theWHO (2012) permissible limits for drinking and the FAO (1985) for livestock.The copper level of the water ranged from 0.1 to 0.27 mg kg^{-1} with themean level of 0.168 mg kg^{-1} .The mean Cu level in this study was greater than that in earlier study by Qiang *et al*., (2021)from Buerhatong River(0.01344mg/L)in China and Adem *et al*. (2023)from Borkena River(0.03 mg/L) in Ethiopia.On the other hand, the mean Cu level of the waterin the present study was lower than that in previous studies byEmily *et al*., (2023)from Sosian River (0.291 mg/L) in Kenya. Its mean concentration in the present study was below theWHO (2012) permissible limits for drinking and the FAO (1985) for livestock.The chromium level of the water ranged from 0.34to 0.46 mg/L with themean level of 0.393 mg/L.The concentration of Cr in this study was greater than thatin previous studies by (Ibukun*et al*., 2018) from Southwest Nigeria (0.059mg/L),(Qiang *et al*., 2021)from Buerhatong River(0.00456mg/L) in China and (Tengku *et al*., 2020)from Tropical River (0.005mg/L),in Malaysia.However, the Cr level in the present study was lower than that inthe study by (Yasemin and Fusun, 2021)from Ackay River (8.296mg/L)in Turkey.The mean concentrations of Cr in the present study was above the permissible limits for drinking water quality (USEPA, 2011;WHO, 2012) but below the FAO permissible limits for livestock (FAO ,1985).The lead level ranged from 0.25 to 0.38 mg kg^{-1} withthe mean level of0.318 mg/L. The mean concentration of Pb in the present study was greater than thatin previous studies by (Emily *et al*., 2023) which was 0.105 mg/L from Kenya, (Ibukun et al., 2018)0.019 mg/L from Nigeria, (Alma *et al*., 2022) 0.0021mg/L from Albania and (Flipos *et al*., 2021)0.04 mg/L from Ethiopia. The finding of the present study was lower than in previous studies by Mariusz and Joanna (2023) which was 9.3mg/L. The mean concentrations of Pb in the present study was above the permissible limits for drinking water quality (USEPA, 2011; WHO, 2012) and FAO for livestock (FAO, 1985).The Possible sources of Pb in the present study may be due the fact that the source of pollution could be from commercial, vehicle traffic, agricultural runoff, Car washing, gas/fuel station and solid wastes which are near the River water from the Omorate town. The lead in the water could also be a result of corrosion of older fittings, combustion of leaded gasoline, corrosion of lead containing materials, irrigation system pipes, burning of building and electronic wastes with residue washed into rivers pipe.

Table 1: Mean concentration of heavy metals (HMs) from the River Water

Heavy metals	N	Concentration		**Anova**		**Drinking Water**		Livestock FAO-1985 (mg/L)	Irrigation water (FAO, 2003))
		Mean	St. dev	**F**	**P**	**WHO,2017**	USEPA, 2018		
Mn	45	**0.439**	0.034	7.90	0.00	0.4	1.6	-	0.2
Zn	45	0.1	0.046	15.04	0.00	-	5	24	2
Cu	45	0.168	0.074	355	0.00	2	1.3	0.5	0.2
Cr	45	**0.393**	0.032	74.6	0.00	0.05	0.1	1	0.1
Cd	45	ND	-	-	-	0.003	0.005	0.005	0.01
Pb	45	**0.318**	0.032	8.13	0.00	0.01	0.015	0.1	5
Ni	45	0.007	0.005	62.1	0.00	0.07	0.1	--	0.2
Fe	45	**8.926**	2.287	36.0	0.00	0.3	0.3	-	5
Co	45	0.06	0.014	50.4	0.00	0.01		1	0.05

The variations in heavy metal concentrations from water at different sampling points are presented in Table 2. Mean Concentration of all HMs at all sample points in River are significantly different at 5% level of significance. To see in which sample point the mean concentration is significantly different; the Tukey test of multiple comparison was used shown in the Table 2.The data are the average of triplicate data that the numbers followed by the same superscript letter in the same column are not significantly different according to Duncan's multiple range tests at ($p < 0.05$). The mean concentration of Mn at site one was significantly different from the mean concentration at sites five, ten and twelve.

The mean concentration of Zn at site one was significantly different from the mean concentrations at sites four to fourteen. Similarly, the mean concentration of Pb at site one was significantly different from the mean concentrations at all sites except for sites seven and fifteen. This difference might be due to the difference in the pollution sources of the heavy metals and the difference in physicochemical properties of water at different sampling points.

Heavy metal pollution index: The water quality pollution indices were assessed after the concentrations of the heavy metals were determined. The HPI, HEI, MI, and CD were calculated to evaluate the quality of the River water regarding the heavy metal levels for each sampling location and are presented in Table 3.The heavy metal pollution index (HPI) indicates the overall quality of the water in terms of heavy metals. The HPI of the River water regarding the heavy metal levels for each sampling location and are presented in Table 3.

The HPI of the Lower Omo River ranges from 656.8 to 999.5 with a mean of 720 (Table 5) for drinking water while the values for irrigation usage ranges from 164.8 to 211.6 with a mean value of 182.01.The HPI value revealed that all sample sites were heavily polluted as the concentration of all exceeded the threshold value of the pollution index which is 100. This indicates that the water is unsafe for drinking and irrigation usage.

Table 2: Concentration of Heavy metals from River water at different sample sites (multiple comparisons)

Site	Mn		Zn		Cu		Cr		Pb		Ni		Fe		Co	
	Mean ± SD		Mean ± SD		Mean ± SD		Mean ± SD		Mean ± SD		Mean ± SD		Mean ± SD		Mean ± SD	
1	0.41	0.00^{a}	0.08	0.01^{b}	0.27	0.02^{d}	0.43	0.01^{d}	0.38	0.02^{ef}	0.00	0.00^{a}	6.49	0.02^{a}	0.06	0.00^{c}
2	0.45	0.01^{a}	0.07	0.01^{b}	0.13	0.01^{b}	0.37	0.01^{c}	0.31	0.01^{bcd}	0.00	0.00^{a}	7.25	0.21^{a}	0.08	0.00^{d}
3	0.43	0.00^{a}	0.08	0.02^{b}	0.15	0.01^{b}	0.36	0.00^{b}	0.29	0.03^{abc}	0.00	0.00^{a}	7.37	0.21^{a}	0.07	0.01^{d}
4	0.42	0.00^{a}	0.15	0.00^{d}	0.24	0.01^{c}	0.38	0.00^{c}	0.32	0.01^{cdef}	0.01	0.00^{c}	8.71	1.48^{b}	0.06	0.01^{c}
5	0.48	0.05^{b}	0.17	0.00^{d}	0.23	0.01^{c}	0.39	0.00^{c}	0.28	0.02^{ab}	0.01	0.00^{c}	12.82	0.07^{c}	0.04	0.01^{ab}
6	0.44	0.01^{a}	0.06	0.01^{ab}	0.10	0.00^{a}	0.42	0.00^{d}	0.33	0.02^{def}	0.00	0.00^{a}	9.32	0.04^{b}	0.05	0.00^{ab}
7	0.41	0.00^{a}	0.04	0.07^{a}	0.11	0.01^{a}	0.44	0.01^{d}	0.35	0.01^{ef}	0.00	0.00^{a}	6.36	0.02^{a}	0.07	0.00^{c}
8	0.40	0.00^{a}	0.16	0.00^{d}	0.10	0.00^{a}	0.34	0.01^{b}	0.33	0.02^{def}	0.01	0.00^{c}	8.83	1.39^{b}	0.06	0.00^{c}
9	0.43	0.00^{a}	0.07	0.01^{ab}	0.12	0.05^{b}	0.27	0.07^{bc}	0.30	0.02^{abc}	0.00	0.00^{a}	7.34	0.21^{a}	0.09	0.00^{d}
10	0.51	0.00^{b}	0.15	0.01^{d}	0.26	0.01^{d}	0.46	0.01^{d}	0.27	0.01^{a}	0.01	0.00^{d}	12.79	0.06^{c}	0.04	0.00^{ab}
11	0.42	0.00^{a}	0.06	0.00^{ab}	0.10	0.00^{a}	0.45	0.01^{d}	0.34	0.02^{def}	0.01	0.00^{e}	9.32	0.04^{b}	0.05	0.00^{ab}
12	0.50	0.00^{b}	0.14	0.00^{d}	0.24	0.00^{c}	0.39	0.01^{c}	0.25	0.02^{a}	0.01	0.00^{c}	12.85	0.07^{c}	0.09	0.00^{d}
13	0.42	0.00^{a}	0.05	0.00^{ab}	0.14	0.00^{a}	0.36	0.01^{b}	0.34	0.01^{def}	0.01	0.00^{c}	9.37	0.04^{b}	0.05	0.00^{ab}
14	0.43	0.01^{a}	0.14	0.00^{d}	0.10	0.01^{a}	0.35	0.00^{b}	0.33	0.01^{def}	0.01	0.00^{c}	8.76	1.48^{b}	0.06	0.00^{c}
15	0.44	0.05^{a}	0.09	0.02^{b}	0.25	0.01^{d}	0.44	0.01^{d}	0.37	0.01^{ef}	0.00	0.00^{a}	6.50	0.02^{a}	0.07	0.00^{c}

Table 3: Drinking and irrigation water quality indices

Stations	Drinking Water						Irrigation water			
	∑Wi	∑WiQi	HPI	HEI	MI	CD	∑Wi	∑WiQi	HPI	HEI
1	0.151319	103.3085	682.7201	18.14433	18.14433	10.14433	0.0459	8.609802	187.5774	9.514
2	0.151319	122.7068	810.9143	19.13567	19.13567	11.13567	0.0459	8.985411	195.7606	2.547
3	0.151319	112.4682	743.2519	18.70767	18.70767	10.70767	0.0459	8.413108	183.2921	3.372
4	0.151319	107.7656	712.1748	24.49619	24.49619	16.49619	0.0459	8.129201	177.1068	8.431
5	0.151319	101.4648	670.5357	35.74019	35.74019	27.74019	0.0459	7.647943	166.6219	8.605
6	0.151319	101.825	672.9157	22.57867	22.57867	14.57867	0.0459	8.269616	180.1659	0.66
7	0.151319	112.9583	746.4908	15.043	15.043	7.043	0.0459	9.155585	199.4681	0.862
8	0.151319	106.6763	704.9763	22.00819	22.00819	14.00819	0.0459	7.701463	167.7879	0.662
9	0.151319	128.8824	851.7261	20.07567	20.07567	12.07567	0.0459	8.321857	181.3041	2.113
10	0.151319	104.0723	687.7676	36.24119	36.24119	28.24119	0.0459	8.440445	183.8877	10.387
11	0.151319	102.8361	679.5976	22.77152	22.77152	14.77152	0.0459	8.475212	184.6451	0.612
12	0.151319	151.2451	999.5112	40.79419	40.79419	32.79419	0.0459	9.713337	211.6195	10.24
13	0.151319	99.39883	656.8825	23.77619	23.77619	15.77619	0.0459	7.564809	164.8106	2.817
14	0.151319	106.8646	706.2206	21.84586	21.84586	13.84586	0.0459	7.902171	172.1606	0.788
15	0.151319	113.6541	751.0892	18.73467	18.73467	10.73467	0.0459	9.21486	200.7595	8.769
Mean	**0.151319**	**109.0904**	**720.9296**	**24.01**	**24.01**	**16.1**	**0.0459**	**8.354259**	**182.01**	**4.7**

The mean value of the present study (720) is lower than those reported by Josephine et al. (2021) in the Mgoua river (1990.64) of South-western Cameroon while it is greater than those reported by Mansour et al.(2018) in drinking water(HPI =48.5) from Khorramabad city in Iran. Heavy metal evaluation index (HEI) and metal index (MI): The values of HEI for drinking water ranged from 18.1 to 40.8 with a mean value of 24.01, while the values for irrigation water varied from 0.66 to 10.4 with a mean value of 4.7. The HEI values for both drinking and irrigation are greater than one which was unfit for domestic usage. According to the classification proposed by Edet and Offiong (2002), 11 samples were categorized as 'high pollution' and the rest 4 samples were found under moderate pollution category for drinking. According to MI, the maximum value of metals in the River was 40.8 and 9.7 for drinking water and irrigation respectively. The minimum amount for drinking water was 15.4 and that of irrigation was 0.612.

Table 4: Chronic daily intake and noncancer hazard quotients for children and adults through oral and dermal routes

HMs	Concentration	CDI ingestion		CDI dermal		HQ ingestion		HQ dermal	
		Children	Adult	Child	Adult	Children	Adult	Children	Adult
Mn	**0.439**	0.029267	0.016097	0.000193	7.64E-05	**1.219**	0.609	0.201	0.0795
Zn	0.1	0.006667	0.003667	0.000264	0.000104	0.0222	0.0111	0.0044	0.00174
Cu	0.168	0.0112	0.00616	7.39E-05	2.92E-05	0.28	0.14	0.00616	0.00244
Cr	**0.393**	0.0262	0.01441	0.000173	6.84E-05	**8.73**	**4.367**	**2.306**	**0.912**
Cd	ND	0	0	0	0	0	0	0	0
Pb	**0.318**	0.0212	0.01166	0.00056	0.000221	**6.057**	**3.0286**	**1.066**	0.422
Ni	0.007	0.000467	0.000257	3.08E-06	1.22E-06	0.0233	0.0117	0.00057	0.000226
Fe	8.926	0.595067	0.327287	0.003927	0.001553	0.851	0.4251	0.02805	0.0111
Co	0.06	0.004	0.004767	2.64E-05	2.26E-05	0.133	0.1445	0.00165	0.00141
HI						**17.32**	**8.737**	**3.6**	**1.43**

The mean index for drinking and irrigation was 24.01 and 4.7 respectively. According to classifications proposed by Edet and Offiong (2002), all the sampling stations except 1, 2, 3, 7, and 15 are highly polluted for drinking.

Human health risk assessment from River water
Noncarcinogenichealth risks (HQ and HI): The CDI and HQ of the heavy metals Pb, Mn, Fe, Cu, Co, Ni and Zn for children and adults through oral and dermal routes of drinking water from Lower Omo River are presented in Table 4. The HQs through oral intake (ingestion) for both children and adults were in the order of Cr >Pb>Mn> Fe >Cu > Co > Ni > Zn. Similarly, the HQ via the dermal route follows the order Mn> Cr >. In the present study, the HQ greater than 1 was observed for Cr, Pb, and Mn both in children and adults through ingestion and dermal ingestion. As shown in Table 6, the hazard quotient (HQ) values for Cr (8.73**),**Pb (6.057) and Mn(1.219) in children via ingestion was intolerable risk seeing that HQ>1.Similarly, The HQs values in adults for Cr (4.67) and Pb (3.030 were greater also unacceptable risk. Regarding the dermal route, the HQs values for Cr (2.306**)** and Pb (1.066) in children via dermal route was intolerable risk (HQ>1).The HIs of the heavy metals for children and adults via ingestion route were 17.32 and 8.737 respectively. Likewise, the HI of the heavy metals via dermal route of exposure in children was 3.6 and the value in adult was 1.43 indicating intolerable noncarcinogenic health risk effect. Chromium and lead followed by manageress contributed more to the noncancer risks both via ingestion and dermal route of exposure in children and adults. The HIs value of the present study in children were higher than those for adults indicating that children would experience more noncancer risks and absorb more chemicals than adults (Bamuwamye*et al.*, 2015;Ugwu *et al.*, 2022)).The HQ value in children via ingestion for Cr, Pb, and Mn in the present study was greater than that in the study by Ibukunetal (2018) which was 0.48 for (Cr) , 0.33 (Pb), and 0.21 (Mn) from Dandaru River in south west Nigeria. The HQ value in children via ingestion for Cr in the present study was also greater than that in the study by Bamuwamye*et al.* (2017) from drinking Water (0.002) in Uganda for children .However, the HQ value via ingestion for Pb in children and adult of the present study was lower than that in the study by Bamuwamye*et al.* (2017) for Pb in children (46.481) and adult (19.921).Ugwu*et al.*, (2022)also reported greater HQ for Pb in children (48.89) and in adult (10.48) than the present study.

Carcinogenic health risks (CR): Cancer risks were expressed in terms of incremental lifetime cancer risk (ILCR), which is the possibility that an individual may develop cancer over a 60 year lifetime due to a 24 hour exposure to a potential carcinogen (Bamuwamye et al., 2017).In this study, cancer risk (CR) assessed for Pb, Cr, and Ni are considered to be carcinogenic for humans. The results are presented in Table 5. The CRs for both children and adults followed the order Cr > Pb. The CRs of Pb, and Cr, in children were 0.0001802 and 0.0131, respectively. Similarly, the CRs in adults were 9.011×10^{-5} and $7.0\times^{-3}$, respectively. Chromium exhibited the higher probability of cancer risks (mean CR= 1.31×10^{-2}) followed by lead (mean CR= 1.8×10^{-4}) for children. The cumulative effect of the heavy metals for carcinogenic ∑CR) both in children and adults of the present study was above acceptable values (10^{-6} to 10^{-4}) s which is intolerable cancer risks due to heavy metals in drinking water over a lifetime.

Table 5. Incremental lifetime cancer risks for the children and adult through ingestion

HMs	Concentration	CDI ingestion		CR ingestion	
		Children	Adult	Children	Adult
Pb	0.393	0.0212	0.0106	0.0001802	0.0000901
Cr	0.318	0.0262	0.0131	0.0131	0.00655
∑CR				0.01328	0.00664

Ecological risks from the River water: The potential ecological risk of the River water was estimated using Risk index factor (RI) and the Comprehensive risk index (CRI) as presented in Table 6. The Risk index factor (RI) for the heavy metals in the River water was in the order Fe > Pb > Co > Cr > Mn > Ni > Cu > Zn. The Ri for each heavy metals in the River water show that, Zn (Ri = 0.02), Cu (Ri = 0.42, and Ni (Ri = 0.5) had no potential environmental danger, Mn (RI = 1.1), Cr (Ri= 15.72) and Co (Ri = 30) have low possible environmental danger, Pb (Ri = 159) had Considerable possible environmental danger and, Fe (RI = 297.5) had sever potential environmental danger (Table 6). The major contribution to the risk factor (RI) was made by Iron and lead which could pose major pollution risk in the River water. According to the classification of environmental risk using Comprehensive risk factor (CRI) (Table 8) the lower Omo River water could be classified as very high environmental risk (CRI = 504)

Table 6: Environmental risk of the heavy metals in water using the risk index factor

HMs	OC	Ti	NOE	OC/NOE	RI	CRI
Mn	0.439	1	0.4	1.0975	1.0975	504.291
Zn	0.1	1	5	0.02	0.02	
Cu	0.168	5	2	0.084	0.42	
Cr	0.393	2	0.05	7.86	15.72	
Pb	0.318	5	0.01	31.8	159	
Ni	0.007	5	0.07	0.1	0.5	
Fe	8.926	10	0.3	29.7533	297.533	
Co	0.06	5	0.01	6	30	

*Conclusion:*The present study addressed the level of heavy metals and associated ecological and human health implications from the Lower Omo River as a first hand report. Thus, this study has provided baseline information on the pollution level of heavy metals and associated health risk from Lower Omo River. The HPI value indicates that the River water was polluted by heavy metals. The HQ value greater than 1 was examined for Cr, Pb, and Mn both in children and adults through ingestion and dermal route from the River water. According to CRI value, the River water could be classified as very high ecological risk. The mean levels of lead (Pb), manganese (Mn), and chromium (Cr) were above the acceptable limits for water set by WHO guideline values thus posing a human health concern. Therefore, regular monitoring of the River water quality with regard to heavy metal level is vital for environmental and human health concern.

REFERENCES

Abdullah, A; Ahmad, T (2016). White Popinac as Potential Phyto-coagulant to reduce Turbidity of River Water. *ARPN JEAS.11* (11):7180-7183.*http://www.arpnjournals.org/jeas/research_papers/rp_2016/jeas_0616_4408.pdf*

Adem, M, Kerem, Seid; Bereket, W (2023). Heavy Metals Accumulation in Water and Human Health Risk Assessment via the Consumption of Labeobarbusintermedius Samples from Borkena River, Ethiopia. Sci. World *J* .2023: 1-10.https://doi.org/10.1155/2023/4210574

Ahmad, B; Hamed, S; Samaneh, S; Iman, P; Amin, M; Omid, A; Parviz, J; Hossein, F; Kamal, BN (2023). Comprehensive health risk analysis of heavy metal pollution using water quality indices and Monte Carlo simulation in R software.*Sci. Rep.*13:15817.

Akaninyene, J; Uwem, E; Eno, I; Sarah, E (2022).Health implications of the oral and dermal exposure to heavy metals in borehole water from a poorly remediated Ikot Ada Udo community, AkwaIbom State, South–South Nigeria.*Sci Africa*. *18* (e01416): 1-9.

Alma, S; Majlinda, V; Sonila, D; Loreta, V; Nevila, B; Sadik, C (2022). Assessment of health risk induced by heavy metal contents in drinking water. *J. Water Sanit. Hyg. Dev.12 (11): 816-827*

Andreea, MD (2018). Water Pollution and Water Quality Assessment of Major Transboundary Rivers from Banat (Romania).*J. Chem.2018: 1-8.* https://doi.org/10.1155/2018/9073763

APHA (American Public Health Association) (2017).American Public Health Association,American Water Works Association, Water Environment Federation. Standard Methods of the Examination of Water and Wastewater, 23 rd edition.

Asrafuzzaman, Md**;** Fakhruddin**,** AN; Alamgir, H (2011).Reduction of Turbidity of Water Using Locally Available Natural Coagulants.*ISRNJ*. 2011:1-6. doi:10.5402/2011/632189.

Avery, ST (2012). African Studies Centre, Oxford University. Lake Turkana & the Lower Omo: Hydrological Impacts of Gibe III & Lower Omo Irrigation Development.*Oxon*..https://www.ajol.info/index.php/jasemhttp://ww.bioline.org.br/ja.

Azlini, R; Sharifah, NS; Suriyani, A; Sarva, MP; Emilia, ZA (2018). Heavy Metals Contamination and Potential Health Risk in Highland River Watershed (Malaysia).*MJMHS.14*(SP2):45-55.

Bamuwamye, M; Ogwok, P; Tumuhairwe, V (2015).Cancer and noncancer risks associated with heavy metals exposure from street foods: evaluation of roasted meets in an urban setting. *J. Environ. Pollut. Human Health.*3(2):24–30. doi: 10.12691/jephh-3-2-1

Bamuwuwamye, M; Ogwok, P; Tumuhairwe, V; Eragu, R; Nakisozi, H; Ogwang, PE (2017). Human health risk assessment of heavy metals in Kampala (Uganda) drinking water. *J. Food Res.* 6(4):6–16

Collins, KT; Michael, D; Louis, KD (2019). Human Exposure Risks Assessment of Heavy Metals in Groundwater within the Amansie and Adansi Districts in Ghana using Pollution Evaluation Indices. *West Afr. J. Appl. Ecol.* 27(1): 23 – 41

Dugasa, G; Endale, T (2018).Determination of Heavy Metals Concentration in Water, OreochromisNiloticus and LabeobarbusIntermedius Samples from Abaya and ChamoLakes. *J BiolAgricHealthc.8(19):85-95*.www.iiste.org

Edet, AE; Offiong, OE (2002).Evaluation of water quality pollution indices for heavy metal contamination monitoring.A study case from Akpabuyo-Odukpani Area, Lower Cross River Basin (Southeastern Nigeria).*Geo Journal*.5: 295–304. https://doi.org/10.1023/B:GEJO. 0000007250.92458

Emily N. Munene,Nadir O. Hashim, and Willis N (2023).Ambusso.Human health risk assessment of heavy metal concentration in surface water of Sosianriver, Eldoret town, Uasin-Gishu County Kenya. *MethodsX.11* (102298):1-7
.

FAO (1985).Food and Agriculture Organization of the United Nations Rome.water qualityfor agriculture.

Gabriela, M (2019). Evaluation of Health Risks Due to Heavy Metals in a Rural Population Exposed to Atoyac River Pollution in Puebla, Mexico. *Water*. *11*(2): 277.

Goher, M. E. et al. Evaluation of surface water quality and heavy metal indices of Ismailia Canal, Nile River, Egypt. *Egypt. J. Aquat. Res*. 40(3: 225–233 (2014)

Govind,M; Naresh, K; Sayan, S; Arthur, LF; Mradul, KD; Mongjam, MS, Tushar, KJ; IS (2022). Human Health Risk Assessment due to Heavy Metals in Ground and Surface Water and Association of Diseases with Drinking Water Sources: A Study From Maharashtra, India.*EHI*.16:1-11.

Gure, A; Kedir, K; Abduro, F (2019). Heavy Metal Concentrations in Fish Tissues from Gilgel Gibe (I) Hydroelectric Dam Reservoir, Ethiopia. *J. Appl. Sci. Environ. Manage.* 23 (8): 1411-1416.DOI: https://dx. doi.org./10.4314/jasem.v23i8.1.

Hakanson, L (1980). An ecological risk index for aquatic pollution control.A sedimentological approach. *Water Res.* 14: 975–1001.

Ibukun, MA, Mary, BJ, Omolara, TA,Anthony, O; Aderemi OO (2018).Concentrations and Human Health Risk of Heavy Metals in Rivers in Southwest Nigeria.*J Health Pollut. 8*(19), 180907.

Jafarabadi, AR; Bakhtiyari, AR; Toos, AS; Jadot, C (2017). Spatial distribution, ecological and health risk assessment of heavy metals in marine surface sediments and coastal seawaters of fringing coral reefs of the Persian Gulf, Iran. *Chemosphere.* 185: 1090–1111.

Josephine, N; George, M; Biram, EB; Yvette, CMW; Carine, T; Amina, A; Opportune, LAD; Armel, ZEB (2021). Evaluation of Surface Water Contamination Using Heavy Metal Pollution Indices in the Mgoua Watershed, Southwestern Cameroon.*Int.J.Curr.Microbiol.Appl. Sci*. 10(11): 142-156

Kang, T; Qiumei, W; Peng, L; Wenyou, H; Biao, H; Bin, S; Yunqiao, Z; Bong-Oh, K; Kyungsik, C, Jongseong, R, Jong, SK,Tieyu, Wangc (2020). Ecological risk assessment of heavy metals in sediments and water from thecoastal areas of the Bohai Sea and the Yellow Sea. *Environ. Inter. 136*:105512.

Mansour,G; Bahram, k; Ali J; Afshin, G; Mohammadamin, K (2018). Heavymetalsanalysisandqualityassessment in drinking water – Khorramabad City,Iran. *Data in Brief.16:* 685–692.

Mariusz, K; Joanna, J (2023).Variability and Heavy Metal Pollution Levels in Water and Bottom Sediments of the Liwiec and Muchawka Rivers (Poland). *Water*: *15*(15), 2833

Mehjbeen, J; Nazura, U (2017).An Overview of the Adverse Effects of Heavy Metal Contamination on

Fish Health.*Proc. Natl. Acad. Sci., India, Sect. B Biol. Sci.* DOI 10.1007/s40011-017-0875-7

Mekonnen, MT; Amsalu ZT (2018). Causes and impacts of Shankila River water pollution in Addis Ababa, Ethiopia. *Environ Risk Assess Remediat.*2(4):21-30.

Mohan, SV., Nithila, P., Reddy, SJ (1996).Estimation of heavy metals in drinking water and development of heavy metal pollution index. *J. Environ. Sci. Health Part A*.31:283–289. doi: 10.1080/10934529609376357

Ojwang, W; Ojuok, JE; Omondi, R; Malala, J; Abila, R; Ikmat, P (2010). Impact of river impoundments. The case of hydropower projects on Omo River of Lake Turkana, Samaki News, Department of Fisheries, Kenya.

Pramita, G; Priyajit, B; Pradip, M; Nimai, CS (2021). Effect of Heavy Metals on Fishes: Toxicity and Bioaccumulation. *J. Clin. Toxicol.*11(1):1-10.

Qiang, L, Yan, C; Chunnan, F (2021). Pollution Characteristics and Health Exposure Risks of Heavy Metals in River Water Affected by Human Activities.*Sustain.15*(10): 8389.

Rofhiwa, TM; Joshua, NE, Elijah TV; Olatunde, SD; John, OO (2021).Water Quality Assessment and Evaluation of Human Health Risk in Mutangwi River, Limpopo Province, South Africa.*IJERPH*. *18*(13): 6765.

Samuel, B; sorsa, S; Daniel, F; Riise, G; Zinabu, GM (2020). Heavy Metals in Fish Muscle from an Ethiopian .Rift-Valley Lake (Hawassa) and a Neighboring Stream (Boicha): Assessment of Human Health Risks.*J. Appl. Sci. Environ. Manage*.24 (8): 1409-1418.https://www.ajol.info/index.php/jasem

Teng, Y, Wu J, Lu S, Wang Y, Jiao X, Song L (2014) Soil and soil environmental quality monitoring in China: a review. *Environ. Int.* 69:177–199

Ugwu, CE;Maduka,IC; Suru, SM; Anakwuo, IA (2022). Human health risk assessment of heavy metals in drinking water sources in three senatorial districts of Anambra State, Nigeria.*Toxicol Rep.9*: 869-875.

UNEP (2010).Africa Water Atlas.Division of Early Warning and Assessment (DEWA). United Nations Environment Programme (UNEP). Nairobi, Kenya

USEPA (2004).*Risk assessment guidance for superfund Volume I: human health evaluation manual (Part E, Supplemental Guidance for Dermal Risk Assessment)* Washington DC, USA.

USEPA (2005). Human Health Risk Assessment GE/Housatonic River Site, Rest of River.VolumeIV, Appendix C, Consumption Fish and Waterfowl Risk Assessment.pg 4-42. USEPA Region I, Boston. http:/lwww.epa. gov/region01/ge/thesite/restofriver/reports/hhra 219190/219190 HH R A Vol4 FW.pdf

USEPA (United States Environmental Protection Agency) Region III (1995).Risk Assessment: Technical Guidance Manual Assessing Dermal Contact. http://www.epa.gov/reg3hwmd/risk/solabsg2.htm

USEPA (2011). RegionalScreeningLevel (RSL)summarytable:https://www.epa.gov/risk/regional-screening-levels-rsls-generic-tables-Accessed

USEPA. United State Environmental Protection Agency (EPA) (1989).*Risk assessment guidance for superfund Volume I: human health evaluation manual (Part A)* Washington DC, USA

Wakjira, M and Getahun, A (2017). Ichthyofaunal diversity of the Omo-Turkana basin, East Africa, with specific reference to fish diversity within the limits of Ethiopian waters.*J.Biodiv. Data.*13(2): 1-22. Doi: https://doi.org/10.15560/13.2.2059

WHO (2012). WHO Country Cooperation Strategy: Ethiopia. Regional Office for Africa.

WHO (2015).World Health Statistics. 1211 Geneva 27, Switzerland.

Yasem Leventeli and FusunYalcin (2021).Information analysis of heavy metal content in river water: multivariate statistical analysis and inequality expressions (2021). *J. Inequalities and Applica. Toxicol Rep.9*: 869-875.