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ASSESSMENT OF ARTISANAL GOLD MINING IMPACT ON MALE WORKERS' HEALTH IN MACALDER GOLD MINES, MIGORI, KENYA

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Abstract: Concentrations of metals in samples of fish and drinking water from the study area and nails and scalp hair of male adults between the ages of 28 and 45 years working in Macalder Gold mines in the low lying areas of Migori Gold Mining Belt, collected between Jan, 2014 and December, 2014, are reported in this paper. Purposeful random sampling was used to pick 50 males who worked in the small scale mines area whilst another 50 males from the control which is over 270Kms away, Eldoret, were also included. The control study area is in the highland regions of Eldoret Municipality which forms part of the water catchment area of Lake Victoria. The samples were processed, packed and shipped for analysis in ACME laboratories, Vancouver, Canada. The mean concentration results revealed that the exposure to contaminants from gold mining activities have significantly increased the concentrations of the studied metals in the bodies of the target group working in the gold mines in various gold extraction activities either digging, crushing or roasting the amalgamated mercury –gold. Lead, Cd, Cr, Cu, and Zn concentrations were significantly higher ($p < 0.05$) in the hair samples collected from the polluted area as compared to control area. The research indicated that the male workers in the mines are exposed to high health risks associated with heavy metal contamination and exposure to other metals associated with gold mining. The study advocates for strict adherence to safety measures and remediation practices that would reduce health risks and the degradation of the environment. Education and drastic interventions need to be encouraged to protect the workers from multiple health risks associated with gold mining activities in Migori Gold Belt in Kenya.
Keywords: Gold mines; exposures, heavy metals, human hair; human nails.
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INTRODUCTION

Heavy metals are natural components of the earth's crust that cannot be degraded or destroyed (Duruibe, *et. al*., 2007, Sani, 2011, Imasuen and Egai, 2013). They have been defined variously by different authors. Some researchers refer to these metals as potentially harmful elements (PHE) (Wragg , *et. al*., 2014, Obunwo and Boisa, 2014). What is common is that heavy metals are metallic elements that have a relatively high density, toxic and poisonous. According to many researchers , for example, Blaber, 2000; Farombi, *et al.,* 2007; Ashraj, 2005; Brewer, 2010, heavy metals can cause contaminations that result in long lasting effect on the ecological balance of the environment and the diversity of the different aquatic species living in it. Thereafter contaminants are passed on to humans through the food chain. The potentially harmful elements (PHE), to which most of heavy metals belong, may enter the human organism via respiratory and digestive tracts or skin (Ljung 2006; Nieć *et al.* 2013, Kicińska and Klimek, 2015). During gold mining operations other elements are often present and also dissolved and include Cu, Pb, Zn, Fe, Co, Hg (Boyle and Smith, 1994, Hang *et al*., 2009), with geologically enriched environments containing high concentrations. Analyses of human biomarkers have been used to demonstrate occupational or environmental exposure to toxic elements (Were *et al*., 2008, Ghorbani, *et. al*., 2013). Human hair and nails reflect metal mean level in human body during a period of 2–5 and 12-18 months respectively (Were et al., 2008, Parizanganeh, *et al*. 2014). Simultaneous use of hair and nails for biological monitoring in relation to male exposure through fish and drinking water consumption has not been studied sufficiently well for drawing tangible correlations with the exposure levels in this study area. The study focused on assessment of the contribution of gold mining activities and consumption of fish and drinking water to body metal burden in male adults in Migori Gold Belt, Kenya, through determining the concentration of metals in hair and nails. In aquatic ecosystem, heavy metals are considered as the most important pollutants, since they are present throughout the ecosystem and are detectable in critical amounts. Heavy metals, such as Hg, Cd, Cu, Pb, and Zn are some of the most important pollutants which have effects on the aquatic environment and its resident organisms particularly fish. Therefore these pollutants are extremely dangerous for the health of fish and consequently humans that feed on them. Most of these metals characteristically accumulate in tissues, and lead to the poisoning of fish. These heavy metals can effectively influence the vital operations and reproduction of fish; weaken the immune system, and induce pathological changes. As such, fish are used as bio-indictors, playing an important role in monitoring heavy metals pollution (Authman, *et al*., 2015). Fish has turned into a favourite biomarker in research (van der Oost, *et al*., 2003, *et. al*., 2003), because of its sensitivity to temperature changes, natural surroundings (Dalzochio and Gehlen, 2016) and water quality deterioration and additionally aquatic contamination antagonistically influence the fish health (Procópio , *et. al*., 2014, Paulino *et. al*., 2014), which might bring mortalities and ecosystem degradation (Skouras *et al*., 2003). Fish are widely used as biondicator organisms and they represent the most feasible organisms for pollution monitoring in aquatic systems (Linde-Arias *et al*., 2008, Boamponsem, 2013, Jalal, *et al*., 2013). Fish can be found virtually everywhere in the aquatic environment and they play a major ecological role in aquatic food-webs because of their function as carrier of energy from lower to higher trophic levels (van der Oost *et al*., 2003, Sabullah *et al*.,2015). Fish is at higher feeding level in the food chain and human relying on the fish as a common food in their diet as is in the study case may be at great danger if the fish is contaminated. Due to this, fish may be used as a reliable biomarker to determine the health risks exposed to human who feed on them. In this study, heavy metals recorded from the fish were correlated to health risks in males working in the gold mines. In the recent past, increasing interests towards biomarkers of heavy metals have been recorded by many researchers. The interest in biomarkers for heavy metals impact is that it allows for development of bio monitoring program, according to the test subject either had been exposed in the past or currently exposed to environmental stimuli. This study used 'sardine' *Rastrineobola argentea* (Cyprinidae) as a biomarker to assess health risks exposed to the target group in an area where gold mining is carried out throughout the year and as well as drinking water within the mines.Due to its size, the whole fish was used in the analysis of metals as its eaten whole (Khaled, 2004, Edward, 2013).

EXPERIMENTAL

Study Area Setting: The study area contains rich deposits of metals from geological origin (Figure 1). Compounding the problem of metal pollution in the region is the continuous operation of small scale artisanal gold mining over the last few decades. Water for human consumption is obtained directly from either the ground that is bore hole or rivers draining through the basin. The fish used in the study is a commonly available commodity and was provided by the participants whose hair and nails were used in the study.

Sampling Design and Procedure: Samples were collected between Jan, 2014 and December, 2014. Helsinki 1996 protocols were followed and permission obtained from the Institutional Research and Ethics Committee (IREC) of Moi University, Kenya. The sampling site S1 (Macalder North), S2 (Macalder), S3 (Karungu) and S4 (Eldoret Municipality). In S1, gold mine activities are mostly done in homesteads, S2 depicts true picture of small scale mining activities on an expansive land occupied by over 100,000 persons with a 24 hour economy of gold mining activities, S3 is near the Lake Victoria where rivers draining through Macalder area empty into the Lake Victoria. S4 which is mainly an agricultural area is Eldoret Mucipality has no gold mining activities but form part of the watershed and catchment area for Lake Victoria and rivers flowing towards the Lake Victoria. Samples of drinking water, fish, hair, and nails were collected from the study sites 1-4 as shown in figure 2. Scalp hair and nails were collected from each individual in triplicate (IAEA, 1985). All equipment used were pre-soaked with concentrated nitric acid (65%) and sulphuric acid (30%) solutions of 1:1 volume ratio, washed in 2 L of tap water, rinsed three times with ultra-pure water and dried prior to the field work. Hair samples were collected from 50 men working in the small scale gold mining area and 70 men from the reference site (Eldoret Municipality: 270 Kilometres away). The mine workers were informed of the purpose of the study and their consent obtained. Inclusion criteria were as follow: Sample population comprised men who worked in the mines with no diagnosed terminal illnesses or dyed hair and subjects who must have worked in the mines for at least 5years. Every concern of the participants was addressed. Confidentiality was upheld as the participants were each referred to by a coded name. The participants were assured that the hair and nail analysis results were basically for research only and not for medical purposes. Further, Helsinki 1996, protocols were followed and permission to carry out the study was obtained from the Research and Ethics Committee (IREC) of Moi University, Kenya.

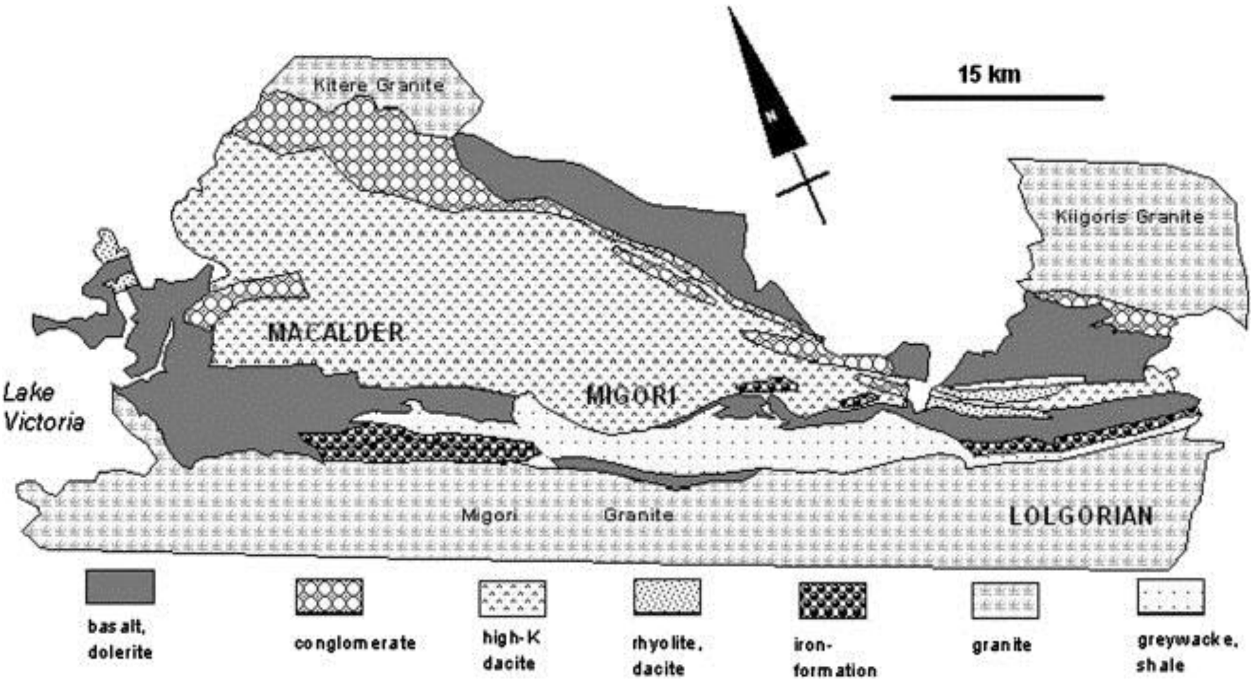

Figure 1. The geology of the Migori complex (Ichang'i and Maclean, 1990), in the Migori artisanal gold mining belt of southern Nyanza, Kenya

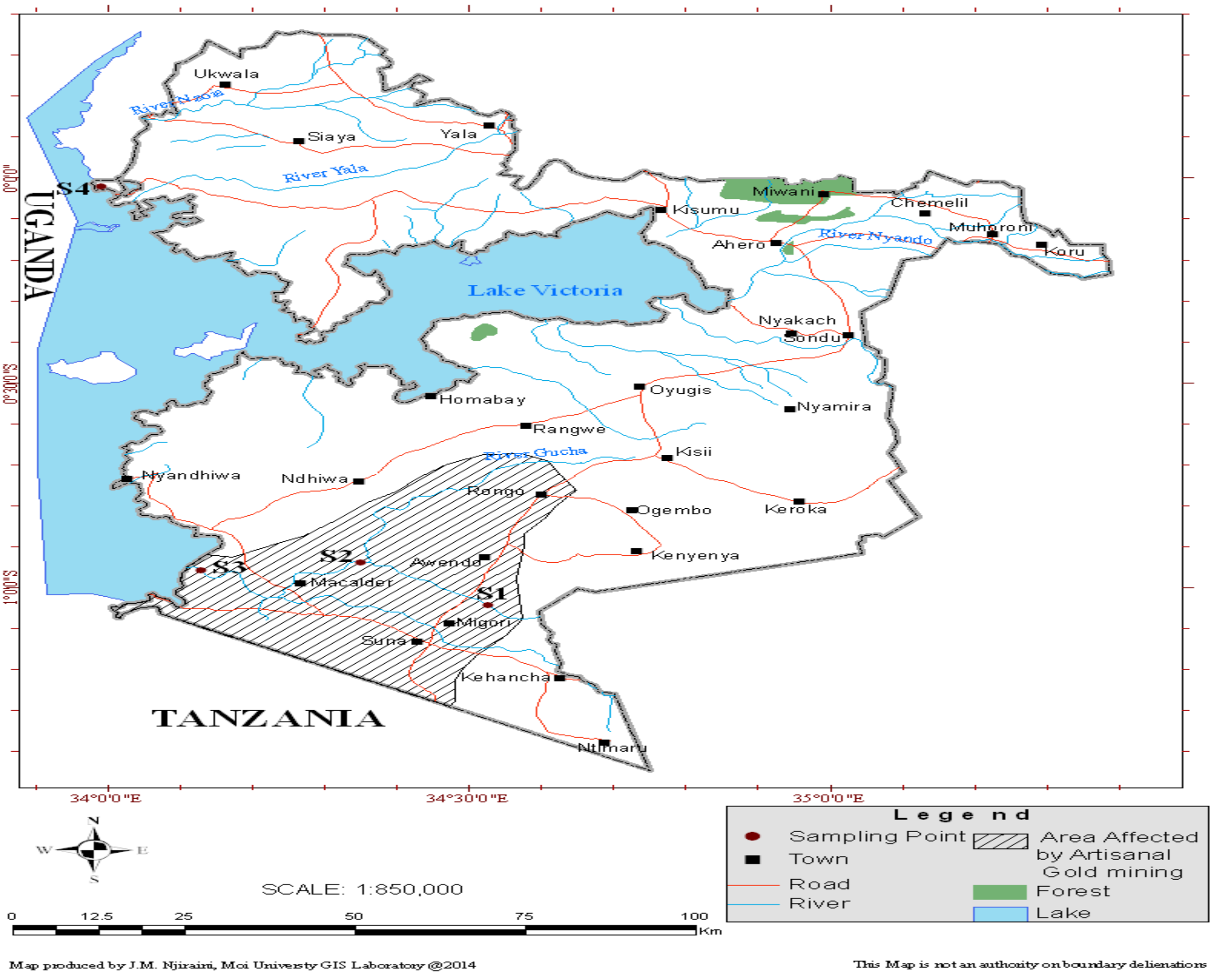

Figure 2. Sketch map of studied area in Macalder Gold Mines, Migori, Kenya, showing sampling sites

At least 0.20 g hair was collected from the scalp region of each individual in triplicate washed in a beaker with distilled water on a stirrer for 15 min and then washed with acetone–water–water–water–acetone (IAEA, 1985). Washed samples were placed individually in glass beakers and allowed to dry at 50 ◦C overnight in a drying oven. Nail samples were obtained from the men using stainless razors and were treated in a similar way as the hair samples. Water and fish samples were collected from the same sites where the individuals who donated hair and nail samples obtained their water for drinking and grew their vegetables respectively within the mining sites. Water samples were obtained from the four sites approximately 20 m from the dug wells and the main rivers, Kucha and Migori, at about 0.50–0.75 m below the surface using a 3 L Van Dorn bottle. Water samples were acidified to pH 2 with concentrated nitric acid (65%), placed into cool boxes and transported to the laboratory for chemical analyses. Fish collected from the study sites was oven dried, crushed in a pulveriser, then lyophilized (72 h) and subjected to acid digestion. 0.200 g of each sample was placed in a Teflon digestion vessel with 7.0 mL of concentrated nitric acid (65%), 1.0 mL concentrated hydrochloric acid (30%) and 1.0 mL hydrogen peroxide (30%). Ethos D (Type Ethos plus 1) microwave (purchased from Milestone Inc., Monroe, CT, USA) was used to digest the samples. Digestion involved four steps namely: 25–200 ◦C for 10 min at 1000 W; 200 ◦C for 10 min at 1000 W. Digests were made up with ultra-pure de-ionised water to 25.0 mL in acid washed standard flasks. The final diluted solutions were transferred into acid cleaned polyethylene bottles respectively.

Data Analysis

Data on the heavy metal concentrations in the water and fish were presented as means (± SEM) per sampling site. For the scalp hair and nail samples, geometric mean (GMs ±

0.95*Confidence Interval) was calculated for each PHE at every sampling site. For comparison of PHE concentrations in the samples (between sampling sites), one-way ANOVA was used. Whenever the null hypothesis was rejected, a multiple comparison test (DMRT) was used for post hoc comparison.

RESULTS AND DISCUSSION

The results are presented as means of the PHE concentrations (M±). Water samples analyzed indicated concentration of heavy metals (ugL^{-1}) that were higher than the WHO maximum allowable limits in drinking water in all the four sampling sites. Mercury concentrations were elevated in all the sampled areas above the WHO maximum acceptable limits except in the control site S4 (Table 1). The control area had concentration below WHO maximum limits except the Cd concentration (0.27±1.7µg/L-1). S1 showed a significant difference to the other sites in Hg concentration. Copper was elevated above WHO acceptable maximum limits in all the samples analyzed from both the exposed and control areas. The results for fish, hair and nails element analysis are shown in Tables 2, 3 and 4.

Table 1. Concentration of potentially harmful elements (µgL^{-1}) in water at the different sampling sites

Metals	S1	S2	S3	S4	WHO
Hg	0.92± 1.9^{a}	18.1±1.6^{b}	18.9± 3.6^{b}	0.001± 31^{a}	<0.002
As	0.042±6.8^{a}	0.029±6.2^{a}	0.097±2.9^{b}	0.001±4.6^{c}	<0.001
Pb	59.2±7.5^{c}	69.6±1.7^{a}	89.3 ±5.1^{b}	0.001±2.2^{a}	<0.005
Cd	0.33±5.1^{c}	0.13±3.3^{a}	0.36±2.9^{d}	0.27±1.7^{b}	<0.001
Cr	27.7±5.1^{a}	26.3±6.4^{a}	87. 7±7.2^{c}	0,002±2.7^{b}	<0.005
Cr	27.7±5.1^{a}	26.3±6.4^{a}	87. 7±7.2^{c}	0.001±2.7^{b}	<0.005

Table 2. Concentration of PHE (mg/Kg) in *R. argentea* at the different sampling sites

Metals	S1	S2	S3	S4	WHO
Hg	0.285 ± 0.03^{a}	0.344 ± 0.04^{b}	0.346 ± 0.01^{b}	0.028 ± 0.05^{a}	<0.05
As	0.31 ±0.02^{a}	0.29 ±0.07^{a}	11.7 ±0.02^{c}	0.019 ±0.03^{d}	<0.05
Pb	0.37 ± 0.05^{b}	0.57 ± 0.01^{a}	11.75 ± 0.02^{d}	0.034 ± 0.03^{b}	<0.05
Cd	0.15 ± 0.01^{a}	0.15 ± 0.01^{b}	0.29 ± 0.01^{d}	0.017 ± 0.01^{b}	<0.001
Cr	0.51 ± 0.03^{b}	0.49 ± .07^{b}	0.79 ± 0.09^{c}	0.027 ± 0.02^{a}	<0.05
Cu	5.18 ± 0.03^{a}.	6.186 ± 1.52^{a}	4.78 ± 1.14^{a}	4.92 ± 1.21^{a}	<0.05

Table 3. Concentration of heavy metals (mg/Kg) in scalp hair at the different sampling sites

Metals	S1	S2	S3	S4	*EU,2001, FAO, 1993
Hg	0.19 ± 0.012^{a}	0.21± 0.019^{a}	0.32 ± 0.011^{b}	0.12 ± 0.019^{a}	0.02-0.2
As	0.012 ± 0.012^{a}	0.021 ±0.1 4^{ab}	0.019 ± 0.73^{c}	0.009 ± 0.017^{a}	0.02-0.5
Pb	0.61 ± 0.025^{b}	0.606 ± 0.03^{b}	0.86 ± 0.026^{c}	0.68 ± 0.022^{b}	0.03-1.4
Cd	0.18 ± 0.014^{b}	0.840 ± 0.019^{a}	0.079 ± 0.009^{b}	0.077 ± 0.012^{b}	No Value
Cr	0.032 ± 0.090^{e}	0.041 ± 0.042^{b}	0.054 ± 0.024^{c}	0.005 ± 0.019^{b}	0.03-1.88
Cu	0.021 ± 0.001^{a}	0.025 ± 0.002^{a}	0.026 ± 0.002^{c}	0.029 ± 0.001^{a}	0.03-0.11

Table 4. Concentration of heavy metals (mg/Kg) in nails at the different sampling sites

Metals	S1	S2	S 3	S4	*EU,2001, FAO, 1993
Hg	0.353 ± 0.031^{a}	0.436 ± 0.031^{a}	0.498 ± 0.031^{c}	0.236 ± 0.031^{b}	0.02-0.5
As	0.015 ± 0.011^{a}	0.0311 ±0.074^{b}	0.0371± .072^{b}	0.002± 0.029^{a}	0.18-1.32
Pb	0.61 ± 0.025^{a}	0.608 ± 0.031^{a}	0.87 ± 0.026^{c}	0.667 ± 0.022^{b}	0.03-1.4
Cd	0.18 ± 0.014^{c}	0.820 ± 0.019^{a}	0.079 ± 0.009^{b}	0.077± 0.012^{b}.	No value
Cr	0.032 ± 0.090^{b}	0.041 ± 0.042^{b}	0.055± 0.024^{c}	0.005± 0.019^{a}	0.03-1.88
Cu	0.021 ± 0.001^{a}	0.025 ± 0.002^{a}	0.028 ± 0.002^{a}	0.029 ± 0.001^{a}	0.03-0.11

Mean (± SEM) values with different superscripts for each heavy metal were significantly different within the sites at $\propto$ = 0.05. *(European Union and FAO)

The study investigated the heavy metal risks involved in working in Migori Gold Belt and consuming drinking water in small scale gold mining area of Macalder Area. Human exposure to the heavy metals studied is considered high, on the basis of the significantly high concentrations of these elements found in fish and drinking water. This is unsurprising, considering that the area receives increasing pollutants from geological terrains rich in gold deposits and associated elements. Additional contributions of heavy metals from the gold mining activities have led to elevation of the heavy metals above the background levels and above recommended maximum limits for heavy metals by WHO standards and as well as Italy, Japan and England allowable for unpolluted water, fish, hair and nails references as observed in all the study sites especially S2 and S3. Additional contributions of heavy metals from the gold mining activities have led to elevation of the heavy metals above the background levels and above recommended maximum limits for heavy metals by WHO standards and as well as Italy, Japan and England allowable for unpolluted water, fish, hair and nails references as observed in all the study sites especially S2 and S3 (Wolfsperger *et. al.,* 1994).

Measuring the concentrations of heavy metals in hair and nails as biomarker for short term and long- term exposures gave an insight into the levels of exposure for the men working in the small scale mines. The drinking water, fish, nails and hair element concentrations in the gold mining area are generally above WHO recommended levels and mostly above levels in the control area. The metal concentration in the fish and water show elevated levels which though are not well reflected in the scalp hair and nails of the males working in the mines, indicate grave health consequences for the males. All studied metal concentrations in fish exceeded reported permissible levels. Increased level of Hg, As, Pb, Cd, Cr and Cu in the environment from gold mining activities may have led to the degradation of the quality of the water and fish through the food chain. Heavy metals are usually both bio accumulated and biomagnified in living organisms and may result in irreversible health consequences to the male workers in the gold mines. The observed elevated levels of mercury and associated metals in the gold mines in Migori Gold Belt have resulted in the dispersion of increased levels of the metals studied against their background levels in the surrounding areas. Metals from the gold mines activities are rain-washed into near-by surface and drinking water systems causing increased metal concentrations in drinking water and fish. WHO recommended guidelines and other countries maximum metal levels for Hg, As, Pb, Cd, Cr and Cu are well exceeded for the water and the fish. Mean scalp hair Hg concentration (0.32 ± 0.011) is above maximum permissible level based on European Union maximum recommended limits in site 3. Site 2 has mean Hg (0.21 ± 0.019) that is slightly above the maximum range. The analysed samples of nails showed metal concentration that were within the range of recommended limits of Italy/Japan/England for all but Hg concentration in S2 and S3are near max permissible levels.

Recommendations

Encouragement to use of protective gear at all times during gold mining and processing; retorts, simple fume chambers, *etc*. Active role of Government authorities on health and pollution control, *e.g.,* protection of water sources; Trained personnel to oversee the health aspects both to the worker and the environment and biological remediation and interventions: such as use of plants that concentrate the metals thus extracting from the environment: must be part of the considerations before the issue of permits to carry out gold mining. Growing plants can help contain or reduce heavy metal pollution.

CONCLUSION

Men working in the gold mines and consuming water and fish from these localities are exposed to high, probably irreversible health risks through heavy metal pollution in drinking water and fish. Considering heavy metals are toxic even in low concentrations, the observed mean concentrations of the studied metals poses a great danger to the studied subject. WHO recommended guidelines and other countries maximum metal levels for Hg, As, Pb, Cd, Cr and Cu are well exceeded for the water and fish but this is also observed in the scalp hair and nails in the study area. Dependence of gold mining in this area has caused both human and environmental health problems. There are high multiple health risks posed to the men who are very vulnerable to heavy metal poisoning through mining exposure and drinking water and feeding on the fish that are contaminated with heavy metals.

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