Journal of Environmental Science and Engineering A 12 (2023) 163-175
doi:10.17265/2162-5298/2023.05.001

Trace Metal Levels of Groundwater, Surface Water and Sediments in Kinsevere Industrial Zone and Its Surroundings, Southeastern Democratic Republic of Congo

Bamba Bukengu Muhaya[1] and Benjamin Busomoke Badarhi[2]

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

2. Department of Zootechnics, Faculty of Veterinary Medicine, University of Lubumbashi, Lubumbashi 1825, Democratic Republic of Congo

Abstract: Arsenic, barium, bismuth, cadmium, cesium, chromium, cobalt, copper, iron, lead, manganese, molybdenum, nickel, strontium, thallium, tungsten, uranium, vanadium, and zinc concentrations were investigated in forty-two groundwater samples, twenty-four surface water and six surface sediment samples in Kinsevere industrial zone and its surroundings in February and march 2017, January, February and March 2018 to evaluate the potential human health risk. Chemical analyses were carried out by using ICP-SF-MS (Inductively Coupled Plasma-Sector Field Mass Spectrometry, Thermo Scientific Element II). The trace metals were detected at various concentrations in all the analyzed samples. Pb, Mn and Fe concentrations exceeded the European Union acceptable maximum limits for water intended for human consumption in 4.76%, 28.57% and 61.90% of the groundwater samples, respectively and in 0%, 50% and 100% of the surface water samples, respectively. As, Cr, Cu and Ni concentrations exceeded the recommended lower sediment quality guideline values in 33.33%, 50%, 83.33% and 83.33% of the surface sediment samples, respectively. All those elevated trace metal concentrations in the groundwater, surface water and sediments represent a risk for the health of local population as well as for aquatic organisms.

Key words: Trace metals, groundwater, surface water, sediments, DR Congo.

1. Introduction

Trace metal contamination of surface water and groundwater is of concern worldwide, mainly due to industrialization. Safe drinking water is scarce, especially in most developing countries such as the DRC (Democratic Republic of Congo) where many people living in urban and rural areas are not covered by water supply facilities. Those people have therefore to resort to groundwater and/or surface water to meet their water needs for drinking, cooking, bathing, washing, and for watering their animals and plants.

In many parts of the Upper-Katanga province (Southeastern DRC), such as the Lubumbashi and Kipushi areas where industrial and artisanal mining and ore processing activities have been carried out since early 1910, many reports have indicated high trace metal contamination of surface water [1, 2], surface sediments [3, 4] and groundwater [5-7].

Sediment-associated trace metals may persist in aquatic environment and represent a risk for benthic organisms and for those living in the water column, especially invertebrates and fish, but also for humans through human food chain [3, 4, 8-11]. Indeed, resuspension events from natural and anthropogenic origin can disturb the biogeochemistry of sediments and potentially result in trace metal remobilization

Corresponding author: Bamba Bukengu Muhaya, Ph.D., professor, research fields: assessment of environmental and health impacts of abandoned mines.

from sediment particles to the water column [3, 4, 12]. Numerous other researchers have reported on various deleterious effects of trace metals on the health of people who live near mining and ore processing areas in the province [13-19].

The objective of this study was to investigate trace metal levels of groundwater, surface water and sediments in Kinsevere mining and hydrometallurgical plant zone and its surroundings to evaluate the potential human health risk. No similar study had been carried out in the area in the past.

2. Material and Methods

2.1 Study Area

The study area (Fig. 1) is located in Kinsevere mining and ore processing zone and its surroundings in Kipushi territory, one of the six rural administrative territories (Kambove, Kasenga, Kipushi, Mitwaba, Pweto and Sakania) of the Upper-Katanga province. The Kinsevere mining and ore processing plants are operated by MMG (Minerals Mining Group) company.

2.2 Sampling Campaign

Forty-two groundwater samples were collected from six public drilled wells and one private spade-sunk (hand-dug) well, twenty-two surface water samples and six sediment samples were collected from two rivers (Kandulwe and Kiswishi rivers) and MMG hydrometallurgical plant effluent in the Kinsevere mining and ore processing zone and its surroundings. Sampling campaigns were conducted once a month in February and March, 2017 and January, February and March 2018. At each sampling campaign, two water samples were collected from each one of the sampling sites. The depth of the private hand-dug well was 3 m and that of the public drilled wells ranged from 20 to 70 m. The six surface sediment samples were collected at 20-cm depth in February and March 2017.

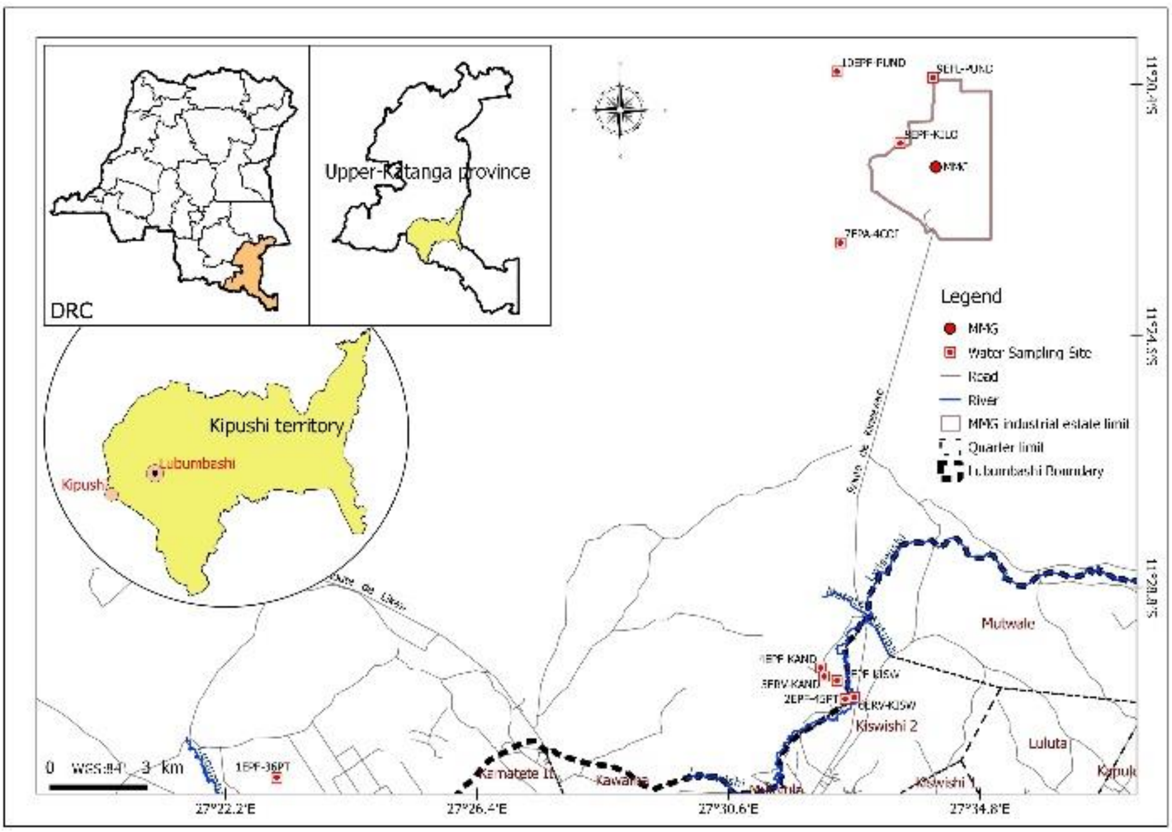


Fig. 1 Location of the sampling sites in Kinsevere mining and ore processing zone and its surroundings, Kipushi territory, Upper-Katanga province.

2.3 Analytical Methods

2.3.1 Sample Pretreatment

The collected water samples were filtered on 0.45 µm disposable syringe filters (Chromafil, cellulose mixed ester) and acidified with concentrated hydrochloric acid after determining the pH of the samples.

2.3.2 Trace Metal Analysis

Trace element analysis was carried out by ICP-SF-MS (Inductively Coupled Plasma-Sector Field Mass Spectrometry) (Thermo Scientific Element II). The instrument was equipped with an ESI (Elemental Scientific Incorporation) Fast autosampler, PFA-ST (Perfluoroalkoxy Series Type) MicroFlow nebulizer, Peltier cooled glass cyclonic spray chamber, quartz injector and torch and Ni cones. Regarding the resolutions used, low resolution was used for strontium, molybdenum, cadmium, caesium, lead, bismuth and uranium; medium resolution was used for vanadium, chromium, nickel, copper, zinc, manganese, iron, cobalt; high resolution was used for arsenic. Rhodium (1 ppb) was used as internal standard in all resolutions.

Standard solutions were prepared from multi-element standard solutions and single element standard solutions. Blanks, standards and QC (Quality Control) samples were reanalysed throughout the procedures. The reference materials SW1 (SPS) and LGC6139 were used as QC samples for water and sediments, respectively.

2.4 Statistical Analysis

The data were statistically processed by R statistical software before being filed by Excel and Excelstat. With the R software, we calculated the means and standard deviations of trace metal concentrations in the groundwater, surface water and sediments in Kinsevere industrial zone and its surroundings. The correlations that would exist between metals in the media have been verified.

R statistical software is an open source of statistics and a data science software supported by the R Foundation for Statistical Computing. It is part of the list of GNU packages. GNU is a free software distributed under the terms of the GNU General Public License and available under GNU/Linux, FreeBSD, NetBSD, OpenBSD, MacOS X and Microsoft Windows. For this study, we used the version 4.3.0 released in April 2023.

3. Results and Discussion

The results of chemical analyses of the water samples from seven groundwater wells (one private and six public wells), two rivers and one hydrometallurgical plant effluent and surface sediment samples from those rivers and hydrometallurgical plant effluent in Kinsevere are presented in Tables 1 and 2. A total of nineteen trace metals were detected at various concentrations in each one of the analyzed samples. The trace metals included arsenic (As), barium (Ba), bismuth (Bi), cadmium (Cd), cesium (Cs), chromium (Cr), cobalt (Co), copper (Cu), iron (Fe), lead (Pb), manganese (Mn), molybdenum (Mo), nickel (Ni), strontium (Sr), thallium (Tl), tungsten (W), uranium (U), vanadium (V), and zinc (Zn) (Tables 1 and 2, and Figs. 2-4).

The levels of some of these trace metals were elevated and higher than the EU (European Union) [20], US EPA (United States Environmental Protection Agency) [21] and/or World Health Organization [22] acceptable maximum contaminant levels for drinking water. That was the case of Pb with a mean concentration of 5.181 µg/L in the Kiswishi village public drilled well (3EPF-KISW). Fe concentrations were higher than the EU [20] indicator parameter for water intended for human consumption (200 µg/L) or the US EPA [21] drinking water health advisory indicator (300 µg/L) in all the sampled wells, except the public drilled well in the 36th electricity pylon village (1EPF-36PT) and in the private hand-dug well of the 4-Coins village (7EPA-4COI). Mean Fe concentrations were more than 7 fold higher than the EU [20] indicator parameter of 200 µg/L in the public drilled well of the 45th electricity pylon village 2EPF-45PT (14,926.71 µg/L),

Table 1 Mean concentrations and standard deviations of trace metals in groundwater wells and rivers (μg/L) in Kinsevere and its surroundings in 2017 and 2018, and acceptable maximum contaminant levels set for drinking water by the EU [20], the US EPA [21] (2018) and the WHO [22].

MCLs		Sr (μg/L)	Mo (μg/L)	Cd (μg/L)	Cs (μg/L)	Ba (μg/L)	W (μg/L)	Tl (μg/L)	Pb (μg/L)	Bi (μg/L)	U (μg/L)	V (μg/L)	Cr (μg/L)	Mn (μg/L)	Fe (μg/L)	Co (μg/L)	Ni (μg/L)	Cu (μg/L)	Zn (μg/L)	As (μg/L)
EU (2020)		Na	Na	5	Na	Na	Na	Na	5	Na	30	Na	50	50*	200*	Na	20	2,000	Na	10
US EPA (2018)		4,000**	40**	5	Na	2,000	Na	2	15	Na	30	Na	100	300*	300**	Na	100**	1,300	2,000	10
WHO (2017)		Na	Na	3	Na	Na	Na	Na	10	Na	30	Na	50	Na	Na	Na	70	2,000	Na	10
Sampling site	Sample code	Sr (μg/L)	Mo (μg/L)	Cd (μg/L)	Cs (μg/L)	Ba (μg/L)	W (μg/L)	Tl (μg/L)	Pb (μg/L)	Bi (μg/L)	U (μg/L)	V (μg/L)	Cr (μg/L)	Mn (μg/L)	Fe (μg/L)	Co (μg/L)	Ni (μg/L)	Cu (μg/L)	Zn (μg/L)	As (μg/L)
1EPF-36PT	1EPF	146.444	0.099	0.340	0.090	61.987	0.229	0.017	1.207	0.004	0.949	0.870	0.388	20.424	136.659	16.392	1.748	22.706	40.107	1.710
SD		10.991	0.075	0.325	0.062	27.807	0.227	0.017	0.761	0.001	0.863	0.360	0.317	20.129	1.411	12.857	0.630	3.676	44.574	0.953
2EPF-45PT	2EPF	121.883	0.570	0.129	0.054	96.372	0.247	0.018	1.562	0.006	1.084	0.802	0.451	52.388	360.728	2.018	2.759	26.435	27.564	2.503
SD		56.152	0.986	0.179	0.001	55.388	0.223	0.012	0.047	0.004	0.118	0.778	0.260	46.929	28.345	0.524	0.164	8.619	1.940	1.505
3EPF-KISW	3EPF	78.978	0.132	0.131	0.060	23.636	0.164	0.003	5.181	0.003	0.518	0.462	0.413	45.352	1,596.589	12.451	5.493	27.393	65.763	0.888
SD		5.887	0.301	0.267	0.020	16.587	0.378	0.001	0.276	0.001	0.055	0.327	0.327	49.382	1,131.932	0.676	4.611	11.602	31.036	0.119
4EPF-KAND	4EPF	122.625	0.250	0.630	0.073	22.698	0.186	0.004	1.302	0.004	0.880	0.696	0.566	8.398	245.068	1.431	1.367	8.227	195.447	1.983
SD		33.506	0.066	1.658	0.029	2.618	0.181	0.002	0.528	0.000	0.019	0.089	0.163	8.483	106.595	2.201	0.924	3.310	211.317	1.394
7EPA-4COI	7EPA	106.595	0.789	0.035	0.041	44.048	0.299	0.004	3.471	0.005	0.235	0.337	0.816	23.180	135.183	2.032	4.384	35.626	39.165	0.966
SD		34.315	0.136	0.018	0.023	34.145	0.093	0.001	1.401	0.004	0.206	0.079	0.302	1.323	34.609	0.919	0.001	29.699	2.498	0.939
8EPF-KILO	8EPF	70.517	0.232	0.045	0.070	56.535	0.690	0.006	2.795	0.004	0.672	0.455	0.737	64.723	146.258	9.360	4.888	63.628	58.689	2.707
SD		67.734	0.011	0.001	0.018	37.120	0.043	0.003	1.478	0.004	0.018	0.083	0.264	0.633	122.904	5.228	4.257	39.347	23.604	1.132
10EPF-PUND	10EPF	25.441	0.056	0.054	0.071	30.262	0.042	0.004	2.440	0.002	0.105	0.479	0.835	35.315	955.396	1.381	3.904	20.737	34.852	1.418
SD		1.528	0.064	0.012	0.002	0.078	0.011	0.001	0.905	0.001	0.019	0.144	0.330	1.554	922.624	0.078	0.366	2.077	18.419	0.365
5ERV-KAND	5ERV	111.419	0.173	0.049	0.032	41.484	0.110	0.005	2.030	0.003	0.405	0.741	0.409	54.306	615.981	1.614	2.237	14.902	19.156	1.310
SD		1.493	0.031	0.000	0.023	2.392	0.214	0.001	0.207	0.002	0.061	0.197	0.462	14.258	3.333	0.574	0.883	8.266	7.084	0.578
6ERV-KISW	6ERV	102.615	0.063	0.036	0.028	68.730	0.063	0.004	1.286	0.003	0.351	0.958	0.308	53.984	675.713	1.744	0.640	8.984	46.788	1.045
SD		8.106	0.040	0.001	0.018	14.154	0.109	0.002	0.658	0.005	0.003	1.104	0.537	17.647	500.560	0.841	0.692	4.933	21.166	0.023
9EFL-PUND	9EFL	142.662	0.652	0.082	0.090	87.154	0.633	0.047	2.376	0.003	3.282	0.718	1.296	36.158	2,312.887	44.423	2.681	46.211	15.851	1.916
SD		1.698	0.054	0.057	0.009	52.078	0.386	0.024	0.717	0.002	0.555	0.655	1.189	16.387	1132.144	42.559	1.872	4.502	5.196	0.316

* European Union Drinking Water Indicator Parameters; ** United States Environmental Protection Agency Drinking Water Health Advisories.

Table 2 Mean concentrations and standard deviations of trace metals in surface sediments (mg/kg dw) in Kinsevere industrial zone and its surroundings in February and March 2017, and the recommended sediment quality guideline values [24].

Recommended SQGV		Sr (mg/kg)	Mo (mg/kg)	Cd (mg/kg)	Cs (mg/kg)	Ba (mg/kg)	W (mg/kg)	Tl (mg/kg)	Pb mg/kg)	Bi (mg/kg)	U (mg/kg)	V (mg/kg)	Cr (mg/kg)	Mn (mg/kg)	Fe (mg/kg)	Co (mg/kg)	Ni (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	As (mg/kg)
SQGV		Na	Na	1.5	Na	Na	Na	Na	50	Na	Na	Na	80	Na	Na	Na	21	65	200	20
SQGV-high		Na	Na	10	Na	Na	Na	Na	220	Na	Na	Na	370	Na	Na	Na	52	270	410	70
Splng site	Sple code	Sr (mg/kg)	Mo (mg/kg)	Cd (mg/kg)	Cs (mg/kg)	Ba (mg/kg)	W (mg/kg)	Tl (mg/kg)	Pb (mg/kg)	Bi (mg/kg)	U (mg/kg)	V (mg/kg)	Cr (mg/kg)	Mn (mg/kg)	Fe (mg/kg)	Co (mg/kg)	Ni (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	As (mg/kg)
5ERV-KAND	5ERV	9.18	0.88	0.17	4.47	105.79	1.48	12.53	12.53	0.23	1.21	101.82	54.24	288.00	31,300.5	55.89	29.04	73.27	34.00	15.01
SD		0.54	0.03	0.01	0.28	8.12	0.35	0.59	0.59	0.01	0.12	8.85	5.76	16.97	2,335.57	7.05	1.46	13.08	2.83	1.42
6ERV-KISW	6ERV	7.55	1.50	0.22	2.00	139.84	1.14	14.16	14.16	0.32	1.54	128.41	93.69	840.00	52,242.5	95.54	37.02	238.89	49.00	63.65
SD		0.51	0.04	0.01	0.08	1.10	0.12	0.40	0.40	0.01	0.04	5.30	3.82	12.73	4,169.81	56.21	2.07	59.86	1.41	5.74
9EFL-PUND	9EFL	6.42	0.89	0.15	4.25	113.39	0.57	6.54	6.54	0.27	1.79	111.26	59.32	139.00	27,616.0	98.41	22.22	363.59	14.50	12.41
SD		1.59	0.37	0.13	0.12	7.86	0.16	1.73	1.73	0.01	0.78	61.42	36.00	16.97	15,451.7	68.73	3.46	317.52	2.12	7.13
Reference material		Sr (mg/kg)	Mo (mg/kg)	Cd (mg/kg)	Cs (mg/kg)	Ba (mg/kg)	W (mg/kg)	Tl (mg/kg)	Pb (mg/kg)	Bi (mg/kg)	U (mg/kg)	V (mg/kg)	Cr (mg/kg)	Mn (mg/kg)	Fe (mg/kg)	Co (mg/kg)	Ni (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	As (mg/kg)
LGC6139		127.86	0.93	2.51	6.59	1,355.76	11.87	0.72	166.64	1.12	1.12	63.1	91.63	1,134.0	27,308.0	14.8	42.57	85.32	530.0	29.69
Certified concentration LGC6139		Na	Na	2	Na	Na	Na	Na	160	Na	Na	Na	80	Na	Na	Na	38	92	513	27

dw: dry weight; Feb: February; KAND: Kandulwe river; KIN: Kinsevere zone; KISW: Kiswishi river; Mar: March; Na: no available data; PUND: MMG hydrometallurgical plant effluent flowing near Pundu village; SED: sediment; Sple: sample; Splng: Sampling; SQGV: lower sediment quality guideline value; SQGV-high: upper sediment quality guideline value.

almost 7 fold higher in the public drilled well of the Kiswishi village 3EPF-KISW (1,346.59 µg/L), more than 3 fold higher in the public drilled well of the Kandulwe village 4EPF-KAND (624.351 µg/L), more than 11 fold higher in the public drilled well of the Kilongwe village 8EPF-KILO (2,331.64 µg/L), 5 fold higher in the public drilled well of the Pundu village 10EPF-PUND (1,000.4 µg/L), more than 3 fold higher in the Kandulwe river 5ERV-KAND (615.98 µg/L), 3 fold higher in the Kiswishi river 6ERV-KISW (600.93 µg/L), and more than 15 fold higher in MMG hydrometallurgical plant effluent 9EFL-PUND (3,113.43 µg/L).

Also mean Mn concentrations in the public wells 2EPF-45PT (52.388 µg/L) and 8EPF-KILO (64.723 µg/L), in the Kandulwe river 5ERV-KAND (54.306 µg/L) and Kiswishi river 6ERV-KISW (53.984 µg/L) were higher than the EU [20] indicator parameter of 50 µg/L for water intended for human consumption. The high concentrations of Mn in the groundwater and surface water represent a high risk for the health of people who consume that water. Batschauer et al. [23] reported that there is an increasing concern about daily exposure to low doses of Mn beyond nutrient requirements and the possible toxicity of this metal, especially to children, in which it may induce cognitive and behavioral disorders. They concluded that developmental exposure to environmental relevant doses of Mn can affect cognition, particularly related to short-term and long-term memory, and anxiety.

The concentrations of the other sixteen trace elements (As, Ba, Bi, Cd, Cs, Cr, Co, Cu, Mo, Ni, Sr, Tl, U, V, W, and Zn) were lower than the permissible maximum levels set for drinking water by the EU [20], US EPA [21] and WHO [22]. As and U concentrations found in groundwater wells in the current study were also much lower than those reported for some wells in the State of Connecticut (United States of America) by Communications and Publishing [25]. Despite the low concentrations of As and U noted in groundwater in Kinsevere industrial zone and its surroundings, those metals are still dangerous due to their respective toxicity [17, 26-29].

The trace metal concentrations noted in groundwater wells in this study were much lower compared with those reported for groundwater wells in Lubumbashi, Kampemba and Kamalondo communes (municipalities) of Lubumbashi city [6] and in Katuba and Kenya municipalities of Lubumbashi city [7]. Also, Cr, Cu, Fe, Pb, and Zn concentrations reported for groundwater in Haramaya Woreda, Oromia Regional State, Ethiopia [30] were higher than those found in the present study, except the Fe concentration of 530 µg/L that was much lower than the mean concentrations of that element noted in groundwater wells in this study.

The mean trace metal levels of surface water samples from Kandulwe and Kiswishi rivers and from MMG hydrometallurgical plant effluent were also lower than those reported for water of Lubumbashi river basin, Kafubu, Kimilolo and Kinkalabwamba rivers in Lubumashi city [1] and for water of Naviundu river basin, Luano and Ruashi rivers and Luwowoshi spring in Lubumbashi city [2]. The mean levels of Cd, Cr, Cu, Fe, Mn, Pb and Zn noted in the current study were also less elevated than those of 0.03 to 0.04 mg/L, 0.03 to 0.05 mg/L, 0.11 to 0.17 mg/L, 2.5 to 7.6 mg/L, 0.86 to 4.3 mg/L, 0.03 to 0.06 mg/L and 0.11 to 0.16 mg/L, respectively reported for surface water of Megech river (Ethiopia) by Engdaw et al. [31] and they were within the international guidelines for drinking water.

Seven of the nineteen trace metals only, including Co, Cr(III), Cu, Fe, Mn, Mo and Zn noted in this study are essential for human body and they play an important biological role at low concentrations in the body [27, 32]. However, in the case of deficiency or high concentrations of these substances in the body, adverse health effects may occur and induce some dysfunction of the body [27, 32, 33]. The other twelve trace metals found in water in this study have no known biological importance for human body and most of them are toxic to humans, even at low concentrations [27]. Tl, Cd, As, Pb, U, Cr(VI) and Ni are those which respectively have the most deleterious impacts on human body, even at very low concentrations [17, 27-29, 35-39]. Although no international drinking water standards have been set so far for the other trace metals such as Bi, Cs, Sr, V, and W found in groundwater, surface water and superficial sediments in this study (except Sr for which the US EPA drinking water standard is 4,000 µg/L), all these trace metals have been reported to be toxic to humans [17, 29, 37, 39-46]. Mean W concentrations in surface waters and sediments noted in the current study were respectively higher than those reported by Steenstra et al. [46] for surface waters and sediments (0.217 µg/L and 0.669 mg/kg) in watersheds with W-bearing underlying rock types and those (0.068 µg/L and 0.352 mg/kg) in watersheds without such underlying geology in Washington States (USA).

Trace metals always evolve together. Thus, the presence of one indicates the presence of another or more others. Thanks to statistical analysis, trace metals which evolve together were predominantly found in the studied groundwater (Fig. 2). The correlation is shown by the red color. The more bright-red is the color, the greater the correlation between the metals from 60% to 100%. The less vivid it is from 1% to 50% and the threshold is above or moderately above the EU [20] standards for drinking water: Cd and Cu, Cd and Ni, Cd and U, Cd and W, and Cd and Zn. Then there is a weak correlation and the threshold is below 50% of the acceptable MCLs (Maximum Concentration Limits) set by EU [20] for the trace metals in drinking water. The color is white when the correlation is zero (0% correlation).

In Fig. 3, some of the trace metals grouped/gathered in dimension 1 (Dim 1), such as Cd, U and Ni, are very toxic and they have very high concentrations. They are shown in very dark blue/navy blue color. Other Dim 1 trace metals such as W, Cu, and Zn are potentially toxic, they also have high concentrations and they are shown in midnight blue color. Other potentially toxic metals of Dim 1 have relatively low concentrations and they are indicated in yellow color (Pb, Tl, V, and Co) and yellowish color (Cs and Mn). Others, such as Mo, Bi,

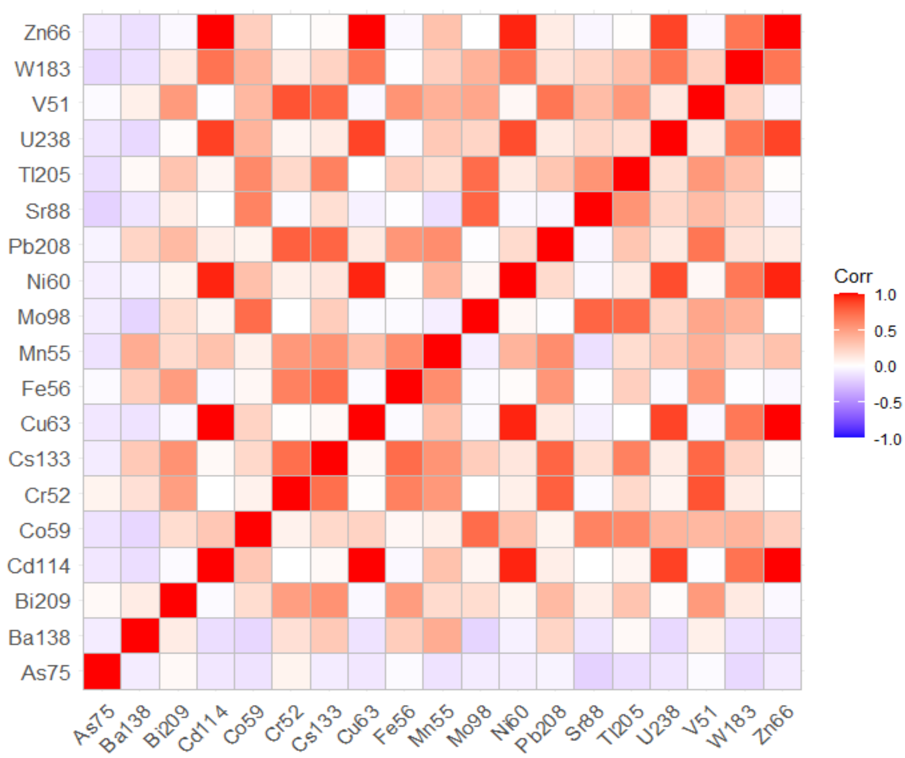


Fig. 2 Correlations between metal concentrations in water at various sampling sites in Kinsevere industrial zone and its surroundings.

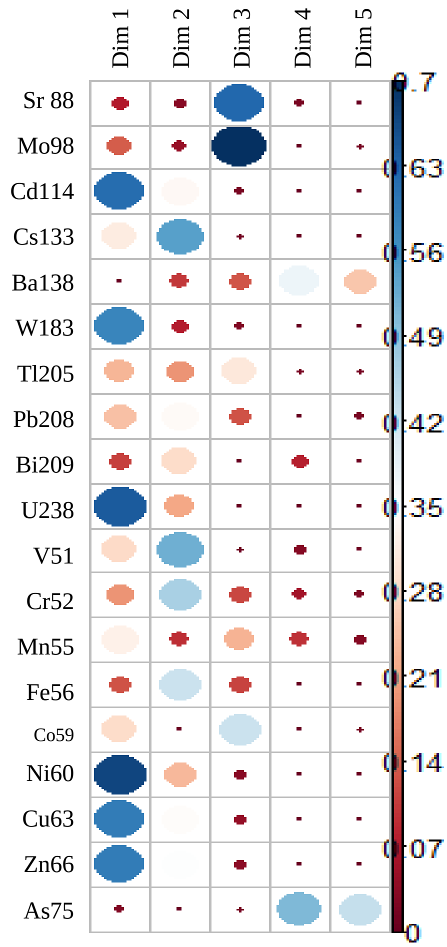


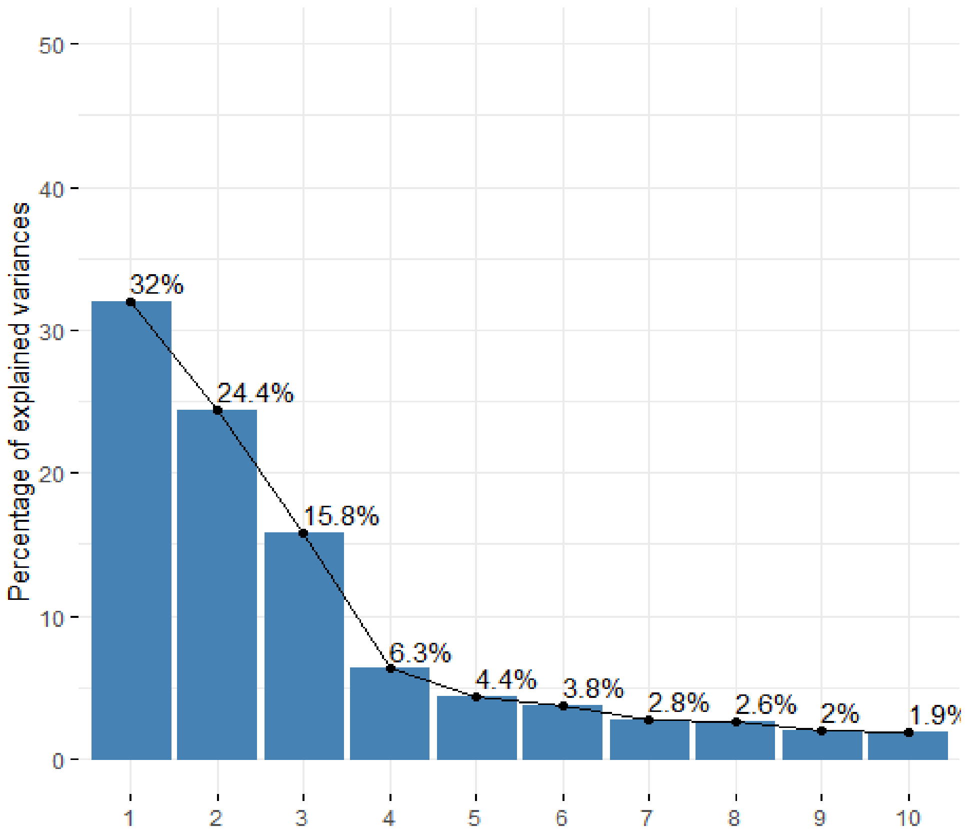
Fig. 3 Classification of potentially toxic metal concentrations in water into five dimensions of toxicity in Kinsevere industrial zone and its surroundings.

Fe, Sr, and As, have low concentrations and are shown in red to reddish color. The other potentially toxic elements grouped in Dim 2, Dim 3, Dim 4 and Dim 5 are indicated in various colors according to their concentrations and toxicity levels. High concentrations and toxicities are illustrated with navy blue and midnight blue colors, relatively low concentrations and toxicity are shown in bluish color and yellowish to reddish colors.

In this study, mean trace metal concentrations in surface sediments that exceeded the recommended lower sediment quality guideline values [24] were As in Kiswishi river (63.65 mg/kg dw), Cr in Kiswishi river (93.69 mg/kg dw), Cu and Ni in Kandulwe river (73.27 mg/kg dw and 29.035 mg/kg dw), in Kiswishi river (238.89 mg/kg dw and 37.015 mg/kg dw), and in MMG hydrometallurgical plant effluent (363.59 mg/kg dw and 22.215 mg/kg dw), respectively (Table 2). Fig. 4 illustrates the evolution of metal concentration variances in surface sediments of Kandulwe river, Kiswishi river and MMG hydrometallurgical plant effluent in Kinsevere industrial zone and its surroundings, with Cd having the highest variance percentage (32%) and Mo having the lowest percentage (1.9%).

The mean trace metal levels of surface sediments recorded in this study were lower than those noted in most surface sediments of Lubumbashi river basin, Kafubu, Kimilolo and Kinkalabwamba rivers in Lubumbashi city [3] and in some surface sediments in Naviundu river basin, Luano and Ruashi rivers and Luwowoshi spring in Lubumbashi city [4]. They were also far lower than those reported for surface sediment samples from Lwilu and Musonoie rivers in Kolwezi [10] but the Cu maximum concentration (370.8 mg/kg) in surface sediments of Musonoie river was similar to that recorded in surface sediment samples from MMG hydrometallurgical plant effluent. Mean As and Cr concentrations in surface sediment samples from Kiswishi river exceeded the recommended SQGV of 20 mg/kg and 80 mg/kg, respectively. Also, mean Cu and Ni concentrations exceeded the recommended SQGV (65 mg/kg and 21 mg/kg, respectively) in all the analyzed superficial sediment samples with a maximum of 363.59 mg/kg in samples from the MMG hydrometallurgical plant effluent and 37.015 mg/kg in samples from the Kiswishi river, respectively. The elevated concentrations of As, Cr, Cu and Ni in the surface sediments of those rivers and hydrometallurgical plant effluent represented a risk for aquatic organisms and for human beings as resuspension events from natural and anthropogenic origin could disturb the biogeochemistry of sediments and potentially result in trace metal remobilization from sediment particles to the water column [3, 4, 12].

Mean concentrations of Co, Cu, Fe, Mn, Pb and Zn in the current study were much higher than those



Cd114 Cu63 Zn66 W183 Pb208 Ni60 Ba138 Tl205 Fe56 Mo98

Fig. 4 Evolution of variance percentages of metal concentrations in sediments in Kinsevere industrial zone and its surroundings.

reported by Hasimuna et al. [47] for surface sediments of Solwezi and Kifubwa rivers in Northwestern province (Zambia), except for Zn concentration in surface sediment samples from MMG hydrometallurgical plant effluent that was lower than the 39 ± 14 mg/kg reported by those authors for surface sediment of Kifubwa river. Mean As, Cd, Cr, Co, and Cu concentrations noted in surface sediments in the current study were also higher than those reported by Tshibanda et al. [48] for sediments of Lukaya and N'djili rivers in Kinshasa (DRC) but Pb and Zn levels of sediments in this study were much lower than those recorded at most sampling sites by those authors.

4. Conclusion

Concentrations of nineteen trace metals were assessed and detected at various concentrations in groundwater samples from one private hand-dug well and six public drilled wells, and in surface water and sediment samples from two rivers and one hydrometallurgical plant effluent in the Kinsevere mining and ore processing zone and its surroundings. Trace metal analysis was performed by ICP-SF-MS (Inductively Coupled Plasma-Sector Field Mass Spectrometry). Concentrations of Pb, Mn and Fe were respectively elevated in many of the groundwater and surface water samples and exceeded the European Union acceptable maximum limits for water intended for human consumption. As, Cr, Cu and Ni concentrations in most of the surface sediment samples respectively exceeded the recommended lower sediment quality guideline values. The elevated trace metal levels of groundwater, surface water and sediments represent a risk for the health of local population who use the groundwater and surface water to meet their drinking water needs, and for organisms dwelling in those surface water and sediments.

Authors suggest that further research be carried out to investigate seasonal variation of trace metal concentrations in groundwater, surface water and sediments in the area.

Acknowledgements

This study was carried out in the framework of the research project entitled "Assessing and Mapping the Environmental and Health Impacts of Abandoned and Ongoing Mining Activities in Lubumbashi and Its Neighborhood, Democratic Republic of Congo" with UNESCO-Sida Project funds (Contract No. 4500309530). The authors would like to express their appreciation to UNESCO-Sida Project for the financial support. They are also thankful to Professors Martine Leermakers and Willy Baeyens of the AMGC (Analytical, Environmental and Geochemistry) Laboratory at VUB (Vrije Universiteit Brussel) in Belgium for their partial financial contribution to the chemical analyses of the samples. Also, Ms. Sonia Catherine Mulongo, Senior Assistant Lecturer at the Department of Geology and Mr. Alexis Woot Mpomanga, Research Assistant at the Department of Geography and Environment, Faculty of Science of the University of Lubumbashi are respectively thanked for her participation in all sampling campaigns and her elaboration of the study area map.

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