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Original Article

Mercury Levels in Groundwater near Artisanal Small-Scale Gold Mines in Migori County, Kenya

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ABSTRACT

In Migori County, artisanal and small-scale gold mining (ASGM) is an economic activity that uses mercury during the amalgamation process to obtain gold. The waste generated in the form of soil tailings and pan-pond water contains mercury and is located close to community boreholes. The proximity may predispose groundwater to mercury contamination. Boreholes are one of the main water sources in Migori County. Ingestion is one of the ways mercury can get into the human body. This study was conducted to establish mercury concentration in groundwater from boreholes, soil tailings and pan-pond water located near five mine sites in Migori County during dry and wet seasons in comparison with drinking water standards required by KEBS and NEMA effluents discharge standards. The five mines were: - Masara, Osiri Matanda, Macalder, Kitere and Kehancha. The study used a cross-sectional-analytical study design and focused on boreholes found within a distance of 6 km from each of the five mines. Fifteen boreholes were proportionately sampled to obtain groundwater samples. 20 pan-pond water and soil tailing samples were collected in both dry and wet seasons as per the respective sampling protocols applied. Inductively Coupled Plasma –Mass Spectroscopy (7900 ICP-MS) was used to measure mercury levels. A paired t-test was used to compare the means of the levels of mercury in groundwater obtained within the two seasons. The study established that during the dry season, all of the boreholes had groundwater mercury levels higher than the recommended limit by KEBS of 0.001 mg/L. There was a decrease in the levels of mercury in groundwater as distances from the mine increased. However, during the wet season, all of the boreholes had mercury levels below the limit of detection. The study established a significant difference in the levels of mercury in groundwater between wet and dry seasons at a 95% confidence level. Mercury levels in soil tailings and pan-pond water were above the NEMA effluents discharge standards of 0.05 mg/kg and 0.05 mg/L, respectively, in the dry season. During the wet season, all pan-pond water achieved the recommended mercury level of NEMA effluent discharge limits, while the soil tailings had mercury levels above the recommended limit. This study recommends that there is a need to implement mine waste remediation. Communities near the mines continuously conduct groundwater heavy metal analysis during the dry season to protect their health.

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INTRODUCTION

Artisanal and Small-Scale Gold Mining (ASGM) uses inexpert skills in extracting minerals in the casual sector, and it is practised in over 70 emerging countries (UNEP, 2012). Fifteen million people worldwide are hired through such mining, while people relying on it directly are estimated to range from 80 to 100 million. ASGM discharges mercury universally, and it's one of the most meaningful regarding pollution on water because it releases 37% of it (Esdaile & Chalker, 2018). In Africa, pollution of heavy metals in the past decade has reached levels never known before. Therefore, human contact with heavy metals has developed into a great health threat, attracting attention from the world and national organisations. The parts of the continent accused of being major sources of this pollution are the southern, east, west, and north. The levels of pollution are compared to globally acceptable limits, which showed contaminations in fish and food animals. Impacts on the human population are evident since toxic elements cause serious health hazards. 2.97 million deaths of humans occur in Africa yearly due to environmental risk factors (Yabe et al., 2010).

ASGM in Migori County started in 1920, and it involves mercury usage in the mining procedure to obtain gold easily. As a result of climate change and rising poverty levels in the county over the past decade, ASGM has intensified (Responsiblemines, 2018). An amalgam is a combination of mercury and gold in the same proportion. To recover gold, it is heated to evaporate mercury. During the panning process, over 40% of the mercury applied is lost, and 71% of the lost mercury is retained in soil and water wastes (UNEP, 2013).

Artisanal gold mining activities in Migori County are done using water near rivers and water sources. The gold panning process is, in most cases, done by hand or makeshift tools, and a small pond is dug to train the wastewater. Pan-pond water accumulates a lot of mercury due to the repeat amalgamation process on them (Ogola et al., 2002). Soil tailings are treated as waste soils after the recovery of amalgam, which is a mixture of gold and mercury. The soil tailings are normally dumped in heaps at the mine sites exposed to the environment (UNEP, 2002). At the end of the processing, mercury remains in pan pond water and soil tailings (Macháček, 2019).

It is hypothesised in many studies that artisanal small-scale mining may lead to groundwater contamination in various ways. Some of the reasons are leaks or disposal of pan pond water because it has been used before, contaminated runoff from soil tailings and pan pond water. These can infiltrate the soils through open pits whose ore has been extracted (Palumbo-Roe et al.,

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2021). Therefore, the presence of mercury in the mines was thought to be a potential source of mercury pollution for groundwater. Mercury is known to be carcinogenic and can lead to poisoning when ingested by human beings. Mercury is also associated with birth defects in unborn children (Solan & Lindow, 2014).

Mercury contamination adversely affects human life and can lead to mortality after chronic exposure. Mine waste remediation can be able to reduce the risks; however, many ASGM activities do not practice it (UNEP, 2013). There are recommendations that suggest that information on heavy metal levels in groundwater located near artisanal miners may assist in protecting environmental health. This information is said to be influenced by various factors such as soil geology, distance to the mines, as well as the climate of the area (Palumbo-Roe et al., 2021).

Problem Statement

Mercury, as a heavy metal, is considered harmful to human health, according to the World Health Organization. During artisanal gold processing, mercury remains in waste soil tailings and pan-pond water (Abdul-Wahab & Marikar, 2012). Mercury accumulating in the mines can potentially lead to groundwater contamination (Palumbo-Roe et al., 2021). Boreholes are one of the main water sources in Migori County (MoALFC. 2021).

Research done by the Center of Environmental Justice and Development in 2017 showed the presence of mercury in human hair from people around Masara mine, Migori County (CEJAD, 2017). Another research conducted in Mikie and Masara mines revealed that 70% of the women involved in the study had mercury levels over 0.58 ppm. Mercury disposes them to developing neurological damage in the foetal development in times of pregnancy (IPEN, 2018). Therefore, this study sought to establish whether groundwater sources used for drinking have traces of mercury during both dry and wet seasons.

MATERIAL AND METHODS

A cross-sectional analytical design was used in the research to measure the mercury levels during both wet and dry seasons. The study focused on artisanal small-scale gold mining sites and boreholes within Migori County, Kenya. It was carried in Macalder mines, Osiri Matanda mine, Masara mine, Kehancha and Kitere mines located within Migori County. The climate in Migori County experiences long rains between March and May, while from October to December, short rains are experienced with rainfall patterns varying from 700 mm to 1800 mm. The dry season is within the period between January to February and June to September (County government of Migori, 2018). The soil geology has no natural existence of mercury (Ogola et al., 2002).

In this study, mercury concentration in groundwater from boreholes was measured quantitatively, and the reference value for drinking water quality was placed at 0.001 mg/l according to WHO and KEBS (WASREB, 2008). The distance from mines to the boreholes (km), seasonal variation (wet and dry seasons) and the duration of mining activity in the mine (years) were the independent variables. Mercury concentration in soil tailing and pan-pond water was measured quantitatively in reference value to the effluent discharge of mercury placed at 0.05 mg/1 and 0.05 mg/kg, respectively, by NEMA (WASREB, 2008).

In 2021, a total of 46 boreholes in use were mapped in collaboration with community resource persons within a distance of 6 kilometres from the five mines in Migori County. A distance of 6 km was preferred, as used in a similar study by scientists (El-Salam & Abu-Zuid, 2015; Hu et al., 2020). The depth of the boreholes targeted was between 80 m – 200 m, as estimated in the Regional Master Plan (1975). The mines had been in operation for 10 years by the time of the study (Cossa et al., 2022). Groundwater, which is being undertaken through water treatment before it is released for use, was excluded from the study.

1 kg of soil tailings was obtained in line with the sampling and analysis protocol outlined in

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Ontario Regulation 267/03 and in concurrence with protocols for Environmental and Health Assessment of Mercury Released by Artisanal and Small-Scale Gold Miners (Veiga et al., 2004). 500 ml of pan-pond water was taken in a plastic bottle as depth-integrated samples as outlined in protocols for Environmental and Health Assessment of Mercury Released by Artisanal and Small-Scale Gold Miners (Veiga et al., 2004). 500 ml water samples from boreholes were collected from outlet taps in plastic bottles following water sampling procedures as described by US Environmental Protection Agency operating procedures (Barcelona, 1985). Five per cent of concentrated nitric acid was added for preservation and to keep metal ions in the solution (Kar et al., 2008).

Water samples from pan-pond water and soil tailings samples were collected during both the dry and wet seasons as per sampling protocols. In this regard, 20 samples were to be collected in both seasons. A sample size of 30% is a recommended minimum sample size acceptable to represent a population (Mugenda & Mugenda, 2008). Out of 46 boreholes mapped within 6 km distance, 15 (32% of 46), in accordance with the sampling frame below, were proportionately sampled.

Table 1: Sampling Frame of boreholes near the identified near the five mine sites

Mine site	No. of Boreholes	Sample size of the boreholes near each mine site	N/n
Masara	9	(9/46) *15=3	3
Osiri Matanda	8	(8/46) *15=3	3
Macalder	8	(8/46) *15=3	3
Kitere	10	(10/46) *15=3	3
Kehancha	11	(11/46) *15=3	4
Total	46	15	

Systematic sampling was used using calculated intervals (N/n), as displayed in the table above. The samples were analysed using the Inductively Coupled Plasma-Mass Spectroscopy (7900 ICP-MS) (Agilent.com, 2022; Kingston & Walter, 1998). Data from the laboratory analysis was analysed using Microsoft Excel (version 2016). A paired t-test was used to compare the means of the levels of mercury in groundwater obtained within the two different seasons. The distances from the mines to the boreholes were analysed using GIS software (ArcGIS 10.8.2). For analysis purposes in this research, any below limit of detection figures obtained after analysing the mercury levels from water samples was replaced with 0.0000141421 mg/L. This replacement value was derived by dividing the limit of detection by the square root of 2 (Croghan & Egeghy, 2003). The limit of detection of ICP-MS (7900) for mercury is stipulated as 0.01 ppb/0.00001 mg/L (Agilent.com, 2022).

RESULTS AND DISCUSSION

Mercury Concentration in Groundwater from Boreholes

The results of mercury levels in groundwater from boreholes during dry and wet seasons in Migori County are presented in *Table 1* below. These results are disaggregated by season of the year. The dry season experienced in Migori County runs from July to September, while wet seasons happen between the months of March to May and October to December (County Government of Migori, 2018). From the results, it is observed that mercury was present in all groundwater samples during the dry season. The results were higher than the KEBS recommended levels of 0.001 mg/l for drinking water. Therefore, the water might be a public health concern when used for drinking water. However, during the wet season, mercury levels in groundwater were below the limits of detection (*Table 2*). Therefore indicating the water was safe.

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Table 2: The levels of mercury in groundwater from boreholes during dry and wet seasons

Mines	Borehole samples codes	Mercury levels in groundwater from boreholes		Distance from the mine (KM)
		dry season	wet season	
Osiri	OS11	0.19 mg/L	<LOD	<1km
	OS 12	0.13 mg/L	<LOD	1km<2km
	OS 13	0.17 mg/L	<LOD	3km<6km
Kitere	KIT 21	0.11 mg/L	<LOD	<1km
	KIT 22	0.21 mg/L	<LOD	1km<2km
	KIT 23	0.08 mg/L	<LOD	3km<6km
Masara	MAC 31	0.28 mg/L	<LOD	<1km
	MAC 32	0.35 mg/L	<LOD	1km<2km
	MAC 33	0.36 mg/L	<LOD	3km<6km
Macalder	MAC 42	0.76 mg/L	<LOD	<1km
	MAC 41	0.49 mg/L	<LOD	1km<2km
	MAC 43	0.46 mg/L	<LOD	3km<6km
Kehancha	KEH 51	0.12 mg/L	<LOD	<1km
	KEH 52	0.11 mg/L	<LOD	1km<2km
	KEH 53	0.10 mg/L	<LOD	3km<6km

*<LOD **means** Below Limit of Detection*

This finding concurs with research conducted by Hathhorn and Yonge (1995), which attributed the dilution of pollutants in groundwater to the groundwater recharge systems and the increase of water quantity within the aquifers. It acknowledged that rainfall, soil surface and biological methods play a role (Hathhorn & Yonge, 1995). The rationale above explains the difference in findings between the two seasons.

The results of this study are also consistent with research on groundwater quality in the Wassa West District of Ghana; the water from wells sampled displayed mercury levels above the 0.001 mg/L recommended limit set by the WHO during the dry season. This was attributed to the characteristics of mining areas near the wells. Due to public health concerns elicited by the findings, the study recommended reconsidering the use of groundwater for drinking within the District (Obiri, 2007).

Lusilao-Makiese et al. (2014) agreed with the finding of this study that artisanal small-scale mining may affect the mercury level in groundwater near the sites. This conclusion was arrived at when the mercury level in the sample's groundwater was found to be 3310 ng L^{-1}. They recommended a need to address the issue urgently to reduce the impact on other water systems situated near the mine sites like the Vaal River (Lusilao-Makiese et al., 2014).

These findings of this study support research done in Migori County that found that total mercury levels in all groundwater samples were all below WHO recommended limits of 6 µg/l for drinking water. The groundwater was from a dug well in proximity to the artisanal mining areas- in Migori County. The study found that 0.016 µg/l was the median value of mercury level from the groundwater samples (Palumbo-Roe et al., 2021).

Influence of Distance of Mine to Borehole on Groundwater Contamination

Figure 1 below presents the levels of mercury in groundwater during the dry season against the distances of the boreholes to the mines. The results indicate that the wet season values of mercury concentration in groundwater were constantly below the detection limit as distances from mine to boreholes increased. However, the dry season values showed a decrease in the levels of mercury in groundwater as distances from the mine increased. The mean values of mercury levels in the dry season ranged from 0.292 mg/L for <1km, 0.258 mg/L for 1km<2km, and 0.234

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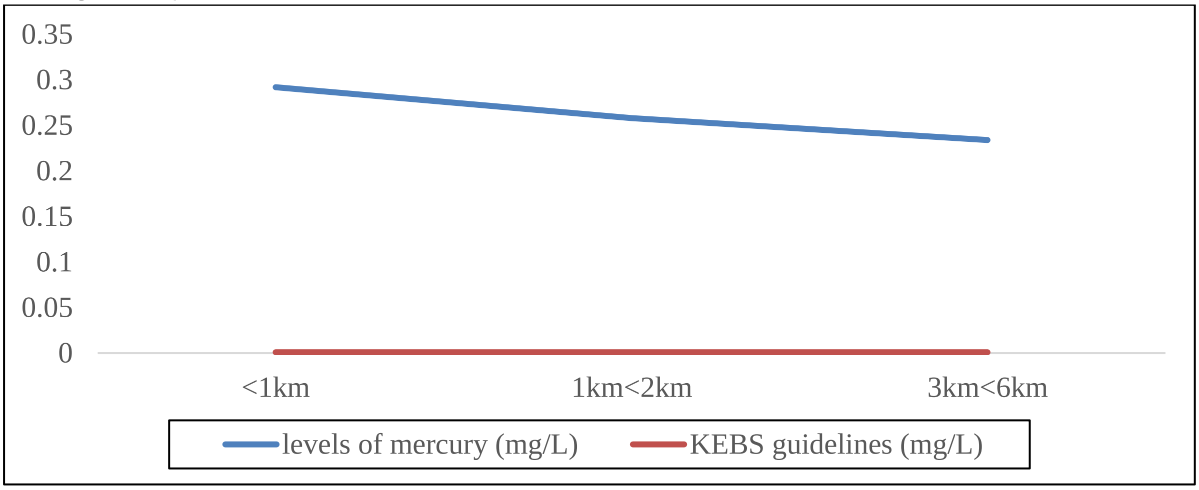
mg/L for 3km<6km. These values are above KEBS recommended standards of 0.001 mg/L for drinking water.

Figure 1: Levels of mercury in groundwater in relation to distances of the mines to borehole during the dry season



Groundwater system contains potential energy that is distributed. It is approximated that the direction of groundwater flow is from high to low hydraulic head. This is further explained by the gradient. The distance between the point of pollution and the possibility of contaminants travelling through the aquifer because of the gradient is a key issue to be determined (Michael & Demian, 2022).

It is important to determine the suspected point of pollution as the true source of mercury before attributing the contamination in groundwater. This finding concurs with a study by Ochiba (2020) conducted in Kajiado County, Kenya, which stipulated that there was an indication of higher levels of heavy metals in boreholes closer to septic tanks in both dry and wet seasons. Proximity to the point of pollution and the season may have influenced the findings found.

Udofia et al. (2019) investigated the level of pollution in groundwater adjacent to dumpsites within Akwa Ibom State, Nigeria. In concurrence, this study concluded that heavy metal presence in groundwater was influenced by distance to the source of contamination (Udofia et al., 2019).

Seasonal Influence on Levels of Mercury in Groundwater from Boreholes

Seasons are known to influence the recharge of groundwater and artisanal mining activities within the study area (Macháček, 2019). Reduction of groundwater volume is suggested to affect the concentration of pollutants according to previous studies (Dorleku et al., 2018). This study made comparisons of mercury levels in groundwater samples between wet and dry seasons. A paired sample t-test was used to determine if there were differences in the means of mercury levels in boreholes during the two seasons. A probability figure of $p < 0.05$ was used to determine significant differences statistically. From the calculations, it is observed that the P-value is less than 0.05. This means that the levels of mercury in groundwater in the two seasons are significantly different. *Table 3* below shows a summary of paired sample t-test results.

As part of the western part of Kenya, Migori County experiences two rainy seasons. During the wet seasons, artisanal mining operations get affected, causing slowdowns. Artisanal gold mining uses amateur methods to access the ores, leading to potentially fatal accidents (Macháček, 2019). During the dry season, the conditions for agricultural practices become unconducive,

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causing low farm produce and reduced incomes in households within Migori County. These conditions force many residents to migrate to gold mining areas to survive. Therefore, it is a period of high mining operations in mines (Macháček, 2019).

Table 3: Paired sample t-test results

t-Test: Paired Two Sample for Means		
	0.19	**1.41421E-05**
Mean	0.266429	1.41421E-05
Variance	0.039302	1.23625E-41
Observations	14	14
Pearson Correlation	1.76E-16	
Hypothesised Mean Difference	0	
Df	13	
t Stat	5.028244	
P(T<=t) one-tail	0.000116	
t Critical one-tail	1.770933	
P(T<=t) two-tail	0.000231	
t Critical two-tail	2.160369	

In a study carried out in the Pra Basin of Ghana, wet season recordings of heavy metals in groundwater suggested less pollution in comparison to the dry season. It stated that increased rainfall and infiltration caused the aquifers to be diluted, therefore, influencing the recorded levels of mercury (Dorleku et al., 2018). Another research conducted in the Goa region in India established lower pollution values during wet seasons. Similarly, it also attributed the results to increased rainfall, causing groundwater recharge (Singh & Kamal, 2015).

Mercury Levels in Soil Tailings and Pan Pond Water as A Source of Mercury to the Environment

Mercury used in the mines might find themselves in the wastes generated from gold processing (Macháček, 2019). The study measured levels of mercury in soil tailings and pan-pond water from mines during the wet and dry seasons are displayed in *Table 4*. The results were compared to NEMA effluent discharge values of 0.05 mg/kg for soil and 0.05 mg/L for pan pond water.

Table 4: Levels of mercury in water and soil samples from mine sites during wet and dry season

Mines	Samples		Mercury levels in seasons		Mean
	State of Samples	Codes of samples	Wet season	Dry season	
Osiri Mine	Water samples	PPW 1	0.02 mg/L	2.08 mg/L	1.05 mg/L
	Soil samples	SS 1	2.81 mg/kg	9.08 mg/kg	5.945 mg/kg
Kitere Mine	Water samples	PPW 2	0.01 mg/L	0.21 mg/L	0.11 mg/L
	Soil samples	SS 2	0.73 mg/kg	0.50 mg/kg	0.615 mg/kg
Masara Mine	Water samples	PPW 3	0.01 mg/L	0.16 mg/L	0.085 mg/L
	Soil samples	SS 3	0.66 mg/kg	0.52 mg/kg	0.59 mg/kg
Macalder Mine	Water samples	PPW 4	<LOD	0.17 mg/L	0.085 mg/L
	Soil samples	SS 4	9.64 mg/kg	7.64 mg/kg	8.64 mg/kg
Kehancha Mine	Water samples	PPW 5	0.04 mg/L	0.41 mg/L	0.225 mg/L
	Soil samples	SS 5	0.46 mg/kg	0.95 mg/kg	0.705 mg/kg

Where, PPW = Pan Pond Water; SS= Soil sediment

All the mercury concentration values obtained from soil tailings during the dry season were above the recommended NEMA effluent discharge value (0.05 mg/Kg). Masara and Macalder recorded the lowest values at 0.52 mg/Kg and 0.50 mg/Kg, respectively. The highest

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value was 9.08 mg/kg found in the Osiri Matanda mine (*Table 4*). During the wet season, none of the mercury concentration values from the soil tailings were below the recommended NEMA effluent discharge value of 0.05 mg/Kg. The lowest mercury levels were recorded from Masara and Kitere mines at 0.73 mg/Kg and 0.066 mg/Kg, respectively. The highest value was 9.64 mg/kg in Macalder mine (*Table 4*).

Mercury values determined in pan pond water during the dry season were all above the recommended NEMA effluents discharge value (0.05 mg/L). The highest level of mercury measured was 2.08 mg/L (Osiri Mine), while the lowest value was 0.16 mg/L (Masara Mine), as shown in *Table 4*. However, mercury concentrations during the wet season in pan pond water were all below the recommended NEMA effluent discharge value of 0.05 mg/L. The range of mercury levels determined was from 0.04 mg/L to <LOD (*Table 4*).

This study agrees with scientist Ogola et al. (2002), who also found high levels of mercury in soil tailings and pan pond water samples in Macalder Mine, Migori County. Also another research conducted in nine mine sites in the western region of Ghana also found elevated mercury levels in soils obtained from the sites (Mantey et al., 2016).

Githiria et al. (2020) carried out a study at the Kapsaos mine site in Kenya. The findings indicated the presence of mercury in the unregulated soil tailings. Potentially creating a chance of it making its way into water systems located nearby. Therefore putting the public health of the community and aquatic life at risk.

Detected levels of mercury in the mines create a risk of spreading the poisonous element further into the environment and causing harm. Therefore, a study by Esdaile and Chalker (2018) framed the issue as a chemistry challenge. They advised scientists to come up with mercury-free methods that require less technical skills to use to protect the health of communities worldwide. In addition, the methods are required to be affordable and easily accessible by artisanal miners like Borax technology (Esdaile & Chalker, 2018).

CONCLUSION

From this research, it was interpreted that mercury levels in all groundwater samples were above KEBS recommended limits in the dry season; however, all groundwater samples had levels of mercury below the limit of detection during the wet season. There was a decrease in the levels of mercury in groundwater as distances from the mine increased during the dry season. In the mines, the levels of mercury in soil tailings and pan pond water from the mines were higher than the NEMA effluents discharge standards in the dry season, but during the wet season, mercury levels in pan pond water were within the recommended standards, while the soils tailings recorded mercury levels above the NEMA effluents discharge standards. Conclusively, the study interprets that mercury levels in groundwater during the dry season are significantly different from wet season values.

Recommendations

This study makes recommendations to different stakeholders with the aim of protecting public health:

- During the dry season, communities using boreholes within a 6 km distance of the five mines need to routinely carry out heavy metal analysis.
- Artisanal small-scale gold miners need to practise mine waste remediation to reduce the levels of mercury in waste soil tailings and pan pond water.
- Licensed water service providers need to provide alternative sources of drinking water during the dry season to communities using groundwater from around the five mines.

Recommendations for Further Study

Further research should seek to understand aquifer characteristics and the vulnerability of

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groundwater in boreholes located within 6km of the five mines.

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