IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT)
e-ISSN: 2319-2402,p- ISSN: 2319-2399.Volume 14, Issue 10 Ser. IV (October 2020), PP 21-29
www.iosrjournals.org

Heavy metals in environmental media and potential human health risks associated with active gold mining in Migori, Kenya: Community health implications.

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Abstract
Mercury (Hg), arsenic (As), chromium (Cr), copper (Cu), Molybdenum (Mo), Selenium (Se) and Iron (Fe) were analyzed in drinking water, soils, vegetables, maize, human scalp hairs and nails samples collected in the low lying areas of Migori Gold Mining Belt within Lake Victoria basin and an agricultural region of Eldoret (control site). All samples, except water and soils, were washed with deionized water, dried and acid digested, and later analyzed using ICP-MS in Bueritas Labs, Vancouver, Canada. The results revealed elevated metal concentrations which could lead to a significant risk of exposure and a substantial increase of contaminants in the consumers of water and food items grown on contaminated soils. Iron showed positive correlation with As and negative correlation with Cr and Cu, at 0.01 sig level (2- tailed), and negative correlation with Hg at 0.05 (2-tailed) in water. Water Mo concentration showed significant positive correlation at the 0.05 level (2-tailed) with Mo, Se. and Cr total concentrations in human scalp hair and nails. Mercury concentrations in maize showed elevated levels above the WHO recommended levels. Mercury, Cr, and Cu concentrations were significantly higher ($p < 0.05$) in the soil samples collected from the polluted area as compared to control area and showed elevated levels above maximum allowable concentration for arable soils. The research findings indicated grave health implications associated with heavy metals' exposure and possible deficiency of essential elements for communities within the study area.

Key words:** **Gold mines; contaminants, Human exposure, water, soils, food items

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Date of Submission: 26-10-2020 Date of Acceptance: 06-11-2020

I. Introduction

Environmental impacts due to mining are commonly associated with large-scale mechanized activities.[1] However, over the years, several researchers[2,3] have reported case studies showing that artisanal and informal mining may intensify metal concentrations linked to mining activities in the environmental media such as soil, water, food items as well as in human beings with dire implications to human health.[4,5] Various studies have established elements in analyzed samples from gold mining vicinities such as Cu, Pb, Zn, Fe, Co, Hg[2,4,6] with geologically enriched environments showing elevated contents which may find their way into the human beings through the food chain.[6.7,8]

Generation of mine waste, tailings and effluents, with significant quantities of toxic metals such as Hg, Cr, Cd, Pb, Zn,[9] lead to extensive contamination of the ecosystem.[10,11] Food items grown on metal contaminated soils tend to accumulate the toxic metals.[12,13] Majority of the human beings who do not work in metal related industries are thus exposed to the metals through the diet,[6,14] including water[15] with dire implications on human health.[4]

Various researchers have indicated that analyses of heavy metals in food items locally grown in the soils and drinking water within mining regions such as gold mining sites may give pointers of the possible exposure levels to the consumers.[6,13.14] Published findings[12] indicate that food crops and vegetables cultivated on contaminated soils tend to contain appreciable amount of toxic elements with high concentrations of Pb, Zn, Cr and Cd above EU and WHO/FAO standards, which may be passed on to the consumers through the food chain accumulating the elements' body burden. Thus, assessing metals in water and soils may provide information on the status of pollutants in the environment and the potential level of exposure for the communities.

Previous researchers have indicated that human scalp hair and nails may be used as human biomarkers to analyze possible work-related or ecological exposure to toxic metals[16, 17]to assess mean metal burden in the human body.[18] Further, commonly used diet may also be used to measure exposure of pollution through the food chain.[12,13,14] This paper reports on the assessment of soils, drinking water, vegetables, maize, human scalp hair

and nails to draw tangible correlations with the exposure levels within the gold mining region of Masara in Migori, Kenya. Further, the paper points out possible implications of the metal concentrations in environmental media to human health especially the non-essential metals and the essential metals. The study focused on assessment of the input of gold mining activities to body metal load in consumers in the study area through determining the total concentration of mercury (Hg), arsenic (As), chromium (Cr), copper (Cu), molybdenum (Mo), selenium (Se) and iron (Fe) in the selected samples. The study findings enhance knowledge on the gold mining contributions of elements to the environment and the implications to human health for exposed populations.

Study area setting

The study was carried out in Migori Gold mines in Migori County. This is one of 47 counties in Kenya, with an approximate area of 2,596 km^2, population of 1,152,164 and borders Lake Victoria to the west and the republic of Tanzania to the south as indicated in previous work.[2, 6] The study area which lies within a geologically[19] metal rich region within the Lake Victoria Basin with Lake Victoria (68,800 km^2), the second largest fresh water in the world (catchment area is about 84,000 km^2) and is shared by three riparian states (Kenya, Tanzania and Uganda). The main human economic activities comprise fishing, subsistence agriculture and gold mining mainly artisanal. The main source of water for human consumption is the groundwater, rivers draining through the basin and limited piped water. About 90% of the population within the study area depends on gold mining both directly and indirectly. This implies that an enormous population in the study area maybe at a high health risk related to contaminated environments through gold mining and process activities.

Sampling design and procedures

All equipment used was pre-soaked with concentrated nitric acid (65%) and sulphuric acid (30%) solutions of 1:1 volume ratio. Drinking water samples were collected from the rivers and groundwater wells accessible within the gold mining areas. Both the maize and vegetable (Brassica oleracea (collard greens)) samples were obtained from the same farms where soil samples were obtained. The human scalp hair and nails were collected from volunteers who worked in the mines and had lived in the area for more than five (5) years. Similar samples were also collected from Eldoret Municipality which was the control site. Eldoret Municipality is 312 Kilometers from Nairobi, the capital city of Kenya and 270km from the mining sites. Eldoret, is at latitude of 0.52 (0° 31' 0 N) and a longitude of 35.28 (35° 16' 60 E), a populated place located in the Great Rift Valley in Kenya. Four sites were purposively selected for as described in previous work.[2] Sites S1, S2 and S3 were located within the study area which is rich in gold deposits, with numerous artisanal mining activities.[20] The control site, S4 was located in Eldoret Municipality with mainly farms in different topographical locations in agricultural fields.

Sample sampling

Soil, water, maize, vegetables, human scalp hair and nail samples were sampled and collected, as described by various authors.[2,6] Triplicate soil samples of 250g were collected near surface (10–30 cm below Ao) using a soil anger from different farms within each of the selected S1-S4 sites. The samples were homogenized and quartered in accordance with IGCP 259 recommendations.[21] Water samples collected in 500 ml metal free Van Dorn plastic bottles from wells, boreholes, Migori River (S1) and Gucha River (S2), lower side of the mining area near Lake Victoria (S3), and Eldoret: Control area (S4) (as described in previous work[2]), were acidified, with about pH 1.5 to 2.0 of ARISTAR grade concentrated hydrochloric acid, to prevent adsorption of dissolved heavy metals onto the interior walls of the storage bottles, and to minimize microbial activity. Maize grain and edible parts of commonly consumed vegetables: *Brassica oleracea* (collard greens), samples were collected from where the soils and water samples were in different farmlands in the study area. Twenty (20) human scalp hair and twenty (20) nail samples from each sampling sites, were obtained from residents on the farms where the soil, drinking water, maize and vegetables were collected. Approximately 20mg of hair samples were collected from the back of the head close to the neck from at least three people in homesteads in the study area and in the mines using stainless pair of scissors. The nail samples were collected using stainless scalpels.

Laboratory processing

Soil, maize, *Brassica oleracea*, human scalp hair and nail samples were processed and analyzed in the laboratory as described by various researchers.[6,12,22] The samples were first air dried before drying using hot air circulating oven (Gallenkemp DV 330) at 65^0C as described by various researchers. The soils were weighed (0.2 g) and acid digested using 5 ml of 65% HNO_3, 10 ml of 40% HF and 4 ml of 70% $HClO_4$ at 100 °C for trace elements and analyzed by the Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) by ACME Laboratories, Vancouver, Canada. Maize samples were dried to constant weight for 18-24h, crushed and

homogenized using a Fritsch, Pulverisette 5, planetary mill (Fritsch GmbH Laborgerate, Idar-Oberstein, Germany) for 5 min at 400 rpm, to powder and stored in screw capped containers at 4^o -6^o C. About 0.2000 g of maize were accurately weighed in Teflon (& polytetra-fluor-etheen (PTFE), DuPontTM) high pressure vessels, sieved through 0.002mm sieve, and acid digested. Thirty samples of edible parts of commonly consumed vegetables (*Brassica oleracea*) (collard greens)) were dried, homogenized. About 2 g were digested using HNO_3 and $HClO_4$ in the portions of 5:1 at 180 °C. The samples were filtered and de-ionized water was added to 50 ml and analyzed at ACME Laboratories for total concentration of elements. Human scalp hair and nail samples were washed twice in de-ionized water, dried on a clean paper and packed. Nail samples were first washed with distilled water on a stirrer for 15 min in a beaker, and then washed with acetone-water-water-water-acetone as recommended by the International Atomic Energy Agency.[23] The washed samples were placed in glass beakers and individually allowed to dry at 50^0C overnight in a drying oven. Before washing the nail samples, any visible dirt on the surface of the nails were thoroughly washed using MilliQ water. Both human scalp hair and nails were acid digested and analyzed at ACME Laboratories for total concentration of elements.
The total heavy metal contents in the soils, maize, vegetables, hair and nail were determined and reported in mg/kg while drinking water as µg/l.

Quality assurance and Quality control

Blank reagent and standard solutions of the elements were prepared for each metal from their stock solution. The precision and accuracy were checked by repeated analysis against the standard materials with confidence limit of over 95%. (For further enquiries, see www.acmelab.com). The standard reference materials (SRM) supplied by Bueritas Veritas Mineral (BVM) laboratories for Hg, As, Cr, Cu, Mo, Se and Fe for drinking water, soils, food items (vegetables, maize), human scalp hairs and nails were STD DS10, STD TMDA- 70.2, STD CDV-1, STD CDV-1 and STD V16, respectively and were used to check for accuracy and precision of analysis of each sample. For soil samples the following detection levels; 0.1 mg/kg for the Cr and As, 0.01 mg/kg for Cu and Hg, 0.01 wt% for Fe, 0.1 mg/kg for Se and 0.01 mg/kg. Aqua regia-ICP (Code AQ252-EXT) was used by the BVM laboratory as described by several researchers.[13,] Accuracy and precision were within acceptable limits and analyses of standards and blanks fell within acceptable ranges of the expected value.

Further, analytical grade reagents were used to clean the equipment used to collect and prepare samples for element analysis. The ground samples were packed in polythene bags to avoid contamination and stored at cool temperatures to avoid growth of mold on them.[13] The following were also observed namely; use of quality control validation solutions which were analyzed with experimental samples to validate each run and to confirm that each analytical run had been performed correctly.[13, 24, 25]

Ethical Considerations

Since human scalp hair and nail samples were collected from human volunteers in the study, Helsinki Protocol, which underline appropriate ethical considerations for studies involving human participants, was followed.[24,25] Confidentiality of any information provided was maintained and each volunteer was accorded a code name. Only residents who had lived for five years and more and were aged between 18-55 years and worked in the gold mines were sampled. The procedure was first explained to each participant and permission sought to participate in the study by donating hair and nail sample. An informed voluntary consent was obtained from all participants for the study before donating their hair and nail samples. The assumption was that the respondents sampled had consumed the food crops grown on the soils within the sampling sites and drank waters drawn from the sampling sites. Immigrants, sick people and people with colored or treated hair were purposely excluded from the study cohort. The study was approved by the Directorate of Research, Innovation and Consultancy, Laikipia University, Kenya.

Data Analysis

All analyses were performed, using IBM SPSS Statistics for Windows, Version21. The W test[26] was used to test log–normal distribution of the data for all samples. To meet the criterion of normality before statistical procedure, all nonparametric data were log-transformed, using the equation, $x' = \log (x + 1)$.[27] All data among sampling sites were calculated as geometric means (GMs). Comparison of heavy metal concentrations in drinking water, soils, maize, vegetables, and human scalp hair and nail samples in different sampling sites was done, using one way ANOVA. Whenever the null hypothesis was rejected, a multiple comparison test the Tukey HSD test, [28] was used to determine the differences between individual groups. The relationships between the heavy metal concentrations in samples were analyzed using the Pearson Correlation significant at the 0.05 level (2-tailed) and at the 0.01 level (2-tailed). All the levels of the statistical significance were set at $P<0.05$, unless otherwise stated.

II. Results

The total number of drinking water, soil, maize, vegetables, scalp human hair and nail samples from the sites 1-4 in the study area are shown in table 1. The results are presented as ranges, means (M±) and SD of the concentrations as shown in table 2. Generally, samples analyzed indicated elevated concentrations of some of studied metals above the International set standards of maximum acceptable limits (Table 2). The control area had concentrations which were generally below WHO maximum limits except the Cu concentration (0.27±1.7dµg/L1) in water. Table 3 presents ANOVA results of metal contents in the samples analyzed. Table 4 shows correlations of water metals. Soil, vegetable, maize, human scalp hair and nails tables are not included in this paper.

Table 1 Total number of water, soil, maize grains, human scalp hair and nails samples from the sites 1-4 in the study area.

Samples	S1	S2	S3	S4(control)	TOTAL
Drinking Water	30	30	30	30	120
Soil	30	30	30	30	120
Maize	30	30	30	30	120
Vegetables	30	30	30	30	120
Human scalp hair	20	20	20	20	80
Nails	20	20	20	20	80

The total number of samples analyzed and reported in this paper was 640 and the total metal concentrations obtained and the data analyzed showed varied levels in concentration ranges, means and SD. Table 2 and table 3 show a summary of the reported metal concentrations in environmental media analyzed indicating metal ranges, mean ± and SD compared to MAC with international standards (Water (µg/l, other samples; mg/kg). Toxic metals Hg and As in water were above recommended MAC level for drinking water. This is reflected in vegetables where the samples analyzed recorded concentrations above recommended MAC concentrations for food items for human consumption. Essential elements such as Cu in water, maize and vegetables reported extremely low concentrations.

Table 2. Heavy metal concentration in water and food items (n= 320)

Samples analyzed	Range	Mean	MAC	Ref
Water Fe	0.155 - 3.649	2.13±1.31	0.3	29
Water Hg	0.1.000 - 1.705	0.097±0.43	0.001	30
Water Mo	1.000 - 1.497	0.481±0.64	70	31
Water Se	0.000 - 1.004	0.0595±0.398	0.05	29
Water Cr	0.222- 3.614	1.218±1.361	50	29
Water Cu	0.155 - 2.461	1.258±0.655	2000	29
Water As	1.097- 1.155	0.139±0.701	0.01	29
Maize Fe	1.328 - 1.892	1.696±0.392	N/E	32
Maize Hg	0.1328 - 0.180	0.169±0.392	<.05	33
Maize Mo	0.2030 - 0.414	0.470±0.844	N/E	-
Maize Se	0.018 -0 .273	0.139±0.281	03	34
Maize Cr	0.010 - 1.301	0.206±0.414	2.3	35
Maize Cu	0.202 - 0.255	0.208±0.448	73.3	35
Maize As	0.010 - 0.011	0.010±0.100	0.02	35
Vegetable Fe	0.319 - 0. 889	0.623±0 .335	425	36
Vegetable Hg	0.100 - 2.772	1.413±0.881	0.3	37
Vegetable Mo	0.319 - 0.888	0.223±.0334	N/E	36
Vegetable Se	0.100 - .0756	0.334±0.405	0.1	36
Vegetable Cr	0.000 - 2.387	0.956±0.723	2.3	36
Vegetable Cu	0.030 - 2.141	1.215±0.684	73	36
Vegetable As	0.100 -. 0601	0.852±0.883	0.3	36

NE= Not established

Heavy metal concentration in human biomarkers (human scalp hair and nails) and soils are presented in table 3. The mean metal concentration of toxic metals in hair, nails and soils were relatively elevated. Essential elements such Cu in hair is elevated but this is not reflected in the nails. Mean Cu and Cr concentration recorded concentrations that were above MAC recommended for agricultural soils.

Table 3. Heavy metal concentration in human bio markers and soils (n= 320).

Samples analyzed	Range	Mean		MAC	Ref
Hair Fe	1.128 -1.300	1.696±0.392		425	36
Hair Hg	0.010 -.315	0.480±0.844		77	38
Hair Mo	0.018 -.728	0.138± 0.281		.05	39

Hair Se	0.010- .176	0.023±0 .053		0.15	38
Hair Cr	0.100 -1.299	0.219±0 .440		3	38
Hair Cu	0.0200 -1.799	0.402±0 .715		0.03	38
Hair As	0.0100 -.0150	0.010±0 .001		20	38
Nails Fe	1.328 -2.100	2.69± 0.302		77	38
Nails Hg	0.001 -.415	0.490±0 .814		0.05	39
Nails Mo	0.58 -.615	0.639±0 .281		0.15	38
Nails Se	0.0100- .166	0.023± .0529		3	38
Nails Cr	0.020 -1.199	1.193±0 .440		0.03	38
Nails Cu	0.125 -2.769	0.402± 0.715		20	38
Nails As	.0010 -.0200	0.010± .001		≤1	38
Soil Fe	2.523 -6.1430	0.473±0.394		150	36
Soil Hg	1.230 -2.599	1.822±0.349		0.05-0.08	40
Soil Mo	0.0222 -1.030	0.377±0		75	36
Soil Se	0.635 -1.274	0.0720±0		0.1-2.0	39
Soil Cr	0.699 -2.077	1.519±0.319		0.1	40
Soil Cu	0.606 -16.254	1.57±0.396		0.1	40
Soil As	0.176 -1.573	0.677±0.321		3-12	41

The ANOVA results are shown in table 4, and indicated highly significant differences between and within metals studied in soil and nail samples at 0.05 level.

Table 4: ANOVA analyses of metal concentrations showing F value and significant

Samples		Sum of Squares	df	Mean Square	F-value	Sig.
Soil	Between Groups	.081	6	.014	11.443	.000
	Within Groups	.020	17	.001		
	Total	.101	23			
Nails	Between Groups	.081	6	.014	10.043	.000
	Within Groups	.020	17	.001		
	Total	.101	23			
Significant difference @ α ≤0.05						

Metal concentration showed highly significant differences between soil and nail samples (p≤0.05).

Pearson's correlation analysis of the determined elements in water, soil, vegetables, hair and nails carried out showed positive and negative significant correlation between the metal concentrations in the different samples analyzed. Correlation results in table 4 showed both negative and positive relationships between the reported metals in water samples. Table 4 shows that there was significant negative correlation between water Fe and Hg at 0.05, Fe with Cr and Cu at 0.01, and positive correlation of Fe with As at 0.01. Mercury showed negative correlation with Cr and As at 0.05. Water Se showed negative correlation with As, while Mo indicated positive correlation with Cu and Cr.

Table 5: Inter-elemental correlation coefficients (r-value) of heavy metals in water samples.

Water samples				
Metal 1	Metal 2	n	r	p-value
Fe	Hg	30	-0.377	0.042
	Cr	30	-0.864	0
	Cu	30	-0.688	0
	As	30	0.787	0
Hg	Cr	30	0.401	0.028
	As	30	-0.388	0.034
Mo	Cr	30	0.619	0
	Cu	30	0.750	0
Se	As	30	-0.452	0.012
Cr	Cu	30	0.828	0
	As	30	-0.793	0

Pearson's correlation analysis carried out between different samples showed both water Fe and water Se had significant correlation in the studied metals in the hair and nails but water Mo concentration showed positive significant correlation with Mo, Se, and Cr in both hair and nails at 0.05. Water Fe showed significant negative correlation with vegetable Hg (0.05), and Cr and As (0.01).

Water As showed significant negative correlation at 0.01 with vegetable Cr, and Hg. Results obtained on different metal concentration in water and soil showed that water Mo, Cu, As had significant positive correlation with soil Hg (0.05) and soil Cr (0.01) while water Fe had significant negative correlation with soil

Hg (0.05 and 0.01 respectively). Vegetable Se had a significant negative correlation (0.01) with Fe, Cr, Cu in soil samples analyzed. Vegetable Fe had a significant negative correlation (0.01) with Se in vegetable, human hair and nails.

III. Discussion

The study investigated the total concentration of metals in soils, drinking water from different sources; rivers, water wells, boreholes, and commonly consumed food items in active artisanal gold mining area of Masara in Migori Gold Belt and a non –gold mining region, Eldoret Municipality, in Kenya. Further, communities working and living within the experimental and control sites provided human scalp hair and nails for metal analyses to assess human exposure. Human exposure to the heavy metal studied is considered high, on the basis of the significantly high concentrations of these metals found in commonly consumed food items; vegetables and maize, as well as in the soils and drinking water in the analyzed samples as indicated in Table 2. This is a reflection of pollutants emitted from the geological terrains rich in gold deposits and associated metals. Measuring the contents of heavy metals in human scalp hair and nails as biomarkers for short term and long-term exposure gave an insight into the levels of metal exposure for the communities within the study areas. Generally, with the exception of Cu in soil samples, the reported metals showed significant difference between the experimental and control sites in samples analyzed. Some of the samples analyzed in the gold mining area, drinking water, soils, vegetables and maize, had element contents generally above maximum allowable concentrations and recommended levels as shown in Table 2 and table 3. This maybe as a result of the type of geology[19] of Migori which contains gold and related elements that are released into the environment during mining and processing of the gold ore.[42] Diffusion and amplification processes may lead to metal concentrations being elevated against their background levels in the adjacent areas of mines over the years.[43] Dispersed metals find their way into near-by surface and groundwater systems as well as soils, with food items grown taking up the metals[44,45,46] exposing human beings through the food chain. Results in Table 2 indicate the ranges and means of the metals reported compared to recommended allowable limit levels. Based on recommended guidelines, maximum allowable concentrations of Fe, Hg, As are generally well exceeded in water and soil samples analyzed (Table 2 and table 3). Further, human scalp hair Hg concentration is near maximum permissible level compared to internationally maximum acceptable recommended limits especially in site 3 as observed in table 3. The analyzed samples of nails showed metal concentrations that were within the recommended limits. Increased contamination of Hg, As, Cr and Cu in the environment have degraded the quality of the water and soils resulting in food items grown for human consumption taking up the potentially harmful elements with severe health consequences to the consumers. The reported significant Hg in the human scalp hair and nail samples could be as a result of the elevated Hg in water, soils, maize and vegetables grown and consumed within the study area. The communities in the experimental sites are exposed to high potentially harmful elements that may lead to irreversible health conditions. Although, recommended guidelines and maximum metal level for As[38,39] is exceeded in water, this is not reflected in the maize, vegetable, human scalp hair, nails analyzed in the study area. On the other hand, toxic Hg mean contents in all samples; soil, water, vegetables, maize hair and nails, exceeded the recommended levels as observed in Table 2 and table 3.

Amongst the metals analyzed and reported in this paper, Fe, Mo, Se, Cr and Cu are essential for various biological functions[47] in living organisms such as human beings but in small quantities. An excessive amount of these metals produces cellular and tissue damage leading to a variety of adverse effects and human diseases whilst Hg and As are considered as non-essential metals with no known biological functions[48] and are toxic even in very low concentrations with severe health effects in the body. Numerous research continue to indicate that Hg and As may interfere metabolically with essential metals; Fe and Cu.[49,50] Researchers have indicated that Cr and Cu have a very narrow range of concentrations between beneficial and toxic effects.[47,50] This study observed elevated levels of toxic non-essential and low concentration of essential elements in the analyzed samples which implies a grave situation for the communities within the experimental area. Insufficient supply of Se, Cu and Fe in drinking water and food items grown in soils deficient of the essential metals may result in a variety of deficiency diseases or syndromes. The results observed and recorded in Table 2 and table 3 for water, maize, vegetables and soils show Hg contents which are elevated above recommended contents compared to various internationally accepted levels. This has a grave implication on the health of the communities who maybe at high health risks associated with excess Hg. Further, results shown in Table 2, generally show low concentrations of essential metals such Se, Mo, Cu in water.

Established data indicate that toxic metals compete with the essential metals, even at low levels of metal exposure, thus effecting cellular damage.[50] Consumers of water in the study area may suffer from cell damage leading to development of non-communicable diseases as a result of continued intake of contaminated water with excess toxic metals and low concentrations of essential elements.

ANOVA results in table 4, indicated highly significant differences between and within metals studied in soil and nail samples at 0.05 level. No significant difference was observed in the other sampled media; hair, maize, vegetables and drinking water.

Table 5 results of Pearson's correlation analysis indicated positive and negative significant relationships between the toxic and essential metals in water samples analyzed. The negative correlation observed between water Fe and water Hg and water Cu at 0.05, and positive correlation with As at 0.01 imply a very grave situation for the residents in the mining region since the toxic metals (As, Hg) and nutritional essential (Cr, Cu, Fe, Mo, Se) tend to interact at cellular level with health consequences to the body. Similar trends were observed in the other samples such as soils, food items, hair and nails. Considering the significance of instantaneous and long term exposure to manifold heavy metals present in the study area, and their possible effects in human beings due to their a toxic effect that is additive, antagonistic or synergistic, there is need to address the concentration levels of the toxic metals and encourage growing of food items that can bio accumulate the essential metals to alleviate the deficiency risks.[48,49,50] The knowledge of these correlations tests could provide crucial information on the dynamics of the toxic and essential metals kinetic interactions such as additive, synergistic or antagonistic effects and their implications in the trace metal metabolism and human health in exposed populations.

Considering that human beings depend on diet as a source of essential elements such as Se, Zn, Fe, Mo, Cu and Cr, availability of the same in the vegetables, maize and drinking water in the study area is crucial. The elevated levels of Hg in water, soils, vegetables though not significantly reflected in the human hair and nails, has a grim implication as water Fe, Mo, Cr, Cu, and As, all showed a significant positive correlation at both 0.05 and 0.01 with Hg in the soil with the exception of Se.

IV. Conclusion

Dependence on gold mining in this area has caused both human health and environmental problems. There are possible high health risk potential posed to the miners and residents who are very vulnerable to heavy metal poisoning through mining exposure, consuming food items grown on the contaminated soils and drinking water within the vicinity of gold mining activities. Further, the observed metal correlations between essential and toxic metals in the samples of soils, commonly consumed food items, water and reflected in the human hair and nails (biomarkers), contributed by the participants, may pose grave implications to the human health for the communities within the vicinity of gold mines. Based on this findings; the researchers recommended appropriate health information on risks associated with heavy metal exposure to be developed and disseminated by heath workers in all public meetings to create awareness of the problem and possible protective measures. Further, the study advocates for use of appropriate 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.

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Acknowledgement

This study was supported by funding from UNESCO-SIDA under the Project title: UNESCO-Sida Project 503RAF2000, "Mapping and Assessing the Environmental and Health Impacts of Abandoned Mines in Sub-Saharan African Countries" (grant no.326218). We are very grateful for the assistance of Bueritas Vancouver, Canada for metal analysis, Agnes Wangila, Kenyatta University for her assistance in the laboratory sample preparation before shipment. We also thank the miners in the study area who volunteered and gave their hair and nail samples for analysis. The authors also thank the volunteers who provided the food items for the analysis.

Author contributions

Veronica Ngure: Did research, processing of the samples in the field before laboratory processing , wrote draft manuscript, data analysis using SPSS and looked for journal for publication.

Lazarus Okioma: Did research, edited the manuscript and verified the results reported and the references.

Competing interests

The authors declare no competing interests

Ngure Veronica. "Heavy metals in environmental media and potential human health risks associated with active gold mining in Migori, Kenya: Community health implications. *IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT)*, 14(10), (2020): pp 21-29.