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Treatment of well water polluted with metallic trace elements by Moringa seeds: Case of the Kisanga District in the Democratic Republic of Congo

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Abstract
The study was initiated with the aim of determining the metallic trace elements (MTE) contents of the waters of the wells of the Kisanga district but also to treat these waters by coagulation-chelation of the MTE using the powder extracted from the dry seeds of *Moringa oleifera* (M. oleifera), with a view to making it potentially suitable for consumption. The treatment of water samples from the wells at a dose of 300 mg•L^{-1} of *M. oleifera*, and after 2 hours of decantation made it possible to achieve average reductions of around 92% in Cu 99 % in Pb, 97% in Co and 62% in Zn, 99% in Cd, 99% in Ni and 90% in Cr. This made it possible to obtain acceptable levels of MTE, according to the WHO standard for drinking water.
The treatment of water polluted with MTE and unfit for consumption makes it potentially drinkable by the coagulation-chelation of MTE. In view of the state of poverty of the populations of the KISANGA district unable to permanently buy well-conditioned drinking water. Viable methods for water treatment, in addition to their performance, must be simple, accessible and inexpensive.

Keywords: *M. oleifera*; Kisanga; determination of MTE

1. Introduction

Access to drinking water remains a major concern in Africa, particularly in rural areas where populations are confronted with optimal management of water points, insufficient hygiene and sanitation and the lack of appropriate methods. family-scale disinfection (Kabore, 2011) [18]. Food in its own right, any water intended for human consumption must be continuously available, in sufficient quantity, and must not present any health risks. Indeed, many organisms can exist or live without breathing, but none can do so without water (Ndibwalonzi, 2013) [33].

If water does not constitute a disaster for Western countries in terms of potability, it does constitute a headache for underdeveloped countries, particularly the Democratic Republic of Congo (DRC). As a result, the use of biological drinking water treatment processes could be a sustainable alternative in improving the quality of drinking water, due to the availability and non-toxicity of the substances. This study focuses on the treatment of well water polluted with metallic trace elements by Moringa seeds: case of the Kisanga district in the Democratic Republic of Congo. The mining town of Lubumbashi has seen a population explosion in recent years and a proliferation of rapidly developing mining activities (www.mine-rdc.cd).

Mining is one of the most important sources of heavy metals in the environment. High levels of these metals can be encountered around and in metalliferous mines, due to the discharge and dispersion of mine tailings in nearby agricultural soils and in watercourses. This eventually constitutes a potential risk for the inhabitants of the mining regions (Lee, 2001) [29].

According to WHO and UNICEF (2000) [36] Artisanal and industrial mining activities lead to a deterioration in the quality of groundwater and surface water. This leads to the pollution of drinking water. According to Traore (2003) [38] and Dianou *et al* (2011) [4] some river and backwater waters continue to be used in rural areas for human consumption, particularly in the Sourou valley in Burkina Faso and According to Eurolux Wantashi (2020) [5], the The waters of the Somika district contain copper, lead, cadmium, arsenic, mercury and uranium levels above the WHO standards for drinking water. It is clear that there is a need to treat water in certain regions for effective access to good quality water and to achieve the Millennium Development Goals (MDG) in this sector. Mining is truly one of the means par excellence that generates employment. However, it generates huge quantities of discharges likely to contain metallic trace elements (MTE) whose particularity is to be indestructible and toxic sometimes at very low levels (Mbungu, 2004 & Ministère de l'emploi, 2007) [30, 31].

The problems caused by MTE in the environment, arouse the interest of the scientific world, because the protection of the environment passes by the knowledge of the fate of these contaminants and their effects on the living beings. Their presence in the environment is often caused by anthropogenic activities including agriculture, livestock, industry and transport. Humans can be exposed to MTE due to their presence in the soil and in the atmosphere or through the consumption of contaminated foodstuffs or water (Bazin, 1988) [2].

The precipitation of cations in the form of poorly soluble salts and coagulation-chelation are methods for eliminating positive ions (Desjardins 1997; Kabore *et al* 2013; Rudof, 2015) [3, 19, 37]. These two very important processes are among the stages of conventional water treatment and the first process generally uses quicklime, acids as precipitants. While the second generally uses Ethylene Diamine Tetraacetic Acid (EDTA) and other substances as chelates. In addition to these chemical substances, studies have shown the effectiveness of certain organic substances as a coagulant and chelate. According to JAHN (1988b) [15], plants used for water treatment must fulfill certain conditions. They must be available or easy to produce and their coagulant easy to dose. In addition, they must not exhibit any toxicity. M. oleifera seeds meet these criteria very well. In view of the state of poverty of the populations of the Kisanga district, viable methods for water treatment, in addition to their performance, must be simple, accessible and inexpensive. According to Folkard and Sutherland (1992) [7], technologies associated with water treatment should be as simple as possible, robust and affordable to install and maintain in developing countries. Thus, some studies (Kabore, 2011; Kabore *et al*. 2013; Jayaprakash *et al*., 2015; Kasanya *et al*., 2021) [18, 19, 16, 22] have shown the effectiveness of M. oleifera seeds in water demineralization. The aim of the article is to treat this water by coagulation-chelation of ETM with the seeds of *M. oleifera* in order to make it suitable for consumption. The use of *M. oleifera* seeds that we have proposed to the populations of Kisanga unable to permanently buy packaged drinking water, allows the chelation of ETM.

Material and methods

The chelating properties of the dry seeds of *M. oleifera* have been exploited to carry out coagulation-chelation in order to eliminate the metallic ions contained in the water. The approach consisted in bringing the fine powder obtained from the grinding of the dry seeds of *M. oleifera* to samples of raw water drawn from the wells of people who declared that they used it for all purposes (drinking, cooking food, laundry, etc.) and assess their chemical and physico-chemical characteristics.

The chemical and physico-chemical characteristics of the treated water samples were compared to those of the untreated samples and to the water potability standards of WHO (WHO, 1987 & WHO, 2011) [40, 41].

Sampling

The water from the wells was sampled during two sampling campaigns (December 2020 and August 2021) in plastic bottles with a capacity of one and a half liters, rinsed several times with water to be analyzed and tightly closed. tightly without leaving air bubbles. It was, moreover, necessary to use an intermediate vase, the one that the owners usually use in the manner of (Kisanguka, 2010) [25]. This vase was washed and rinsed carefully before use. On the ground, this vase was washed three times with water from the targeted well. The users of the wells had decided to carry out these operations in our place, fearing being poisoned. Four water wells were randomly selected for the two campaigns; for each well, a sample of 1.5 liters of water was taken, that is a total of eight samples taken for the 2 campaigns and sent to the analysis laboratory. The four water samples from the rainy season were numbered from Ap1 to Dp4 and those from the dry season were numbered from As1 to As4. The samples thus taken were kept and transported in a cooler and were taken directly to the OCC laboratory for physicochemical and chemical analyses.

Preparation of *M. oleifera* coagulant

The dry seeds of *M. oleifera* were shelled and then ground according to the technique described by Folkard and Sutherland (1992) [7] and Kasanya (2021) [22]. Then, 300 mg of fine powder from the grinding of *M. oleifera* seeds was dissolved in 1 liter of sampled water (almost 6 g, or the equivalent of a tablespoon in a 20-litre container). The resulting mixture was stirred for 1 hour to extract the chelating coagulant which was used to treat the water (Jahn, 1988a; Kabore *et al*., 2013; Kasanya *et al*, 2021) [14, 19, 22]. The ETM contents, the pH and the conductivity were measured before and after 2 hours of settling (Conditions deemed optimal for highly mineralized waters by (Jahn, 1988b and Kasanya, 2021) [15, 22], in order to assess the effect of the treatment on the chemical and physico-chemical composition of waters.

Laboratory analysis

The chemical and physico-chemical characteristics of the raw water as well as those of the coagulant-chelating agent extracted from the dry seeds of M. oleifera were determined. The total contents of MTE, the pH and the conductivity (CE) were determined before and after treatment for 2 hours of decantation except the temperature which was determined before treatment only, the dosage of MTE was carried out by absorption spectrometer (VARIAN 220) at the OCC laboratory. Temperature and pH were measured using pH meter coupled with HANNA brand thermometer.

Statistical analysis

The results obtained were subjected to an analysis of variance (ANOVA) with the statistical software XLSTAT-Pro7.5 and the means were compared using the T test for paired samples at the probability threshold P = 5%. The total hardness was evaluated according to the WHO reference standards for drinking water.

Results and discussion

Chemical and physicochemical analyzes were carried out on six samples of well water in order to determine their concentrations of mineral pollutants: cadmium (Cd), zinc (Zn), copper (Cu), Nickel (Ni), arsenic (Ar), chromium (Cr), cobalt (Co) and lead (Pb).

The analysis results of the water samples from the wells before treatment are presented in Table I.

Table 1: Chemical and physico-chemical parameters of coagulant and raw water from different wells before treatment with M. oleifera

Sample Code	CE (µS/cm)	pH	T °C	MTE contents of well water (ppm)							
				Cu	Co	Zn	Pb	Cd	Ni	As	Cr
As	3401	5,41	22,5	24,61	16,31	8,72	1.49	0.84	2,43	1,71	2,15
Bs	3357	5,33	23,8	18,56	17,45	11,32	2,53	0,76	2,05	1,53	3,12
Cs	3686	5,42	21,7	19,67	14,61	6,24	0,86	0,90	0,94	0,85	1,67
Ds	2996	5,32	22,4	10,40	7,47	8,00	0,36	0,14	0,42	0,63	1,02
A	**3360**	**5,37**	**22,6**	**18,31**	**13,96**	**8,57**	**1,31**	**0,66**	**1,46**	**1,18**	**1,99**
Ap	4564	4,12	22,3	28,76	19,23	13,86	2,36	1,04	3,34	2,22	3,66
Bp	3722	4,32	23,8	23,65	21,01	14,53	3,76	0,86	2,65	1,83	5,23
Cp	4623	5,42	21,9	22,83	17,36	12,46	1,72	0,98	1,41	0,97	4,72
Dp	3289	5,01	22,4	15,21	12,56	13,73	1,33	0,02	0,93	0,45	1,52
A	**4050**	**4,72**	**22,6**	**22,61**	**17,54**	**13,65**	**2,29**	**0,73**	**2,08**	**1,37**	**3,78**
M. Oléiféra	**179,8**	**7,3**	**-**	**0,03**	**0,05**	**0,06**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**
WHO standard	**400-1200**	**6,5-8,5**	**< 25**	**2**	**1**	**3**	**0,01**	**0,003**	**0,07**	**0,01**	**0,05**

Legends:

■: values outside the WHO standard

- : nd

The results of Table 1, show us that Cu has the highest contents of all the MTEs studied followed by Co then Zn while Cadmium indicates the lowest content. The ETMs studied have levels that exceed the WHO standard for drinking water. In addition, the analyzes carried out on the dry seeds showed that they only contain Cu, Co and Zn in trace amounts. However, the solution prepared with these seeds showed a conductivity (CE) of 179.8 µS/cm

The results of the quantitative analysis before treatment with *M. Oleifera* show us that Cu has the highest levels of all the MTE studied, followed by Co then Zn, while Cd indicates the lowest level (Table 1). The MTE studied have levels that exceed the WHO threshold limit for drinking water. These results corroborate those of the African consulting engineering group "GAIC S.A." (2015) [10] who found that the well waters of the SOMIKA district contained silver, copper, chromium, iron, zinc, barium, magnesium, arsenic, cobalt, potassium, manganese, nickel, molybdenum and cadmium in very high concentrations compared to the standards required either by the DRC in the new Mining Code (2002), or by international standards, in particular those of Canada (2000), France (2000), of the EU (2004) and the WHO (2002) and those of Kitobo (2022) [27] which confirms according of predecessors studies that the water from the wells in the KISANGA district was polluted by the SOMIKA company. This could be explained by the fact that the mining company SOMIKA which is only 100m from the district exploits copper-cobalt minerals. In agreement with our results, Mbungu (2004) [30] & Okuda *et al* (2004) [35] showed that mining industries pollute the acquired materials with Pb, Cd and Hg.

In agreement with our results, many observations, as well as studies have shown that the deposits of the heaps including the mining waste, constitute an important source of contamination (Kaniki, 2008 & Kabir, 2015) [20, 16]

The pH of well water in this neighborhood is acidic. This could be explained by the fact that SOMIKA treats sulphide ores by hydrometallurgy. This situation was noted by Kitobo (2009) [26] who found that the KIPUSHI concentrator was the basis of acid mine drainage (AMD).

Table 2: Mean values of physico-chemical parameters of water sampled during the rainy and dry seasons before treatment with *M. oleifera*

MTE	rainy season	dry season	p
Cu	22,61(b)	18,31(a)	0,0631
Co	17,54(b)	17,54(a)	0,0563
Zn	13,65(b)	8,57(a)	0,0672
Pb	2,29(b)	1,31(a)	0,0457
Cd	0,73(b)	0,66(a)	0,0624
Ni	2,08(b)	1,46(a)	0,0461
As	1,37(b)	1,18(a)	0,0432
Cr	3,78(b)	1,99(a)	0,0485
pH	4,72(b)	5,37(a)	0,9872
CE	4050(b)	3360(a)	0,0463

For each parameter, values that have different letters in the same row are significantly different according to the paired-samples t-test at the probability threshold (p = 5%).

Table 2 presents the average values of the physico-chemical parameters of the water sampled during the rainy and dry seasons before treatment with M. oleifera. It appears that the comparison of the means of the physico-chemical parameters (MTE and conductivity) obtained, by the T test for paired samples, showed for all the parameters, the existence of significant differences for the samples taken in the rainy season. and for those of the dry season (Table 2), the high values of the physico-chemical parameters in the rainy season could be attributed to the contributions of effluents from the SOMIKA company into the aquifers and ground water tables by infiltration. The results agree with those of Kasanya *et al* (2021) [22] who had attributed the high values of the physico-chemical parameters in the rainy season to the contributions of stalactites and stalagmites into the river by runoff. Table 3 showed that the treatment of water samples at a dose of 300 mg•L^{-1} of *M. oleifera*, and after 2 hours of decantation, made it possible to reach MTE levels below the WHO standard for drinking water.

Table 3: Chemical and physico-chemical parameters of raw water from different wells after treatment with *M. oleifera*

Sample Code	CE(µS/cm)	pH	MTE contents of well water (ppm)							
			Cu	Co	Zn	Pb	Cd	Ni	As	Cr
As	375	5,42	1,91	0,41	4,72	0,02	0,01	0,03	0,02	0,63
Bs	287	5,31	1,86	0,12	5,32	0,03	0,00	0,01	0,00	0,12
Cs	368	5,51	1,98	1,09	3,24	0,01	0,00	0,02	0,00	0,67
Ds	386	5,23	1,09	0,06	3,68	0,02	0,01	0,00	0,00	0,00
M	**354**	**5,36**	**1,71**	**0,42**	**4,24**	**0,02**	**0,005**	**0,02**	**0,005**	**0,37**
Ap	378	4,23	2,01	0,48	5,63	0,03	0,00	0,05	0,00	0,5
Bp	312	4,56	1,79	0,32	2,36	0,01	0,01	0,01	0,00	0,00
Cp	302	5,21	1,23	0,25	5,03	0,00	0,00	0,03	0,00	0,35
Dp	298	5,00	1,56	0,22	3,54	0,01	0,01	0,00	0,00	0,00
M	**323**	**4,75**	**1,65**	**0,32**	**4,14**	**0,013**	**0,005**	**0,023**	**0,00**	**0,213**
WHO Standard	**400-1200**	**6,5-8,5**	**2**	**1**	**3**	**0,01**	**0,003**	**0,07**	**0,01**	**0,05**

Legends:

■: Values outside the WHO standard

The treatment of the water samples at a dose of 300 mg•L^{-1} of *M. oleifera*, and after 2 hours of decantation made it possible to reach acceptable levels of MTE, according to the WHO standard. The average reductions of approximately the order of 92% in Cu, 99% in Pb, 97% in Co and 62% in Zn, 99% in Cd, 99% in Ni, 100% in As and 90% in Cr have been recorded. Well water pH in this neighborhood are always acidic. The pH variations recorded before and after treatment are very insignificant.

Table 4: Average values of chemical and physico-chemical parameters before and after treatment with *M. oleifera* of well water collected in the dry season

MTE	Before treatment with *M. oleifera*	After treatment with *M. oleifera*	p
Cu	18,31(a)	1,71(b)	0,0631
Co	13,96(a)	0,42(b)	0,0563
Zn	8,57(a)	4,24(b)	0,0672
Pb	1,31(a)	0,02(b)	0,0457
Cd	0,66(a)	0,003(b)	0,0624
Ni	1,46(a)	0,02(b)	0,0461
As	1,18(a)	0,005(b)	0,0432
Cr	1,99(a)	0,37(b)	0,0485
pH	5,37(a)	5,36(a)	0,9872
CE	3360(a)	354(b)	0,0463

For each parameter, values that have different letters in the same row are significantly different according to the paired-samples t-test at the probability threshold (p = 5%).

Table 5: Average values of chemical and physico-chemical parameters before and after treatment with *M. oleifera* of water collected during the rainy season

MTE	Before treatment with *M. oleifera*	After treatment with *M. oleifera*	p
Cu	22,61(a)	1,65(b)	0,0331
Co	17,54(a)	0,32(b)	0,0463
Zn	13,65(a)	4,14(b)	0,0688
Pb	2,29(a)	0,013(b)	0,0557
Cd	0,73(a)	0,005(b)	0,0624
Ni	2,08(a)	0,023(b)	0,0481
As	1,37(a)	0,000(b)	0,0392
Cr	3,78(a)	0,213(b)	0,0495
pH	4,72(a)	4,75(a)	0,9898
CE	4050(a)	323(b)	0,0363

For each parameter, values that have different letters in the same row are significantly different according to the paired-samples t-test at the probability threshold (p = 5%).

The results (Tables 4 and 5) showed the existence of significant differences in the means of the physico-chemical parameters (MTE and conductivity) obtained, by the T-test for paired samples, for the samples taken during the rainy season and for those from the dry season. In agreement with our results A very significant drop in magnesium and calcium concentrations was observed by Kabore *et al* (2013) [19] & Kasanya *et al* (2021) [22] respectively for the waters of Burkina Faso and those of Mutimi in the DRCongo treated with M. oleifera. The dry seeds of M. oleifera contain essential oils and secondary metabolites, composed of the chemical structures necessary for the chelation, adsorption and absorption of metal ions, including heavy metals (Ali *et al*., 2008; Jayaprakash *et al*, 2015) [1, 16].

According to Folkard and Sutherland (1992) [7], the dose of dry M. oleifera seeds required for treatment is between 75 and 200 mg•L^{-1}, depending on the initial turbidity of the water. Studies conducted by Kabore *et al* (2013) [19] have shown that depending on the turbidity of the water, the optimal dose of coagulant is between 250 and 8000 mg •L^{-1} to obtain values that meet the drinking water standard of beverage. The organoleptic analysis carried out in the field revealed that above 300 mg•L^{-1}, the water from the treated wells remains cloudy due to an excess of organic matter in the coagulant which even affects its organoleptic quality. Fatombi *et al*. (2009) [6] showed that the dry seeds of *M. oleifera* contain nearly 94% organic matter and lead to an increase in the rate of organic matter in the treated water (between 100 and 400%). Showed that the reduction of minerals is not only proportional to the dose, but also takes into account the quality of the seed, the variety of *M. oleifera*, or the concentration of active chemical structures.

The settling time of between 1.5 and 2 hours allowed a very significant elimination of the ETM contents of the water. Although the 24-hour settling period could improve the ETM levels, well users could not withstand this long waiting period, but also this period could affect the organoleptic quality of the treated water (odor, taste, appearance) due to the presence of organic matter from the dry seeds of *M. oleifera*. At the same time, Jahn (1988a)[14] advised decanting for 1-2 hours, followed by filtration to remove residual particles in suspension. Coagulation-chelation with dry seeds of *M. oleifera* is based on the adsorption and neutralization in water of negatively charged particles (colloids) by positive charges of active proteins and metals by essential oils, flavonoids and alkaloids containing chelating chemical structures (Ali *et al*., 2008; Vikashni *et al*. and Jayaprakash *et al*., 2015) [1, 39, 16]. This mechanism could explain the reduction in MTE content with colloids for these samples ($P < 0.01$).

The pH variations recorded before and after treatment are very insignificant. Thus, the physico-chemical composition (pH) of the water changes shortly after treatment with *M. oleifera* (Folkard and Sutherland, 2002) [8]. This is in agreement with our results which indicate that treatment with *M. oleifera* has little influence on the pH of well water, the variation of which is not statistically significant ($p=0.9872$).

Table 6: Avarage values of physico-chemical parameters of water sampled during the rainy and dry seasons after treatment with M. oleifera

ETM	Rainy season	Dry season	p
Cu	1,65(a)	1,71(a)	0,0431
Co	0,32(a)	0,42(a)	0,0363
Zn	4,14(a)	4,24(a)	0,0528
Pb	0,013(a)	0,02(a)	0,0675
Cd	0,005(a)	0,003(a)	0,0224
Ni	0,023(a)	0,02(a)	0,0421
As	1,18(a)	0,005(a)	0,0382
Cr	0,00(a)	0,37(a)	0,0443
pH	4,75(a)	5,36(a)	0,9872
CE	323(a)	354(a)	0,0435

Table 6 shows the average values of the physico-chemical parameters of the water sampled during the rainy and dry seasons after treatment with *M. oleifera*. By comparing these means found after treatment for the two seasons, it appears from the T-test for paired samples that the values of MTE and conductivity are similar between the rainy season and the dry season.

Table 7: Correlation ETM content, pH-Conductivity

Sources of corrélation	r	p
Cu x CE	0,995	< 0,002
Co x CE	0,987	< 0,003
Zn x CE	0,998	< 0,001
Pb x CE	0,983	0,003
Cd x CE	0,981	0,001
Ni x CE	0,991	< 0,002
As x CE	0,987	< 0,002
Cr x CE	**0,993**	< 0,002
pH x CE	**0,001**	**0,759**

The correlations (r) obtained were 0.995 for Cu; 0.987 for Co; 0.998 for Zn; 0.983 for Pb; 0.981 for CD; 0.991 for Ni; 0.987 for Ace; 0.993 for Cr and 0.001 for pH (Table 7). These results corroborate those of Kaniki (2008) [20] who had found that the more the levels of MTE increased, the more the conductivity also increased.

Conclusion

The aim of the study was to determine the levels of MTE in the waters of the wells in the Kisanga district, but also to treat this water by coagulation-chelation of the MTE using the powder extracted from the dry seeds of *M. oleifera*, with a view to make it potentially fit for consumption.

The results of the qualitative analysis of the water from the wells revealed trace metal elements. This made it possible to identify the elements Cu, Ni, Co, Cr, As, Cd, Pb and Zn.

The results of the quantitative analysis before treatment with *M. Oleifera* show us that Cu has the highest levels of all the MTE studied, followed by Co and then Zn, while Cd indicates the lowest level. The MTE studied have levels that exceed the WHO threshold limit for drinking water. This could be explained by the fact that the mining company SOMIKA which is only 100m from the district exploits copper-cobalt minerals. According to JAHN (1988b), plants used for water treatment must fulfill certain conditions. They must be available or easy to produce, their coagulant easy to

dose and to cultivate intensively. In addition, they must not exhibit any toxicity. *M. oleifera* seeds meet these criteria very well. Although the powder of *M. oleifera* seeds poses taste and odor problems, the treatment allows a clear improvement in the quality of drinking water.
The treatment of the water samples at a dose of 300 mg•L^{-1} of M. oleifera, and after 2 hours of decantation made it possible to reach acceptable levels of MTE, according to the WHO standard. Average reductions of approximately 92% in Cu, 99% in Pb, 97% in Co and 62% in Zn, 99% in Cd, 99% in Ni and 90% in Cr were observed.
Based on our results, we were able to prove the use of traditional plants to clean up water loaded with MTE. We believe that further research should identify methods of reducing residual organic matter in treated water that causes taste and odor problems in order to stabilize treated water and extend shelf life.

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