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

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ABSTRACT: The Omo River passes through Olorate 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 0.439 mg/L for (Mn), 0.1 (Zn), 0.168 (Cu), 0.393 (Cr), 0.318 (Pb), 0.007 (Ni), 8.926 (Fe), and 0.06 (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 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.

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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.
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 biomagnifications in 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 not been yet reported, it is a major source of water for domestic use, agriculture (irrigation), and livestock. 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.
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, high-density; pre sterilized polypropylene bottles, each with 2 litter capacities. The water samples were acidified with 5% HNO₃ 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% HNO₃ (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) 305, 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 quality were comprehensively evaluated using HPI (Taygi et al., 2013) and is calculated according to the following equation [1] (Mohan et al., 1996; Ahmed et al., 2023)

\[
\text{HPI} = \frac{\sum^n_{i=1} W_i Q_i}{\sum^n_{i=1} W_i} (1)
\]

\[W_i = \frac{K}{S_i} (2)
\]

\[K = \frac{1}{\Sigma (V_{standard})} (3)
\]

\[Q_i = \frac{M_i - I_i}{(S_i - I_i)} \times 100 (4)
\]

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; Elsiddiget al., 2020; Talae 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) (Jafarbadi et al., 2017; Goher et al., 2020; Ahmad et al., 2023).

\[\text{MI} = \frac{n}{\sum_{i=1}^{n} CI} (5)
\]
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 domestic use (Edet and Offiong, 2002; Alma et al., 2022). According to Caerio et al. (2005), it was also classified as presented in Table 1 (Caerio et al., 2005).

### Table 1. Water Quality Classification using MI

<table>
<thead>
<tr>
<th>MI</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0.3</td>
<td>Very pure</td>
</tr>
<tr>
<td>0.3-1</td>
<td>Pure</td>
</tr>
<tr>
<td>1-2.2</td>
<td>Slightly affected</td>
</tr>
<tr>
<td>2-4</td>
<td>Moderately affected</td>
</tr>
<tr>
<td>4-6</td>
<td>Strongly affected</td>
</tr>
<tr>
<td>6</td>
<td>Seriously affected</td>
</tr>
</tbody>
</table>

**Exposure assessment:** The health risks for the heavy metals from water through oral ingestion and dermal absorption were estimated according to the 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 contaminant, was used (USEPA, 2005; Bamuwamye 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):

\[
\text{CDI ingestion} = \frac{(C \times IR \times EF \times ED)}{(BW \times AT)} \quad (7)
\]

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

Where: CDI is the chronic daily intake (mg/kg/day); C is the 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 an adult) (Bamuwamye 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) (USEPA, 2005); BW is average body weight (15 kg for a child and 60 kg for adults) (WHO, 2012) over the exposure period; AT is the average time representing the period over which exposure is averaged [(for carcinogens, AT=65x365=23725 days for both children and adults; for non-carcinogens, AT=EDx365 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 cm² for adults; 6000 cm² for children) (USEPA, 2004); KP is dermal permeability coefficient of heavy metal in water (cm²/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 (0.001 L/cm³) (USEPA, 2004; Bamuwamye et al., 2017; Govind et al., 2022).

**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.

\[
\text{HQ ingestion} = \frac{CDI_{ingestion}}{RfD_{ingestion}} \quad (9)
\]

\[
\text{HQ dermal} = \frac{CDI_{dermal}}{RfD_{dermal}} \quad (10)
\]

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

Where HQ 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_{oral}) 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, Mn, Fe, and Cr are 0.00525, 0.0054, 0.012, 0.06, 0.016, 0.00055, 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 cancer risk; a value > 1 indicates significant cancer risk, which increases with increasing HQ or HI (Govind et al., 2022; Ugwu et al., 2022).

**Carcinogenic risk assessment (CR):** Cancer risk was calculated as the quotient of the CDI (mg/kg/day) and cancer slope factor (CSF) measured in mg/kg/day. 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:

\[
\text{CR}_{ ingestion} = \frac{CDI_{ ingestion} \times CSF_{ ingestion}}{} \quad (11)
\]

\[
\text{CR}_{ dermal} = \frac{CDI_{ dermal} \times CSF_{ dermal}}{} \quad (12)
\]

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 (ΣCR). The United States Environmental Protection Agency (USEPA, 2004) classified exposure as presented in Table 1 (Caerio et al., 2005).
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 \times 10^{-6} to 1 \times 10^{-4} represents an acceptable risk to human health (USEPA, 1989).

### 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 ≤ RI < 40), Modest possible environmental danger (40 ≤ RI < 80), Considerable possible environmental danger (80 ≤ RI < 160), Severe possible environmental danger (160 ≤ RI < 320), Very severe potential environmental danger (RI ≥ 320) and for CRI; Low (CRI < 60), Moderate (60 ≤ CRI < 120), high (120 ≤ CRI < 240), Very high (CRI ≥ 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). Cadmium was 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 (12.85 mg/L) with min level (8.926 mg/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 in the study by Gabriela et al. (2019) from Atoyac River (0.209 mg/L) in Mexico and Rolhiwa et al. (2021) from Mutangwi River (0.24 mg/L) in South Africa. The Fe levels in the River water was above the WHO (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 0.439 mg/L. The Mn level of the water in the present study was larger than that in the 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 by Tengku et al. (2020) from Malaysia (0.497 mg/L) and Yasemin and Fusun (2021) from Akcay River of Turkey (6.48 mg/L). The mean concentration of Mn in the present study was above the WHO (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 Azlin et al. (2018) from Highland River (0.033 mg/L) in Malaysia. However, the Zn level of the River water in this study was lower than that in earlier study by Filipose et al. (2021) from Megech River (0.13 mg/L) in Ethiopia and Mariusz and Joanna (2023) from Muchawaka River (176 mg/L) in Poland. Its mean concentration in the present study was below the WHO (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 the mean level of 0.168 mg kg^{-1}. The mean Cu level in this study was greater than that in earlier study by Qi et al., (2021) from Buerhatong River (0.01344 mg/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 water in the present study was lower than that in previous studies by Emily et al., (2023) from Sosian River (0.291 mg/L) in Kenya. Its mean concentration in the present study was below the WHO (2012)
permissible limits for drinking and the FAO (1985) for livestock. The chromium level of the water ranged from 0.34 to 0.46 mg/L with the mean level of 0.393 mg/L. The concentration of Cr in this study was greater than that in previous studies by (Ibukun et al., 2018) from Southwest Nigeria (0.059 mg/L), (Qiang et al., 2021) from Buerhatong River (0.00456 mg/L) in China and (Tengku et al., 2020) from Tropical River (0.0055 mg/L) in Malaysia. However, the Cr level in the present study was lower than that in the study by (Yasemin and Fusun, 2021) from Ackay River (8.296 mg/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 with the mean level of 0.318 mg/L. The mean concentration of Pb in the present study was greater than that in 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) 0.0021 mg/L from Albania and (Flimos 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 9.3 mg/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 to 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

<table>
<thead>
<tr>
<th>Heavy Metals</th>
<th>N</th>
<th>Concentration</th>
<th>Anova</th>
<th>Drinking Water</th>
<th>Livestock</th>
<th>Irrigation Water</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>St. dev</td>
<td>F</td>
<td>P</td>
<td>WHO, 2017</td>
</tr>
<tr>
<td>Mn</td>
<td>45</td>
<td>0.439</td>
<td>0.034</td>
<td>7.90</td>
<td>0.00</td>
<td>0.4</td>
</tr>
<tr>
<td>Zn</td>
<td>45</td>
<td>0.1</td>
<td>0.046</td>
<td>15.04</td>
<td>0.00</td>
<td>-</td>
</tr>
<tr>
<td>Cu</td>
<td>45</td>
<td>0.168</td>
<td>0.074</td>
<td>355</td>
<td>0.00</td>
<td>2</td>
</tr>
<tr>
<td>Cr</td>
<td>45</td>
<td>0.393</td>
<td>0.032</td>
<td>74.6</td>
<td>0.00</td>
<td>0.05</td>
</tr>
<tr>
<td>Cd</td>
<td>45</td>
<td>ND</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.003</td>
</tr>
<tr>
<td>Pb</td>
<td>45</td>
<td>0.318</td>
<td>0.032</td>
<td>8.13</td>
<td>0.00</td>
<td>0.01</td>
</tr>
<tr>
<td>Ni</td>
<td>45</td>
<td>0.007</td>
<td>0.005</td>
<td>62.1</td>
<td>0.00</td>
<td>0.07</td>
</tr>
<tr>
<td>Fe</td>
<td>45</td>
<td>8.926</td>
<td>2.287</td>
<td>36.0</td>
<td>0.00</td>
<td>0.3</td>
</tr>
<tr>
<td>Co</td>
<td>45</td>
<td>0.06</td>
<td>0.014</td>
<td>50.4</td>
<td>0.00</td>
<td>0.01</td>
</tr>
</tbody>
</table>

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.
The mean value of the present study (720) is lower than those reported by Josephine et al. (2021) in the Mgoa river (1900.64) 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.
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**

Noncarcinogenic health 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 > Pb. In the present study, the HI 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 HI of heavy metals via dermal 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 1.4 indicating intolerable noncarcinogenic health risk effect. Chromium and lead followed by managerness contributed more to the cancer risks both via ingestion and dermal route of exposure in children and adults. The HI 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 (Bamuwameyet 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 Ibukun et al. (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 Bamuwameyet 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 Bamuwameyet 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 (Bamuwamey 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, Cr, and Ni in children were 0.001802 and 0.0131, respectively. Similarly, the CRs in adults were 9.011×10⁻³ and 7.0×³, 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 (10⁻⁴ to 10⁻²) which is intolerable cancer risks due to heavy metals in drinking water over a lifetime.

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

<table>
<thead>
<tr>
<th>HMs</th>
<th>Concentration</th>
<th>CDI ingestion</th>
<th>CDI dermal</th>
<th>HQ ingestion</th>
<th>HQ dermal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mn</td>
<td>0.439</td>
<td>0.029267</td>
<td>0.01697</td>
<td>7.64E-05</td>
<td>1.219</td>
</tr>
<tr>
<td>Zn</td>
<td>0.1</td>
<td>0.006667</td>
<td>0.00368</td>
<td>0.001000</td>
<td>0.0222</td>
</tr>
<tr>
<td>Cu</td>
<td>0.168</td>
<td>0.0112</td>
<td>0.00616</td>
<td>7.39E-05</td>
<td>2.92E-05</td>
</tr>
<tr>
<td>Cr</td>
<td>0.393</td>
<td>0.0262</td>
<td>0.01441</td>
<td>6.84E-05</td>
<td>8.73</td>
</tr>
<tr>
<td>Cd</td>
<td>ND</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Pb</td>
<td>0.318</td>
<td>0.0212</td>
<td>0.01166</td>
<td>0.0056</td>
<td>6.057</td>
</tr>
<tr>
<td>Ni</td>
<td>0.007</td>
<td>0.000467</td>
<td>0.00257</td>
<td>3.08E-06</td>
<td>1.22E-06</td>
</tr>
<tr>
<td>Fe</td>
<td>8.926</td>
<td>0.595967</td>
<td>0.327287</td>
<td>0.003927</td>
<td>0.001553</td>
</tr>
<tr>
<td>Co</td>
<td>0.06</td>
<td>0.004</td>
<td>0.004767</td>
<td>2.64E-05</td>
<td>0.133</td>
</tr>
<tr>
<td>HI</td>
<td></td>
<td>17.32</td>
<td>8.737</td>
<td>3.6</td>
<td>1.43</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>HMs</th>
<th>Concentration</th>
<th>CDI ingestion</th>
<th>CR ingestion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pb</td>
<td>0.393</td>
<td>0.0212</td>
<td>0.0001802</td>
</tr>
<tr>
<td>Cr</td>
<td>0.318</td>
<td>0.0262</td>
<td>0.0000901</td>
</tr>
<tr>
<td>∑CR</td>
<td></td>
<td>0.01328</td>
<td>0.00864</td>
</tr>
</tbody>
</table>

ABIY, A. K.; GIRMA, T. Y.; SOLOMON, S. S; YOHANNES, S. B
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 severe 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).

<p>| Table 6: Environmental risk of the heavy metals in water using the risk index factor |
|---------------------------------|-------|-------|-------|-------|-------|-------|</p>
<table>
<thead>
<tr>
<th>HMs</th>
<th>OC</th>
<th>Ti</th>
<th>NOE</th>
<th>OC/NOE</th>
<th>RI</th>
<th>CRI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mn</td>
<td>0.439</td>
<td>1</td>
<td>0.4</td>
<td>1.0975</td>
<td>1.0975</td>
<td>504.291</td>
</tr>
<tr>
<td>Zn</td>
<td>0.1</td>
<td>1</td>
<td>5</td>
<td>0.02</td>
<td>0.02</td>
<td>0.5</td>
</tr>
<tr>
<td>Cu</td>
<td>0.168</td>
<td>5</td>
<td>2</td>
<td>0.084</td>
<td>0.42</td>
<td>15.72</td>
</tr>
<tr>
<td>Cr</td>
<td>0.393</td>
<td>2</td>
<td>0.05</td>
<td>7.86</td>
<td>15.72</td>
<td></td>
</tr>
<tr>
<td>Pb</td>
<td>0.318</td>
<td>5</td>
<td>0.01</td>
<td>31.8</td>
<td>159</td>
<td></td>
</tr>
<tr>
<td>Ni</td>
<td>0.007</td>
<td>5</td>
<td>0.07</td>
<td>0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fe</td>
<td>8.926</td>
<td>10</td>
<td>0.3</td>
<td>29.7533</td>
<td>297.533</td>
<td></td>
</tr>
<tr>
<td>Co</td>
<td>0.06</td>
<td>5</td>
<td>0.01</td>
<td>6</td>
<td>30</td>
<td></td>
</tr>
</tbody>
</table>

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.

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