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Heavy Metal Contamination of Well Water in the Kipushi Mining Town (Democratic Republic of Congo)

Bamba Bukengu Muhaya[1], Rachel Mulunda Numbi[2], Francois Toto Lubala[2], Joel Bacirheba Mugisho[2] and Dieudonne Kabumana Tshibanda[1]

1. Department of Chemistry, Faculty of Science, Lubumbashi University, Lubumbashi 1825, Democratic Republic of Congo

2. Department of Geology, Faculty of Science, Lubumbashi University, Lubumbashi 1825, Democratic Republic of Congo

Abstract: Concentrations of eleven heavy metals (Al, Cd, Co, Cu, Cr, Fe, Mn, Mo, Ni, Pb and Zn) and pH determination in water from nine spade-sunk wells of 2-15 meter depth, five drilled wells of 30-72 meter depth, and two water supply faucets in the Kipushi mining town, south-east of the Democratic Republic of Congo, were investigated from February to July 2011. The results were compared with the World Health Organization (WHO) drinking water pH and heavy metal guidelines. Mean concentrations of Pb in water from four spade-sunk wells and three drilled wells, those of Al and Fe in water from four and two spade-sunk wells, and those of Cd in water from four drilled wells were higher than the WHO drinking water maximum permissible contaminant limits of 0.01 mg/L, 0.2 mg/L, 0.3 mg/L and 0.003 mg/L respectively, probably due to the mining activities carried out in Kipushi for about 90 years. The pH mean values of water from five spade-sunk wells and three drilled wells were lower than the WHO drinking water pH optimum of 6.5-9.5, suggesting that the water from those eight wells was not conform to the chemical quality of water for human consumption.

Key words: Heavy metals, pH, drinking water, well water, WHO guidelines, Kipushi.

1. Introduction

The Democratic Republic of Congo (DRC) has the most important hydrologic resources of the African continent, but it nowadays faces an acute crisis of drinking water supply. Actually, many urban and rural areas in the country are facing drastic shortage of drinking water. According to statistics published by the Congolese Ministry of Energy and the United Nations Environmental Program (UNEP), the DRC national rate of drinking water service which was 69% in 1990, fell down to 22% in 2005 before currently rising again to 26% [1].

In a technical report ("water issues in DRC: challenges and opportunities") [2], the UNEP showed the major challenges concerning drinking water in urban, out-of-town and rural areas in DRC. According to that UN institution [2], the situation is due to:

- neglected infrastructures (one third of the water treatment plants is non-operational);
- the rate of rapid urban population growth;
- the high price of water;
- the low investment return and the low financial viability of the public services in charge of water;
- the informality of water services provision/delivery in out-of-town areas;
- the degradation of the watersheds increasing the costs of water treatments.

Social and sanitary consequences of the rupture of water services are considerable. The poorest people are concerned in a disproportional manner by the decline of the water services and the increase of water prices. Such a situation has been observed not only in rural areas but also in urban areas with rapid population expansion [2].

The Kipushi mine and its adjacent town with an estimated population of 120,000 inhabitants are located between 11°44' and 11°48' of latitude south and between 27°11' and 27°16' of longitude east, in

Corresponding author: Bamba Bukengu Muhaya, Ph.D., associate professor, research fields: mapping and assessing the environmental and health impacts of abandoned mines in Sub-Saharan African countries. E-mail: bbmuhaya@gmail.com.

the south-west at about 30 kilometers from the Lubumbashi—the capital city of the Katanga province, DRC, close to the DRC-Zambia border (Figs. 1a and 1b). Its altitude is about 1,350 m above the sea level.

The climate is tropical humid characterized by a rainy season from October to April, with a maximum of rains in February, and a dry season from May to September. The annual mean temperature is 20.3 °C with a minimum of 11 °C in June and a maximum of 30 °C in October.

From geological point of view, the Kipushi Cu-Pb-Zn-Cd-Ge deposit is hosted in dolomitic and shales rocks overlying a glaciogenic diamictite (grand conglomerate) related to the Nguba Group of Neoproterozoic age. The economic minerals mainly consist of major sphalerite, chalcopyrite, pyrite and bornite with minor chalcocite, molybdenite, arsenopyrite and galena. The distribution of the ore bodies is strongly fault controlled, and/or controlled by lithological competence barriers between shales and massive dolomite reported as Kakontwe Dolomite. The deposit has a magmatic hydrothermal origin and contains major Cu, Zn and Fe as chalcopyrite, bornite, sphalerite and pyrite and minor Pb occurring as galena [3]. In addition, low concentrations of metals such as Ga, Ge, Se, Ni, Ag, Co, Cd, As and Mo etc., are found in the forms of renierite, arsenopyrite and molybdenite etc. [3].

Kipushi deposit was mined since 1925 by the Union Miniere du Haut-Katanga (UMHK) up to 1967 and by the "Generale des Carriereset des Mines" (GECAMINES) until 2003. Kipushi Mining Company (KICO) took over the mine since 2013. The mine and town have over the years become interlinked with the tailings disposal system for concentrator running very close to habitations. From 1926 to 1993, production from the mine was approximately 60 million tons of ore with average grade of 11% Zn, 7% Cu and 5% Pb.

Around the year 1935, the company put in service concentrators which used floatation to process sulfide ores. Those operations have generated huge quantities

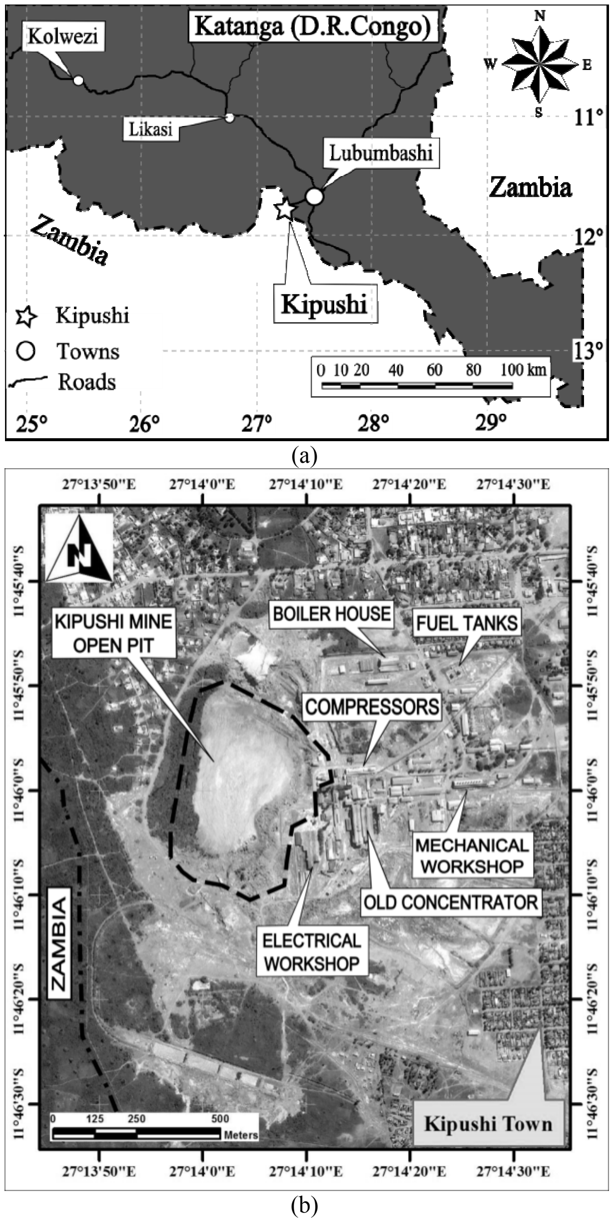

Fig. 1 (a) Location of the Kipushi studied area in southeast D.R. Congo and (b) map of the Kipushi mine layout.

of wastes under pulp form moved to artificial basins for the decantation of contained water. The progressive filling of those basins gave place to solid wastes (tailings).

The most comprehensive previous work carried out in the area was that of Kitobo et al. [4, 5], who sampled and assayed the material from dumps and impoundments and assessed their impacts on the environment. He pointed out that this material randomly stockpiled in river flats and sulfides minerals underwent oxidation at contact with air and water generating Acid Mining Drainage (AMD).

The aim of this study is to assess the impact of those wastes on the underground water in particular by using geochemical tools. In this respect, pH and heavy metal concentrations of water from spade sunk wells, drilled wells and water supply faucets in the Kipushi mining town were investigated. The results were compared with the WHO [6] pH optimum and heavy metal guidelines for drinking water in order to point out the level of heavy metal contamination of water used for human consumption.

2. Material and Methods

2.1 Sampling Sites

Once a month from February to July 2011, water samples were collected from two water supply faucets (EDD1 and EDD2), nine spade-sunk wells (EPA1, EPA2, EPA3, EPA4, EPA5, EPA6, EPA7, EPA8 and EPA9) of 2-15 meter depth, and five drilled wells (EPP1, EPP2, EPP3, EPP4 and EPP5) of 30-72 meter depth in the Kipushi mining town. The sampling sites are shown in Fig. 2.

The samples were collected in 50 mL polyethylene bottles and processed following classic protocol. Chemical analyses were performed by Robinson International in Africa laboratory in Lubumbashi. The sample codes, types and collection sites are shown in Table 1 and Fig. 2.

2.2. Analytical Methods

Water pH was determined with a pH-meter and heavy metal concentrations in the water samples were investigated using Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES) after pulverization of acidic solvent and sample pre-concentration.

3. Results and Discussion

REGIDESO (the Congolese water supply company)

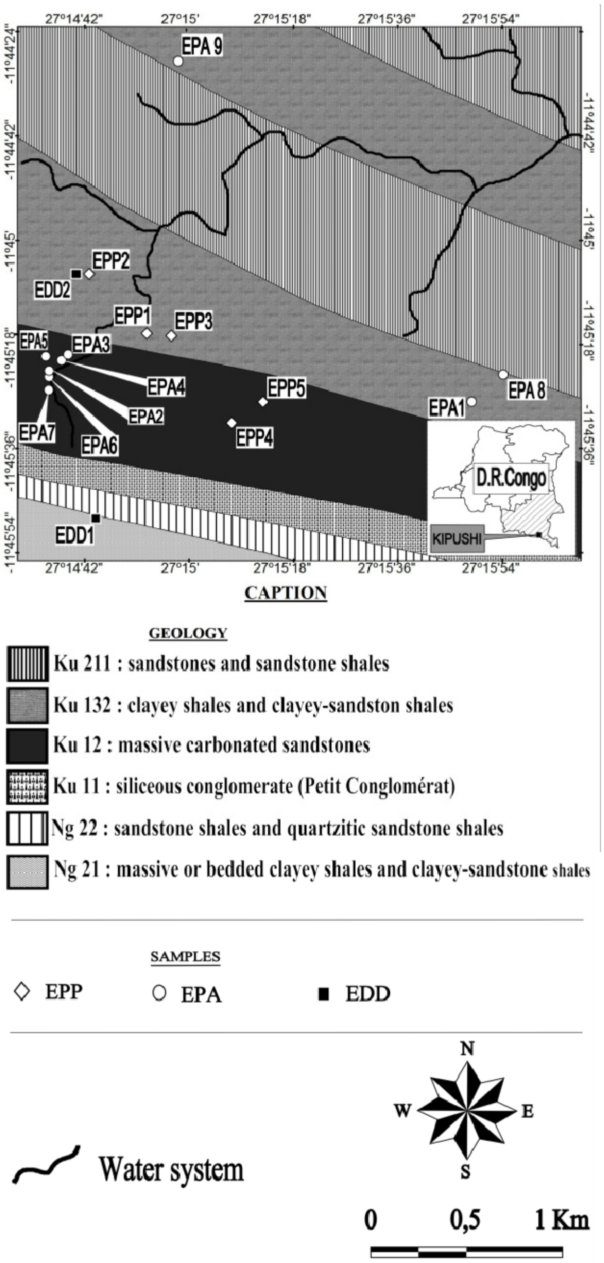

Fig. 2 Location of the sampling sites on the geological map of the Kipushi mining town.

is facing technical problems and cannot meet its customers' needs. This situation pushed the Kipushi population, including REGIDESO customers, to spade sink or drill wells in their parcels in order to get a permanent and easy access to water.

3.1 Water PH

The pH values of faucet water (EDD1 and EDD2), those of water from spade-sunk wells EPA2, EPA3,

Table 1 Water sample codes and types, sampling site coordinates, types and depths of various water wells in the Kipushi mining town in 2011.

Sample code	Sample type	Sampling site coordinates and depth
EDD1	Faucet water	9 B, Shituru avenue, Shituru area; water supply faucet
EDD2	Faucet water	Kipushi prison, Prison camp area; water supply faucet
EPA1	Spade-sunk well water	56, Shindaika avenue, Chachacha area; 15-meter deep well sunk with a spade on November 11, 1981
EPA2	Spade-sunk well water	Street 4, Mailamene area; 3-meter deep spade-sunk well
EPA3	Spade-sunk well water	254, Street 3, Mailamene area; 4-meter deep spade-sunk well
EPA4	Spade-sunk well water	1, Street 3, Mailamene area; 2-meter deep spade-sunk well
EPA5	Spade-sunk well water	Street 2, Mailamene area; 3-meter deep spade-sunk well
EPA6	Spade-sunk well water	7, Grand Luapula avenue, Mailamene area; 10-meter deep spade-sunk well
EPA7	Spade-sunk well water	4, Grand Luapula avenue, Mailamene area; 6-meter deep spade-sunk well
EPA8	Spade-sunk well water	Mobutu avenue, Sapin area; 15-meter deep spade-sunk well
EPA9	Spade-sunk well water	City area near Kipushi lake; 5-meter deep spade-sunk well
EPP1	Drilled and well protected well water	Mwanga school complex, Grand Luapula avenue, city area; 60-meter deep well
EPP2	Drilled and well protected well water	Kipushi prison, prison camp area; 30-meter deep well
EPP3	Drilled and well protected well water	Betty health center, Grand Luapula avenue, city area; 72-meter deep well
EPP4	Drilled and well protected well water	Mukuba school complex, Mobutu avenue; 60-meter deep well
EPP5	Drilled and well protected well water	Imani institute, Kiluba avenue; 57-meter deep drilled well

EPA4 and EPA9 as well as drilled wells EPP1 and EPP2 during the period of February to July 2011 are given in Tables 2-12. On the whole, they were in accordance with the WHO [6] pH optimum interval of 6.5-9.5 for drinking water. On the other hand, the water pH mean values (5.6 ± 0.3 to 6.4 ± 0.2) of five of the nine spade-sunk wells (EPA1, EPA5, EPA6, EPA7 and EPA8) and those (6.1 ± 0.1 to 6.3 ± 0.2) of three of the five drilled wells (EPP3, EPP4 and EPP5) were outside the WHO [6] pH optimum interval for drinking water, suggesting that the water from those eight latter wells was not suitable for human consumption with regard to its pH.

3.2 Heavy Metals

The mean concentrations of heavy metals in those samples for the same period are given in Tables 2-12, and illustrated in Fig. 3.

3.2.1 Lead (Pb)

Pb levels of faucet water ranged from 0.001 mg/L to 0.47 mg/L, those of water from spade-sunk wells from 0 mg/L to 0.039 mg/L and those of water from drilled wells vary between 0.001 mg/L and 0.05 mg/L. With Pb levels equal to or higher than the WHO [6]

Table 2 Mean values and standard deviations of pH and Pb levels of supply water and well water in Kipushi in 2011, and the WHO [6] guidelines.

	WHO* drinking water pH optimum and maximum permissible Pb concentration limit, and Pb mean concentration values with standard deviation of the water samples	
	pH	Pb (mg/L)
WHO* guidelines	6.5-9.5	0.01
water sample		
EDD1	7.4 ± 0.1	0.002 ± 0.001
EDD2	7.2 ± 0.1	0.014 ± 0.019
EPA1	5.7 ± 0.2	0.007 ± 0.005
EPA2	6.9 ± 0.2	0.02 ± 0.008
EPA3	6.5 ± 0.2	0.009 ± 0.002
EPA4	6.8 ± 0.1	0.028 ± 0.007
EPA5	6.0 ± 0.1	0.014 ± 0.002
EPA6	5.8 ± 0.1	0.009 ± 0.005
EPA7	6.4 ± 0.2	0.015 ± 0.007
EPA8	5.6 ± 0.3	ND
EPA9	7.4 ± 0.1	0.003 ± 0.001
EPP1	6.5 ± 0.2	0.027 ± 0.009
EPP2	6.9 ± 0.1	0.017 ± 0.02
EPP3	6.3 ± 0.2	0.001 ± 0.001
EPP4	6.1 ± 0.1	0.015 ± 0.017
EPP5	6.1 ± 0.3	0.006 ± 0.007

* WHO: World Health Organization, ND: not detected.

Pb guideline of 0.01 mg/L, water from spade-sunk wells EPA2, EPA4, EPA5 and EPA7 and from drilled wells EPP1 and EPP2 is the most contaminated by Pb for the period of February 2011. Pb concentrations of water from spade-sunk wells ranged from 0.012 mg/L to 0.031 mg/L with a mean of 0.02 ± 0.008 mg/L for EPA2, from 0.02 mg/L to 0.039 mg/L with a mean of 0.028 ± 0.007 mg/L for EPA4, from 0.01 mg/L to 0.017 mg/L with a mean of 0.014 ± 0.003 mg/L for EPA5, and from 0.008 mg/L to 0.024 mg/L with a mean of 0.015 ± 0.007 mg/L for EPA7, those of water from drilled wells varied from 0.01 mg/L to 0.033 mg/L with a mean of 0.027 ± 0.009 mg/L for EPP1 and from 0.001 mg/L to 0.05 mg/L with 0.017 ± 0.02 mg/L mean concentration for EPP2.

Pb concentrations equal to or higher than the WHO [6] 0.01 mg/L Pb guideline for drinking water were also periodically found in water from spade-sunk wells EPA1 (0.017 mg/L in March), EPA3 (0.01 mg/L in February and 0.011 mg/L in April), EPA6 (0.016 mg/L in May and 0.012 mg/L in July), EPA7 (0.02 mg/L in February, 0.024 mg/L in March, 0.019 mg/L in April and 0.01 mg/L in May) and in water from drilled wells EPP2 (0.05 mg/L in February, 0.03 mg/L in March and 0.02 mg/L in April), EPP4 (0.05 mg/L in February) and EPP5 (0.01 mg/L in February and 0.017 mg/L in March). More than 93% (93.8%) of analyzed water samples contained Pb and 44.8% of the samples had concentrations higher than the WHO [6] maximum permissible Pb concentration of 0.01 mg/L in drinking water.

For the whole period of February to July 2011, the mean Pb levels and standard deviations of faucet water EDD2 (0.014 ± 0.019 mg/L), spade-sunk well water EPA2 (0.02 ± 0.008 mg/L), EPA4 (0.028 ± 0.007 mg/L) and EPA5 (0.014 ± 0.002 mg/l) and drilled well water EPP1 (0.027 ± 0.009 mg/L), EPP2 (0.017 ± 0.02 mg/L) and EPP4 (0.015 ± 0.017 mg/L) were higher than the WHO [6] Pb guideline of 0.01 mg/L for drinking water (Table 2).

The high Pb concentrations of water from different spade sunk-wells and drilled wells and, from one water supply faucet may result from a surface contamination by tailings and also from interaction between groundwater and underground minerals contained in geological formations.

Pb concentrations higher than the WHO [6] 0.01 mg/L Pb guideline for drinking water present a risk to the public health due to the high toxicity of that metal. Pb has been recognized since decades to be a general and cumulative metabolic poison [7]. Children are particularly sensitive to Pb exposure due to high gastro-intestinal absorption and permeable blood-brain barrier [8]. Martin and Griswold [9] reported that Pb is a probable carcinogen for man and that long term exposure to Pb may result in reduced performance to some tests that measure the functions of the nervous system, weakness of fingers, wrists or ankles, light increase of blood pressure and anemia.

According to Martin, S., and Griswold, W. [9], exposure to high Pb levels may cause severe damage to brain, kidneys and ultimate death. Exposure to high Pb levels may cause abortion to pregnant women and may damage the organs responsible for sperm production in men. Other studies have linked Pb exposure, even at low concentrations, to an increase of arterial pressure as well as a weak intelligence quotient in children and a disorder in attention [10-12]. Also Glover-Kerkvliet [13] reported that exposure high Hg, Au and Pb concentrations is associated with auto-immunity development that drives the immunity system to attack its own cells, mistaking them for invaders. According to the author, auto-immunity may lead to the development of kidney and articulation diseases, such as rheumatoid arthritis, and circulatory system and central nervous system diseases.

Exposure to high Pb levels may result in toxic biochemical effects in human beings, effects which in return cause problems of hemoglobin synthesis, negative effects on kidneys, digestive tube, articulations and reproductive system and acute or chronic damage to the nervous system [14]. The same source indicates that at intermediate Pb levels, there is a persuasive evidence that Pb may have small subtle sub-clinical effects, particularly on the neuropsychological developments in children, and certain other studies suggest that there may be loss of Intelligence Quotient (IQ) till 2 IQ points for an increase of Pb levels of 10-20 micrograms per deciliter (µg/dL) in young children.

3.2.2 Aluminium (Al)

All analyzed water samples had detectable Al concentrations except samples collected from the drilled well EPP2. About 78% of water samples from spade-sunk wells (seven over nine wells) periodically had Al concentrations higher than the 0.2 mg/L WHO [6] maximum permissible Al concentration limit in drinking water. Very high Al concentrations greater than the WHO maximum permissible Al concentration limit of 0.2 mg/L in drinking water were noted in water from spade-sunk wells EPA1 in February (1 mg/L), EPA2 in February and March (1.84 mg/L and 0.92 mg/L, respectively), EPA3 in February (0.22 mg/L), EPA6 in February and March (0.46 mg/L and 0.35 mg/L, respectively), EPA7 in February (0.34 mg/L) and EPA8 in February and March (4.31 mg/L and 2.05 mg/L, respectively). From February to July 2011, mean Al concentrations of water from spade-sunk wells EPA1 (0.228 ± 0.381 mg/L), EPA2 (0.539 ± 0.713 mg/L), EPA6 (0.241 ± 0.132 mg/L) and EPA8 (1.106 ± 1.758 mg/L) were higher than the 0.2 mg/L WHO [6] maximum permissible Al concentration limit in drinking water (Table 3 and Fig. 3). These results indicated that water from spade sunk wells, which is a shallow groundwater of 2-15 meter deep, was highly contaminated by Al.

Al is absorbed through the digestive tract or the lungs and can reach other body tissues. Neurological diseases such as the Alzheimer's disease, the Parkinson's disease and many others are presently being studied with connection to excess Al in the brain tissues [15].

Table 3 Mean values and standard deviations of pH and Al levels of supply water and well water in Kipushi in 2011, and the WHO [6] guidelines.

	WHO* drinking water pH optimum and maximum permissible Al concentration limit, and Al mean concentration values with standard deviation of the water samples	
	pH	Al (mg/L)
WHO* guidelines	6.5-9.5	0.2
water sample		
EDD1	7.4 ± 0.1	0.012 ± 0.007
EDD2	7.2 ± 0.1	0.003 ± 0.004
EPA1	5.7 ± 0.2	0.228 ± 0.381
EPA2	6.9 ± 0.2	0.539 ± 0.713
EPA3	6.5 ± 0.2	0.176 ± 0.025
EPA4	6.8 ± 0.1	0.153 ± 0.036
EPA5	6.0 ± 0.1	0.038 ± 0.032
EPA6	5.8 ± 0.1	0.241 ± 0.132
EPA7	6.4 ± 0.2	0.117 ± 0.121
EPA8	5.6 ± 0.3	1.106 ± 1.758
EPA9	7.4 ± 0.1	0.059 ± 0.019
EPP1	6.5 ± 0.2	0.021 ± 0.019
EPP2	6.9 ± 0.1	ND
EPP3	6.3 ± 0.2	0.012 ± 0.01
EPP4	6.1 ± 0.1	0.004 ± 0.004
EPP5	6.1 ± 0.3	0.018 ± 0.01

* WHO: World Health Organization, ND: not detected.

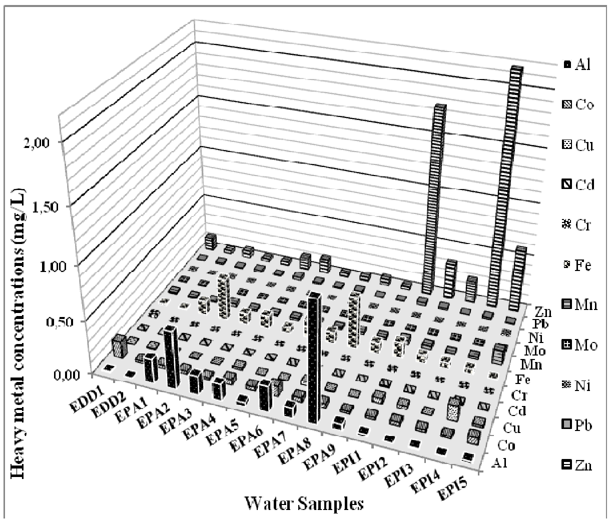

Fig. 3 Mean concentrations of various heavy metals in supply water and well water (mg/L) in the Kipushi mining town in 2011.

Al and Hg would be implicated in the Alzheimer's disease etiology as well as in certain forms of cancer such as lymphomas and reticulo-sarcomas [16].

According to the same source, the oxidative alteration by the metals (Al, Fe, Zn and Cu), their deregulation and their accumulation in the cerebral tissue cause the formation of free radicals.

3.2.3 Cadmium (Cd)

Over the five drilled wells, four (EPP1, EPP2, EPP4 and EPP5) had water with Cd concentration periodically higher than the 0.003 mg/L WHO [6] maximum permissible Cd concentration limit in drinking water. Cd concentrations varied from 0.001 mg/L to 0.04 mg/L with a mean of 0.011 ± 0.015 mg/L in the drilled well water EPP1, from 0.001-0.01 mg/L with a mean of 0.003 ± 0.004 mg/L in the EPP2 water, from 0-0.03 mg/L with a mean of 0.008 ± 0.011 mg/L in the EPP4 water, and from 0-0.01 mg/L with a mean concentration of 0.003 ± 0.004 mg/L in the EPP5 water (Table 4).

Cd was not detected in samples of faucet water EDD1 and in water samples from the spade-sunk wells EPA1, EPA2, EPA5, EPA6 and EPA9 and from the drilled well EPP3. Cd concentrations found in the other water samples ranged from 0-0.001 mg/L in faucet water EDD2, from 0-0.003 mg/L in water from the spade-sunk wells EPA3, EPA4, EPA7 and EPA8, and from 0-0.04 mg/L in water from the very deep wells EPP1, EPP2, EPP4 and EPP5. Over the five drilled wells, four (EPP1, EPP2, EPP4 and EPP5) had water with Cd concentration periodically higher than the 0.003 mg/L WHO [6] maximum permissible Cd concentration limit in drinking water. Cd concentrations varied from 0.001-0.04 mg/L with a mean of 0.011 ± 0.015 mg/L in the EPP1 drilled well water, from 0.001-0.01 mg/L with a mean of 0.003 ± 0.004 mg/L in the EPP2 well water, from 0-0.03 mg/L with a mean of 0.008 ± 0.011 mg/L in the EPP4 well water, and from 0-0.01 mg/L with a mean concentration of 0.003 ± 0.004 mg/L in the EPP5 well water.

The Cd found in water from spade-sunk wells and drilled wells of 30-60 meter depth probably came from the host rock which contains different metals of which Cd, but also from the releasing and the migration of that metal from the Kipushi tailings to the groundwater table. Cd concentrations similar to those found in water from four drilled wells (EPP1, EPP2, EPP4 and EPP5) in the Kipushi mining town were noted by Iqbal and Gupta [17] in groundwater sources in Naregaon (India), by Makkasap and Satapanajaru [18] in groundwater in the Rayong province (Thailand), and by Akoteyon et al. [19] in groundwater in Alimosho, Lagos (Nigeria).

Table 4 Mean values and standard deviations of pH and Cd levels of supply water and well water in Kipushi in 2011, and the WHO [6] guidelines.

	WHO* drinking water pH optimum and maximum permissible Cd concentration limit, and Cd mean concentration values with standard deviation of the water samples	
	pH	Cd (mg/L)
WHO* guidelines	6.5-9.5	0.003
water sample		
EDD1	7.4 ± 0.1	ND
EDD2	7.2 ± 0.1	0.001 ± 0.001
EPA1	5.7 ± 0.2	ND
EPA2	6.9 ± 0.2	ND
EPA3	6.5 ± 0.2	0.001 ± 0.001
EPA4	6.8 ± 0.1	0.001 ± 0.001
EPA5	6.0 ± 0.1	ND
EPA6	5.8 ± 0.1	ND
EPA7	6.4 ± 0.2	0.001 ± 0.001
EPA8	5.6 ± 0.3	ND
EPA9	7.4 ± 0.1	ND
EPP1	6.5 ± 0.2	0.009 ± 0.015
EPP2	6.9 ± 0.1	0.003 ± 0.004
EPP3	6.3 ± 0.2	ND
EPP4	6.1 ± 0.1	0.008 ± 0.011
EPP5	6.1 ± 0.3	0.003 ± 0.004

* WHO: World Health Organization, ND: not detected.

Knowing that Cd is a very toxic metal and that concentrations of that metal in drinking water are generally low, lower than 0.001 mg/L [20], the high Cd levels of water from the very deep drilled wells EPP1, EPP2, EPP4 and EPP5 in the Kipushi mining town constitute a serious health risk for the people who consume that water. Cd and Cd compounds are known to be carcinogenic and ingestion of very high Cd concentrations severely irritates the stomach, leading to vomiting and diarrhea when in fact long-term exposure to low Cd concentrations carries to the accumulation of that metal in the kidneys and possible kidney disease, damage of lungs, and weakening of bones [9]. Other studies indicate that the negative effects on health may occur due to exposure to Cd at concentrations lower than those previously expected, mainly in the form of damage to kidneys but also possibly effects on bones and the fracture of the latter [8, 21-23]. The highest Cd concentration (0.04 mg/L) was found in water from the drilled well EPP1 in February and the same water had the highest mean Cd concentration (0.009 mg/L) for the period of February to July 2011.

Cd causes renal, lung and bone injuries and prostate cancer. Cd concentrated in the body also causes high blood pressure, liver disease and problems in the nervous system. The kidneys normally evacuate toxins in urine produced by the former. But Cd accumulates in the kidneys where it damages the filtration mechanisms. That causes the excretion of essential proteins and sugar from the organism. It takes a lot of time for the Cd that has been accumulated to get excreted from the body. The other problems created by Cd are: diarrhea, stomach pains and important vomiting, bone fracture, sterility, central nervous system problems, psychological disorder, problems at the immune system level, alteration of the deoxyribonucleic acid (DNA) and cancer development [16, 24, 25]. In human beings, long-term exposure to Cd is associated to renal dysfunction. High Cd exposure may lead to lung obstructive disease and is even linked to lung cancer [14]. According to the same source, Cd may also cause bone diseases (osteomalacia, osteoporosis) in human beings and animals and, besides, that metal may be linked to high blood pressure and negative effects on the myocardium in animals. The same source indicates that in human beings the mean daily Cd intake is estimated to 0.15 µg from the air and 1 µg from water and that smoking a pack of 20 cigarettes may lead to the inhalation of about 2-4 µg Cd, but Cd levels may vary a lot.

3.2.4 Cobalt (Co)

Co concentrations ranged from 0.003-0.18 mg/L in faucet water, from 0-0.16 mg/L in water from spade-sunk wells and from 0-0.15 mg/L in water from drilled wells (Table 5). Faucet water EDD1 had the highest Co concentration (0.18 mg/L) in March and the highest mean concentration (0.162 ± 0.013 mg/L for the period of February to July 2011. No guideline for Co in drinking water has been determined by WHO [6].

Studies carried out in the United States of America have shown that Co concentration in surface water and groundwater in that country is generally low, between 1-10 ppb in densely populated zones but the concentration may be hundred or thousand times higher in zones rich in minerals containing Co or in zones near mining extraction operations or smelting [26]. According to the same source, Co concentrations normally found in the environment are not sufficiently higher to result in excessive Co concentrations in food or water. Co has beneficial effects and harmful effects on human health.

Co is beneficial to human beings because it enters in the composition of vitamin B12 which is essential to maintain human health. Co (0.16-1 mg/kg Co of body weight) is also used in anemia treatment including pregnant women because it causes red blood corpuscle production. Also Co is essential for the health of various animals, such as cattle and sheep. Exposure of human beings and animals to Co levels normally found in the environment is not harmful. However, when one is exposed to high Co levels by ingestion, by respiration or by contact, the harmful effects to health may occur [25].

Chronic exposure of human beings to Co by inhalation results in effects on the respiratory system, such as respiratory irritation, noisy or wheezing respiration, asthma, pneumonia, reduced pulmonary

Table 5 Mean values and standard deviations of pH and Co levels of supply water and well water in Kipushi in 2011, and the WHO [6] guidelines.

	WHO* drinking water pH optimum, and Co mean concentration values with standard deviation of the samples	
	pH	Co (mg/L)
WHO* guidelines water sample	6.5-9.5	-
EDD1	7.4 ± 0.1	0.162± 0.013
EDD2	7.2 ± 0.1	0.021 ± 0.018
EPA1	5.7 ± 0.2	0.029 ± 0.021
EPA2	6.9 ± 0.2	0.028 ± 0.042
EPA3	6.5 ± 0.2	0.018 ± 0.018
EPA4	6.8 ± 0.1	0.055 ± 0.07
EPA5	6.0 ± 0.1	0.033 ± 0.033
EPA6	5.8 ± 0.1	0.094 ± 0.055
EPA7	6.4 ± 0.2	0.04 ± 0.041
EPA8	5.6 ± 0.3	0.041 ± 0.058
EPA9	7.4 ± 0.1	0.019 ± 0.026
EPP1	6.5 ± 0.2	0.022 ± 0.015
EPP2	6.9 ± 0.1	0.033 ± 0.023
EPP3	6.3 ± 0.2	0.023 ± 0.043
EPP4	6.1 ± 0.1	0.019 ± 0.031
EPP5	6.1 ± 0.3	0.064 ± 0.063

* WHO: World Health Organization.

function, and fibrosis [25, 26]. Other Co effects due to Co exposure by inhalation include cardiac effects, such as functional effects on ventricles and heart enlargement, congestion of liver, kidneys and conjunctivitis, and immunological effects which include sensitivity to Co that can speed asthmatic attack in sensitive individuals [25, 27]. Gastrointestinal effects (nausea, vomiting and diarrhea), effects on blood, liver, wounds and allergic dermatitis have been reported in human beings due to Co exposure by ingestion [25].

3.2.5 Chromium (Cr)

Cr analyzed in water is total Cr which includes Cr(III) and Cr(VI). The U.S. Environmental Protection Agency (EPA) regulation assumes that the measure of total Cr is 100% Cr(VI)—the most toxic form [28]. Cr was not detected in most water samples from spade-sunk wells and drilled wells EPP2 and EPP5. Cr levels of faucet water (0-0.03 mg/L), those of water from spade-sunk wells (0-0.001 mg/L) and from drilled wells (0-0.04 mg/L) were lower than the 0.05 mg/L WHO [6] maximum permissible Cr concentration limit in drinking water (Table 6).

Those Cr levels were similar to those noted by Iqbal and Gupta [17] in groundwater sources near a solid waste municipal discharge in Naregon, India. Cr concentrations found in faucet water and in well water in the Kipushi mining town were lower than those of Cr(VI) found in faucet water in 25 of the 31 large cities of the United States of America in 2010. The Cr(VI) concentrations found in faucet water of the 25 American cities were lower than the 0.1 mg/L guideline established by the U.S. EPA for all combined forms of Cr in drinking water [29].

Table 6 Mean values and standard deviations of pH and Cr levels of supply water and well water in Kipushi in 2011, and the WHO [6] guidelines.

	WHO* drinking water pH optimum and maximum permissible Cr concentration limit, and Cr mean concentration values with standard deviation of the water samples	
	pH	Cr (mg/L)
WHO* guidelines water sample	6.5-9.5	0.05
EDD1	7.4 ± 0.1	0.024 ± 0.005
EDD2	7.2 ± 0.1	0.0002 ± 0.0004
EPA1	5.7 ± 0.2	ND
EPA2	6.9 ± 0.2	ND
EPA3	6.5 ± 0.2	ND
EPA4	6.8 ± 0.1	ND
EPA5	6.0 ± 0.1	ND
EPA6	5.8 ± 0.1	ND
EPA7	6.4 ± 0.2	0.001 ± 0.001
EPA8	5.6 ± 0.3	0.001 ± 0.001
EPA9	7.4 ± 0.1	ND
EPP1	6.5 ± 0.2	0.008 ± 0.016
EPP2	6.9 ± 0.1	ND
EPP3	6.3 ± 0.2	0.001 ± 0.001
EPP4	6.1 ± 0.1	0.005 ± 0.006
EPP5	6.1 ± 0.3	ND

* WHO: World Health Organization, ND: not detected.

Cr(VI) compounds are toxins and they are known to be carcinogenic for man. Whereas, Cr(III) is an essential nutrient and long-term exposure to Cr may cause damage to the liver and kidney circulatory and nervous tissues, as well as skin irritation [9].

According to Martin, S., and Griswold, W. [9], breathing high Cr levels may cause nose mucus irritation, nose ulcers, cold and breathing problems such as asthma, cough, short respiration or wheezing respiration, and that skin contact with Cr may cause skin ulcers. Furthermore, they reported that allergic reactions consisting in severe redness and skin swelling have been noted, and that long-term exposure to Cr may cause damages to liver, circulatory and nervous tissues of the kidneys, as well as skin irritation. Exposure to low Cr levels may irritate the skin and cause ulceration, whereas, long-term exposure may damage the kidneys and the liver, and also damage the tissue of the circulatory system and nerves [14].

3.2.6 Copper (Cu)

Cu levels ranged from 0.001-0.019 mg/L with a mean of 0.007 mg/L in faucet water, from 0-0.077 mg/L with a mean of 0.01 mg/L in water from spade-sunk wells, and from 0-0.39 mg/L with a mean of 0.048 mg/L in water from drilled wells, but they were lower than the 2 mg/L WHO [6] maximum permissible Cu concentration limit in drinking water (Table 7).

Cu was not detected in water samples from the drilled well EPP3. The highest Cu concentration (0.39 mg/L) was found in water from the drilled well EPP4 in February and that water had the highest mean Cu concentration (0.143 mg/L) for the period of February to July 2011.

The low Cu concentrations found in the Kipushi well water suggested that those wells were less contaminated by that metal of which mobility is lower than that of As, Cd, Pb and Zn [4, 5].

Cu is an essential element present in all tissues and it is necessary for cellular respiration, peptide amidation, neurotransmitter biosynthesis, pigment formation and connective tissue strength. It is a cofactor for numerous enzymes and it plays an important role in the development of the central nervous system [30] but, in high concentrations it can cause anemia, liver and kidney damages, and stomach and intestine irritation [14]. Cu is present in the brain and it is the most notable in the essential ganglions, hippocampus, cerebellum, numerous synaptic membranes and in the cell bodies of cortical pyramidal and granular neurons of the cerebellum [30, 31]. Cu is directly or indirectly implicated in the pathogenesis of many neurological diseases, especially aceruloplasminemia, Alzheimer's disease, lateral amyotrophic sclerosis, Huntington's disease, prion disease and Wilson's disease [30].

Table 7 Mean values and standard deviations of pH and Cu levels of supply water and well water in Kipushi in 2011, and the WHO [6] guidelines.

	WHO* drinking water pH optimum and maximum permissible Cu concentration limit, and Cu mean concentration values with standard deviation of the water samples	
	pH	Cu (mg/L)
WHO* guidelines	6.5-9.5	2
water sample		
EDD1	7.4 ± 0.1	0.004 ± 0.003
EDD2	7.2 ± 0.1	0.009 ± 0.006
EPA1	5.7 ± 0.2	0.007 ± 0.006
EPA2	6.9 ± 0.2	0.006 ± 0.007
EPA3	6.5 ± 0.2	0.001 ± 0.001
EPA4	6.8 ± 0.1	0.022 ± 0.024
EPA5	6.0 ± 0.1	0.001 ± 0.0004
EPA6	5.8 ± 0.1	0.006 ± 0.007
EPA7	6.4 ± 0.2	0.036 ± 0.038
EPA8	5.6 ± 0.3	0.008 ± 0.007
EPA9	7.4 ± 0.1	0.002 ± 0.001
EPP1	6.5 ± 0.2	0.048 ± 0.045
EPP2	6.9 ± 0.1	0.029 ± 0.007
EPP3	6.3 ± 0.2	ND
EPP4	6.1 ± 0.1	0.143 ± 0.147
EPP5	6.1 ± 0.3	0.020 ± 0.024

* WHO: World Health Organization, ND: not detected.

3.2.7 Iron (Fe)

Fe concentrations ranged from 0.009-0.017 mg/L with a mean of 0.013 mg/L in faucet water, from

0.003-1.83 mg/L with a mean of 0.181 mg/L in water from spade-sunk wells and from 0.001-0.31 mg/L with a mean of 0.065 mg/L in water from drilled wells (Table 8).

The spade-sunk wells EPA1, EPA2 and EPA8 and the drilled well EPP1 had water which periodically presented Fe concentrations higher than the 0.3 mg/L WHO [6] Fe guideline for drinking water. Water from the spade-sunk well EPA8 had the highest Fe concentration (1.83 mg/L) in February and the highest Fe mean concentration (0.491 mg/L). That water also had the lowest pH value (pH 5.2) in February and the lowest mean pH value (5.6 ± 0.3) for the period of February to July.

It is known that pH plays an important role in the mobility of metals. An acidic pH causes the putting in solution of metallic salts, the putting in solution of retention phases, desorption of cations and adsorption of anions [32]. Thus, solubility decreases when pH increases, reaches the minimum, then it increases when the element gets back to anionic form. Certain metals are more or less mobile according to their oxidation-reduction status. For instance, Cr is considered as toxic and mobile under the Cr(VI) form but not under its Cr(III) form. It has been noted that oxidative alteration by metals such as Al, Fe, Zn and Cu, their deregulation and their accumulation in the brain tissue cause the formation of free radicals [16].

3.2.8 Manganese (Mn)

Mn concentrations ranged from 0.001-0.031 mg/L with a mean of 0.013 mg/L in faucet water, from 0.001-0.052 mg/L with a mean of 0.021 mg/L in spade-sunk well water, and from 0.002-0.19 mg/L with a mean of 0.027 mg/L in drilled well water (Table 9).

Table 8 Mean values and standard deviations of pH and Fe levels of supply water and well water in Kipushi in 2011, and the WHO [6] guidelines.

	WHO* drinking water pH optimum and maximum permissible Fe concentration limit, and Fe mean concentration values with standard deviation of the water samples	
	pH	Fe (mg/L)
WHO* guidelines	6.5-9.5	0.3
water sample		
EDD1	7.4 ± 0.1	0.014 ± 0.002
EDD2	7.2 ± 0.1	0.012 ± 0.002
EPA1	5.7 ± 0.2	0.131 ± 0.211
EPA2	6.9 ± 0.2	0.396 ± 0.458
EPA3	6.5 ± 0.2	0.1 ± 0.029
EPA4	6.8 ± 0.1	0.125 ± 0.095
EPA5	6.0 ± 0.1	0.057 ± 0.062
EPA6	5.8 ± 0.1	0.175 ± 0.057
EPA7	6.4 ± 0.2	0.074 ± 0.063
EPA8	5.6 ± 0.3	0.491 ± 0.735
EPA9	7.4 ± 0.1	0.098 ± 0.014
EPP1	6.5 ± 0.2	0.152 ± 0.127
EPP2	6.9 ± 0.1	0.074 ± 0.023
EPP3	6.3 ± 0.2	0.052 ± 0.019
EPP4	6.1 ± 0.1	0.047 ± 0.051
EPP5	6.1 ± 0.3	0.003 ± 0.001

* WHO: World Health Organization.

Table 9 Mean values and standard deviations of pH and Mn levels of supply water and well water in Kipushi in 2011, and the WHO [6] guidelines.

	WHO* drinking water pH optimum and maximum permissible Mnconcentration limit, and Mn mean concentration values with standard deviation of the water samples	
	pH	Mn (mg/L)
WHO* guidelines	6.5-9.5	0.4
water sample		
EDD1	7.4 ± 0.1	0.014 ± 0.005
EDD2	7.2 ± 0.1	0.011 ± 0.011
EPA1	5.7 ± 0.2	0.01 ± 0.001
EPA2	6.9 ± 0.2	0.031 ± 0.02
EPA3	6.5 ± 0.2	0.017 ± 0.002
EPA4	6.8 ± 0.1	0.014 ± 0.009
EPA5	6.0 ± 0.1	0.022 ± 0.004
EPA6	5.8 ± 0.1	0.025 ± 0004
EPA7	6.4 ± 0.2	0.02 ± 0.005
EPA8	5.6 ± 0.3	0.025 ± 0.008
EPA9	7.4 ± 0.1	0.021 ± 0006
EPP1	6.5 ± 0.2	0.04 ± 0.02
EPP2	6.9 ± 0.1	0.033 ± 0023
EPP3	6.3 ± 0.2	0.01 ± 0.006
EPP4	6.1 ± 0.1	0.022 ± 0.007
EPP5	6.1 ± 0.3	0.135 ± 0.068

* WHO: World Health Organization.

All those water Mn levels were lower than the 0.4 mg/L WHO [6] maximum permissible Mn concentration limit in drinking water. Water from the drilled well EPP5 had the highest Mn concentration (0.19 mg/L in February) and the highest Mn mean concentration (0.135 ± 0.068 mg/L) for the period of February to July 2011. That water had pH 6.1 in February, the lowest pH 5.6 in March and the highest pH 6.4 in July with a mean pH of 6.1 ± 0.3 for the period of February to July.

Mn is an essential element necessary for normal metabolism of amine acids, lipids, proteins and carbohydrates [33, 34]. Mn deficiency is rare, the body Mn needs being insured by the daily food intake through retention of 3% to 5% of ingested Mn. The nervous system is the main organ target of Mn. Exposure to low Mn concentrations leads to subtle changes, particularly in motor functions and humor, and exposure to high Mn levels leads to manganism, a degenerative neurological disorder with a lot of similarities with the Parkinson's disease [34, 35]. Till recently, less attention was turned to Mn in drinking water but reports suggesting increased infantile mortality [36], intellectual deficiencies [37], and increased hyperactive behavior in children [38] associated with high Mn concentrations in drinking water have increased new worries on Mn in drinking water. The fact that one may observe signs and mechanisms of evolution of clinical symptoms of the Parkinson's syndrome in cases of Mn, Fe, Cu and Zn poisoning as well as in cases of intoxication by carbon monoxide and Mg deficiency has drawn attention on the role of heavy metals in that context [39-41].

3.2.9 Molybdenum (Mo)

Mo was not detected in most (77%) analyzed water samples. Mo concentrations did not exceed 0.001 mg/L in faucet water and they ranged from 0-0.009 mg/L in spade-sunk well water and from 0-0.002 mg/L in drilled well water (Table 10). Those Mo concentrations were lower than the 0.07 mg/L WHO [6] maximum permissible Mo concentration limit in drinking water. It has been reported that Mo concentrations in groundwater are generally very low [41-43].

3.2.10 Nickel (Ni)

Ni was not detected in all faucet water samples and in spade-sunk well EPA8 and drilled well EPP2 water samples. The Ni levels of water from the other spade-sunk wells (0-0.008 mg/L) and drilled wells (0-0.027 mg/L) in the Kipushi mining town were very low and lower than the 0.07 mg/L WHO [6] maximum permissible Ni concentration limit in drinking water (Table 11).

The human body needs small quantities of Ni to produce blood red cells. However, excessive Ni quantities may gradually become toxic. Short-term Ni overexposure does not cause any health problem but long-term exposure may cause body weight loss, heart and liver damages, and skin irritation [14]. Ingestion of

Table 10 Mean values and standard deviations of pH and Mo levels of supply water and well water in Kipushi in 2011, and the WHO [6] guidelines.

	WHO* drinking water pH optimum and maximum permissible Mo concentration limit, and Mo mean concentration values with standard deviation of the water samples	
	pH	Mo (mg/L)
WHO* guidelines water sample	6.5-9.5	0.07
EDD1	7.4 ± 0.1	ND
EDD2	7.2 ± 0.1	0.001 ± 0
EPA1	5.7 ± 0.2	ND
EPA2	6.9 ± 0.2	ND
EPA3	6.5 ± 0.2	0.001 ± 0.001
EPA4	6.8 ± 0.1	0.001 ± 0.001
EPA5	6.0 ± 0.1	ND
EPA6	5.8 ± 0.1	0.001 ± 0.001
EPA7	6.4 ± 0.2	0.002 ± 0.004
EPA8	5.6 ± 0.3	ND
EPA9	7.4 ± 0.1	ND
EPP1	6.5 ± 0.2	0.001 ± 0.001
EPP2	6.9 ± 0.1	0.0003 ± 0.0005
EPP3	6.3 ± 0.2	ND
EPP4	6.1 ± 0.1	ND
EPP5	6.1 ± 0.3	ND

* WHO: World Health Organization, ND: not detected.

Table 11 Mean values and standard deviations of pH and Ni levels of supply water and well water in Kipushi in 2011, and the WHO [6] guidelines.

	WHO* drinking water pH optimum and maximum permissible Ni concentration limit, and Ni mean concentration values with standard deviation of the water samples	
	Ph	Ni (mg/L)
WHO* guidelines	6.5-9.5	0.07
water sample		
EDD1	7.4 ± 0.1	ND
EDD2	7.2 ± 0.1	ND
EPA1	5.7 ± 0.2	0.001 ± 0.001
EPA2	6.9 ± 0.2	0.001 ± 0.001
EPA3	6.5 ± 0.2	0.001 ± 0.001
EPA4	6.8 ± 0.1	0.001 ± 0.001
EPA5	6.0 ± 0.1	0.001 ± 0.001
EPA6	5.8 ± 0.1	0.001 ± 0.001
EPA7	6.4 ± 0.2	0.002 ± 0.003
EPA8	5.6 ± 0.3	ND
EPA9	7.4 ± 0.1	0.001 ± 0.001
EPP1	6.5 ± 0.2	0.001 ± 0.002
EPP2	6.9 ± 0.1	ND
EPP3	6.3 ± 0.2	0.001 ± 0.001
EPP4	6.1 ± 0.1	0.004 ± 0.003
EPP5	6.1 ± 0.3	0.014 ± 0.013

* WHO: World Health Organization, ND: not detected.

Table 12 Mean values and standard deviations of pH and Zn levels of supply water and well water in Kipushi in 2011, and the WHO [6] guidelines.

	WHO* drinking water pH optimum and maximum permissible Zn concentration limit, and Zn mean concentration values with standard deviation of the water samples	
	pH	Zn (mg/L)
WHO* guidelines	6.5-9.5	3
water sample		
EDD1	7.4 ± 0.1	0.126 ± 0.047
EDD2	7.2 ± 0.1	0.029 ± 0.01
EPA1	5.7 ± 0.2	0.065 ± 0.026
EPA2	6.9 ± 0.2	0.023 ± 0.023
EPA3	6.5 ± 0.2	0.032 ± 0.008
EPA4	6.8 ± 0.1	0.113 ± 0.043
EPA5	6.0 ± 0.1	0.136 ± 0.063
EPA6	5.8 ± 0.1	0.034 ± 0.006
EPA7	6.4 ± 0.2	0.038 ± 0.023
EPA8	5.6 ± 0.3	0.056 ± 0.022
EPA9	7.4 ± 0.1	0.023 ± 0.038
EPP1	6.5 ± 0.2	1.771 ± 2.199
EPP2	6.9 ± 0.1	0.34 ± 0.691
EPP3	6.3 ± 0.2	0.208 ± 0.133
EPP4	6.1 ± 0.1	2.17 ± 0.859
EPP5	6.1 ± 0.3	0.593 ± 0.469

* WHO: World Health Organization.

high Ni quantities may also cause cancer, respiratory arrest, abortions, allergies and cardiac arrest [45]. The phagocytosis of Ni compound particles and their dissolution in the nucleus induces an oxidative stress with genetic mutation [46].

3.2.11 Zinc (Zn)

Zn concentrations in faucet water (0.016-0.17 mg/L) and those in spade-sunk well water (0.001-0.25 mg/L) were lower than the 3 mg/L WHO [6] maximum permissible Zn concentration limit in drinking water (Table 12) and were similar to the Zn concentrations found in boreholes and hand dug wells in Ife area (Nigeria) by Jeje and Oladepo [47].

In drilled well water, concentrations of that metal ranged from 0.016-5.52 mg/L. The Zn concentrations in water from the EPP1 and EPP4 drilled wells in February (5.52 mg/L and 3.91 mg/L respectively) were higher than the 3 mg/L WHO maximum permissible Zn concentration limit in drinking water, but the mean Zn concentrations in water from those two wells (1.771 ± 2.199 mg/L and 2.17 ± 0.859 mg/L, respectively) and the other wells were lower than the WHO maximum permissible Zn concentration limit in drinking water (Table 12).

The source of Zn high content in drilled well water seems to be the host rock and/or soil infiltration of that metal from the surface to the groundwater table.

4. Conclusion

Levels of eleven heavy metals (Al, Cd, Co, Cr, Cu, Fe, Mn, Mo, Ni, Pb and Zn) and pH of water from two water supply faucets, nine spade-sunk wells and five drilled wells in the Kipushi mining town were investigated from February to July 2011 to know the chemical quality of the water consumed by the population of that town. The results were compared with the WHO pH and heavy metal guidelines for drinking water. Supply water was in accordance with the WHO pH optimum and heavy metal maximum permissible limits for drinking water, except Pb concentrations in water samples from one of the water supply faucets which were higher than the WHO Pb maximum permissible concentration limit of 0.01 mg/L. Waters from only two over fourteen wells were in accordance with the WHO pH optimum and heavy metal guidelines for drinking water. The pH of water of five spade-sunk wells and two drilled wells was slightly acid, lower than 6.5. Water of only four spade-sunk wells and two drilled wells was good for human consumption in view of their pH values. Al in water of six spade-sunk wells, Cd in water of three drilled wells, Fe in water of five spade-sunk wells, Mn in water of two spade-sunk wells and three drilled wells, and Zn in two drilled wells were the heavy metals of which levels were periodically higher than the WHO heavy metal maximum permissible concentration limits in drinking water.

The high concentrations of those metals in water in the Kipushi mining town mainly came from the tailings stocked at the surface in that town and from interaction between groundwater and those metals found in high or less concentrations in the subsoil. The physical and chemical instability of those tailings has a negative impact on the closest surrounding environments (natural rivers, underlying soils, groundwater tables etc.) by migration and dispersion of the heavy metals.

Due to high concentrations of certain heavy metals in faucet and well waters in the Kipushi mining town, the population consuming those waters runs a health risk. Further investigations on heavy metal contamination of groundwater in Kipushi are necessary to keep on assessing the chemical quality of that water consumed by the local population.

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