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Exploring the Impact of Climate Change on Metals in Water: A Case Study of Artisanal Gold Mines in Kenya's Lake Victoria Basin

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Abstract

The emissions from fossil fuels, power plants, vehicles, and mining activities have contributed to increased atmospheric carbon levels associated with climate change threat. Carbon enrichment in aquatic habitats impacts pH, salinity, and the mobility of toxic metals like Cu, Cd, Zn, and As. Climate change poses significant challenges for hydrologists, as water resource management systems historically focused on climatic stability. Maintaining the quality of river water, which constitutes a major source of drinking water, is vital for environmental health as well as for the well-being of humans and animals. Consequently, a study was undertaken to examine the presence of potentially harmful metals in water prior to and following the El Nino event of 2020. A total of forty-eight samples of drinking water were collected in triplicate using Van Dorn water bottles from twenty randomly selected sites. The sampling sites, all located in Migori County, included River Kucha and River Migori, both of which discharge into Lake Victoria and pass through the Migori artisanal mining sites. The samples were processed, packed, and sent to Bureau Veritas, Vancouver, Canada, for heavy metal analysis using inductively coupled plasma-mass spectrometry (ICP-MS). The analysed heavy metals included mercury (Hg), chromium (Cr), copper (Cu), cadmium (Cd), zinc (Zn), lead (Pb), and arsenic (As). Water mercury levels were found to be elevated both before October, 2016 and after El Nino in October, 2021. The study indicated that mean metal concentrations in water samples decreased in the following order: Zn >Pb >Cu >Cr >As >Cd >Hg. The analysed metals exhibited concentrations higher than the permissible limits by WHO for drinking water. The results of the ecological risk assessment indicated that there is an urgent need to prioritize the control and management of heavy metal contamination and

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the associated risks in the studied rivers and water sources. Additionally, it is crucial to maintain ongoing monitoring of potentially harmful metal levels in order to mitigate the unnecessary risks associated with their toxic effects. Importantly, the analysis revealed that the levels of heavy metals, in general, were elevated after the El Nino event compared to the period prior to it.

Keywords: Ecological risk estimation, EL Nino, heavy metals, ICP-MS, water pollution

Introduction

The presence of potentially harmful metals in the environment is a matter of global concern. When the concentration of metals exceeds acceptable levels, they are regarded as pollutants and pose significant risks to the environment (Kim et al., 2019; Zhang et al., 2020). Heavy metal pollution is attributed to various human activities, and multiple studies have demonstrated the significant contribution of industrial operations in intensifying metal concentrations. Consequently, this amplification of metal levels due to mining activities leads to severe environmental issues (Sharma et al., 2020). Heavy metals can easily aggregate in the water and sediment and may create lethal effects on aquatic organisms as well as on human expanded by food chains (Chen & Luo, 2019; Khan et al., 2019).

Climate change can have a significant impact on heavy metal concentration in drinking water in gold mining regions, such as Migori County in Kenya. Climate change-induced changes in rainfall patterns and temperatures can affect the concentration, speciation, mobilization and transport of heavy metals in water bodies, leading to increased levels of heavy metal contamination in the environment (Jarsjö et al., 2020), and thereafter in humans through the food chain. The possible increased threats of flooding caused by climate change has ramifications for the inundation of polluted land, increasing the likelihood of pollutants being remobilized in flood water and contaminated sediment and water reaching the freshwater and marine environment.

According to a study conducted by Crawford et al. (2022), the occurrence of intense flood events brings about significant threats to human and environmental well-being due to the re-release of pollutants. One study conducted in Migori County found that climate change has contributed to increased heavy metal contamination in water resources in the area, with mining activities exacerbating the problem (Odhiambo et al., 2020). The study found high

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levels of heavy metals such as lead, cadmium, and mercury in water samples taken from the area, which pose a significant risk to human health and the environment.

Another study conducted in neighbouring Tanzania also found that climate change has contributed to increased heavy metal contamination in water resources in gold mining regions in the country (Mwakalobo et al., 2018). The study found that changes in rainfall patterns and temperatures have led to increased erosion and transport of heavy metals from mining sites to nearby water bodies, leading to elevated levels of heavy metal contamination in drinking water sources. Furthermore, a study conducted in Ghana found that climate change can affect the quality of groundwater resources in gold mining regions, with increased temperatures and reduced rainfall leading to increased levels of heavy metal contamination in groundwater (Asumadu-Sarkodie et al., 2018).

Migori County in Kenya is a region rich in gold deposits, and the mining activities in this region have been associated with the release of heavy metals into the environment. This has led to concerns about the potential impact of heavy metal contamination on human health and the environment. In recent years, there have been indications that the region is experiencing changes in climate, including increases in temperature and changes in precipitation patterns (MoALFC, 2021). This has led to concerns about the potential impact of climate change on heavy metal concentration in water in the region. Therefore, this study aimed to evaluate the metal concentrations (Hg, Cd, Cr, Cu, Zn, As and Pb) in water in Migori gold mines in the Lake Victoria basin, Kenya and to assess the intensity of contamination.

Materials and Methods

Study Area

This study focused on the gold mines situated in Migori County, which is located in the southwestern part of Kenya's Lake Victoria basin. The study area, approximately 309 km away from Kenya’s capital city Nairobi, possesses geographical coordinates of latitude -1.070698 and longitude 34.475272 (Table 1) Migori, Kenya, is positioned approximately 262.1 kilometres west of Nairobi. The region experiences an average annual temperature of 25.0°C, along with an annual precipitation of approximately 1521 mm. The study location is characterized by artisanal gold mining activities and subsistence agricultural practices. The sampling took place in the years; 2016, 2017, 2019, 2020 and 2021.

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Figure 1 depicts the map showcasing the position of Migori County within Kenya, as well as the sampling sites. The study employed a systematic approach to ensure the uniformity of sampling points throughout a five-year period. Utilizing GPS technology, precise coordinates for each sampling site were determined, establishing it as the primary method for accurate location. Furthermore, a centralized digital database was established to meticulously store essential information about each site, including GPS coordinates, unique identifiers, details regarding physical markers, and other relevant data. This methodological framework not only facilitated consistent sampling across the study duration but also provided a reliable foundation for data management and analysis.

Table 1: Global Positioning System (GPS) of Sampling Points in the Study Area, Migori, Kenya

Sampling Points	Longitudes	Latitudes
	34.2268	-1.0115
	34.2271	-1.0137
	34.2382	-1.0147
	34.2584	-1.0123
	34.2739	-1.0218
	34.2882	-1.0290
	34.2889	-1.0301
	34.3215	-1.0314
	34.3453	-1.0468
	34.3003	-1.0069
	34.2901	-0.9882
	34.2928	-0.9889
	34.2904	-0.9887
	34.2780	-0.9813
	34.2791	-0.9820
	34.2669	-0.9806
	34.2605	-0.9823
	34.2559	-0.9903
	34.2421	-0.9934
	34.2728	-1.0086

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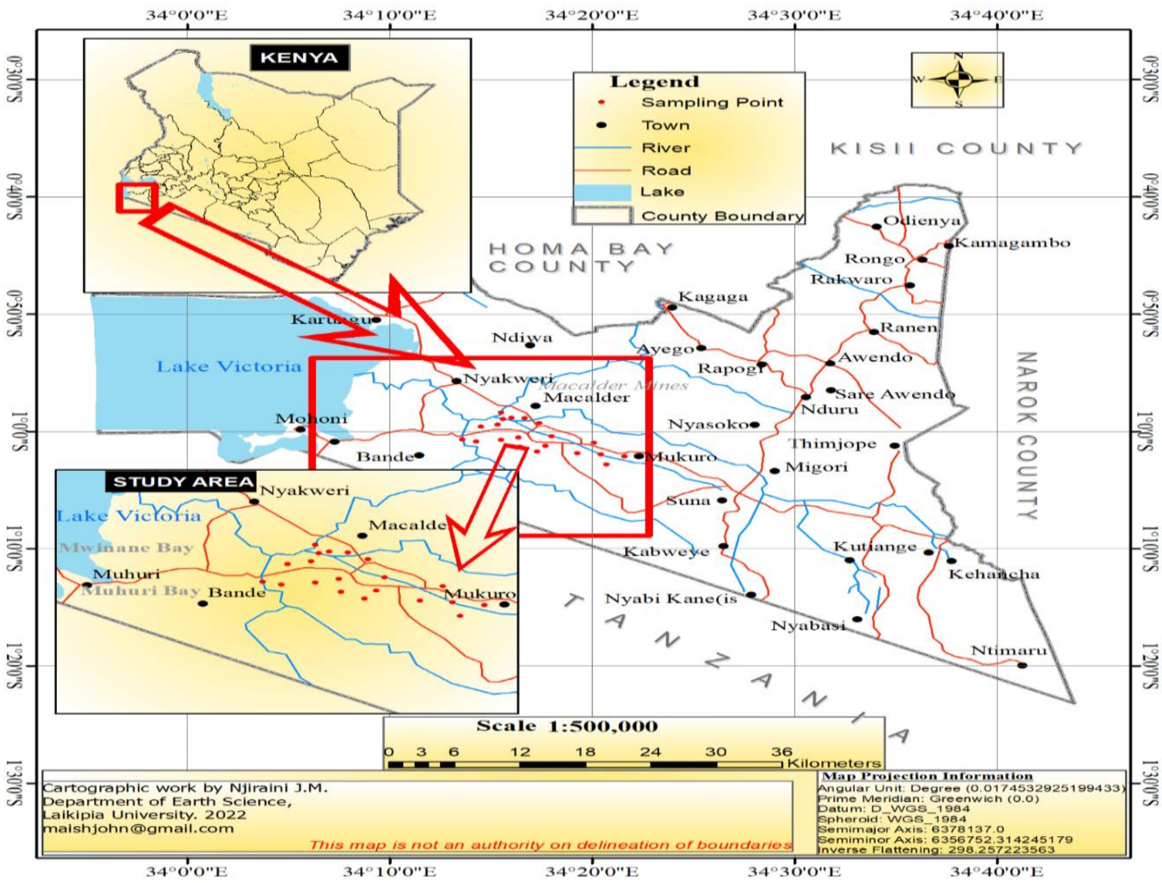

Fig. 1: Map of Kenya Depicting the Geographical Location of Migori County and the Sampling Sites

Sample Collection and Analysis

Field observations were conducted to document changes in the climate (Rainfall, pH, salinity, and temperature) and identify potential changes in heavy metal concentration in water. Water samples were collected from different sampling sites in the artisanal mining sites in Migori County in October of each year (2016, 2017, 2019, 2020 and 2021), to analyse them for heavy metal concentration variation. Use of statistical tools such as ANOVA was employed to analyse the data obtained from water samples and identify any significant changes in heavy metal concentration that can be linked to climate change events such as rainfall, pH, salinity, and temperature. Laboratory analysis was done on water samples to determine the composition or species of the heavy metals.

A total of 48 water samples were collected from 20 sites in 2016, 2017, 2019, 2020 (El-Nino) and 2021. About 100 ml of water samples were collected in triplicates using a Van

Dorn water sampler at a depth of 20cm. To preserve the samples, 2 ml of 100 percent concentrated HNO_3 was added to each sample, acidifying them. The acidified samples were then stored in the laboratory at 4°C. The metal concentrations in the water samples were determined using inductively coupled plasma-mass spectrometry (ICP-MS)- ICPMS-2030 series at Bureau Veritas Laboratory in Canada.

Statistical Analysis

Statistical tools were used to analyse the data collected from laboratory analysis and identify any significant changes in the concentration of the heavy metals that can be linked to climate change events. Additionally, a historical analysis of heavy metal concentration in water in the study area over a five years' period of time was assessed to provide insights into how heavy metal concentration has changed over time. Descriptive analysis was conducted using SPSS 23 software. Furthermore, a one-way ANOVA was performed to examine the significant differences among the metal concentrations in water samples for the selected seasons, with a significance level set at $p < 0.05$. The normality test for the elements was conducted using the Kolmogorov-Smirnov and Shapiro-Wilk tests (Razali & Wah, 2011), while the homogeneity of data was evaluated using Levene tests (Pardo-Fernández, et al., 2020). In cases where the data variables did not exhibit normality or homogeneity, the Kruskal-Wallis test was utilized (Huang & Pei, 2020).

Degree of Contamination (Cd) with Metals in Drinking Water

The degree of contamination (Cd) of heavy metals in the environment is a critical concern due to their potential harmful effects. Numerous studies have investigated the levels of heavy metal contamination in various environmental compartments, such as water, soil, and biota. For instance, a study by Li et al. (2021) assessed the contamination of heavy metals in urban soils and found elevated concentrations of lead (Pb), cadmium (Cd), and other metals exceeding the recommended limits. Similarly, research conducted by Wang et al. (2020) focused on the contamination of heavy metals in aquatic ecosystems, revealing significant accumulations of mercury (Hg), arsenic (As), and other metals in water bodies, indicating a potential risk to aquatic organisms and human health. These findings underscore the importance of monitoring and mitigating heavy metal contamination to safeguard environmental and human well-being.

In this study, degree of contamination (Cd) of studied metals was calculated using the following equation: (i) (Sharifi et al., 2016).

$$Cd = \frac{C_i sample}{Cref} \qquad (i)$$

Where,

C_i is the heavy metal concentration in water samples; C_{ref} is the reference value of the element (WHO, 2017a).

Estimated Daily Intake (EDI) of Metals through Drinking Water

The estimated daily intake of metals in drinking water is a critical factor in assessing health risks. It helps determine if metal levels are within acceptable limits and guides the development of guidelines for safe water quality. Monitoring and managing this intake allow authorities to mitigate risks and protect public health. Overall, it provides a quantitative assessment for decision-making in water quality management.

To calculate the estimated daily intake, factors such as the concentration of metals in drinking water, daily water consumption rates, and body weight were considered. The estimated intake was compared to established regulatory limits or reference doses to evaluate the potential health risks associated with metal exposure. The risk assessment of specific elements aims to evaluate their exposure and potential for accumulation in the human body as described in ATSDR (2019).

In the context of water samples collected, two distinct pathways were considered for element exposure; ingestion, which occurs through the intake of water (Rodríguez-Seijo et al., 2021); and dermal contact, which happens through skin contact (Kwon & Yang, 2020). To assess the potential health hazards associated with these exposure pathways, the US Environmental Agency has established specific formulas. Equations (ii) and (iii) in the ATSDR (2019) report represent the calculation methods utilized for determining the human health hazard related to ingestion and dermal contact absorption, respectively.

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$$\text{EDI (ingestion)} = \frac{CM \times EF \times ED \times IR}{BWt \times AT} \quad \text{(ii)}$$

$$\text{EDI (dermal)} = \frac{CM \times SA \times KC \times EF \times ED \times ET \times ABS}{BWt \times AT \times 10^6} \quad \text{(iii)}$$

where,

CM denotes metal concentration (mg/kg); EF represents exposure frequency: 365 days per year; and ED indicates exposure duration: 70 (adult) and 6 (child). The ingestion rate (IR) is 30 L/d, and the body weight is 70 for adults and 15 for children. AT is the element's average time: 365 x ED d for non-carcinogenic elements and 365 x 70 for carcinogenic elements. SA is the skin surface area for interaction with the environment: 5700 cm^2/d (adult) and 2800 $cm^{2/}d$ (child); The permeability factor for dermal contact is KC: 0.001cm/hour; the exposure duration/time is ET which is 24 g/d; the proportion of dermal absorption presented as ABS is 0.03 (for As) and 0.001 (for the other metals studied) while the conversion factor is 10^6 (USEPA, 2011, ATSDR, 2019).

Results and Discussion

Mean Concentrations of Heavy Metals in Drinking Water Samples

The ICP-MS technique was employed to analyse the heavy metal levels in the water samples obtained, and the average metal concentrations in the samples are provided in Table 2. The findings of this investigation demonstrated a decline in metal concentrations in the following sequence: zinc (Zn) > lead (Pb) > copper (Cu) > chromium (Cr) > arsenic (As)>cadmium (Cd) > mercury (Hg) for the year 2020. According to Table 2, the average concentrations of all the studied metals exceeded the recommended drinking water standards set by the World Health Organization (WHO, 2017a).

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Table 2: Comparison of Mean Concentrations (mg/L) of Heavy Metal in Water Samples

Elements	Mean (mg/L) 2020 El-Nino event	Maximum allowable concentration (WHO, 2017a)
Hg	0.19±0,015	0.002
Cr	16.8±0.011	0.005
Zn	279±0.002	3.00
Cu	30.3±0.013	2.00
Pb	108.7±0.022	0.005
Cd	5.18±0.031	0.001
As	13.1±0.011	0.001

Heavy Metal Concentration and Climate Change (Temperature and Precipitation)

The findings of the study revealed a possible relationship between rising temperatures, declining precipitation, and an upward trend in heavy metal concentrations in drinking water samples from the Migori gold mining area. The results are shown in Table 3, which presents the average concentrations of heavy metals before and after the El Niño event in 2020 with a descending order of magnitude as Zn >Pb >Cu >Cr >As >Cd >Hg.

Table 3: Mean of Heavy Metal Concentrations in Water Samples Collected through the 2016-2021(El-Nino Event Year 2020)

Elements	**Mean (mg/L): of the years 2016, 2017, 2019, 2020, and 2021**							Rank	MAC (WHO, 2017)
	2016	2017	2019	**Mean 2016-19**	2020	2021	**Mean (2020-21)**		
Hg	0.01	0.11	0.16	**0.093**	0.19	0.18	**0.25**	7	0.002
Cr	14.0	12.6	15.6	**14.06**	16.8	19.3	**18.05**	4	0.005
Zn	178.2	212	272	**220.7**	279	393.7	**336.35**	1	3.00
Cu	3.3	9.1	20.6	**11.0**	30.3	70.8	**37.06**	3	2.00
Pb	4.7	8.3	103.7	**38.9**	108.7	143.0	**125.85**	2	0.005
Cd	0.12	0.38	0.58	**0.36**	5.18	3.36	**4.27**	6	0.001
As	2.4	2.8	2.9	**2.07**	13.1	12.9	**13.0**	5	0.001
MAC		Maximum allowable concentration							

The metal historical data was collected by the researcher in the indicated years. Secondary data on temperature and rainfall in the months of October collected in 2016, 2017, 2019, 2020 and 2021 are indicated in appendices 1-5 (Grosell, 2011). The data was compared to the recorded observed values of the studied heavy metals. The findings revealed that there are observable increases in heavy metal concentrations which can be attributed to changes in temperatures and precipitation in the study area for the period 2016-2021.

This is consistent with findings from other studies that have shown that increases in temperature and changes in precipitation patterns lead to increased leaching of heavy metals from soils into water sources (Wijngaard et al., 2017). The researchers observed that increasing warmth and decreased precipitation were related with greater amounts of heavy metals in water samples, which is similar with the finding by Adhikari and Khanal (2019).

This shows that climate change is increasing the region's heavy metal pollution. In addition to variations in heavy metal concentrations, the study revealed substantial changes in the composition of heavy metals in water. Some metals, such as Zn, Pb and Cu., increased in concentration more than others, such as Hg and Cr (Table 3). This is consistent with prior research, which has demonstrated that various heavy metals have distinct mobilities and are influenced differently by changes in climatic factors (Ponting et al., 2021). These findings are significant since heavy metal poisoning can have detrimental effects on human health and the ecosystem, as well as contribute to long-term environmental deterioration (Briffa et al., 2020).

Changes in Heavy Metal Composition

In addition to alterations in the levels of heavy metals, the research unveiled that climate change has also influenced the composition of heavy metals present in water. The study revealed that certain metals; namely Pb, Zn and Hg experienced a more pronounced elevation in concentration compared to others such as chromium and copper (see tables 2 & 3). Similar observations were reported by Adhikari and Khanal (2019) and Obasi and Akudinobi (2020). These findings suggest that different heavy metals are influenced disparately by shifts in climate variables, such as temperature increases and decreased precipitation.

The observed increase in concentrations of Pb, Zn and Hg may be attributed to various factors influenced by climate change. For instance, rising temperatures can accelerate the weathering of geological formations, leading to the release of these metals into water sources (Xing et al., 2022). Further, Xing et al. (2022) observed that reduced precipitation can result in a higher concentration of heavy metals in water due to decreased dilution effects. Additionally, changes in the pH and redox conditions of water bodies influenced by climate change can also contribute to the altered composition of heavy metals in the study area.

Understanding these differential responses of heavy metals to climate change is crucial for assessing and mitigating potential risks to aquatic ecosystems and human health. By identifying the metals that are most affected, appropriate management strategies can be implemented to minimize their impact and ensure the safety of water resources. Future research should continue to explore the intricate relationships between climate change, heavy metal concentrations, and their ecological consequences.

Implications of Climate Change on Studied Heavy Metal Toxicity

While the study did not directly investigate the influence of climate change on the toxicity of metals in water within Migori County, the findings regarding the elevated concentrations of heavy metals carry significant health implications, particularly in light of the observed rise in temperatures and decrease in precipitation indicated by secondary data for the region. The study area has experienced a general pattern of increasing temperatures and reduced rainfall over the years, except for the year 2020. Climate projections indicate that Migori County (Figure 1) will remain susceptible to drought and heat stress, both of which can negatively affect agricultural and livestock production. The average duration of dry periods between 1985 and 2015 was 10 days, and this is projected to increase to 13 days by 2050, according to the Ministry of Agriculture, Livestock, Fisheries and Cooperatives (MoALFC, 2021).

Additionally, considering the observed concentrations of heavy metals in the water samples, the combination of increasing temperatures and low precipitation could potentially exacerbate the toxicity of these metals. Elevated temperatures can enhance the transformation of certain metals into more toxic forms, increasing their potential impact on ecosystems and human health. Moreover, the reduced precipitation can lead to decreased water volume and increased concentrations of heavy metals in water bodies, intensifying their potential adverse effects (Xing et al., 2022). The limited availability of water resources during dry periods may also result in the consumption of contaminated water, further increasing the risk of exposure to toxic metals (WHO, 2017b).

It is important to note that the specific interactions between climate change, heavy metal concentrations, and their toxicity are complex and may vary depending on the characteristics of each metal, as observed by Amanullah et al. (2020). Further research is needed to fully understand the combined effects of climate change and heavy metal

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contamination in order to implement effective mitigation strategies and safeguard the well-being of both ecosystems and human populations in Migori gold mines.

The toxicity of Hg can be modulated by various factors such as pH, salinity, and temperature. Increased temperature can potentiate the conversion of inorganic mercury to the more toxic form, methylmercury (Briffa et al., 2020). However, the impact of pH and salinity on Hg toxicity can vary depending on the specific environmental conditions (Rebolledo et al., 2021). Similarly, the toxicity of Cr can be shaped by pH, although the response to changes in salinity and temperature is less definitive. According to Ferreira et al. (2020), Cr(VI) species generally exhibit greater toxicity than Cr(III), and the prevalence of each species can be contingent upon pH.

Copper toxicity can be influenced by pH and salinity, while the significance of temperature is comparatively lesser. Acidification (lower pH) can amplify the bioavailability and toxicity of copper, whereas elevated salinity levels can ameliorate its toxicity, as indicated by Rebolledo et al. (2021). The toxicity of Cd is known to be influenced by pH and salinity. Acidic conditions (lower pH) can heighten the solubility and bioavailability of Cd, thereby augmenting its toxicity, while increased salinity can mitigate its toxic effects to some extent (Costa et al., 2020).

Zinc toxicity is generally not substantially altered by changes in pH, salinity, or temperature within typical environmental ranges. However, extreme pH conditions or exceedingly high temperatures can exert an impact on its toxicity (Rebolledo et al., 2021). Lead toxicity can be impacted by pH and salinity. Acidification (lower pH) and reduced salinity can escalate the solubility and bioavailability of lead, consequently intensifying its toxicity (Costa et al., 2020). The toxicity of As can be shaped by pH, although the response to changes in salinity and temperature is less definitive. Under alkaline conditions (higher pH), the solubility and bioavailability of arsenic can escalate, thereby rendering it more toxic (Rebolledo et al., 2021).

According to published literature, it has been observed that certain heavy metals can exhibit increased toxicity under specific climate conditions (Kumar et al., 2018). Moreover, available evidence suggests that climate change has influenced the toxicity of heavy metals in water, leading to alterations in their bioavailability and toxicity (Fang et al., 2019). Although pH, salinity and conductivity of the water samples was not determined in this study, published literature show that these parameters have an impact on the toxicity, distribution and concentration of heavy metals in water (Senze et al., 2023). Parameters such as pH, salinity and conductivity of the water are influenced by climate changes which in turn has an impact on the concentrations of heavy metals in water (Frogner-Kockum et al., 2020). These changes in climate variables have the potential, therefore, to elevate the toxicity, mobility, and availability of heavy metals in the food chain, posing risks of heavy metal poisoning to the environment, animals, and humans.

Ecological Risk Calculation

The Risk Quotient (RQ) formula was used to estimate the ecological risk. The RQ compares the exposure concentration of the contaminant to an effect threshold (Zhang et al., 2017). The following equation was used:

RQ = Exposure Concentration (EC) / Effects Threshold (ET)

Where:

1) Exposure Concentration (EC) represents the concentration of the contaminant in the water sample.
2) Effects Threshold (ET) refers to the concentration below which adverse effects on aquatic organisms are not expected to occur. This threshold can be derived from toxicity data or established guideline values.

The resulting RQ value indicated the potential risk level. If RQ is less than 1, it suggests that the contaminant concentration is below the effects threshold and is considered low risk. On the other hand, an RQ greater than 1 indicates a potential risk, suggesting that adverse effects may occur.

In this study, the ecological risk calculation for water samples indicated that the levels of heavy metal contamination and associated ecological risks were relatively high compared to the reference values provided in environmental guidelines (WHO, 2017b). The calculated ecological risk was found to be one to a hundred fold orders of magnitude higher than the established low reference values. This implies that heavy metal contamination and ecological risks is a highly significant concern in this study area now as well as for future pollution control and management plans for the drinking water sources including the rivers. It is important to note that continued monitoring of heavy metals is necessary to prevent the potential risks that arise and to ensure the ongoing protection of the environment and associated ecosystems as recommended by Li et al. (2019) and Yu et al. (2018).

Degree of Contamination (Cd)

Degree of contamination was done to assess the degree of pollution by metals and is reported as contamination factor (CF). Among the studied metals, Cr, Cd, Pb, As were shown to have very high contamination in the study area (Table 4).

Table 4: Contamination Factor of Heavy Metals in Water Categorized for Aquatic Life (CCME, 2007)

Elements	Average conc (mg/L)	ERA	Aquatic life permissible limits (mg/L)	WHO, 2017a MAC	Aquatic life		Calculated EDI
					CF	Degree of contamination	
Hg	0.13	65	0.002	0.002	65	High	**3.9**
Cr	18.46	9.3	2	0.005	3692	Very high	**55.3.8**
Zn	266.98	8.899	30	3.00	88.99	High	**80.09**
Cu	26.82	6.705	4	2.00	13.41	Moderate	**60.8**
Pb	73.68	10.52	7	0.005	14736	Very high	**78.9**
Cd	1.924	1.069	1.8	0.001	1924	Very high	**26.9**
As	6.82	6820	0.001	0.001	6820	Very high	**18.45**
ERA	Ecological risk assessment= Risk Quotient						
EDI	Estimated dietary intake						
MAC	Maximum allowable concentration						

Estimation of Daily Intake (EDI)

In accordance with the description provided by Kasozi et al. (2019), this study employed equations (ii) and (iii) to estimate the daily intake (EDI) for the selected pathways. The findings of the study demonstrated that the daily intakes of heavy metals followed the following descending order: Zn > Pb>Cu> Cr> Cd> As> Hg (see table 4). These findings indicate that Zn had the highest intake value through the ingestion route for all consumers. The significance of the ingestion pathway in terms of metal intake aligns with previous literature findings (Proshad et al., 2020; Dash & Kalamdhad, 2021). These studies have also highlighted the importance of the ingestion route as a major contributor to heavy metal intake.

The daily intake of heavy metals through the ingestion pathway is of significant concern due to the potential health risks associated with chronic exposure. Elevated levels of Hg, Zn, Cr, Zn, Cu, As and Cd in water sources can lead to various health issues, including gastrointestinal problems, organ damage, and increased susceptibility to certain diseases (Teschke, 2022). Understanding the relative intake of heavy metals through different pathways, such as ingestion, is crucial for assessing human exposure and managing health risks. It allows for the development of targeted strategies to minimize exposure and safeguard public health. Further research and continuous monitoring are warranted to assess the potential health risks posed by heavy metal intake through the ingestion pathway and to ensure the implementation of appropriate control measures.

Conclusion and Recommendations

The study findings provide valuable insights into the contamination characteristics of heavy metals in drinking water from various water sources that drain into Lake Victoria within the Migori gold mining areas. It was observed that the mean concentrations of all detected heavy metals in the research locations exceeded the acceptable limits set by the World Health Organization (WHO, 2017a). The mean concentrations of heavy metals under study exhibited a noticeable decline before the El Niño period in comparison to the post-El Niño period (2021). This variance can be attributed to an increase in temperatures and an overall decrease in precipitation during the post-El Niño period. These climatic changes may have facilitated the mobilization of heavy metal concentrations into water systems, providing a plausible explanation for the observed shift in metal levels. Water ecological risk analyses revealed that the predicted hazards were 1 to more than 100 times higher than the recommended limit values or reference values. Additionally, the study underscored the significance of ingestion pathways in determining the daily intake of heavy metals (EDI) in the human body.

While the study successfully explored the impact of climate change on heavy metals concentration in artisanal gold mining areas in Migori, Kenya, it is recommended that future research endeavours to delve into the specific influence of temperature variations and rainfall amounts on the raised concentration of heavy metals in these regions. This targeted investigation would provide a more nuanced understanding of the climatic factors contributing to heavy metal contamination in the context of artisanal gold mining. Furthermore, assessing the interplay between climatic conditions and mining practices can inform adaptive strategies and sustainable environmental management approaches for these areas. To complement this research, it is also suggested to consider studying the effectiveness of regulatory policies in mitigating heavy metal pollution from gold mining activities to ensure a comprehensive and actionable approach to environmental sustainability.

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Appendices

Appendix 1: Temperature and Rainfall for Year 2016

Temperature	Max	Average	Min
Max Temperature	28.0°C (82.4°F)	26.23°C (79.21°F)	23.0°C (73.4°F)
Avg Temperature	23.0°C (73.4°F)	22.29°C (72.12°F)	20.0°C (68.0°F)
Min Temperature	17.0°C (62.6°F)	15.39°C (59.7°F)	13.0°C (55.4°F)
Dew Point	Max	Average	Min
Dew Point	16.0°C (60.8°F)	13.68°C (56.62°F)	12.0°C (53.6°F)
Precipitation	25.8mm | 1.02in	7.61mm | 0.3in	0.2mm | 0.01in

Appendix 2: Temperature and Rainfall for Year 2017

Temperature	Max	Average	Min
Max Temperature	31.0°C (87.8°F)	27.68°C (81.82°F)	20.0°C (68.0°F)
Avg Temperature	25.0°C (77.0°F)	22.45°C (72.41°F)	19.0°C (66.2°F)
Min Temperature	18.0°C (64.4°F)	16.45°C (61.61°F)	14.0°C (57.2°F)
Dew Point	Max	Average	Min
Dew Point	17.0°C (62.6°F)	14.32°C (57.78°F)	10.0°C (50.0°F)
Precipitation	32.9mm | 1.3in	8.15mm | 0.32in	0.0mm | 0in

Appendix 3: Temperature and Rainfall for Year 2019

Temperature	Max	Average	Min
Max Temperature	27.0°C (80.6°F)	25.23°C (77.41°F)	22.0°C (71.6°F)
Avg Temperature	22.0°C (71.6°F)	21.19°C (70.14°F)	20.0°C (68.0°F)
Min Temperature	18.0°C (64.4°F)	15.58°C (60.04°F)	14.0°C (57.2°F)
Dew Point	Max	Average	Min
Dew Point	17.0°C (62.6°F)	15.06°C (59.11°F)	12.0°C (53.6°F)
Precipitation	19.8mm | 0.78in	5.28mm | 0.21in	0.0mm | 0in

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Appendix 4: Temperature and Rainfall for Year 2020

Temperature	Max	Average	Min
Max Temperature	30.0°C (86.0°F)	27.13°C (80.83°F)	20.0°C (68.0°F)
Avg Temperature	24.0°C (75.2°F)	21.74°C (71.13°F)	19.0°C (66.2°F)
Min Temperature	18.0°C (64.4°F)	15.58°C (60.04°F)	14.0°C (57.2°F)
Dew Point	Max	Average	Min
Dew Point	17.0°C (62.6°F)	15.06°C (59.11°F)	12.0°C (53.6°F)
Precipitation	27.6mm | 1.09in	5.5mm | 0.22in	0.0mm | 0in

Appendix 5: Temperature and Rainfall for October, Year 2021

Temperature	Max	Average	Min
Max Temperature	30.0°C (86.0°F)	27.68°C (78.22°F)	24. 3.0°C (73.4°F)
Avg Temperature	25.0°C (77.0°F)	22.26°C (72.07°F)	20.0°C (68.0°F)
Min Temperature	19.0°C (66.2°F)	16.61°C (61.9°F)	15.0°C (59.0°F)
Dew Point	Max	Average	Min
Dew Point	17.0°C (62.6°F)	14.71°C (58.48°F)	10.0°C (50.0°F)
Precipitation	33.5mm | 1.32in	12.49mm | 0.49in	0.0mm | 0in

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