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Assessment of Heavy Metals (As, Cd, Hg, Pb) in Sources of Water for Human Consumption in Sub-Saharan Africa: A Literature Review

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Abstract: In the world and particularly in Africa, the supply of drinking water by rural communities is still a challenge to be met due to the unavailability of water in quality and quantity. Indeed, 76% of the population in sub-Saharan Africa does not have access to drinking water. This situation is more pronounced in rural and peri-urban communities than in urban areas. Some communities, particularly in rural areas, are therefore condemned to consume surface water, rainwater and well water of dubious quality due to the contamination of this water and especially the lack of a drinking water distribution network. Several research studies on metal contamination of surface water, groundwater and rainwater have reported high levels of metals. This review article focuses on the contamination of waters in sub-Saharan Africa by cadmium, lead, mercury and arsenic, because of their toxicity and the health and ecotoxicological consequences linked to their presence in water. These are heavy metals at the origin of several dangerous diseases such as lead poisoning, hydrarygysmus, Itai Itai disease, etc. This article reviews the problems of accessibility to drinking water in communities in terms of quantity and quality, the origins and levels of water contamination by metals as well as analytical methods for metals and the consequences related to the consumption of these waters.

Keywords: Toxic Metals, Drinking Water, Rivers, Ponds, Underground, Rainwater

1. Introduction

Water is essential to all forms of life and there is no known substitute for it; It is essential for eradicating poverty and is closely linked to health, agriculture, energy and biodiversity [1-3]. The United Nations has recognized the right to safe and clean water as a fundamental human right, essential to the full exercise of the right to life and all human rights [4]. Unfortunately, the water is frequently contaminated by pollutants due to the lack of sanitation measures, the management method and the socio-cultural constraints of the populations [5].

In recent decades, the contamination of water by metallic pollutants has become more and more recurrent and is a topic addressed by many researchers around the world and particularly in sub-Saharan Africa. Toxic metals are among the most formidable contaminants, but unfortunately water quality control analyzes are rare even for public bodies responsible for the supply of drinking water. This state of affairs is even more accentuated in rural areas where people obtain their drinking water from nature, from unsanitary traditional wells, rivers, ponds, etc. [6, 7].

The problem of toxic metals such as mercury, cadmium, lead and arsenic is not only linked to water for human consumption. They are ubiquitous in aquatic ecosystems where they not only accumulate in sediments but also concentrate in water and aquatic living organisms [8-16] with the possibility that the latter are transformed into molecules still more toxic such as methylmercury [17-19]. From the sediments, these metals are remobilized in the water through water currents and other anthropogenic activities [20].

This article aims to take stock of the contamination of sources of water for human consumption with cadmium, mercury, lead and arsenic in sub-Saharan Africa and to ask the major questions related to water supply in this part of the world where people are most vulnerable because of the great ambient poverty.

2. Problem of Supply in Drinking Water

In Africa, around 1.1 billion people have no access whatsoever to an improved source of safe water [21].

In sub-Saharan Africa, only 24% of the population has access to a safe source of drinking water. (World Water Development Report [4], 39% of inhabitants do not have access to basic water access services and one hundred and thirty-five (135) million people make more tents (30) minutes of travel per day to have access to drinking water. The proportion of the population with access to drinking water is 68%. Between 1990 and 2016, the performance index calculated in relation to the average annual progression of households that have access to an improved source of drinking water is as follows [22]:

1) Rwanda, Burkina-Faso and Ethiopia achieved the best performances (more than 2 points);
2) Zambia and Zimbabwe have seen no substantial progress;
3) Côte d'Ivoire, Madagascar, Tanzania, Senegal and Cameroon experienced a slight increase (less than 1 point);
4) Benin, Kenya, Ghana, Niger, Malawi, Mozambique, Namibia and Uganda experienced substantial progress (more than 1 point).

Despite the efforts made, the issue of access to water arises repeatedly in developing countries, particularly in rural areas, due to demography and uncontrolled urbanization [23].

While some Maghreb countries such as Algeria, Morocco and Tunisia have respectively 79%, 61% and 83% access to drinking water in rural areas, other countries such as Ethiopia, Mozambique and Uganda are still at a rate of less than 50% access to drinking water; 86% of rural populations in Cameroon, 30% of the population and 3 out of 5 people in rural areas in Benin do not have access to drinking water with strong disparities between departments [24]. Faced with this not very rosy situation and the fact that the supply of priced water is developing in Africa and concerns the minority of populations able to pay for a connection and a subscription, the majority of Africans resort to multiple solutions, which are often dangerous expedients, to meet their water needs: drawing from rivers, lakes, backwaters, even puddles of putrid water. Supplying hundreds of millions of people with clean drinking water is very expensive at all levels, whether in terms of investments and maintenance of facilities. This is why, in sub-Saharan Africa, surface water is consumed directly in rural areas in the absence of public water supply or when public boreholes are out of service. This is the case for example in Niakhar (Senegal), and Oumako, Kpanroun and Hêvié (Benin), in rural areas in Cameroon, in Burkina-Faso where the ponds are used by the villagers either for laundry, dishes, washing, cooking or drinking [25-27, 21]. This is also the case in certain villages of Agbangnizoun and Za-kpota in southern Benin where people use surface water for drinking and domestic purposes. Apart from surface water, wells, boreholes and developed springs constitute the different types of groundwater supply on the one hand and the common means of supplying drinking water in the event of a deficit in the drinking water network in the most developing countries on the other [27-30].

3. Problems Related to Inaccessibility to Water

Throughout the world, the difficulties of access to water are the cause of many diseases that lead to the loss of human lives. Africa is the most disadvantaged continent, particularly in rural areas. Up to 80% of diseases encountered in developing countries and more than a third of deaths are attributable to the quality of water, first affecting the poorest and most marginalized sections of the population [21]. The unavailability of water continues to hamper economic activities and waterborne diseases continue to plague especially in rural areas [31]. Of the 37 major diseases that plague developing countries, 27 are waterborne (cholera, diarrhoea, dysentery, hepatitis A, typhoid fever and poliomyelitis, etc.) and 15 million he children die every year from drinking unclean water [32]. In these countries, because of the low rate of access to drinking water, especially in rural areas, populations depend on natural water resources for their survival. However, around these resources, we note the poor management of solid and liquid waste and the development of human activities which contribute to the enrichment of these environments in pollutants and other undesirable or potentially dangerous elements for health. Water resources are therefore threatened by pollution linked to solid waste, wastewater, agricultural and even industrial waste [33]. The pollution of water resources compromises the quality of water, which itself depends on the state of sanitation and human activities carried out in the surrounding territory. Contaminated water can pose a serious threat to human health in rural areas where treatment systems and technologies are almost non-existent; and the main causes of disease and poor health of populations in sub-Saharan Africa are related to water [5]. Industrialization, the non-rational use of fertilizers and pesticides, as well as the lack of awareness of the population for the protection of the environment, lead as much to an imbalance of the ecosystem and generate polluting elements which can affect the quality physico-chemical waters. These pollutants are not without risks for the local population, with the persistence of exposure to pollutants, the possible migrations towards surface or underground waters, responsible for a degradation of drinking water resources. Surface water and traditional wells are, for the most part, unfit for consumption because of their level of contamination and may contain toxic pollutants for humans [5].

In developing countries, human activity, whatever its origin, industrial, urban or agricultural, produces a quantity of polluting substances of all kinds which generate different types of pollution. These pollutants can be permanent (domestic discharges from a large city, for example), periodic or even accidental or acute [34].

4. Origin and Distribution of Metals in the Environment

4.1. Synthesis

Unlike most organic contaminants, heavy metals are natural constituents in rocks and mineral deposits. Thus, these elements are normally present at low levels (in trace amounts, less than 0.1%) in soils, sediments, surface waters and living organisms [35]. These low concentrations of heavy metals constitute the geochemical background of a certain environment. To assess the impact of a heavy metal in the environment, its mere presence is not sufficient. This impact is potential if the given metal is found at abnormally high concentration levels relative to the geochemical background [35]. This is why a good knowledge of the geochemical background is essential to determine heavy metal contamination caused by anthropogenic activity [36].

These natural metals are found in the various compartments of the environment by degassing of the earth's crust and/or by the alteration of rocks.

Due to their different specific characteristics, heavy metals have been widely used in new technologies (metallurgical and electronic). As a result, their anthropogenic sources (Table 1) are extensive and their introduction to the environment is rather recent. Among the anthropogenic sources of heavy metals we can point out: mining activity, the metallurgical and iron and steel industry, fertilizers and pesticides applied in soil cultivation, incinerators and ashes from waste incineration, medical waste, most urban waste, city dumps, factory and combustion engine emissions, sewage effluent and sewage sludge [37-45, 35].

Table 1. *Industrial and agricultural sources of metals in the environment.*

Uses (sources)	Metals
Batteries and other electrical devices	Cd, Hg, Pb, Zn, Mn, Ni.
Pigments and paints	Ti, Cd, Hg, Pb, Zn, Mn, Sn, Cr, Al, As, Cu, Fe
Alloys and solders	Cd, As, Pb, Zn, Mn, Sn, Ni, Cu
Biocides (pesticides, herbicides, preservatives)	As, Hg, Pb, Cu, Sn, Zn, Mn
Catalytic agents	Ni, Hg, Pb, Cu, Sn
Glass	As, Sn, Mn
Fertilizer	Cd, Hg, Pb, Al, As, Cr, Cu, Mn, Ni, Zn
Plastic materials	Cd, Sn, Pb
Dental and cosmetic products	Sn, Hg
Textiles	Cr, Fe, Al
Refineries	Ni, V, Pb, Fe, Mn, Zn
Fuels	Ni, Hg, Cu, Fe, Mn, Pb, Cd

Source: Biney et al. 1994 [46].

The main sources emitting these heavy metals are mining industries and foundries, processing industries (metallurgy, electroplating, etc.), incineration plants and the agricultural sector (phosphate fertilizers) [45].

Compared to the natural flow, the flow of heavy metals from human activities is significant. (Table 2).

Table 2. *Heavy metals flows from natural and human activities.*

Elements	Anthropogenic flow	Natural flow
As	150	90
Cd	43	4.5
Cr	7810	810
Cu	9162	375
Pb	3665	180
Hg	17.8	0.9
Ni	1134	255
Zn	7467	540

Source: Kabir et al., 2012 [47].

Thus, the highest concentrations of heavy metals are related to human activity. They are found in our daily environment in very diverse chemical forms, each of which can confer a particular property (solubility, toxicity, etc.) to the metal studied. In the aquatic environment, heavy metals can occur in various physical (dissolved, particulate) and chemical (mineral, organic) forms. In order to assess the bioavailability of the metal, it is necessary to know its speciation, that is to say its distribution with respect to its different physico-chemical forms. Among the very toxic heavy metals that can accidentally be found in water, we distinguish: lead, cadmium, cyanide, arsenic, chromium, nickel, antimony, selenium [48].

4.2. Lead

Lead is a chemical element of the crystallogens family, with symbol Pb and atomic number 82. It is a soft and heavy metal, bluish gray and with a sweet taste but no particular smell. Lead is a natural product of the decay of uranium [49]. Pb has two oxidation states 2+ and 4+. The tetravalent state is a very strong oxidant, but it is not common in the environment; on the other hand, the divalent state is the most stable in the environment. The lead released into the atmosphere exists mainly in the form of particles. Small lead particles can travel considerable distances, while large particles (>2.5 μm) tend to leave the atmosphere quickly and settle relatively close to the emission source. Lead is removed from the atmosphere mainly by rain, but it can also precipitate by dry deposition. Organic and inorganic forms of Pb have toxic effects in humans. However, the toxicity of organic species is much greater than that of inorganic species; its preferred passage to humans is through the food chain. The World Health Organization also points out the serious risk produced by the form of inorganic Pb introduced into the human organism through the consumption of water. The pathological effects of lead poisoning are numerous and can be separated into two categories: physiological and neurological effects [38, 42].

4.3. Cadmium

Cadmium is a chemical element with symbol Cd and atomic number 48 [49]. It is a silvery-white, soft, ductile and malleable metal. It tarnishes on contact with air. Cadmium is present in almost all zinc ores (cadmium content varies from 0.01 to 0.05%). It is also present in lead and copper ores, as well as in natural phosphates [50]. The toxicity of cadmium has been known since the 1950s. Highly toxic in all its forms (metal, vapour, salts, organic compounds), cadmium is one of the rare elements with no known function in the human body or in humans. 'animal.

4.4. Mercury

Known for more than 2000 years, mercury, symbol Hg is the only liquid metal at room temperature (-10° and +40°C). It is also the only metal whose boiling point is below 357°C. Characterized by extreme volatility and high density, it combines very easily with other metals (formation of amalgams), with inorganic or organic (carbon) sulfur compounds. Mercury is found naturally in the earth's crust at concentrations varying between 0.02 mg/kg and 0.625 mg/kg and in different forms: metallic mercury (Hg0), inorganic mercury (Hg^{+} and Hg^{2+}) whose mercury salts and organic mercury including methylmercury (MeHg). Most of the different complexes formed by mercury are insoluble with a few exceptions, including methylmercury and the mercuric ion Hg^{2+}. In an aqueous medium, two essential chemical reactions are in competition: reduction and methylation. The first favors atmospheric recycling, the second is at the origin of bioaccumulation. It is the reduction or methylation of Hg^{2+} in aquatic systems that will therefore modify its behavior and determine its mobility, its bioavailability and its toxicity.

4.5. Arsenic

Arsenic is a chemical element of the family of pnictogens, symbol As and atomic number 33, presenting properties intermediate between those of metals and metalloids [49].

The electronic configuration of arsenic induces four possible oxidation states: (-3), (0), (+3), (+5). The arsenic compounds encountered in the environment mainly correspond to inorganic species, presenting the two oxidation states As(V) and As(III). The main chemical species of arsenic present in water are oxyanions or inorganic neutral compounds [51]. The toxicity of arsenic depends on its chemical nature: inorganic arsenic is more toxic than organic arsenic. The toxicity of arsenic depends on its degree of oxidation: As(O) > As (III) > As(V). Toxicity increases with the degree of arsenic methylation [38, 35, 52].

5. Summary of Metal Analysis Results (As, Cd, Hg, Pb) in the Waters

5.1. General Synthesis

Using chemical methods such as molecular absorption spectrophotometry [53], plasma mass spectrophotometry [54, 55], atomic emission spectrometry [56], emission spectroscopy with inductive coupling [57, 58], UV/visible spectrophotometry [59] and atomic absorption spectrophotometry [29, 60-62], concentrations of toxic metals such as arsenic, cadmium, mercury and lead, higher than the drinking water standards recommended by the WHO, are recorded in surface waters in sub-Saharan Africa. These concentrations vary from 0.1 mg/L to 20.49 mg/L for cadmium [53, 57, 56, 59, 63, 54]; they vary from 0.02 mg/L to 70.4 mg/L for lead [64, 53, 65, 60, 66, 57, 56, 67, 59, 63, 54, 58, 68, 69, 70]; 0.09 mg/L and 0.32mg/L for arsenic [57, 54] and 0.001 mg/L to 0.38 mg/L for mercury [53, 57, 70].

These metals are also detected in groundwater where concentrations exceeding WHO standards vary from 0.02 mg/L to 0.23 mg/L for cadmium [61, 57, 71]; from 0.01 mg/L to 0.33 mg/L for mercury [57, 72]; from 0.03 mg/L to 4.8 mg/L for lead [61, 62, 57] and from 0.05mg/L to 0.18 mg/L for arsenic [57]. No less significant values (0.017 mg/L) of cadmium and 0.078 mg/L of lead were also recorded in rainwater [73, 74].

The concentrations of toxic metals (As, Cd, Hg, Pb) obtained in the different sources (wells, cisterns and surface waters) by the different researchers vary from one source to another. The values obtained in surface water greatly exceed, in some cases, the values obtained in well water and rainwater. Indeed, while the average Cd concentrations vary from 0.002 to 20.49 mg/L in surface waters, those in well waters vary respectively from 0.006 to 0.23 mg/L. Average Pb concentrations in surface waters are 0.005 to 70.41 mg/L and 0.03 to 0.18 mg/L in well waters. The average values obtained relate to total metals. The forms and species of these metals are not addressed by these various researchers.

5.2. Case of Hg Analysis Results in Africa

The particular case of the contamination of water resources by mercury in Africa is presented in Table 3 below.

Table 3. *Summary of mercury analysis results in water in Africa.*

Authors, Years	Matrices and Hg form	Concentrations
Al-Asadi, (2018) [75]	Water	0.1 to 1.6 µg.L $^{-1}$
Avocefohoun et al. (2022) [76]	Water (THg)	<LOQ
Azokpota et al. (2022) [77]	Rainwater (THg)	<LOQ to 1,060 µg/L
Brunke et al. (2016) [78]	Rainwater (THg)	0.03 to 52.5 ng.L $^{-1}$
Brunke et al. (2016) [78]	Rainwater (THg)	0.03 to 52.5 ng.L $^{-1}$
Campbell et al. (2003) [79]	water (THg)	0.7 to 5.8 ng.L $^{-1}$
Donkor et al. (2016) [80]	Water (THg)	0.145 to 1.078 µg.L $^{-1}$
Donkor et al. (2006) [80]	Water (THg)	28.7 to 462.10 ng.L $^{-1}$
Donkor et al. (2016) [81]	Waters (MeHg)	to 19.640 ng.L $^{-1}$
Gichuki et al. (2013) [82]	Rainwater (THg)	10.6 ng L $^{-1}$ to 15.8 ng.L $^{-1}$
Ikingura et al. (1997) [83]	Water	0.01 to 6.78 µg.L $^{-1}$
Lusilao et al., 2016) [84]	Water (THg)	<0.02 to 26.65±3.53 ng.L $^{-1}$
Lusilao et al., 2016) 84]	Water (MeHg)	0.05- 7.83 ng.L $^{-1}$
Lusilao et al., 2016) [84]	Water (IHg)	0.006- 13.05 ng L $^{-1}$
Lusilao-Makiese et al. (2016) [84]	water (THg)	0.03 to 19.60 ng.L $^{-1}$
Lusilao-Makiese et al. (20 16) [84]	water (IHg)	0.003 to 13.05 ng.L $^{-1}$
Lusilao-Makiese et al. (2016) [84]	water (MeHg)	0.01 to 7.83 ng.L $^{-1}$
Lusilao-Malehase et al. (2016) [84]	water (THg)	0.004 to 0.070 µg.L $^{-1}$
Ouedraogo and Amyot (2013) [85]	Water (THg)	0.04 to 21.38 ng.L $^{-1}$
Ouedraogo et Amyot (2013) [85]	Water (DHg)	0.05 to 4 ng.L-1
Ouedraogo et Amyot (2013) [85]	Water (PHg)	0.04 to 19 ng.L $^{-1}$
Ouedraogo et Amyot (2013) [85]	Water (MeHg)	0.01 ng.L-1 to 0.21 ng.L -1
Poste et al. (2015) [86]	Water (THg)	0.38 ± 0.01 to 1.30 ± 0.09 ng.L -1
Ugbidye et al. (2013) [87]	Water (THg)	0.00mg.kg $^{-1}$
Williams et al. (2010) [88]	Water (THg)	0.06 to 26.65 ± 3.53 ng.L $^{-1}$
Williams et al. (2010) [88]	Water (MeHg)	0.02 ng/L to 2.73 ± 0.10 ng.L $^{-1}$
Youssao et al. (2018) [89]	Water (THg)	0.5 to 616.9 µ gL $^{-1}$

Indeed, the day after the Minamata conference on mercury, the various African countries initiated research work with a very active participation of researchers and involvement of African States in the evaluation process of the Convention bearing its name [90]. This motivated the authors of this article to make mercury a special study.

5.3. Standard Values of Some Metals in Drinking Water

The table 4 shows the standard values of heavy metals in drinking waters.

Table 4. *Standard values of heavy metals in drinking waters.*

Element	Units	WHO	Benin	Canada	MSDA
Mg	mg/L		50		50-125
Ca	mg/L		100		200
Cr	µg/L	50	50	50	1 (Cr^{6+}/l)
Mn	µg/L	400	0.1		20
Fe	µg/L		300		50
Ni	µg/L	70	20		
Cu	µg/L	2000	2000	1000	20 (Cu^{2+}/l)
Zn	µg/L		3000		100
As	µg/L	10	50	10	2
Se	µg/L	40	10	10	1
Cd	µg/L	3	5	5	0.5
Al	µg/L	200			50
Ba	µg/L	700	1000	1000	1300
Hg	µg/L	6	1	1	0.1 (Hg^{2+}/l
Pb	µg/L	10	50	5	1 (Pb^{2+}/l)
U	µg/L	30		20	

MSDA: Swiss food manual

5.4. Standard Values of Some Metals in Drinking Water

The table 5 below presents the pre-industrial levels of certain metals in the sediments of the Loire (France). This represents the geochemical background of this region.

Table 5. *Geochemical background of some metals in the sediments of the Loire (France).*

Metals	Concentrations (µg/kg)
As	20
Bi	0.7
Cd	0.4
Cr	99
Cu	20
Hg	0.02
Ni	28
Pb	35
Sb	0.4
Sn	7.5
U	8.2
W	6
Zn	94

Source: Grosbois et al. 2012 [91].

6. Consequences Related to the Consumption of Waters Containing Metals

Health effects linked to the presence of these toxic metals in drinking water are known. Mention may be made, for lead, of lead poisoning, which results in clinical disorders, biological abnormalities and various histopathological alterations, cognitive and neurobehavioral damage, increased sensitivity to the toxic effects of lead in young children linked to blood-brain barrier permeability, anorexia, vomiting, irritability, behavioral disturbances, abdominal pain, coma, and death; in pregnant women, there is harm to the development of the central nervous system of the fetus [29, 92]. Poisoning by mercury salts (hydrargyrism), characterized by lesions of the nerve centers results in tremors; irreversible renal failure due to long-term effects of mineral derivatives of mercury on the kidneys and effect of organic derivatives (organomercurials) on the central nervous system; the health effects linked to cadmium are: renal disorders, bone alterations and arterial hypertension; " Itai Itai " characterized by bone decalcification, proteinuria and glucosuria; Those linked to arsenic are: more or less pronounced gastrointestinal disorders, hepatic and renal disorders and cardiovascular manifestations; hypertension and tachycardia in the case of acute poisoning; digestive disorders, melano-dermal and neurological syndromes in the case of chronic intoxication [93, 34].

The presence of chromium in drinking water causes, in the case of acute poisoning, tubulonephritis sometimes complicated with toxic hepatitis with jaundice and in the case of chronic poisoning: skin and mucous membrane lesions with damage the respiratory system (bronchitis, asthma, bronchopulmonary cancers) [34, 94].

7. Conclusion

Through this literature review, it appears that the drinking water supply of rural and peri-urban communities in sub-Saharan Africa is a worrying issue in the scientific world. In the absence of drinking water, populations in disadvantaged areas, especially in developing countries of sub-Saharan Africa, consume water from alternative sources (surface water, well water and rainwater) contaminated by toxic metals (Pb, Cd, Hg, As) affecting the quality of these waters. These chemical pollutants generated by anthropogenic activities have harmful consequences on human health. However, the forms and the fate of the toxic metals which are the basis of the most toxic chemical pollution of waters, are fields of investigation to be furnished. It is therefore important to develop concrete actions aimed at protecting water resources for sustainable development.

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