Journal of Agriculture and Ecology Research International

Volume 25, Issue 6, Page 46-54, 2024; Article no.JAERI.125653
ISSN: 2394-1073

Effects of Tin Mining on Water Sources in Mwerasandu Tin Mine, Ntungamo District, Uganda

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Authors' contributions

This work was carried out in collaboration among all authors. Author PA formulated study objectives, searched for related literature, designed the methodology, collected data and analyzed the data. Author ARK searched for the related literature, designed the methodology, proof read the manuscript. Author AB formulated the title of the study and objectives, searched for related literature, analyzed the collected data, discussed the findings, typeset and proof read the entire manuscript. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/jaeri/2024/v25i6638

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/125653

Original Research Article

Received: 23/08/2024
Accepted: 25/10/2024
Published: 29/10/2024

ABSTRACT

Tin mining is a widespread economic activity across various regions worldwide. Understanding the consequences of such operations is crucial for sustainable water management and environmental conservation. The current study aimed at determining the concentrations tin, lead and mercury in the water sources of Nyakahiimbura Stream in Mwerasandu, and assessed the physico-chemical

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Cite as: *Akampondi, Pamela, Amos Ronald Kalukusu, and Alex Barakagira. 2024. "Effects of Tin Mining on Water Sources in Mwerasandu Tin Mine, Ntungamo District, Uganda". Journal of Agriculture and Ecology Research International 25 (6):46-54. https://doi.org/10.9734/jaeri/2024/v25i6638.*

properties including pH, turbidity, and chemical oxygen demand (COD) of the water from the Nyamuhimbura stream, Ntungamo district. Water samples from three locations, that is; the upstream, impact area and downstream of the Nyakahiimbura water stream were collected during the dry and wet seasons of the year 2024. The samples collected were analyzed for the physico-chemical properties in the laboratory while the Inductively Coupled Plasma-Optical Emission Spectrometry (ICP – OES) was used to determine the concentration of heavy metals in the water samples. The pH, COD values obtained were within the acceptable effluent standards while the turbidity values at the upstream and downstream of the dry season and downstream during the wet season were above the acceptable effluent Standards. The tin concentration was high in the dry season (0.09mg/L) as compared to concentration (0.118mg/L) in the wet season. Lead concentration was the same (0.015mg/L) in both seasons. The concentrations of the heavy metals showed some variations in both dry and wet seasons in the upstream, impacted area and the downstream of the study area as compared to the values of the effluent standards. The study recommends that alternative sources of water for domestic use should be sought of. Also, the government officials especially from the Ministry of Health should carry out awareness campaigns to members of the community about the health risks associated with the uptake of the contaminated waters for domestic purposes. Constructed wetlands should be in place around the mining sites to act as filters for the dangerous metals before the water enters the surrounding environment.

Keywords: Tin Mining; water sources; Ntungamo; Uganda.

1. INTRODUCTION

Tin mining, a widespread economic activity across various regions worldwide, presents significant challenges to water resources and aquatic ecosystems. Understanding the consequences of such operations is crucial for sustainable water management and environmental conservation. Studies such as those by Sukarman et al. (2020) and Macklin et al. (2023) have shed light on the adverse effects of tin mining on water quality and river ecosystems, respectively. Furthermore, research by Muhammad et al. (2022) highlights the potential health risks associated with contamination of drinking water by tin mining activities. While limited research specifically focuses on tin levels in Ugandan water resources, some studies investigating broader heavy metal contamination provide valuable insights about heavy metal contamination in the water sources (Pule and Barakagira, 2022). In Uganda, the challenges in the mining sector, including tin, are compounded by inadequate regulatory frameworks for example the Mining and Minerals Act, 2022 which covers only prospecting, exploration and exploitation of minerals and limited environmental impact assessments, resulting in insufficient data on the state of water resources (Mugagga et al., 2018). Despite these challenges, there are examples of successful interventions aimed at mitigating the impact of tin mining on water sources. Initiatives such as the implementation of water treatment technologies and watershed management projects demonstrate the potential for positive change in relation to mitigating effects brought about by mining and agricultural activities along the hill slopes (Barakagira and Ndungo, 2023; Teschner et al., 2020). In Africa, regional initiatives like the African Mining Vision seeks to promote responsible water stewardship through coordinated policies (Barakagira and de Wit, 2017; Barakagira and de Wit, 2019; Jones et al., 2019). By prioritizing water conservation and implementing responsible mining practices, the mining industry can minimize its impact on water resources while ensuring the sustainability of tin extraction activities.

1.1 Effects of Tin Mining on Water Sources

The effects of tin mining and other related mining activities on the physico-chemical parameters of water sources cannot be underrated. Some parameters are explored as follows:

pH: pH is a determined value based on a defined scale, similar to temperature. This means that pH of water is not a physical parameter that can be measured as a concentration or in a quantity. Instead, it is a figure between 0 and 14 defining how acidic or basic a body of water is along a logarithmic scale (Merriam-Webster,2013) The lower the number, the more acidic the water is. The higher the number, the more basic it is. Tin mining operations introduce contaminants into water sources, including suspended solids, mine tailings, and chemical reagents used in ore processing (She et al., 2024). These pollutants alter the physicochemical properties of water, leading to changes in pH levels, turbidity, and dissolved oxygen concentrations.

Chemical Oxygen Demand (COD): COD is a widely used indicator of organic pollution in water. It signifies the amount of oxygen required by microorganisms to decompose organic matter present (APHA, 2021). Elevated COD levels indicate increased organic load, potentially leading to oxygen depletion and harming aquatic ecosystems. Mirembe et al. (2019) investigated the impact of tin mining on the Mpigi River in central Uganda and found a strong correlation between mining activities and elevated COD levels, suggesting organic matter pollution in water sources from mining operations.

Turbidity: Turbidity refers to the cloudiness or haziness of water caused by suspended particles like clay, silt, organic matter, and microorganisms (APHA, 2021). Increased turbidity impacts water quality in several ways. Processing of tin ore generates tailings, a fine-grained waste product rich in clay and silt. Improper disposal of tailings leads to their direct entry into water bodies, significantly elevating turbidity (Akpor & Muchie, 2011). Mirembe et al. (2019) investigated the impact of tin mining on the Mpigi River in central Uganda and revealed a stron correlation between mining activities and elevated turbidity, suggesting increased soil erosion due to mining practices.

1.2 Effects of Heavy Metal Concentration in Water Sources

Tin: Tin (Sn) is a silvery white, shiny metal that can be forged and be formed. Tin is not easily oxidized in the air so it is often used as another metal coating to prevent rust. Tin's primary mineral source is cassiterite (SnO_2), which is processed to extract the metal. Historically, tin has been utilized in alloys, notably bronze (copper and tin), and in various applications such as tinplate for food packaging, solder, and antifouling agents in marine. Recent studies have explored the role of tin in advanced materials. For example, research on Ti_2SnC thin nanocrystalline films highlights tin's impact on microstructure and mechanical properties, demonstrating its importance in modern engineering applications (Klie, 2022).

Lead: Lead is ubiquitous in nature and one of the earliest metals discovered by the human race (Flora et al., 2012). It is found naturally in the earth's crust. Physically characterized by properties such as ductility, high malleability, softness, low melting point and non-corrosiveness, are the major reasons for its widespread usage (Flora et al., 2012). It is non biodegradale and therefore, it is able to persist and pose a potential toxin in the environment. Lead toxicity (saturnism) has been recognized as a major public health risk, particularly in developing countries (Bello et al., 2016). Though, some Heavy Metals such as Cu, Fe, Mn, Zn, Cd and Cr are essential for life, others like Hg, Pb, and As, are unfortunately toxic to human and the environment (Hamza Boko Usman & Yahaya Abubakar, 2021).

Mercury: Mercury is one of the metals with no known biological function in the body and it is very toxic and exceedingly bio-accumulative (Chen et al., 2012). Mercury exists in the form of metallic mercury, inorganic salts and organic compounds with each, possessing different toxicity rating (Azeh et al., 2019).

Focusing on the well enumerated literature above, and bearing in mind of some artisanal tin mining activities in Mwerasandu, Ntungamo district, the current study sought to: assess the physico-chemical properties including pH, turbidity, and chemical oxygen demand (COD) of the water from the Nyamuhimbura stream, Mwerasandu; and determine the concentration of tin, lead and mercury in the water sources of Nyakahiimbura Stream in Mwerasandu, Ntungamo district.

2. MATERIALS AND METHODS

2.1 Study Area

The study was conducted in Mwerasandu tin mine, located in Ntungamo District, Uganda. The geographical coordinates of the study area are approximately 0° 58' 59" S latitude and 30° 22' 59" E longitude. Mwerasandu tin site is located 27km from Ntungamo town and just 15km to the Uganda- Rwanda border as observed in Fig. 1.

2.2 Water Sample Collection

Six water samples were collected during both the dry and wet seasons of the year 2024 from water sources of the Nyakahiimbura stream near Mwerasandu tin mines using the WHO water sample collection guidelines (Godana & Mengistie, 2013). The samples collected from the

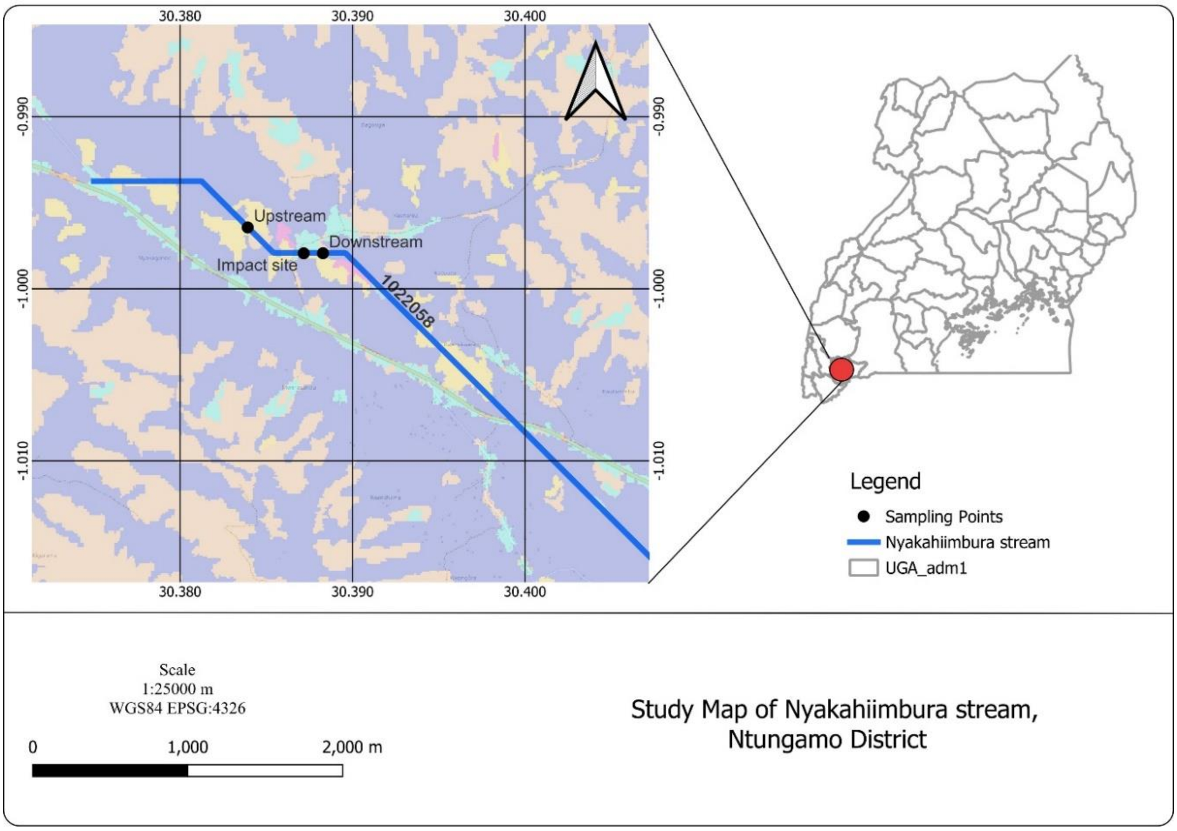

Fig. 1. The location of the study area (Primary Data, 2024)

upstream were used as a reference for the natural state of the research area. Pre-cleaned and sterilized preserved bottles of 1litre were used to collect the samples.

2.3 Water Sample Analysis

Determination of the physiochemical properties including pH, Chemical Oxygen Demand and Turbidity was done using benchtop pH meter, turbidimeter. The concentration of Lead (Pb), Mercury (Hg) and Tin (Sn) was carried out using Inductively Coupled Plasma Optical Emission Spectrometry (ICP – OES) from the Institute of Water resources, the National Water Quality laboratory, Entebbe.

2.4 Data Analysis

The water sample data collected were entered into a Microsoft excel to show the distribution of the contaminants and for analysis. An independent T-test and ANOVA were used to compare the element means differences between the water samples collected during the dry and wet seasons. The results were discussed and compared with the National, and East African wastewater effluent standards of 2020, 2016 respectively.

3. RESULTS

3.1 Physico-chemical Parameters of the Water Samples

Water Samples were collected from Nyakahiimbura Stream during the wet and dry seasons. The physico-chemical parameters analyzed included pH, Chemical Oxygen Demand and Turbidity.

The results show that pH and COD values during both dry and wet seasons were within the acceptable effluent Standards while Turbidity values from the upstream during the dry season and downstream of both dry and wet season are above the acceptable effluent standard limits (300NTU). This indicates some contamination of water sources found in downstream of River Nyakahiimbura probably brought about by tin mining activities.

Table 1. Pysico-chemical properties of Nyakahiimbura Stream water collected during wet and dry season (Primary data, 2024)

SN	Site Name	pH		Turbidity (NTU)		COD (mg/l)	
		Wet	Dry	Wet	Dry	Wet	Dry
1	Upstream area	7.1	7.1	266	475	6	10
2	Impact area	6.7	7.1	62.8	31	31	25
3	Downstream area	6.9	6.9	8683	>10000	<2	<2
4	National Wastewater Effluent Standards of 2020	5.0-8.5		300		70	

Table 2. Heavy meatal concentrations of the water samples during wet and dry seasons (Primary data, 2024)

SN	Site Name	Pd (mg/l)		Sn (mg/l)		Hg (mg/l)	
		Wet	Dry	Wet	Dry	Wet	Dry
1	Upstream area	<0.015	<0.015	0.09	0.118	<0.001	<0.001
2	Impact area	0.125	<0.015	0.363	0.173	<0.001	<0.001
3	Downstream area	<0.015	<0.015	<0.01	0.111	0.019	<0.001
4	National, and East African wastewater effluent standards of 2016	0.1		2.0		0.01	

3.2 Heavy Metal Concentration in Water Sources

Water samples collected from Nyakahiimbura Stream, Mwerasandu in Ntungamo district during the wet and dry season were analyzed for heavy metal concentration. The heavy metals analyzed were Lead (Pb), Mercury (Hg) and Tin (Sn) as shown in Table 2.

For the upstream location, the result revealed that the concentration of Pb, Sn and Hg (<0.015mg/L,0.09mg/L and <0.001mg/L) respectively are low compared to the Effluent Standard of 0.1mg/L,2.0mg/L and 0.01mg/L respectively during the wet season.

For the impact area, the results showed that the concentration of Pb of 0.125mg/l slightly higher compared to the threshold Standard of 0.1mg/L. For Sn, the concentration of 0.363mg/l is slightly above the concentration in the upstream but still below the threshold Standard of 2.0mg/L. For Hg, the concentration remained as it was in the upstream.

For the downstream location, the results revealed that the concentration of Pb (0.015mg/l) is low compared to the threshold standard of 0.1mg/L. For Sn, the concentration of 0.01mg/L is very low compared to the threshold Standard of 2.0mg/L. For Hg, the concentration of 0.19mg/L is high compared to the Effluent Standard of 0.01mg/L. The different results obtained could have been attributed by other factors apart from the mining activities like the agricultural activities taking place in the study area.

3.3 Dry Season

For the upstream location, the result reveal that Pb concentrations of 0.015mg/L which did not vary from those in the wet season. For the Sn, the concentration of 0.118mg/L is above the concentration in the wet season but low compared to the Effluent Standard of 2.0mg/L. Looking at Hg, the concentration of 0.001mg/L did not vary from that obtained during the wet season.

For the impact area, Pb concentration did not vary from that in the upstream concentration of 0.173mg/L is low compared to the wet season and the effluent standard of 2.0mg/L. For Hg, the concentration of 0.001mg/L did not vary from that obtained during the wet season.

Considering the downstream location, Pb concentration did not vary from that in the upstream. The Sn concentration of 0.111mg/L is low compared to the effluent standard of 2.0mg/L. Hg concentration of 0.001mg/L obtained during the dry season did not vary from the results obtained during the wet season.

Table 3. T-test on concentrations of heavy metals in the water samples collected during the dry and wet seasons (Primary data, 2024)

	Variable 1	***Variable 2***
Mean	0.071	0.05
Variance	0.005673	0.005341
Observations	3	3
Hypothesized Mean Difference	0	
Df	4	
t Stat	0.346583	
P(T<=t) one-tail	0.373184	
t Critical one-tail	2.131847	
P(T<=t) two-tail	0.746369	
t Critical two-tail	2.776445	

Table 4. ANOVA test on mean concentration of heavy metals in the water samples during the dry and wet seasons (Primary data, 2024).

Source of Variation	**SS**	**Df**	**MS**	**F**	**P-value**	**F crit**
Between Groups	0.001985	1	0.001985	0.22	0.65	4.49
Within Groups	0.14539	16	0.009087			
Total	0.147375	17				

A independent T-test was conducted to determine whether there was any significant difference between the concentrations of the heavy metals in the collected water samples during the dry and wet seasons and the results are as shown in Table 3.

The results revealed that, for both the wet and dry seasons, there was an almost similar mean value after the independent sample T-test. This lack of variation in the mean values indicates that water samples collected from the study area has no significant difference in concentration at P>0.05.

Similar results were confirmed when a one-way ANOVA was run to test mean differences between the concentrations of the heavy metals in the water samples obtained during the dry and wet seasons as observed in Table 4.

A single factor ANOVA test revealed that there was still no statistically significant variation as evidenced from p-value =0.65, p>0.05, which is above the standard threshold, and a low Fishers statistic of F=0.22 which is also way below the threshold value of F=4.49.

4. DISCUSSION

The study results revealed pH values were within the neutral range, good for the environmental conditions. According to the National, and East African wastewater effluent standards of 2020, 2016 respectively, for discharge of effluents to the water bodies and environment, the recommended pH is in the range of 5.0 – 8.5. Tin mining activities are affecting the pH of Nyakahiimbura stream, although the water turns towards acidity at the impact site in the wet season and at the downstream. A study by Ocheing et al. (2006) showed that the mining processes can lead to acid mine drain, which lowers pH and increases metal concentrations which adversely affect the aquatic ecosystems and water quality.

According to the East African effluent standards, the effluent discharged into the water body or environment should have turbidity of at most 300 NTU. The study revealed that the turbidity levels varied between sampling sites and slightly between the dry and wet seasons. Although Nyakahiimbura stream has some level of turbidity as shown in the upstream, tin mining activities are impacting the water clarity downstream, shown by the very high values both in the wet and dry seasons. As this is also reported by other researchers (Bell &Donnelly,2006; Miller,1999) who revealed that mining activities can mobilize contaminants, resulting in elevated turbidity and COD levels in near water bodies, posing risks to human health and environment. In the study, the high levels could have been brought about by the water volumes trapped at the impact area where washing and panning of tin mineral takes place, which later is released to flow downstream hence more volumes of water downstream hence increasing the turbidity levels in the downstream.

From the results recorded, the concentrations of heavy metals are high at the impact area because of tin mining, washing and panning being the main activity in Nyakahimbura stream, Mwerasandu. Though tin is less commonly discussed, it can cause gastrointestinal problems, skin irritation, and neurological effects (Hamad Mohammed, 2023).

Pb concentrations were detected in concentrations above the National wastewater effluent standards in only the impact area during the wet season. Samples taken during the dry season, all showed below detectable limits. The presence of Pb in wet season in this study could have been due to the run off from use of fertilizers in gardens around Nyakahiimbura stream especially at the impact site that found their way into surface water. Regardless of their levels, Pb has no biochemical advantages to human beings. The results are in agreement with study by (Hamad Mohammed, 2023) who stated that poisonous metals like As and Pb make up the first category, which are entirely unfavorable substances, have no biochemical advantages to human beings, and are hazardous regardless of their levels. Lead is mostly absorbed from respiratory and digestive systems but Pb can be absorbed from the skin, therefore the miners at the impact area of the study area of Mwerasandu tin mines are at a health risk due to exposure to lead in the waters as the findings revealed that lead concentrations were above the national wastewater effluent standards of 2020 at the impact area.

In the study area, Mercury was however detected in concentrations above the National wastewater effluent standards in the only downstream site (0.019mg/l) during the wet season. Hg concentrations in the downstream waters could have been due to other factors such as waste generated from consumer used items. This could pose a health risk to the community, plants and animals that consume the water from Nyakahiimbura stream. In relation to the study findings, Meena et al. (2008) reported that several metals, such as Pb and Hg are extremely harmful to both humans and ecosystems. Big concerns have been raised globally about water contamination brought about by the discharged heavy metals into the environment (Abbas et al., 2016).

5. CONCLUSION AND RECOMMENDATIONS

Artisanal tin mining in Mwerasandu mines, Ntungamo District is among other economic activities such as agriculture and business that members of the local community depend on for a livelihood. The study showed the presence of some levels of concentrations of tin, lead and mercury in the water samples obtained. The concentrations of tin is worth expected since it is the economic activity taking place in the vicinity but the concentrations of other metal including lead and mercury raises community concern as these are very dangerous metals to the people's health. The concentrations of Pb and Hg in the impact area and downstream areas respectively during the wet season which were above the National wastewater effluent standards could have been attributed by other activities like agriculture and other micro businesses.

It is therefore recommended that mine wastes be regulated and turned into a non-harmful form before they are discharged into the streams and swamps around the mines to avoid contamination of the water sources within the mine vicinity. In addition, attention should be drawn to some stakeholders such as Ministry of Health, Ministry of energy and minerals development, to periodically monitor the levels of heavy metals in the water from the study's stream in order to prevent adverse effects the local community may encounter by drinking such water. Water for domestic use should first be treated before it is consumed. Also, a local management policy should be formulated to regulate the mining of tin and only allowing the authorized or registered companies or individuals to mine.

DATA AVAILABILITY

The data presented in the manuscript is available on request.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

ACKNOWLEDGEMENTS

We thank the Institute of Water resources and the National Water Quality Laboratory, Entebbe that allowed us to conduct laboratory tests from their laboratory premises. Additionally, special thanks to the Management at Mwerasandu Tin Mines for the support during the study

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/125653