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Water, Sanitation and Hygiene Practices and Associated Health Risks for Artisanal and Small-Scale Gold Mining at Stamico, Nsangano, and A.S. Lulila Mine Sites in Tanzania

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ABSTRACT: Access to improved water, sanitation, and hygiene is one of the main factors linked to community health risks. Hence, the objective of this paper as to evaluate the water, sanitation and hygiene practices and associated health risks for artisanal and small-scale goldmining at Stamico, Nsangano, and A.S. Lulila Mine Sites in Tanzania using 148 participants with structured questionnaires to harvest quantitative and qualitative data in this study. Findings of the study have revealed that about 95% of the case study area use boreholes water for domestic purposes, and majority use water without treatment. Pit latrines and open defecation are the common practices for most people at the sites. As such, this study revealed that, there is a possibility of microbial infection from salmonella due to the exceeded the limit value of 10^{-4}. The chronic daily intake suggested that the overall hazard quotient of cancer risk from lead (Pb) was less than the tolerable limit for Pb exposure. The human health risk was assessed and the incremental lifetime cancer risk at all sites was low with values below 10^{-6}. It is advised that artisanal and small-scale gold mining sites enhance their sanitation and water supplies in order to maintain excellent hygiene practices.

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Artisanal and Small Scale-Gold Mining (ASGM) in developing countries including Tanzania supports livelihoods of a large section of the population (Maganga *et al*., 2023; Kinyando and Huggins, 2020). However, according to Mutagwaba *et al.*, (2018) and Merket, (2019), ASGM is accompanied by several challenges including poor health status and environmental pollution. Allan-Blitz *et al*., (2022), have also reported that, gold mining operations at ASGM sites involve complex and diverse hazards as most mining sites are exposed to toxic hazards such as mercury, lead and arsenic (Pavilonis *et al*., 2017). Bose-OReilly *et al*., (2017), have also reported that among the risks that ASGM is exposed to include concentrations of heavy metals, which may have impacts on the development of neurocognition (Yorifuji *et al.*, 2007). On the other hand, Egmann *et al*., (2018), have also indicated that ASGM struggles with the challenges related to infectious diseases. In many gold mining sites, access to clean and safe drinking water and sanitation facilities are limited. Miners often lack access to adequate water treatment infrastructure, resulting into the use of contaminated water. This in turn results into triggering and spreading of various disease vectors and consequently health risks to miners and the communities around the mining site neighborhood at large (Hilson, 2012). According to Stephens and Ahern, (2001), poor hygiene practices

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are among serious problems posing mild microbial contamination with water-borne infections and heavy metal contamination due to mining operations. Expansion of ASGM operations has resulted in increased pressure on communities Water, Sanitation and Hygiene (WASH) infrastructure, particularly in developing countries. In Sub-Saharan Africa for example, around 60 million ASGM sites face inadequate drinking water supplies, toilets and solid wastes disposal sites. This endangers safety and health of the miners and the neighboring communities (Schwartz *et al*., 2021). As such, there is a need to improve water treatment and accessibility, use practices as well as sanitation systems and hygiene facilities. According to Arthur -Holmes, (2022) and Kazapoa, (2023), this should go hand in hand with formalization of ASGM sites. Similarly, Puluhulawa *et al.*, (2023) has reported that most of ASGM are until these days conducted without authorized permit and thus can cause environmental harm and therefore needed to be formalized and monitored by law. Assessment of WASH related risks to human health in ASGMs is currently receiving attention due to the increasing ASGM activities in low-income countries, including Tanzania (Maganga *et al*., 2023). This has a potential to influence the improvement WASH conditions. However, there are inadequate studies in Tanzania and many developing countries on WASH conditions and associated risks in ASGM. The aim of this study was to examine water sanitation and hygiene practices and associated health risks due to the operation of ASGM in the communities surrounding the State Mining Cooperation (STAMCO), Nsangano and A.S Lulila mine sites in Geita Gold field region in Tanzania.

MATERIALS AND METHODS

Description of the study area: The study was conducted in three ASGM sites in Geita Region. Geita is a city and regional capital of Geita Region in northwestern Tanzania. Geita Region, with a population of 318,006 (2022 census), is located in the center of a gold mining areas and is known for its gold trade. The specific case study areas in Geita Region are STAMCO, Nsangano and A.S. Lulila. These sites are located within Nyarugusu ward in Geita region. Nyarugusu ward encompasses approximately 179km^2 and is geographically located at 03˚07.903'S latitude and 032°11.340' E longitude. Nyarugusu ward has a population of about 42,669 and is divided into eighteen (18) sub wards (Figure 1). The study area was selected due to high population of the miners, and was thus considered to be a rich case study for data on WASH practices and associated risks. Also, the case study area has a diversity of the mining operational activities including digging process (manual i.e., without using machines), gold amalgamation process, gold processing using VAT leaching and CIP methods.

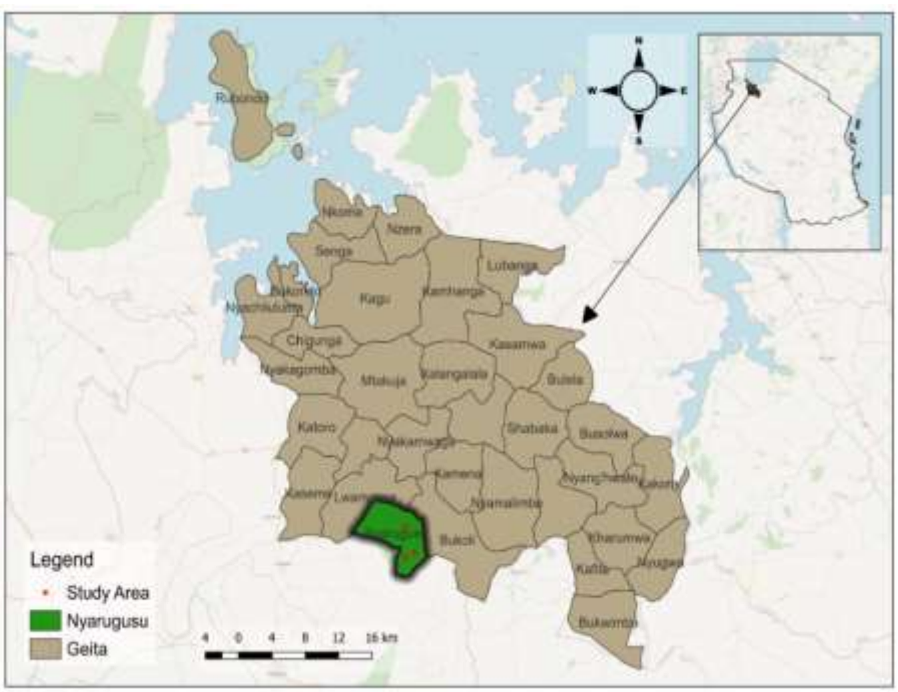

Fig 1: Nyarugusu ward Locational map (Source: STAMICO mine site, 2023)

Description of Nsangano mining site: The mine site deals with mining of gold (Figure 2). The whole process of mining at Nsangano starts from the pit hole up to the gold plant process. The mining site has about 150 temporary and permanent staff/workers. The mining process starts from the shaft holes. Water from the shafts is pumped out into the drainage system which in turn directs the water into gold amalgamation process and finally to the water pond for the storage.

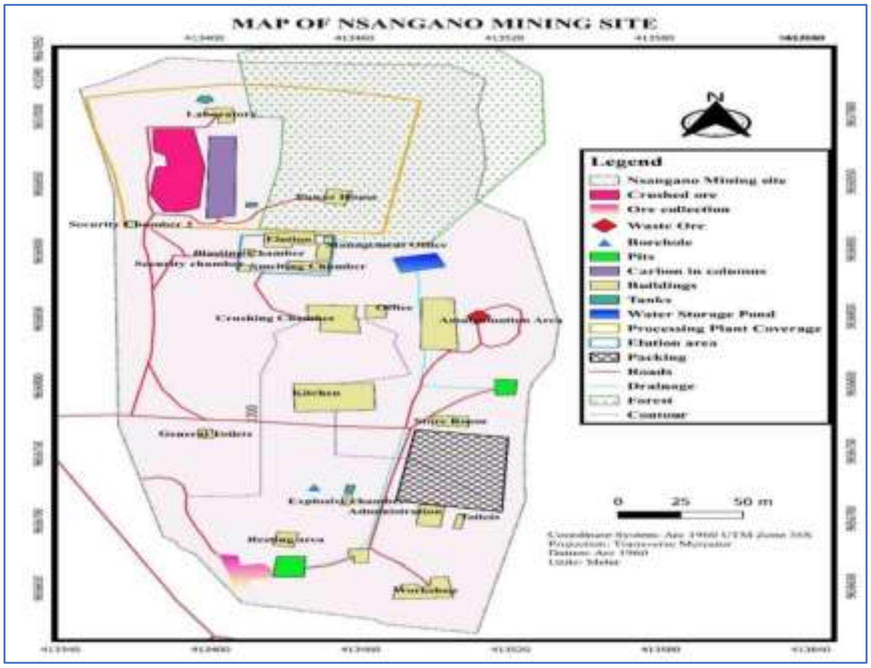

Fig 2: Map of Nsangano mining site (Source: Nsangano mine site, 2023)

Description of A. S. LULILA mining site: The mining site deals with the processing of the gold by the use of carbon in pulp method (CIP) (Figure 3). The mining site has a kitchen, administration block, storage container, toilets, elution area, crushing, carbon in pulp machines and the tailing storage facility. The mine site has about 200 workers both temporary and permanent employed.

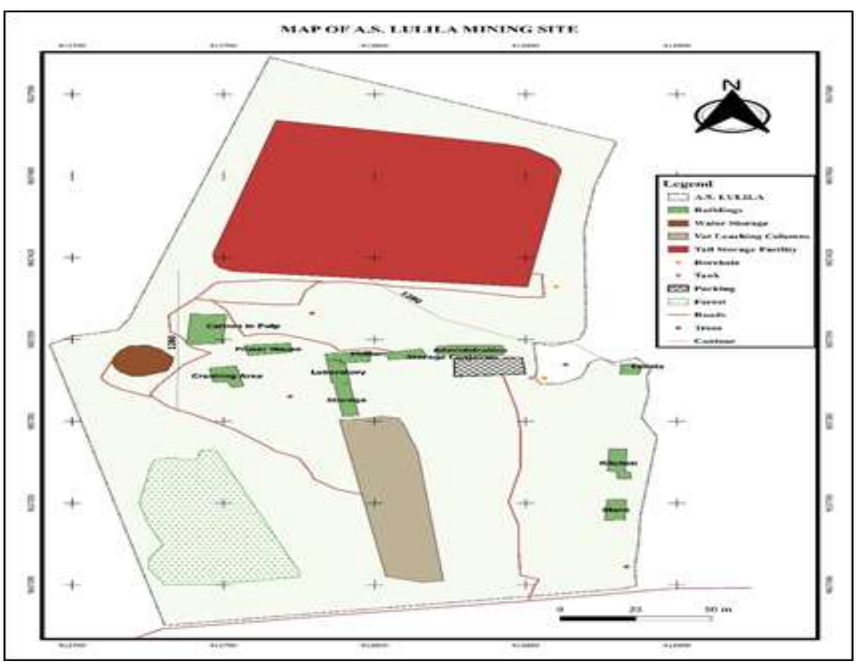

Fig 3: Map showing A.S.LULILA mining site (Source: A.S.LULILA mine site, 2023)

Description of STAMCO mining site: STAMCO mining site has about 24 shaft holes operating on the area. The mine site is operated using gold amalgamation process. The mine site has about 500 miners. The area is composed of the gold called nuggets of which are pure gold which does not need processing. The whole mining area is surrounded by the residential settling of people with other activities taking place form the area (Figure 4)

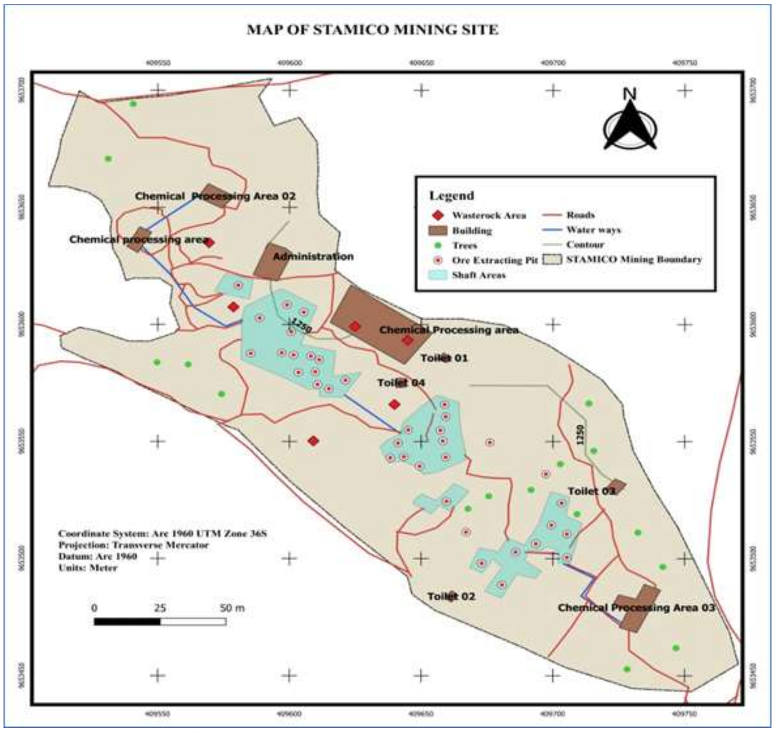

Fig 4: Map of STAMICO mine site (Source: STAMICO mine site, 2023)

Research methodology: To achieve both the main objective and the more focused research objectives, this study employed a variety of methodologies, such as interview and questionnaires, field observations, and experimental study (laboratory water analysis). A mixed approach involving quantitative and qualitative methods was employed during the research

Interview and Questionnaire: Semi structured questionnaires were developed to collect data from miners and the surrounding community, approximately 148 participants were involved in the process. The focus was on responses to miners on water sanitation and hyiegen practices during gold mining activities at the three ASGM sites (STAMICO, Nsangano and A.S.Lulila)

Water sampling and analysis: Water samples were collected from the three mine sites at the Nsangano, STAMICO and A.S.lulila sites, the main water sample collected from the tap water (drilled boreholes). Water samples were collected in 1000 ml plastic bottles for chemical parameters and 500ml glass bottles for biological parameters. Bottles for chemical parameters were cleaned and rinsed with deionized water. For the case of water sample preservation; all samples were stored in a cooling box which contained ice packs. Figure 5 indicates water sampling location map

Heavy metals analysis: Heavy metals were analyzed using AAnalyst 100 and a PerkinElmer Instrument (Atomic Absorption Spectrometer). All analyses followed the standard method (APHA 2012).

*Analysis of Escherichia coli (E.coli) :*The spread plate method was used for the analysis of *E.coli* from the water samples as the method adopted from Leo & Leen (2014), and the M061 MacConkey agar w/Bromo Thymol Blue (HIMEDIA) was used to culture these coliforms. The instruments involved were; petri dishes (BOSOLIC model), pipette (Thermo scientific model), incubator (Fisher scientific: 630D model), analytical balance (SCIENTECH: ZSA210 Rev-E model), and the hot plate (CIMAREC model). The incubation time and temperature were 24 hours and 37ºC respectively. After the preparation of MacConkey agar w/Bromo Thymol Blue for *E.coli*, 1ml of the sterile media was injected into the sterilized petri dishes and left to solidify for 5minutes, then 1ml of water sample measured by micro pipette were spread on the petri dish using glass spreader and the plates were taken into the incubator in inverted style and left there for 24hours at 37ºC for incubation purpose. The results of colony count were taken after the incubation time of 24 hours.

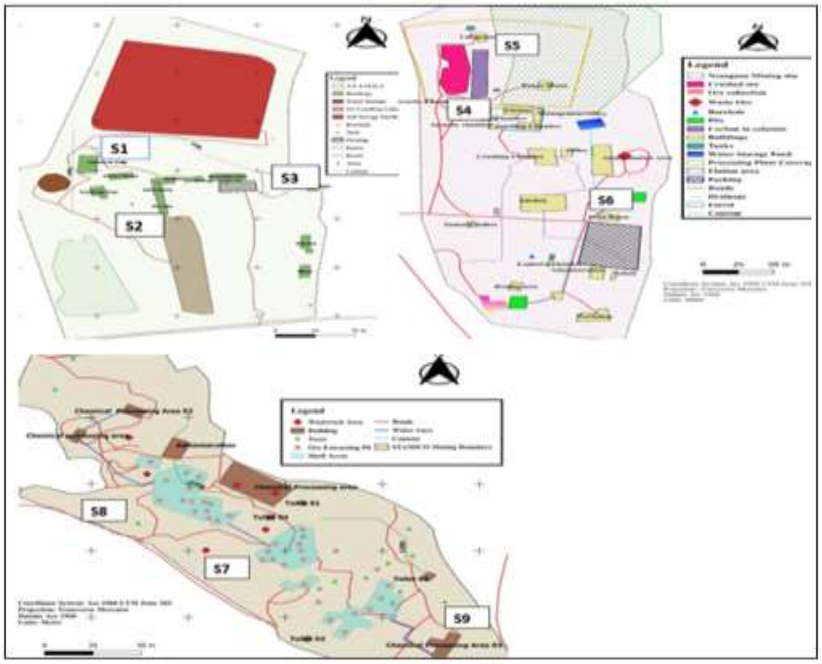

Fig 5: Map of water sampling locations (S1 to S9) at three mine sites (Nsangano STAMICO and A. S. Lulila)

Analysis of pathogenic microbes: The pathogenic microbes analyzed in this study was *Salmonella spp*. These microbes were analyzed through spread plate method as adopted for *Salmonella spp* (APHA, 2017). The media which was used for the culturing is the *Salmonella-Shigella* agar (SSA) media (HIMEDIA M108) and the incubation temperature and time was 37ºC and 24 hours respectively. After the preparation of SSA, 1ml of the sterile media was injected into the sterilized petri dishes and left to solidify for 5minutes, then 1ml of water sample measured by micro pipette were spread on the petri dish using glass spreader and the plates were taken into the incubator in inverted style and left there for 24hours at 37ºC for incubation purpose. The results of colony count were taken after the incubation time of 24 hours.

Health Risks Assessment: The assessment included identifying the hazards, assessing the dose-response relationship, assessing the route of exposure and characterizing the risks to determine the existing human's health risk.

Quantitative microbial risk analysis approach: The beta poison model was used to estimate infectivity for individual exposure events and annual exposure events (EPA (2014). The model has been used to predict the contamination event probability of infection and the annual probability of infection from year -round. In addition, the model was used to the selected annual health benchmark and the infection risk of $1*10^{-4}$ per person per year for drinking water as adopted from Gal *et al*., (2015)

Human health risk assessment for heavy metals: The risk assessment was conducted based on the carcinogenic effects of heavy metals. The exposure pathways were water intake. The reference doses (RfD) and slope factors (SF) for carcinogens were determined in accordance with USEPA (2004). The main human health values in terms of carcinogenic risk were characterized by a threshold dose of toxicity, expressed by the reference dose (RfD). The hazard index (HI) was calculated from the sum of all calculated hazard quotients (HQs). Therefore, HI values below 1 indicated absence of risk and HI values above 1 indicated risk (USEPA, 2001). The total carcinogenic risk (TCR) values were compared with the permissible reference value (USEPA, 2001). If the calculated TCR values greater than $1*10^{-4}$ were considered (with a high degree of certainty) an unacceptable risk and a value less than $1*10^{-4}$ is an insignificant risk

RESULTS AND DISCUSSION

Water supply, sanitation and hygiene practices of surrounding ASGM sites: This study revealed that the main sources of water supply in the mine sites were drilled boreholes. This water is used for drinking, cooking, household laundry and personal hygiene. Majorities of these boreholes are located close to the mining operations (Figure 5). These operations can interfere with the quality of water unless this water is well treated. On the other hand, human activities such as mining, disposal of chemical and microbiological materials can change the water natural composition and quality (Ritter *et al*., 2002). Similarly, the study by (MacDonalde and Calow, 2009) reported that improper construction of borehole could cause ground water contamination.

Treatment of the water supply at ASGM area: In the mine site areas, approximately 86% of people do not use treated water and only 14% treat water. The findings align with WHO, (2019) that due to the nature of their operations and the surrounding communities, most ASGM workers do not treat water for consumption. The existing method for treating water is boiling. Miners also use bottled drinking water, with miners from the Nsangano mine site providing water for employees, while workers at other mine sites purchase the bottled drinking water as a source of treated drinking water.

Quantity of water used in the ASGM operations: The amount of water that miners uses per at the Nsangano mine site ranged from 10 to 32 liters per day, at A.SLulila about 2 to 5 liters per day and at STAMICO between 8 and 44 liters per day as shown in Figure 6. The consumption is relatively lower than the recommendations by Tanzania Water Supply Design Manual and the World Health Organization acceptable standards. In addition, UNDP (2006), has suggested that most of the people categorized as lacking access to clean water use about 5 liters per day. This study has indicated that there was a shortage of water supply especially at A.S. Lulila of which they have shown people use less than 5 liters per day (Figure 6). Other studies reported that The WHO outline a global drinking water availability benchmark which recommends that between 50 and 100 L/capita/day (LPCD) is required to meet domestic needs, including washing, personal hygiene and cleaning (Howard *et al*., 2003). Similarly, in the global considerations on water supply and sanitation , has reported in the 2030 agenda that , have to support of the achievement on water and sanitation. In the study by Hunter et al., (2010) reported that at least 50 liters per person per day is required to ensure all personal hygiene. Furthermore, in adequate water supply prevents good sanitation and hygiene, in this regards its important to improve in all various areas of water supply to enhance public health (Howrd *et al*., 2003)

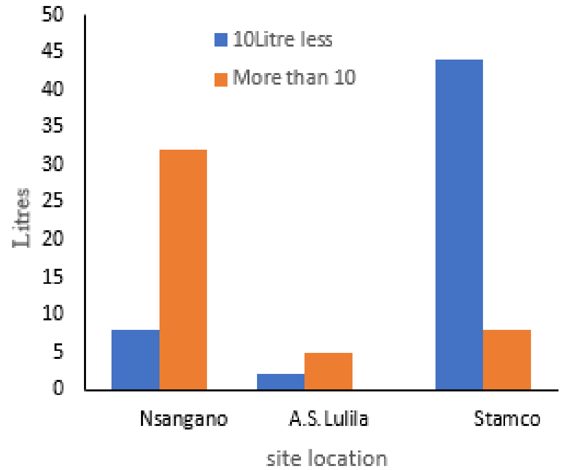

Fig 6: Quantity of the water used for ASGM at case study

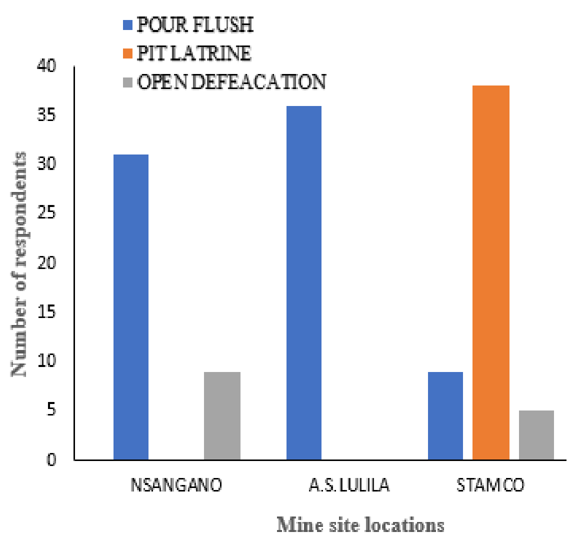

Fig 7: Type of toilet facilities used by ASGM at case study site

Sanitation facilities: This study revealed that majorities of workers at ASGM use pit latrine, especially at STAMCO mine site, while at A. S. Lulila and Nsagano mine sites, flushing and open defecation were used. Most studies indicate that ASGM workers experience problems in accessing quality water supplies because mining sites are located in rural areas and these facilities are not easily accessible. In the study conducted by (URT, 2015) pointed out that about b17% of the rural area remain without access to toilet or latrine which lead to practices of open defecation. There is a need to improve sanitation infrastructure, as the achieving the agenda or sustainable development goal of accessing to safely managed sanitation facilities (UN, 2020). Improving water supply along with sanitation would increase people's health, social and economic well-being (Banjoko, 2017). Likewise, miners should be associated with improvements in access to modern water and sanitation services (Dietler *et al*., 2022).

Washing facilities used by ASGM: This study observed that 34 people responded that don't wash their hands especially while eating and after using the toilet at STAMICO whereas at Nsangano, for 40 participants, about 28 responded that they washed their hands. Few than 5 participants did not use soap when washing their hands as indicated in Figure 8. Unwashed hands can easily transmit diseases. In this study as it's observed most of mine sites they were not treated their water as this can contributed to contamination if the hands practices is not implemented. In addition, the mine sites (Figure 6) used less than 50 liters per capital per day. Other studies (Musa *et al*., 1990) presented that some microorganisms can survive on hands for different times.

Microbial health risk assessment: The assessment of these risks was based on the fact that microbes emerged as a hazard from the study at the mine sites, as indicated in Tables 1 and 2. The infection probability for *E coli* was between 33.2×10^{-7} to 9.5×10^{-7} and the annual risk was 1.2×10^{-4} to 3.5×10^{-4}. Other studies (Busgang *et al.*, 2018), have suggested that the probability of infection is between 10^{4} to 10^{-5}. Therefore, in this study, the extent of infection by *Ecoli* from water supplies in ASGM areas was insignificant (Table 1).

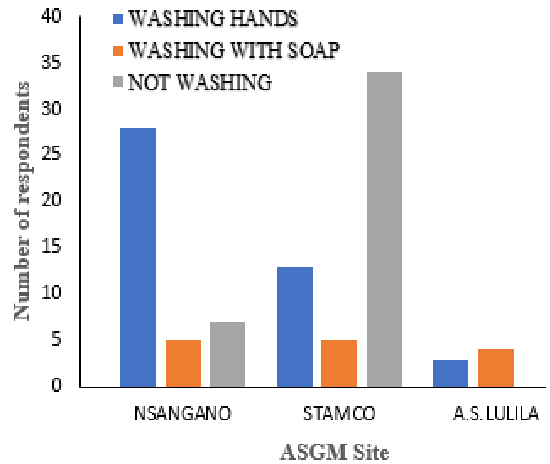

Fig 8: Washing hands as hygiene practices for ASGM

Salmonella infection rate was higher and the calculated annual risk was one as indicated in Table 2. In another study Abuzerr (et al. (2022) have reported that the annual risk of infection from contaminated water with *Ecoli* amounting to 3.21×10^{-4}. This higher than EPA. In this respect, the results of *E.coli* (Table1) for boreholes (S2 and S3-A.S.Lulila mine site), and borehole (S9- Stamico mine site) aligned with Abuzerr *et al*., (2022) findings, and were above EPA standards.

Table 1: Microbial risk estimation for *E coli* at ASGM sites

Mine sites	Source of the water	Samples of water	Number of organisms (*E. coli*) [Count/100ml]	Probability of infection (P)	Annual risk (PA)	Life time risk (PL)
A. S .LULILA	Borehole	S1	N/D	-	-	-
	Borehole	S2	9	9.5×10^{-7}	3.5×10^{-4}	1
	Borehole	S3	9	9.5×10^{-7}	3.5×10^{-4}	1
NSANGANO	Shaft water	S4	3	3.2×10^{-7}	1.2×10^{-4}	1
	Borehole	S5	N/D	-	-	-
	Borehole	S6	N/D	-	-	-
STAMCO	Borehole	S7	N/D	-	-	-
	Borehole	S8	3	3.2×10^{-7}	1.2×10^{-4}	1
	Shaft water	S9	9	9.5×10^{-7}	3.5×10^{-4}	1

Table 2: Microbial risk estimation for Salmonella spp at ASGM sites

Mine sites	Source of the water	Samples of water	Number of organisms Salmonella spp	Probability of infection(P)	Annual risk (PA)	Life time risk (PL)
A. S. LULILA	Borehole	S1	ND	-	-	-
	Borehole	S2	4	0.03	1	1
	Borehole	S3	ND	-	-	-
NSANGANO	Shaft water	S4	3	0.02	1	1
	Borehole	S5	ND	-	-	-
	Borehole	S6	ND	-	-	-
STAMCO	Borehole	S7	2	0.02	1	1
	Borehole	S8	2	0.02	1	1
	Borehole	S9	4	0.03	1	1

ND means not detected

Chronic Daily Intake (CDI), Hazard Quotient (HQ), Incremental Life Cancer Risk (ILCR) value for carcinogenic heavy metals risk assessment: The water samples from the ASGM sites (S3 – A.S.Lulila, S4 – Nsangano and S7- Stamico) showed high CDI for Pb as compared to Cd (Table 3). Also, the hazard quotient of cancer risk for Pb ranged from 1.5×10^{-6} to 2.5×10^{-6} while for Cd ranged from -3.1×10^{8} to 2.5×10^{-6} at all sampling sites (Table 4). The incremental life cancer risks (ILCR) values for Pb at S3, S4 and S7 were higher compared to values of Cd (Table 5)

Table 3: CDI value for heavy metals from water supply at ASGM sites

Sample	Pb	Cd
S1	1.5×10^{-6}	-3.1×10^{-8}
S2	1.5×10^{-6}	2.5×10^{-6}
S3	2.5×10^{-6}	2.5×10^{-6}
S4	2.5×10^{-6}	3.1×10^{-7}
S5	1.5×10^{-6}	1.9×10^{-7}
S6	1.7×10^{-6}	4.7×10^{-7}
S7	2.5×10^{-6}	3.1×10^{-8}
S8	1.9×10^{-6}	6.9×10^{-7}
S9	1.8×10^{-6}	1.6×10^{-7}

Table 4: HQ value for the heavy metals from water supply at ASGM sites

Sample	Pb	Cd
S1	1.5×10^{-6}	-3.1×10^{-8}
S2	1.5×10^{-6}	2.5×10^{-6}
S3	2.5×10^{-6}	2.5×10^{-6}
S4	2.5×10^{-6}	3.1×10^{-7}
S5	1.5×10^{-6}	1.9×10^{-7}
S6	1.7×10^{-6}	4.7×10^{-7}
S7	2.5×10^{-6}	3.1×10^{-8}
S8	1.9×10^{-6}	6.9×10^{-7}
S9	1.8×10^{-6}	1.6×10^{-7}

Table 5: ILCR for Carcinogenic heavy metals.

Sample	Pb	Cd
S1	1.3×10^{-5}	-1.9×10^{-7}
S2	1.3×10^{-5}	1.5×10^{-5}
S3	2.1×10^{-5}	1.5×10^{-5}
S4	2.1×10^{-5}	1.9×10^{-6}
S5	1.3×10^{-5}	1.1×10^{-6}
S6	1.4×10^{-5}	2.9×10^{-6}
S7	2.1×10^{-5}	1.9×10^{-7}
S8	1.6×10^{-5}	4.2×10^{-6}
S9	1.5×10^{-5}	9.7×10^{-7}

The values of CDI of heavy metal concentrations from water were found in the order of Pb>Cd.; the findings are in line with Munene *et al.* (2023). The levels of HQ were very low consistent to Munene et al. (2023), who reported the sum of HQ in groundwater to be less than 1.0. Based on cancer risk assessed, the level of ILCR for Pb carcinogenic ranged from 1.3×10^{-5} to 2.1×10^{-5} for all sampling sites whereas Cd carcinogenic ranged from -1.9×10^{-7} to 4.2×10^{-6}. These findings were very low; cancer risk values reported by Ullah et al. (2017), of between 10^{-6} and 10^{-4} were considered low for health risk whereas greater than 10^{-4} values can cause human health risk. Findings are also lower and consistent to the United State Environmental Protection Agency (USEPA) value of 1×10^{-6} considered as a tolerable value for monitoring purpose of a cancer risk (Kamunda *et al.,* 2016).

Conclusion: The main objective of this study was to evaluate WASH as well as the health risks among small-scale and artisanal gold miners. Due to hygienic practices, ASGM practice open defecation and pit latrines. The majority of ASGM don't wash their hands, and the possibility of human infection and the risks associated with prolonged use of the water were also indicated. However, this study revealed that there is no risk from heavy metal contamination. Findings from this study suggested the needs for improvement in the WASH practices in the ASGM mine sites.

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