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Human health and environmental assessments of small-scale and artisanal mining activities in the Gold City of Ijeshaland, Southwestern Nigeria

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Abstract

Background: This study assessed the health and environmental impacts of artisanal gold mining in Ijesha-land, Osun State, Southwestern Nigeria. Fifty-four environmental samples were collected between 2011 and 2012 and analyzed for major, trace and rare earth elements using standard procedures. Samples were collected from surface water (rivers and streams), groundwater, bottom sediments, fish (Tilapia) and aquatic plants (ferns). Data collected were analysed for simple descriptive and inferential statistics using Statistical Package for Social Sciences (SPSS) for Windows (16.0). Human health risk assessment of noncarcinogenic adverse effects of elements in water and fish samples was determined.

Results: Higher concentrations of most major and trace elements were found in groundwater than surface water, while rare earth elements (REEs) were more concentrated in groundwater than surface water. Bottom sediment samples showed highest concentrations of Ti, Cs and Eu for major, trace and rare earth elements, respectively. The major and trace elements were most concentrated in the fish guts. The sum of REEs was observed highest in the fish guts (31.83 ± 35.90 μg kg^{-1}), followed by muscle (18.70 ± 19.37 μg kg^{-1}), while the lowest ΣREEs was measured in the gills (15.78 ± 22.45 μg kg^{-1}). The human health risk assessment revealed low hazard quotient and hazard index values less than 1.0 for trace and rare earth elements in environmental samples.

Conclusions: The data obtained in this study showed that, the artisanal gold mining activities in the study area may contribute to long term environmental and human health risk.

Keywords: Gold mining, Elements, Risk assessment, Environmental samples

Background

Mining takes place where minerals are available and economically viable. Natural resources, especially metallic and non-metallic minerals are important in the national development. The importance of mining sector includes foreign exchange earnings, employment generation and economic development (Nwajiuba 2000; Obaje et al. 2005). Artisanal and small-scale mining are means of livelihood adopted primarily in the rural areas (Veiga 2003), where minerals are mined using simple tools and equipment on a small scale (Bradshaw 1997; Hruschka 2011). This practice is an informal sector, which is outside the legal and regulatory framework (Azubike 2011).

The discovery of gold in Ijeshaland of Osun State, although mined on a small scale basis, provides thousands of indigenous peoples with employment (Taiwo and Awomeso 2017). The negative impacts on the community since the inception of the small scale mining activities were rapid loss of farm lands, water and soil pollution, and problems of managing the mine wastes (Taiwo and Awomeso 2017). Contaminations of surface and ground water bodies have particularly been

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experienced in gold mining communities in Nigeria (Galadima et al. 2011; Ayantobo et al. 2014a, b). Generally, artisanal gold miners are affected by numbers of challenges including occupational, environmental and social impacts (Hruschka 2011). The major environmental and health concerns of artisanal and small scale gold mining are elemental mercury emissions and cyanide toxicity with consequent effects on humans, animals, plants and aquatic organisms (Eisler and Wiemeyer 2004; Barreto 2011; Nakazawa et al. 2016).

The negative environmental and health impacts of artisanal gold mining activities in many countries of the world had been reported in published studies, e.g. Dooyema et al. (2012), Barreto (2011), Hruschka (2011), Plumlee et al. (2013), Ayantobo et al. (2014a, b), Arifin et al. (2015), Basu et al. (2015), Rajaee et al. (2015), Nakazawa et al. (2016) and Obiri et al. (2016). Most of these studies lacked explicit information on the impacts of gold mining activities on multiple environmental indices such as surface water, groundwater, floating plants, the bottom sediments and fish. The first part of this research work had reported the human risk assessments (carcinogenic and noncarcinogenic) of essential and nonessential trace metals in environmental samples (Taiwo and Awomeso 2017). The health risk assessment established the non-carcinogenic adverse effects of toxic metals including Al, Fe, Hg and Tl having the hazard quotient (HQ) values greater than 1.0 in water and fish samples. The study also revealed high cancer risk values for As, Cr, Cd, Ni and Pb. Similar study on health risk assessment in water and sediment samples collected from the vicinity of artisanal goldmining activities had reported high cancer risk values for As, Cr and Cd (Obiri et al. 2016). The main objective of this study is to assess element concentrations and health risk associated with artisanal gold mining operations in the gold city of Ijeshaland, Osun State.

Methods

The study area

The study areas are the gold mine sites in the gold city of Ijeshaland, Osun State. Around these mining sites are major towns such as Igun-Ijesha, Iperindo, Ijana Wasare, Itagunmodi, and Isanlu (Taiwo and Awomeso 2017). The gold mine sites were within one of the six classes of the Basement Complex rock from slightly a migmatised to nonmigmatised, metasedimentary, metasedimentary and metaigneous rock known as the Schist belt (Ayantobo et al. 2014a, b). The belt is one of the eleven Schist belts discussed in Ademeso et al. (2013) as a part of Ilesha Ife Schist belt. Two contrasting lithologies separated by NNE-SSW trending shear system were identified in the study area (Ayantobo et al. 2014a, b). The eastern part possesses quartzite, quartz schist and amphibole schist. The gold deposit occurs in the eastern area that lies on the east of Ifewara fault zone. Detailed description and geology of the study area had been discussed in Taiwo and Awomeso (2017). Figure 1 shows the map of sampling locations in the study area.

Sample collection and analysis

A total of fifty-four environmental samples (surface water, groundwater, the bottom sediments, floating plants and fish) were collected within the vicinity of the gold mining sites between 2011 and 2012. Samples were analyzed for major, trace and rare earth elements using standard procedure (APHA 2005). Samples were digested with concentrated acids (HNO_3, H_2SO_4 and $HClO_4$) as described in Taiwo and Awomeso (2017). The analyzed parts of fish samples were the gills, the guts and muscle. All digested samples were sent to the ACME Analytical Laboratory in Canada for analysis of elements (major, trace and rare earth) using the inductively coupled plasma mass spectrophotometer (ICPMS) instrument. The procedures of ICPMS had been described in Taiwo et al. (2014).

All analytical chemicals were of ultra-pure grade. Blank samples were also run to cancel the impurities introduced by the extracting reagents (Taiwo et al. 2014).

Data analysis

Data collected were analyzed for descriptive (mean and standard deviation) and inferential (Student's *t* test) statistics using the Statistical Package for Social Sciences (SPSS) for Windows version 16.0.

Health risk assessment

The health risk assessment for trace metals were calculated for average daily dose (ADD), noncancer hazard quotient (HQ) and hazard index (HI) using the procedures described in USEPA (2002, 2007, 2012).

Average daily dose was calculated as:

$$ADD = \frac{C \times IR \times ED \times EF}{BW \times AT} \quad (2)$$

where, ADD = average daily dose in drinking water or fish (μg kg^{-1} day^{-1}), IR = Ingestion rate of water or fish; water = 2 L day^{-1} for an adult, 1 L day^{-1} for a child, 0.75 L day^{-1} for an infant (Ayedun et al. 2015); Fish = 24.7 g day^{-1} for an adult based on the Food and Agriculture Organization (FAO) annual per capita fish consumption statistics for Nigeria given as 9.0 kg (FAO 2008).

C = Concentration of trace metals in water (μg L^{-1}) or fish (μg kg^{-1}) samples, BW = Body weight (kg); 60 kg for an adult, 10 kg for a child, 5 kg for an infant (Ayantobo et al. 2014a).

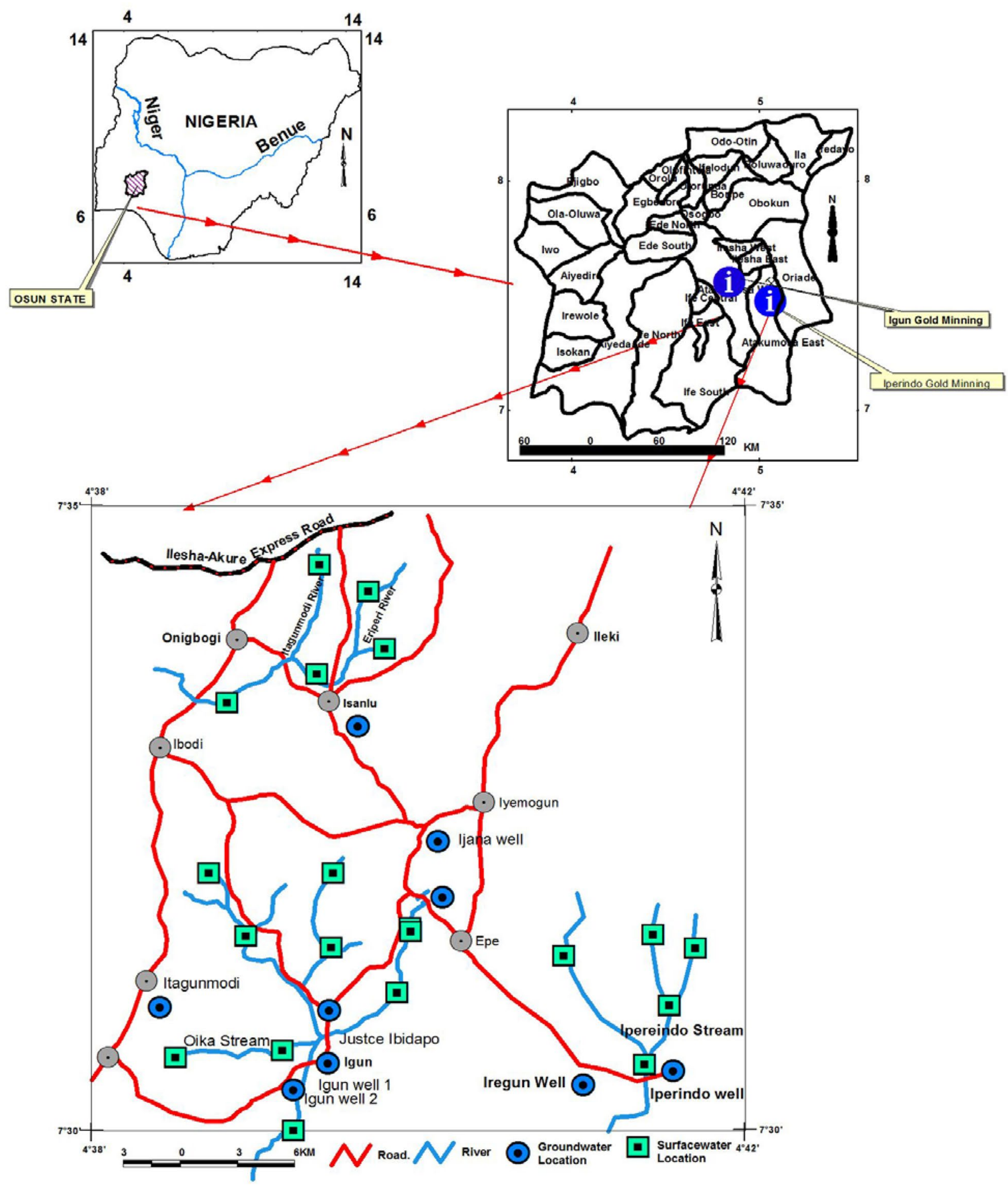

Fig. 1 Map showing the sampling sites in Ijeshaland, Osun State, Southwestern Nigeria (Taiwo and Awomeso 2017)

EF = Exposure frequency (day year^{-1}) = 350 days year^{-1}, ED = Exposure duration (years) = 30 years for an adult, 6 years for a child and 1 year for an infant (USEPA 2001; enHealth 2012).

AT = Averaging time = life expectancy (years), AT = ED for noncarcinogenic effects, while AT = 54.5 years (53 years for men and 56 years for women) for carcinogenic effects on adult (WHO 2015)

(It should be noted that the averaging time for an infant and a child was based on their lifetime exposure where AT = ED).

Noncancer hazard index (HI) was calculated as the sum of hazard quotients (HQ)

$$\mathrm{HI} = \sum_{i=1}^{n} HQ \tag{3}$$

i = 1…n

$$\text{Hazard quotient (HQ)} = \frac{\mathrm{ADD}}{\mathrm{RfD}} \tag{4}$$

where, ADD = average daily dose in drinking water and fish (μg kg^{-1} day^{-1}), RfD = reference dose (μg kg^{-1} day^{-1}) adapted from USEPA (2001), N = numbers of elements observed.

HQ/HI > 1 indicates noncarcinogenic adverse effects, HQ/HI < 1 indicates no adverse effects.

Results and discussion

Major element concentrations in environmental samples

Table 1 shows the average concentrations of major elements observed in surface water, groundwater, bottom sediments, fish and the plant samples. P (0.03 ± 0.04 mg L^{-1}) and Si (10.44 ± 3.45 mg L^{-1}) were observed at significantly higher concentrations ($p < 0.05$) in surface water than groundwater by 67 and 17%, respectively. The presence of P in surface water may be linked to point source pollution from the mining activities.

This value of P observed in the surface water around the Ijeshaland gold mines was within the recommended phosphorus value of 0.03 mg L^{-1} in surface water (Canadian Ministry of the Environment and Energy 1994). Above this value is possible bloom of algae on the surface water with diverse ecological impacts on aquatic organisms (NdumI 2015). High concentration of phosphorus in surface water may also be attributable to human activities such as agriculture, land-use and industrialization (Olajire and Imeokparia 2001; Taiwo 2012a, b).

Ca (37.30 ± 33.86 mg L^{-1}), K (64.99 ± 66.24 mg L^{-1}), Mg (15.01 ± 14.47 mg L^{-1}) and Na (14.44 ± 19.43 mg L^{-1}) concentrations were significantly higher ($p < 0.05$) in groundwater than surface water samples. The presence of higher values of Ca, K, Mg and Na in groundwater may be associated to weathering of bedrock (Gbadebo et al. 2010; Odukoya 2015). The values of these metals were generally lower than the WHO permissible standards (WHO 2011). In this present study, the observed silica concentrations (10.44 ± 3.45 mg L^{-1} in surface water and 8.67 ± 3.61 mg L^{-1} in groundwater) were higher than the value of 5.0 mg L^{-1} naturally found in water (Gbadebo et al. 2013). Although, there is no permissible limit for silica in drinking water; the values obtained in this study was higher than the value that is naturally found in water which might indicate pollution from the gold mining activities.

Ti was the highest measured element in the bottom sediments. Most of the measured parameters in the bottom sediment samples were lower than the WHO permissible standard (WHO 2004). In fish samples, Ca and P were the major elements measured in the gills, while K showed the highest value in muscle and Na in the guts. Most of the major elements were concentrated in the gills because it accumulates pollutants from the aquatic environment and serves as the respiratory and excretory organ (Uzairu et al. 2009; Sharon and Zilberg 2012).

In plant samples, the order of abundance of major elements was Ti > Ca > Mg > K. The Ti concentration in plant samples was very high when compared to Ti values measured in water, sediment and fish samples.

By calculating the bioaccumulation factor (BF) for Ti concentration in plant revealed an extremely high value of 4100. The implication of this is that, most of the Ti released into the surface water was mopped up by the plant. This also reveals the hyper-accumulating ability of fern plants.

Trace element concentrations in environmental samples

The average concentrations of the trace elements measured in the environmental samples are presented in Table 2. Most of the trace elements were generally observed at higher concentrations in groundwater than surface water except Br, Ga and Zr.

The high levels of these metals in groundwater might be linked to seepage of acid mine drainage into the aquifer and possible contaminations from pitting exercise during the gold mining operation (Frank, 2013). The most abundant trace elements measured in the bottom sediments were Cs, Zr, Ga, Th and Sr. These trace elements were extremely higher than those measured in surface and groundwater. The order of abundance of trace elements in fish samples follows: S > Rb > Br > Se > Sn. The sum of trace elements was observed highest in the fish guts followed by the gills and muscle. The trace element concentrations in different parts of the fish samples analyzed revealed the guts as the most contaminated site contrary to the studies of Uzairu et al. (2009) and Ishaq et al. (2011). This anomaly can be explained by the antagonistic effect of Ca on other metals. According to Ghosh and Adhikari (2006), Ca has an antagonistic effect on metal accumulation in fish gills and muscle. The study by Avenant-Oldewage and Marx (2000) had demonstrated higher levels of Fe and Cr in fish muscle than gills. Generally, metal accumulation by fish depends on many factors including sex, age, size, reproductive cycle, swimming

Table 1 Major element concentrations of environmental samples collected at the vicinity of the gold mines

	Surface water (N = 19)		Groundwater (N = 9)		Sediment (N = 10)		Fish muscle (N = 4)		Fish gills (N = 4)		Fish gut (N = 4)		Plant (N = 12)	
	Mean (mg L^{-1})	SD	Mean (mg L^{-1})	SD	Mean (mg kg^{-1})	SD	Mean (μg kg^{-1})	SD	Mean (μg kg^{-1})	SD	Mean (μg kg^{-1})	SD	Mean (mg kg^{-1})	SD
Ca	11.78	4.25	37.30	33.86	0.53	0.69	230.5	343.9	702.0	816.2	116.50	130.6	2.26	2.99
K	6.07	3.30	64.99	66.24	0.07	0.12	34.87	13.67	26.50	21.38	33.32	18.45	1.43	0.51
Mg	5.23	2.78	15.01	14.47	0.38	0.21	10.34	4.96	17.01	14.68	6.80	2.44	0.20	0.07
Na	5.23	5.41	14.40	19.43	0.03	0.02	3.53	7.02	4.03	7.16	5.12	10.21	0.09	0.04
P	0.03	0.04	0.01	0.04	0.03	0.00	136.7	164.2	376.2	396.8	96.77	82.44	0.19	0.03
Si	10.44	3.54	8.67	3.61			4.32	3.72	3.93	4.94	4.34	2.46		
Ti	0.01	0.02	0.01	0.00	2.53	1.43	0.30	0.33	0.16	0.10	0.30	0.23	41.00	41.71

SD standard deviation

Table 2 Trace element concentrations of samples collected at the vicinity of the gold mines

	Surface water (N = 19)		Groundwater (N = 9)		Sediment (N = 10)		Fish muscle (N = 4)		Fish gills (N = 4)		Fish gut (N = 4)		Plant (N = 12)	
	Mean (µg L^{-1})	SD	Mean (µg L^{-1})	SD	Mean (µg kg^{-1})	SD	Mean (µg kg^{-1})	SD	Mean (µg kg^{-1})	SD	Mean (µg kg^{-1})	SD	Mean (µg kg^{-1})	SD
B	11.00	4.30	25.50	30.40	9.74	6.29	0.03	0.01	0.04	0.02	0.03	0.01	6.17	2.71
Be	0.03	0.02	0.16	0.20	0.18	0.11	0.13	0.15	0.05	0.06	0.18	0.24		
Cl	6211	3789	49,625	53,566	<0.1		4.63	2.87	7.00	8.95	7.50	1.91		
Br	56.63	116.25	<0.01		0.97	0.92	24.38	14.59	35.75	41.54	56.00	22.20		
Cs	0.04	0.05	0.69	1.04	77.00	63.65	0.32	0.35	0.20	0.30	0.67	0.86		
Ga	0.09	0.21	0.03	0.00	46.00	22.72	1.00	1.35	0.36	0.41	1.31	1.27	0.92	1.20
Ge	<0.01	0.02	0.03	0.02	<0.01		0.15	0.12	0.08	0.08	0.13	0.13		
Hf	<0.01		<0.01		0.95	0.67	0.20	0.22	0.01	0.01	0.04	0.02		
In	<0.01		<0.01		<0.01		<0.01		<0.01		<0.01			
Pd	<0.2		<0.2		<0.2		<0.2		<0.2		<0.2			
Pt	<0.01		<0.01				0.08	0.06	0.05	0.05	1.11	2.03		
Rb	10.42	5.77	29.28	26.62	14.20	5.37	43.97	50.28	29.48	49.49	56.36	42.16		
Re	<0.01		<0.01		<0.01		<0.01		<0.01		<0.01			
Rh	0.03	0.02	0.03	0.02			0.02	0.01	0.01	0.01	0.03	0.02		
Ru	<0.05		<0.01				0.03	0.00	0.03	0.01	0.03	0.00		
S	1.60	3.14	12.36	13.33			65.25	29.64	43.50	25.56	46.25	9.03		
Se	0.37	0.20	4.91	4.71	0.75	0.35	10.99	11.25	10.88	16.12	20.73	6.08	0.17	0.12
Sn	0.03	0.03	0.03	0.001	1.25	0.49	9.57	16.68	9.02	15.60	8.76	13.32		
Sr	88.64	48.47	237.92	268.86	26.50	10.61	0.57	0.87	1.24	1.22	0.24	0.21	59.95	39.49
Ta	<0.02		<0.02		0.15	0.07	0.03	0.02	0.01	0.001	0.02	0.01		
Te	<0.01		<0.01		<0.01		0.03	0.001	0.05	0.04	0.06	0.04	0.01	0.01
Th	<0.05		<0.05		29.40	7.64	0.61	0.35	0.68	0.66	0.49	0.37	0.08	0.12
Tl	0.01	0.01	0.12	0.12	0.03	0.001	0.10	0.13	0.11	0.18	0.65	0.88	0.03	0.03
U	0.02	0.01	0.04	0.07	1.30	0.85	0.46	0.18	0.50	0.33	0.80	0.60	0.07	0.08
U	0.02	0.01	0.04	0.07	1.30	0.85	0.46	0.18	0.50	0.33	0.80	0.60	0.07	0.08
W	0.04	0.03	0.05	0.02	0.35	0.35							0.10	0.08
Zr	0.19	0.45	0.01	0.001	65.95	66.11								0.05

SD standard deviation

Table 3 Mean concentrations of rare earth elements (REES) in samples

	Surface water		Groundwater		Sediment		Fish muscle		Fish gill		Fish gut	
	Mean (µg L^{-1})	SD	Mean (µg L^{-1})	SD	Mean (µg kg^{-1})	SD	Mean (µg kg^{-1})	SD	Mean (µg kg^{-1})	SD	Mean (µg kg^{-1})	SD
Ce	0.24	0.44	0.15	0.29	31.30	62.42	8.94	9.66	6.58	10.50	15.85	17.76
Dy	<0.01		0.03	0.05	0.02	0.01	0.26	0.29	0.26	0.41	0.51	0.60
Er	<0.01		0.02	0.03	7.25	2.25	0.95	1.34	0.10	0.15	0.33	0.32
Eu	<0.01		0.01	0.01	98.50	94.22	0.05	0.06	0.06	0.11	0.12	0.15
Gd	0.02	0.03	0.05	0.07	0.04	0.02	0.36	0.40	0.41	0.68	0.73	0.83
Ho	<0.01	0.00	0.01	0.01	0.15	0.17	0.07	0.05	0.04	0.05	0.10	0.12
La	0.13	0.25	0.53	0.90	16.67	28.88	3.58	3.02	3.57	3.46	5.99	6.86
Lu	<0.01	0.001	0.01	0.001	<0.01		0.02	0.01	0.01	0.01	0.04	0.04
Nd	0.10	0.16	0.29	0.46			2.64	2.98	2.61	4.29	5.01	5.83
Pr	0.03	0.04	0.08	0.11			0.66	0.75	0.64	1.04	1.28	1.47
Sc	1.00	0.65	0.81	0.63			0.63	0.25	0.88	0.76	0.88	0.75
Sm	0.02	0.03	0.04	0.06			0.45	0.50	0.54	0.88	0.86	1.02
Tb	0.01	0.001	0.01	0.01			0.07	0.05	0.07	0.10	0.10	0.12
Tm	0.01	0.001	0.01	0.001			0.02	0.01	0.01	0.01	0.03	0.04
Y	0.08	0.17	0.47	0.79								
Yb	0.01	0.02	0.02	0.02								

SD standard deviation

patterns, feeding behavior and geographical location (El-Moselhy et al. 2014).

The trace metal levels measured in the aquatic plants are generally low. The most abundant trace elements measured in plant samples were Sr and B. The risks of Sr (stable form) and B to aquatic ecosystem are usually very low (Howe 1998).

Rare earth element concentrations in environmental samples

The mean concentrations of REEs observed in the environmental samples are shown in Table 3. Scandium showed the highest concentration of REE in surface water (1.00 ± 0.65 μg L^{-1}) and groundwater (0.81 ± 0.63 μg L^{-1}). Most of the REEs were observed at higher concentrations in groundwater than surface water. Europium (Eu) (98.50 ± 94.22 μg kg^{-1}) was the most abundant REE measured in the bottom sediments followed by Ce (31.30 ± 64.22 μg kg^{-1}) and La (16.67 ± 28.88 μg kg^{-1}). In fish samples, the sums of REEs were 31.81 ± 35.90 μg kg^{-1} in the guts, 18.70 ± 19.37 μg kg^{-1} in muscle and 15.78 ± 22.45 μg kg^{-1} in the gills.

The abundance of REEs in fish sample follows similar pattern as trace metal distribution in the fish parts i.e. guts > muscle > gills. The toxicity of REEs had been reported to increase mortalities of aquatic and terrestrial organisms, and humans (Paul and Campbell 2011). Exposure to REEs through consumption of contaminated fish may result into accumulation of REEs in the body. This can initiate serious health effects in humans (Chester-Paul 2013). Genotoxicity of REEs in bone marrow cells has been identified by Chen and Zhu (2008). REEs were not measured in the plant samples.

Health risk assessment

Additional file 1: Tables S1–S9 show the average daily dose (ADD) values of major, trace and rare earth elements in surface water, groundwater and fish samples. The ADD values showed highest values for major elements followed by trace elements, while REEs had the lowest ADD values in all the environmental samples. The ADD was calculated from the concentration of elements measured in water (groundwater and surface water) and fish (muscle) samples. The calculation was based on the

Table 4 Non-cancer hazard quotient (HQ) and hazard index (HI) values of elements in water and fish samples

	Surface water				Groundwater				Fish			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
Adult												
B	1.8E−03	6.7E−04	9.6E−04	3.4E−03	4.0E−03	4.9E−03	4.0E−04	1.4E−02	5.6E−04	1.6E−04	4.1E−04	7.7E−04
Be	5.0E−04	3.3E−04	4.0E−04	1.8E−03	2.5E−03	3.2E−03	4.0E−04	9.3E−03	2.5E−04	3.0E−04	4.9E−05	6.9E−04
Se	2.4E−03	1.2E−03	1.6E−03	5.1E−03	3.0E−02	3.0E−02	1.6E−03	7.4E−02	8.7E−03	8.9E−03	2.0E−04	1.9E−02
Sr	4.7E−03	2.5E−03	9.8E−04	9.8E−03	1.5E−02	1.4E−02	5.9E−04	3.7E−02	3.8E−03	5.7E−03	6.0E−04	1.2E−02
Tl	5.7E−03	3.8E−03	2.0E−03	1.6E−02	4.3E−02	4.9E−02	4.0E−03	1.4E−01	5.1E−03	6.6E−03	2.5E−04	1.5E−02
U	2.1E−04	1.7E−04	1.1E−04	6.4E−04	5.8E−04	7.7E−04	1.1E−04	2.2E−03	6.0E−04	2.4E−04	3.4E−04	9.2E−04
HI	0.015	0.009	0.006	0.037	0.095	0.102	0.007	0.277	0.019	0.022	0.002	0.048
Child												
B	5.3E−03	2.0E−03	2.9E−03	1.0E−02	1.2E−02	1.5E−02	1.2E−03	4.2E−02	3.4E−03	9.7E−04	2.5E−03	4.6E−03
Be	1.5E−03	9.9E−04	1.2E−03	5.3E−03	7.4E−03	9.5E−03	1.2E−03	2.8E−02	1.5E−03	1.8E−03	3.0E−04	4.1E−03
Se	7.1E−03	3.7E−03	4.8E−03	1.5E−02	9.1E−02	9.0E−02	4.8E−03	2.2E−01	5.2E−02	5.3E−02	1.2E−03	1.1E−01
Sr	1.4E−02	7.6E−03	2.9E−03	2.9E−02	4.6E−02	4.3E−02	1.8E−03	1.1E−01	2.3E−02	3.4E−02	3.6E−03	7.4E−02
Tl	1.7E−02	1.1E−02	6.0E−03	4.8E−02	1.3E−01	1.5E−01	1.2E−02	4.2E−01	3.1E−02	4.0E−02	1.5E−03	8.9E−02
U	6.4E−04	5.1E−04	3.2E−04	1.9E−03	1.7E−03	2.3E−03	3.2E−04	6.7E−03	3.6E−03	1.4E−03	2.1E−03	5.5E−03
HI	0.046	0.026	0.018	0.110	0.286	0.306	0.021	0.830	0.114	0.132	0.011	0.290
Infant												
B	7.9E−03	3.0E−03	4.3E−03	1.5E−02	1.8E−02	2.2E−02	1.8E−03	6.3E−02	7.9E−03	3.0E−03	4.3E−03	1.5E−02
Be	2.3E−03	1.5E−03	1.8E−03	7.9E−03	1.1E−02	1.4E−02	1.8E−03	4.2E−02	2.3E−03	1.5E−03	1.8E−03	7.9E−03
Se	1.1E−02	5.6E−03	7.2E−03	2.3E−02	1.4E−01	1.4E−01	7.2E−03	3.3E−01	1.1E−02	5.6E−03	7.2E−03	2.3E−02
Sr	2.1E−02	1.1E−02	4.4E−03	4.4E−02	6.9E−02	6.4E−02	2.6E−03	1.7E−01	2.1E−02	1.1E−02	4.4E−03	4.4E−02
Tl	2.6E−02	1.7E−02	9.0E−03	7.2E−02	1.9E−01	2.2E−01	1.8E−02	6.3E−01	2.6E−02	1.7E−02	9.0E−03	7.2E−02
U	9.6E−04	7.7E−04	4.8E−04	2.9E−03	2.6E−03	3.5E−03	4.8E−04	1.0E−02	9.6E−04	7.7E−04	4.8E − 04	2.9E − 03
HI	0.069	0.039	0.027	0.165	0.429	0.459	0.032	1.245	0.069	0.039	0.027	0.165

assumption that a matured adult weighing 60 kg consumes 2 L of water per day, while a child weighing 10 kg consumes 1 L of water per day and an infant weighing 5 kg consumes 0.75 L of water per day (USEPA 2002; 2007). The corresponding ADD and weekly intake values of elements in surface water were lower for Ba and higher for Ce (by 2 times), Ga and Zr (3 times) Nb (8 times) in groundwater. Despite the fact that an infant (of lower body weight) consumes less quantity of water compared to an adult (of higher body weight); an infant would take more of these toxic elements in water than an adult by five times. Likewise, a child would take a triple dose of these elements more than an adult.

The average daily intake data of elements in fish samples are also presented Additional file 1: Tables S3, S6 and S9. It is assumed that an adult weighing 60 kg consumes 24.7 g fish daily in Nigeria (FAO 2008). High ADD values were observed for Ca, Na, Mg, K, P and Si. Calcium, sodium, magnesium and potassium are essential elements required for proper functioning of body e.g. growth and muscle building, regulation of acid–base, cell osmotic balance, enzyme cofactor, and cardiac function (Soetan et al. 2010). The most dosed trace elements in groundwater, surface water and fish samples were Sr, Br and Cl. These elements are of environmental and health concerns. The stable Sr is not harmful, but the radioactive Sr is deleterious to human health, while Cl is toxic to aquatic animals (Lenntech 2017). Organic Br can be very damaging to human health through damage to DNA, enhancing the change of cancer development (Lenntech 2017).

Table 4 shows the hazard quotient (HQ) and hazard index (HI) values of elements whose oral reference dose (RfD) values are available in literature. The sum of risks due to noncarcinogenic adverse effects of trace elements was higher in groundwater than surface water. An infant who consumes water samples collected around the goldmine areas would be two times adversely exposed to these toxic metals than a child and five times than an adult.

The ΣHQ for adult, children and infants in surface water, groundwater and fish samples were generally less than 1.0 indicating non-carcinogenic adverse effects. However, long term exposure to these metals may have serious consequence on human health. The ΣHQ for nonessential trace metals previously reported by Taiwo and Awomeso (2017) was higher than 1.0. The pattern of abundance of HQ for adults, children and infants in this study follows: Tl > Sr > Se > B>Be > U in groundwater, surface water and fish samples. The HI showed the highest values in groundwater followed by surface water and fish samples similar to the reported HI values for essential and nonessential elements (Taiwo and Awomeso 2017).

Conclusions

This study had assessed the human health and environmental impacts of artisanal gold mining activities in the gold city of Ijeshaland, Osun State, Southwest Nigeria. Ca and Si were the most abundant major elements in water and fish samples. The sum of trace elements and REEs were observed at the highest concentrations in the fish guts. The most abundant trace elements measured in the bottom sediments were Cs, Zr, Ga, Th and Sr. In plant samples, Ti and Sr were the most abundant major and trace elements. Most of the analyzed elements showed concentrations not higher than the permissible standards of the World Health Organization. The health risk assessment data showed Sr, Br and Cl as the most dosed trace elements in groundwater, surface water and fish samples. The hazard quotient and hazard index values for metals were generally less than 1.0 in water and fish samples indicating no adverse health effects. The human health assessment of noncarcinogenic adverse effects revealed the greatest risk in groundwater samples followed by surface water samples. This study established that infants were at the greatest risk of noncarcinogenic effects despite their low body weight. The data obtained in this study showed that the artisanal gold mining in the study area may contribute to long term environmental and human health risks.

Additional file

Additional file 1. Additional tables.

Abbreviations

ADD: average daily dose; HI: hazard index; HQ: hazard quotient; ICPMS: inductively coupled plasma mass spectrophotometer; REEs: rare earth elements; RfD: reference dose; SD: standard deviation.

Authors' contributions

JAA collected the data, AMT analyzed the data. JAA and AMT drafted the manuscript, while EOD and OOA participated in proofreading the manuscript. All authors read and approved the final manuscript.

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Competing interests

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