

# Assessment of Surface Water Quality in Kakanda: Detection of Pollution from Mining Activities

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## Abstract

The study focuses on the assessment of the surface water quality of the mining city of Kakanda (Lualaba Province in the DRC) to highlight pollution from mining activity. In addition to literature research, the identification of mining activities and the location of rivers and streams, the methodology adopted consisted in analyzing the water upstream and downstream of different discharge points of final effluents. The choice of parameters was made according to the Congolese legislation on this subject. Field observations indicated that liquid effluents from mining plants are discharged into the natural environment through drains. Chemical analyses have shown that the waters of these drains are loaded with metals at concentrations tens of times higher than standards. The results of the physicochemical analyses also indicated a deterioration of the quality of the water downstream of the discharge points. The level of suspended solids reaches 182 mg/l for an acceptable level of 80 mg/l. The concentration of cobalt and manganese in the streams receiving the final effluents reaches, respectively, 0.659 mg/l and 1.709 mg/l for an acceptable threshold of 0.5 mg/l. The electrical conductivity, the chemical composition as well as the other parameters exploited have revealed pollution of mining origin.

## Keywords

Assessment, Quality, Surface Water, Pollution

## 1. Introduction

Developing a mine can affect qualitatively and quantitatively the waters because

of several activities including diversion and disruption of natural drainage lines; the discharge of wastewater; accidental discharges and spills of industrial effluents (leaching solutions, acids, extractants and fuel), etc. [1].

Therefore, in the context of water-related environmental management, it is recommended to carry out construction and exploitation activities using methods that minimize the negative effects of the project on the environment and natural balance. Staff and contractors need to be trained in surface water management measures so that their daily activities and actions do not compromise it [2] [3].

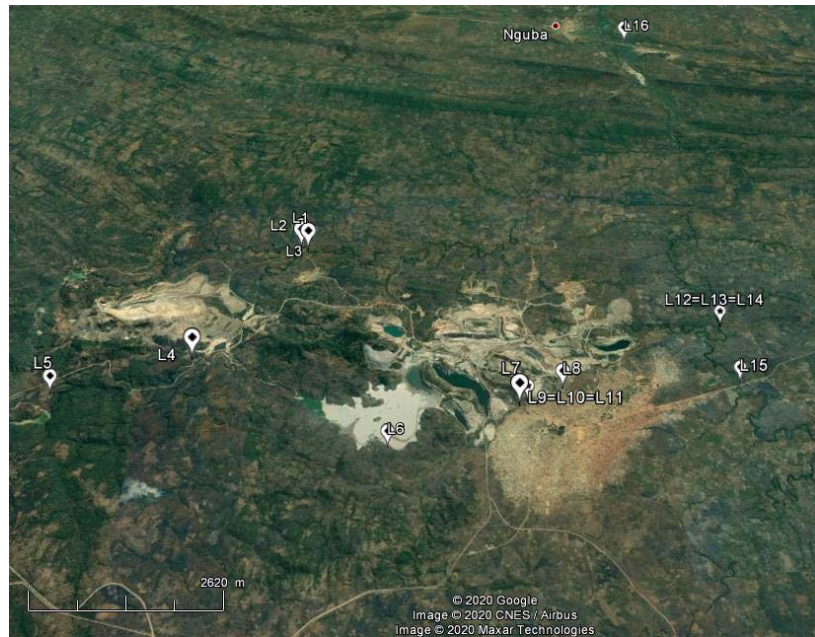
The runoff and wastewater from the process must be collected in a retention structure sized to contain the first 10 minutes of a rainfall event. Water from this device must be pumped and sent to the raw water storage tank for use in the process water system. The remainder of the runoff from the site buffer and mill and the mine runoff can be collected in a stormwater pond. This rainwater will also be pumped and transferred to the raw water basin for use in the process water system. This stormwater basin must be designed to not release more than one release in ten years, on average. Appropriate storage facilities, equipped with secondary containment devices, shall be provided for the storage of oils, greases, fuels, chemicals and other hazardous materials that are used throughout the various production phases. The area within the reservoir should be constructed to avoid surface and groundwater contamination and the installation of underground storage tanks should be avoided [4] [5].

It is known that, in general, mining and metallurgical activities generate wastes. The main environmental impacts due to solid discharges are pollution of soils, surface water and aquifers following the leaching of these solid wastes and the migration of their contained pollutants [6] [7].

When looking at the mining cities of the former province of Katanga, the general practice of discharging solid waste was to close a river valley with a dike and dump the discharges into it up to the fulfilling of the available volume. In most cases, the surface water around this portion of the valley is not diverted and comes into direct contact with the tailings, which poses a significant threat to the environment [7]. Sometimes these dikes give way and the discharges flow downstream with the whole series of environmental problems that this can cause. This practice should therefore be abandoned and disposal yards should be confined sites where surface water does not come into contact with the solid wastes and from which the contaminated water can be recovered for recycling into the process or treated prior to being released into the environment [8] [9].

The mining city of Kakanda is located in the province of Lualaba about 180 km from the city of Lubumbashi northwest of the city of Likasi. **Figure 1** highlights Kakanda City on a map.

The operational mining activities in Kakanda are those of Générale des Carrières et Mines (GCM) and Boss Mining. Boss Mining is an SPRL (Limited Liability Company) that was created in 2005 from a partnership agreement between the GCM and the Center Africa Mining Company (CAMEC). Boss Mining became



**Figure 1.** Kakanda city location on map.

in 2008 after merging with Kabambakola Mining Company (KMC) a metallurgical complex exploiting the mines and quarries of the Kakanda polygon to produce: Copper cathode after treatment of copper ores at hydrometallurgical plants in Luita, copper and cobalt concentrate after flotation of copper-cobalt ores at the Kakanda concentrator, cobalt concentrate from treatment of copper-cobalt ores through gravity separation (the Dense Medium Separation plant) located next to the Kakanda concentrator storage area, Sulfuric acid after sulfur treatment at the acid plant in Kambove.

Boss Mining has two production sites: The hydro-metallurgical plants located on the Luita site, a mountainous area located at 15 km from the mining city of Kakanda and the DMS concentrators as well as the KDC (Kakanda Concentrator) located on the site of Kakanda more or less 3 km from the mining city of Kakanda.

At the Luita plant, the main operations implemented are crushing and washing; heap leaching; copper solvent extraction (SX) and electrowinning. After copper extraction, the organic phase loaded with copper is stripped with spent electrolyte to yield rich electrolyte that is sent to the electrowinning for copper electroplating. The barren aqueous phase of copper is pumped to the cobalt recovery plant where cobalt is precipitated as carbonate after iron removal. During these operations, several types of wastes are inevitably generated. On one hand the rejects of the crushing-washing (slimes) and the leaching residue (rejects for heap) and on the other hand the final tails after iron removal. In principle, these tails and rejects must be contained in lined ponds in order to protect the environment.

## 2. Material and Methods

Sampling was done according to state-of-the-art methods and to avoid changing

the properties of the samples during collection, transportation or storage [10] [11]. The water sampling was carried out in accordance with international standards, in particular ISO 5667. The water samples were taken from rivers and streams using 500 ml sampling vials. By the grappling method sediments were collected from stream beds and banks and at locations where the flow of water is not rapid.

To avoid any suspension caused, the water samples were taken before the sediments. The water samples were stored in such a way as not to modify their characteristics. For this they were kept in a cooler so that they remain in the dark and at a temperature below 8°C. For metals, and their subsequent analyses, a few drops of slightly dilute hydrochloric acid were added. For physicochemical parameters such as pH, turbidity and conductivity, some measurements were done directly on the site. A total of 16 liquid samples and 12 solid samples (sediments) were obtained. They were coded respectively from L1 to L16 and from S1 to S12. **Table 1** and **Table 2** give, respectively for the water and sediment samples, the identification and the location of the sampling site. It can be noted that samples L12, L13 and L14 corresponding to the point of discharge of water from the Kakanda River in Dikuluwe were taken respectively from Kakanda (L12), Dikuluwe (L13) and mixing waters (L14).

For analytical instrument, pH, temperature, and conductivity were measured using the TRIO-MATE MX300 Field Kit (portable). Elemental semi-quantitative chemical orientation analyses were performed using Quantofix semi-quantitative strips. Turbidity and TSS (total suspended solids) were measured using the

**Table 1.** Identification and coding of water samples.

N°	Designation	Code	Location		
			South	East	Alt.
1	Bridge on the Luita River	L1	10°42'43.8"	26°22'25"	1257 m
2	Bridge on the Kibembe River	L2	10°42'42.2"	26°22'20.8"	1256 m
3	Meeting of Kibembe-Luita Rivers	L3	10°42'39.9"	26°22'20.8"	1258 m
4	Bridge on the drain	L4	10°43'58.9"	26°21'26.2"	1317 m
5	Last drain	L5	10°44'16.8"	26°20'14"	1332 m
6	Kakanda River (proper)	L6	10°44'59.8"	26°23'14"	1255 m
7	Kakanda River after Over-Flow	L7	10°44'39.1"	26°24'24.1"	1239 m
8	Kakanda far from the mixing point	L8	10°44'30.3"	26°24'48.3"	1231 m
9	Kakanda mixing DMS-before	L9	10°44'37.3"	26°24'28.8"	1242 m
10	Kakanda mixing DMS-DMS	L10	10°44'37.3"	26°24'28.8"	1242 m
11	Kakanda mixing DMS-Mixing	L11	10°44'37.3"	26°24'28.8"	1242 m
12	Kakanda-Dikuluwe-Kakanda	L12	10°43'54.8"	26°26'23.2"	1183 m
13	Kakanda-Dikuluwe-Dikuluwe	L13	10°43'54.8"	26°26'23.2"	1183 m
14	Kakanda-Dikuluwe-Mixing	L14	10°43'54.8"	26°26'23.2"	1183 m
15	Dikuluwe River-Bridge	L15	10°44'32.4"	26°26'25.5"	1192 m
16	Dikuluwe River Nguba Bridge	L16	10°39'33.0"	26°26'10.6"	1139 m

**Table 2.** Identification and coding of solids samples (sediments).

N°	Designation	Code	Location		
			South	East	Alt.
1	Bridge on the Luita River	S1	10°42'43.8"	26°22'19.7"	1257 m
2	Bridge on the Kibembe River	S2	10°42'42.2"	26°22'18.1"	1256 m
3	Kibembe River farms	S3	10°42'39.9"	26°22'20.9"	1258 m
4	Mukondo Foot Drain (sediment)	S4	10°43'45.9"	26°21'45.6"	1302 m
5	Mukondo Foot Drain	S5	10°43'58.7"	26°21'32.2"	1317 m
6	Drain with a Bridge (sediment)	S6	10°43'58.7"	26°21'32.2"	1317 m
7	Last drain (sediment)	S7	10°44'16.8"	26°20'58.9"	1332 m
8	Kakanda River very far after mixing (sediment)	S8	10°44'30.3"	26°24'48.3"	1231 m
9	Kakanda River Mixing DMS	S9	10°44'37.3"	26°24'28.8"	1242 m
10	Kakanda-Dikuluwe Rivers	S10	10°43'54.8"	26°26'23.2"	1183 m
11	Dikuluwe River-Bridge	S11	10°44'32.4"	26°26'25.5"	1192 m
12	Dikuluwe River Nguba Bridge	S12	10°39'33.0"	26°26'10.6"	1139 m

Wagtech WT3020 turbidity meter and the DR/890 colorimeter. Quantitative chemical analyses were performed using the PC Multi-Aqualytic photometer. Quantitative confirmatory chemical assays were performed by Atomic Absorption Spectrometry on the Analytik Jena AG Nov AA 400 spectrometer. The solid analyses were performed by X-ray fluorescence (XRF) using a Niton branded instrument XL2 Thermo Scientific.

### 3. Results and Discussion

**Table 3** and **Table 4** present the results of the analyses of the different liquid samples. These samples correspond to the river waters (Luita, Kibembe, Kakanda and Dikuluwe) and the water drainage drains of the Luita plant and the Kakanda concentrator. To interpret the results from these tables, we compare them to the reference values. With regard to industrial effluents, means the water flowing in the drains (samples L4, L5 and L10), the reference values are those of the Mining Regulation of the DRC (see article 66 of Annex VIII). The reference values for river water relate to the values usually found in the region as recorded in the database of our laboratory and to those found in the literature.

The examination of the results in **Table 3** indicates that the waters of the Luita, Kibembe, Kakanda and Dikuluwe rivers upstream of the effluent discharge points (samples L1, L2, L3 and L6) are of normal quality. The electrical conductivity is between 300 and 681  $\mu\text{S}/\text{cm}$  which indicates a small amount of dissolved elements in solution. The concentration of the trace metal elements (MTE) is lower than the reference values with the exception of the L6 sample (Kakanda River) for which the Mn concentration (0.906 mg/l) exceeds the reference value of 0.5 mg/l. This situation can be explained by the washing of ores by artisanal

**Table 3.** Results of analysis of river water.

N°	Parameters	Units	Ref.	Samples								
				L1	L2	L3	L6	L7	L8	L9	L12	L13
1	pH	-	7.0	8.8	8.8	8.8	8.2	8.4	8.8	8.2	8.9	8.7
2	TSS	mg/l	80	80	100	80	85	90	136	91	266	62
3	EC*	µS/cm	300	566	482	521	681	1061	2340	1034	987	589
4	TU**	NTU	-	68	75	72	70	77	112	82	245	45
5	Cu	mg/l	0.5	0.014	0.002	0.003	0.437	0.131	0.091	0.057	0.052	0.059
6	Mn	mg/l	0.5	0.053	0.012	0.033	0.906	0.195	0.739	0.139	0.373	0.036
7	Fe	mg/l	25	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
8	Cd	mg/l	0.01	<0.01	<0.01	0.010	0.011	0.012	0.006	<0.01	<0.01	0.002
9	Co	mg/l	0.5	0.030	0.003	0.026	0.209	0.150	1.740	0.229	0.891	0.021
10	Ni	mg/l	0.02	<0.01	<0.01	0.061	0.031	0.050	0.063	0.047	0.050	0.042
11	Pb	mg/l	0.01	<0.01	0.035	0.062	0.019	<0.01	<0.01	0.077	<0.01	<0.01
12	Zn	mg/l	1.0	0.006	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
13	Ca	mg/l	-	84.69	77.62	77.62	92.12	116.6	116.6	132.2	130.20	93.290
14	Mg	mg/l	-	62.5	75.02	75.02	93.99	123.70	123.70	123.90	136.70	62.080
15	SO <sub>4</sub> <sup>2-</sup>	mg/l	100	68	31	87	93	119	>140	>140	137	34

\*EC: Electrical conductivity, \*\*TU: Turbidity.

**Table 4.** Results of analysis of liquid effluents from plants.

N°	Parameters	Units	Reference	Samples		
				L4	L5	L10
1	pH	-	7.0	6.4	8.6	8.7
2	TSS	mg/l	100	96	117	231
3	Conductivity	µS/cm	2700	6830	1267	1136
4	Turbidity	NTU	-	85	100	202
5	Cu	mg/l	1.5	0.789	11.370	0.052
6	Mn	mg/l	1.0	13.430	13.390	0.985
7	Fe	mg/l	6.0	0.014	0.128	<0.01
8	Cd	mg/l	0.5	0.041	0.022	<0.01
9	Co	mg/l	1.0	9.247	9.390	3.326
10	Ni	mg/l	0.1	0.298	0.307	0.074
11	Pb	mg/l	0.5	0.253	0.296	<0.01
12	Zn	mg/l	10	1.510	1.740	<0.01
13	Ca	mg/l	100	89.650	958.1	240.20
14	Mg	mg/l	100	77.180	1035.0	247.20
15	SO <sub>4</sub> <sup>2-</sup>	mg/l	100	103	111	>140

miners upstream of the sampling point. The same is true for samples L2, L3 and L6 for which the concentrations of Ni and Pb exceed the reference values.



The examination of the results in **Table 4** indicates that the industrial liquid effluents collected in the drains are loaded with metallic trace elements (MTE) at concentrations higher than the standards set by the Congolese mining legislation. For example, for sample L4, which corresponds to the water contained in a drain coming from the Luita plant, the concentrations are more than 13 times and more than 9 times higher than standards, for manganese and for cobalt, respectively. The electrical conductivity is 6830  $\mu\text{S}/\text{cm}$ . This value is very high compared to the reference of 2700  $\mu\text{S}/\text{cm}$  and confirms that these waters are actually charged with ions and pose risks for the environment.

The field observations (see photo of **Figure 2**) show that there is a pinkish deposit that forms on the banks of the drain drains Luita factory. The pinkish coloring refers to the saturation of cobalt waters because the cobalt ions have the pink color in solution.

It can also be seen that the water characteristics of the Kakanda River change downstream of the industrial effluent discharge points (samples L7, L8, L9 and L12).

The electrical conductivity of the waters of the Kakanda River (L6), which was 681  $\mu\text{S}/\text{cm}$ , reached the value of 1061  $\mu\text{S}/\text{cm}$  after effluent discharge from the over flow of the Kakanda Concentrator (L7). In the distance, after additional discharge of the DMS effluents (L8), the electrical conductivity increases further reaching the value of 2340  $\mu\text{S}/\text{cm}$ . The cobalt concentration, which was 0.209 mg/l for the same waters, increased to 1.74 mg/l; higher than the reference set at 0.5 mg/l.

**Table 5** presents the results of the analyses that were carried out on the different sediments. These analyses show that the different sediments contain mainly iron. The copper and cobalt grades of the sediments correspond to the grades of these elements in the final tails discharged from the concentrator (ore beneficiation).

It can be seen that the profile of the sediment concentrations in the drains (samples S4 to S7) is almost identical to those taken in the rivers (samples S1 to



**Figure 2.** View of a liquid effluent drain from the Luita plant.

**Table 5.** Results of analysis of sediments.

N°	Samples	Chemical Composition, %						
		Mn	Fe	Co	Cu	Zn	Ni	Pb
1	S1	0.197	4.02	0.18	0.36	0.012	<0.001	<0.001
2	S2	0.064	3.48	0.115	0.146	0.007	<0.001	<0.001
3	S3	0.114	3.19	0.102	0.144	0.007	<0.001	<0.001
4	S4	0.118	2.53	0.103	0.198	0.006	<0.001	<0.001
5	S5	0.134	2.013	0.112	0.188	0.007	<0.001	<0.001
6	S6	0.053	5.49	0.376	<0.001	<0.001	<0.001	<0.001
7	S7	0.044	3.86	0.079	0.534	0.015	<0.001	<0.001
8	S8	0.126	4.07	0.378	1.096	0.017	<0.001	<0.001
9	S9	0.155	3.08	0.208	0.667	0.01	<0.001	<0.001
10	S10	0.153	2.99	0.264	0.851	0.019	0.023	<0.001
11	S11	0.121	3.23	0.334	0.015	0.015	<0.001	0.003
12	S12	0.092	16.01	0.126	0.074	0.015	<0.001	<0.001

**Figure 3.** View of build-up of Sediments at the Kakanda river water discharge point in the Dikuluwe river.

S3 and S8 to S12). Sediments collected in the Kakanda River at far distance after the different mixing points (S8) have a copper concentration which reaches the threshold above 1%. This indicates that these sediments are indeed of mining origin.

Field observations also show sediment accumulation at the Kakanda River water discharge point in the Dikuluwe River (photo in **Figure 3**). The Kakanda River is the outlet for various waters generated by Kakanda's mining activities. This highlights that this pollution is of mining activities origin.

The main uses of river water in Kakanda and nearby villages are: bathing, cloths washing, dishes cleaning, farms watering. Direct consumption of rivers water by human has been reported only in the villages and not in the city of Ka-



kanda, where the population is served by the mines' dewatering water.

As livestock farming is practiced in this city, river waters are used for direct animal consumption.

Since the analyses presented in this study show pollution from mining, there are obvious risks of contamination via the food chain.

According to testimonies, is no sign of fish life of aquatic life in the Kakanda River downstream of the discharge points of the different effluents, while fish fishing was still practiced there ten years ago.

#### 4. Conclusions

The objective of this study was to assess the quality of the rivers and streams of the mining city of Kakanda and its surroundings in order to establish whether mining activities degrade the quality of surface water in the area of concern.

In addition to the literature survey, the identification of mining activities and the location of rivers and streams, the adopted methodology consisted in analyzing the upstream and downstream waters at the different discharge points. The choice of parameters was directed towards highlighting the pollution of mining origin.

The results of the analyzes presented in this study show that the liquid effluents discharged from mining plants are loaded with metals at concentrations ten times higher than standards. The level of suspended solids, electrical conductivity and chemical composition clearly indicate pollution of mining origin.

In fact, the level of suspended solids reaches the value of 182 mg/l for an acceptable threshold of 80 mg/l. The concentration of cobalt and manganese reaches 0.659 mg/l and 1.709 mg/l respectively for an acceptable level of 0.5 mg/l. The electrical conductivity, calcium concentration and magnesium concentration are abnormally high. The results of the analyses also indicate deterioration in the quality of the water downstream of the discharge points of the liquid effluents from the mining activities.

And yet, these polluted waters are still used for bathing, washing, farm watering and other various domestic uses. This represents a risk since the metals contained in these waters can be ingested in the human body and lead to irreversible health problems such as cancer [12].

It is therefore recommended that mining operators based in Kakanda implement good environmental practices as requested by Congolese legislation; because the pollutants identified here (Mn, Cu and Co) have a detrimental effect on the environment and the health of the population [13] [14] [15].

#### Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

#### References

- [1] Bliefert, C. and Perraud, R. (2001) *Chimie de l'environnement: Air, Eau, Sols*,

- déchets. De Boeck Université, Paris, 436 p.
- [2] ICEDD (Institut de Conseil et d'Etudes en Développement Durable, ASBL) (2005) Situation environnementale des industries: L'industrie métallurgique, Rapport établi pour le compte du Ministère de la Région wallonne, Direction Générale des Ressources naturelles et de l'Environnement. Namur, 141 p.
- [3] Plagne, V. (2000) Structure et fonctionnement des aquifères karstiques. Caractérisation par la géochimie des eaux. Editions BRGM, Orléans, 376 p.
- [4] Assani, A.A. and Muteb, M. (1994) Aspect de la pollution de la rivière Lubumbashi par la Fonderie Minière de la Gécamines. *Bulletin de la Société Belge d'Etudes Géographiques*, **2**, 211-223
- [5] Assani, A.A. (1998) L'Etat de l'environnement en République Démocratique du Congo à l'aube du troisième millénaire. Thème II. La pollution des eaux, des sols et de l'air en République Démocratique du Congo. *Environmental Research*, **56**, 15-20.
- [6] Sasseville, J.L. (1980) La problématique des substances toxiques dans l'environnement, tome 1: L'agression toxique, Bureau sur les substances toxiques. Ministère de l'Environnement, Gouvernement du Québec, 46 p.
- [7] SNC-Lavalin International (2003) Étude sur la restauration des mines de cuivre et de cobalt en République Démocratique du Congo, Rapport Préliminaire. Notre dossier: M-6708 (603082), Montréal, 222 p.
- [8] Kalenga, N., Frenay, J., Kongolo, M., de Donato, P. and Kaniki, T. (2006) Inventaire des sites de production, de stockage et de décharge des rejets minéraux au Katanga et évaluation des impacts environnementaux. Rapport du Projet de Coopération Scientifique Inter-universitaire 2005 (PCSI No. 6312PS508), Inédit, 213 p.
- [9] Kaniki, T. (2008) Caractérisation environnementale des rejets minéro-métallurgiques du Copperbelt congolais. Thèse de doctorat, Université de Liège, 250 p.
- [10] Pierre, G.Y. (1998) Echantillonnage. Techniques de l'Ingénieur, Dossier P220, 23 p.
- [11] Hoenig, M. and Thomas, P. (2002) Préparation d'échantillons de l'environnement pour analyse minérale. Techniques de l'Ingénieur, Dossier P4150, 12 p.
- [12] Blazy P. (2003) Les défis majeurs de la métallurgie extractive des métaux non ferreux: économie d'énergie et environnement. Le cas du cuivre, No. 18, Les Techniques de l'Industrie Minérale, 27-49.
- [13] Crine, M., Schlitz, M. and Salmon, T. (1989) Le traitement biologique d'eaux usées chargées en métaux lourds. 2ème Congrès International de l'A.I.Lg, Bio-Indus, 159-173
- [14] Leleyter, L. and Baraud, F. (2005) Evaluation de la mobilité des métaux dans les sédiments fluviaux du bassin de la Vire (Normandie, France) par extractions simples ou séquentielles. *Comptes Rendus Geoscience*, **337**, 571-579.  
<https://doi.org/10.1016/j.crte.2005.01.001>
- [15] Monbet, P. and Coquery, M. (2003) Approches analytiques pour l'évaluation de la biodisponibilité des métaux dans les milieux aquatiques. Rapport Technique, Ministère de l'Ecologie et du Développement Durable, Direction de l'Eau, Paris, 87 p.