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Mercury pollution in Africa: A review

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Since the Minamata conference, the scientific and professional worlds (gold industry, metal extraction, health) have come together to conduct research and raise awareness of the effects of mercury (Hg) in the environment, particularly on public health. Africa has not remained on the sidelines of these events, which have a planetary scope due to the long-range transport of various anthropogenic and natural sources of mercury. Since then, scientific data has been produced both in Africa and other continents in the world on the knowledge of the properties of mercury (Hg) as a poison that can migrate through all the links in the food chain. This scientific article is an analysis of mercury (Hg), its sources, its distribution, its health and environmental impacts (terrestrial, aquatic, atmospheric ecosystems, etc.) in Africa. It also aims to present the recent development in this field in the form of a general analysis and to present the measures taken at the political level to control mercury flows in developing countries while highlighting the shortcomings of these policies at the national level in some African countries.

Keys words: Mercury, pollution, anthropogenic sources, health effects, Africa.

INTRODUCTION

Mercury (Hg) is a heavy, non-essential, toxic metal found in trace amounts in the environmental matrix. (Giacomino et al., 2021; Lamborg et al., 2019; Niane et al., 2019; Park and Zheng, 2012). It is the only metal that is in liquid state at room temperature with electron configuration ([Xe] 4f 14 5d 10 6s 2 (Park and Zheng, 2012; West and Janata, 2020). It is naturally present in the air, water and soil (Kim et al., 2016; Lukina et al., 2021; Saleh et al., 2020). It can stay in the atmosphere for a long time and travel long distances before being redeposited on the earth's surface by dry or wet means (Dastoor and Larocque, 2004; Gabriel et al., 2014; Schroeder and Munthe, 1998; Sprovieri et al., 2010). It is introduced into the environment through both natural and anthropogenic sources (Braune et al., 2015; Huang et al., 2017). Its main sources are volcanic activity, rock weathering, geological deposits, sewage sludge, coal combustion, erosion of contaminated mine soils, forest fires, waste

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incineration, mining of certain precious metals, chlor-alkali production and other industrial activities (Beckers and Rinklebe, 2017; Futsaeter and Wilson, 2013; Green et al., 2019; Horowitz et al., 2014; Kim et al., 2016; Pacyna et al., 2006; Sippl and Selin, 2012; Tang et al., 2018; Wang et al., 2016, 2012; Wu et al., 2018). Once introduced into the environment, it can cause harmful effects on the human species and the environment (Singh et al., 2020). It is also toxic to terrestrial invertebrates and has negative impacts on their survival, reproduction and growth (Dietz et al., 2013). It is a chemical agent that can cause various disorders such as neurological, nephrological, immunological, cardiac, motor, reproductive and even genetic problems; amyotrophic lateral sclerosis, Alzheimer's disease and Parkinson's disease (Bjørklund et al., 2017; Gibb and O'Leary, 2014; Hong et al., 2012; Park and Zheng, 2012; Soltani and Shaheli, 2017). It affects the antioxidant system and photosynthetic system in plant growth and yield, induces oxidative stress and increases lipid peroxidation (Cho and Park, 2000; Israr and Sahi, 2006; Moreno-Jiménez et al., 2009; Patra et al., 2004). Mercury is used in fluorescent lamps (Cheng and Hu, 2012; Lecler et al., 2018), electrical and electronic equipment (Tsydenova and Bengtsson, 2011). It is also used in medical and measuring devices (Cheng and Hu, 2012), batteries (Cheng and Hu, 2012), and dental amalgams (Bjørklund et al., 2017). Mercury is also used in the artisanal mining of certain precious metals (Sippl and Selin, 2012), in the manufacture of certain chemical fertilizers (Mirlean et al., 2008), in the manufacture of certain fungicides (Frank et al., 1976) and in the manufacture of some vaccines (Bjørklund et al., 2017; Mitkus et al., 2014). It is also found in cosmetic products (Banana et al., 2016; Copan et al., 2015; Oyelakin et al., 2010) and in some chemical processes (Busto et al., 2011). It can be found in various chemical forms in the environment, namely elemental Hg (0), divalent inorganic Hg(II), and organic forms (Augelli et al., 2005; Bjørklund et al., 2017; Drevnick and Brooks, 2017; Hong et al., 2012; Singh et al., 2020; Sunderland and Selin, 2013). Several organic forms of mercury are present in the environment (Park and Zheng, 2012). The most dangerous organic form, mono-methyl mercury, is a potent neurotoxin that can bio-magnify and bio-accumulate along the food chain (Clarkson, 1990; Driscoll et al., 2013). It is found in fish, poultry, insecticides, fungicides, pesticides, vegetables, edible parts of crops and in thimerosal (Bjørklund et al., 2017; Qiu et al., 2008; Zhang et al., 2010a). The main sources of exposure for this form are the consumption of corn (Sun et al., 2020), seafood (Castaño et al., 2015; Harris et al., 2003; Lara et al., 2020; Schoeman et al., 2009; Sunderland and Selin, 2013; Sunderland, 2007); and consumption of contaminated rice (Wang et al., 2012; Zhang et al., 2010b). In the absence of seafood, meat consumption and milk may present a likely source of MeHg (Antunović et al., 2020a; Nawrocka et al., 2020). It forms in aquatic environments and at the soil level thanks to the activity of certain bacteria (Park and Zheng, 2012; Vishnivetskaya et al., 2018; Wang et al., 2014). Hg can be transformed into MeHg by living organisms such as sulfate-reducing bacteria (SRB), iron-reducing bacteria (FeRB), methanogenic archaea, syntrophic and acetogenic bacteria (Galloway and Branfireun, 2004; Gilmour et al., 2013, 1992; Hamelin et al., 2011; Benoit et al., 2001; Kerin et al., 2006). Its main targets are the cardiovascular and nervous systems and it can cause damage to the development of the fetus without sparing children and adults. The US EPA (Environmental Protection Agency) (Antunes dos Santos et al., 2016; Antunović et al., 2020b; Grandjean et al., 1997; Hogberg et al., 2009; Liu et al., 2021; Stern, 2005) has classified it as a class C carcinogen. Besides humans, it also has negative impacts on fauna and flora, including affecting seed germination (Liu et al., 2021; Lock and Janssen, 2001; Qiu et al., 2008; Sun et al., 2020). For elemental mercury Hg(0), its main route of exposure is the breathing route (inhalation). Once inhaled, it spreads into the bloodstream and affects certain organs of the human body. The US EPA (Liu et al., 2021) classifies it as a class D carcinogen. Finally, inorganic mercury, soluble in water, can enter the human body either orally or through skin contact (Liu et al., 2021). Its compounds exist in two oxidation states (mercurous, Hg^+, and mercuric, Hg^{++}), which are generally in the solid state in the form of mercuric or mercuric salts (in laxatives, cosmetics, dental powders, diuretics, and antiseptics) and mercury compounds with chlorine, sulfur or oxygen (Bjørklund et al., 2017; Park and Zheng, 2012). It can cause damage to the kidneys, immune system, liver, skin, gastrointestinal tract, fetus, and lungs (Clarkson and Magos, 2006; Holmes et al., 2009). Since the Minamata disaster, mercury has started to generate lively debate from the public, international agencies and numerous associations for the protection of the environment (Donkor et al., 2006). Despite the ratification of the Minamata Convention by African countries, mercury continues to be used in certain anthropogenic activities. This article offers a bibliographical synthesis of mercury pollution in Africa as well as prospects for reducing the use of mercury in certain anthropogenic activities.

STATE OF MERCURY POLLUTION IN AFRICA

Mercury in industrial products: Cosmetics

In Africa for some women to have a clear complexion they use certain cosmetic products sold in pharmacies or black markets. For three decades, this activity of depigmentation of the skin began to grow in scale among women and even some men. The intensification of this activity has drawn the attention of researchers who have analyzed certain chemical elements in these cosmetic products and found element such as mercury, which is

Table 1. Mercury concentrations in some cosmetic products

Author	Methods	Dies and shapes	Concentrations	Detection limit
Oyelakin et al., 2010	CV-AFS	Skin Lightening Toilet Soaps (THg) medical toilet soaps (THg) Ordinary toilet soaps and laundry soap (THg)	3.17 to 12.61 $ng.g^{-1}$ 2.88 to 4.22 $ng.g^{-1}$ 2.87 to 4.13 $ng.g^{-1}$	0.05 $\mu g.kg^{-1}$
Gbetoh et al., 2016	CV-AAS	Creams (THg) Soaps (THg)	$4.8.10^{-5}$ to 0.914 $\mu g.g^{-1}$ $5.45.10^{-5}$ to 8370 $\mu g.g^{-1}$	0.01 $ng.g^{-1}$
Harada et al., 2001	CV-AAS	Toilet soaps (THg)	$0.11.10^{-3}$ to 7.4 $mg.mL^{-1}$	

Source: Author's 2022

dangerous to human health. These Hg concentrations found during this research work are listed in Table 1.

Oyelakin et al. (2010) found low amounts of mercury in medical toilet soaps, skin-lightening toilet soaps, regular toilet soaps and laundry soap. The amounts of mercury found in this research may not cause any short-term mercury-related health problems, but it is not a guarantee for long-term use as it could lead to mercury accumulation in the bodies of these regular users. Gbetoh and Amyot (2016) further found high concentrations of mercury in toilet soaps exceeding regulatory standards. In addition, they observed the existence of a difference between the mercury concentrations marked on the labels of soaps, creams and those measured. So mercury is used in skin-lightening soaps, sometimes at high levels. In addition, research by Harada et al. (2001) showed that soaps made in Europe had significantly elevated mercury concentrations (0.47 to 1.7% as mercury iodide) compared to soaps made in Kenya (0.41-10-4-6.2%). All the subjects with high hair mercury levels (> 36.1 $mg.kg^{-1}$) used to use the European-made soap, and the latter showed various symptoms, such as tremors, lassitude, dizziness, neurasthenia, and black and white spots on the skin. This suggests the effects of inorganic mercury poisoning. Furthermore, all the subjects who did not use European made soap did not exceed a mercury level of 10 $mg.kg^{-1}$ in their hair, which is well within the authorized limits (Harada et al., 1999). In Africa, therefore, most cosmetic products, namely toilet soaps and creams, contain mercury at varying levels. The mercury level indicated on the labels was below the actual concentrations. In addition, some toilet soaps and creams contained mercury but it was not reported on their labels. However, insufficient research hampers a comprehensive understanding of the presence of Hg in cosmetic products in Africa.

Mercury in the atmosphere and in the terrestrial ecosystem

Mercury can be introduced into the atmosphere through certain human activities. Among these activities are the chlor-alkali industry (Busto et al., 2013), the extraction of certain precious metals (Wu et al., 2018), and others. Several studies have shown that in Africa, the main sources of mercury released into the atmospheric air are artisanal gold mining activities, coal-fired power plants, cement production, coal gasification, medical waste incineration, fuel production, ferrous metal production, and fluorescent tubes (Panichev et al., 2019; Black et al., 2017; Masekoameng et al., 2010; Trüe et al., 2012; Leaner et al., 2009; Dabrowski et al., 2008; Jongwana and Crouch, 2012). The work of Panichev et al. (2019) showed that among the relevant study areas, the highest concentration of Hg (218 ± 21 ng g^{-1}) was observed in *Secunda lichens specie* in the Mpumalanga province of South Africa near an industrial coal heat treatment plant. Studies by Masekoameng et al. (2010) on trends in anthropogenic mercury emissions from 2000 to 2006 in South Africa showed that coal-fired power plants release about 27.1 to 38.9 tons per year of Hg into the air and 5.8 to 7.4 tons per year of Hg into solid waste; cement production releases around 2.2 to 3.9 tonnes per year of Hg into the atmosphere; coal gasification releases around 2.9 to 4.2 tonnes of Hg per year into waste. Thus, power plants are the largest contributors of Hg released to air and solid waste, followed by cement production in Hg released to air and coal gasification in solid waste releases. Trüe et al. (2012) found varying concentrations of Hg in lichens and tree bark collected from the cities of Pretoria and Witbank in South Africa. The average mercury concentration in lichens was consistently higher than that in tree bark. So lichens have a higher Hg accumulation capacity than tree bark. But this study reveals that the air of Pretoria and Witbank is less polluted by atmospheric mercury. However, no source responsible for this contamination has been listed.

According to the findings of Leaner et al. (2009) in South Africa, coal consumption by coal-fired power plants, fuel production, cement production, ferrous metal production, medical waste incineration, and consumer products containing Hg have all been identified as potential sources of Hg emissions to the air. However, there is an absence of actual measurements of these Hg emissions from these sources, which would allow us to have more information. Dabrowski et al. (2008) showed that per year, between 2.6 and 17.6 tonnes (with an estimated average emission of 9.8 tonnes) of Hg are emitted from coal-fired power plants in South Africa. However, there is a majority presence of inorganic mercury accompanied by a small amount of organic mercury in these coals (Jongwana and Crouch, 2012). Besides the burning of coal, the production of synthetic fuels is another likely source of Hg emissions into the atmosphere. However, the atmospheric Hg emission data found during this research is lower than those suggested by other authors. Research is necessary to validate and have a better understanding. Several studies have also reported the presence of mercury in the soils and eggs of certain living species for human consumption (Daso et al., 2015; Nnorom et al., 2012; Ali et al., 2018; Podolský et al., 2015; Noubissie et al., 2016). Daso et al. (2015) reported Hg concentrations in the eggshells of the Southern ground hornbill (*Bucorvus leadbeateri*) and wattled crane (*Bugeranus carunculatus)* in the Mpumlanga and KwaZulu-Natal areas of South Africa. These Hg concentrations are higher than those reported in previous studies, which may cause adverse reproductive health effects in avian species on embryonic development, which can cause the decline of the population of these species. On the other hand, research by Nnorom et al. (2012) showed that some champion species intended for human consumption can accumulate Hg. This is the case of wild *Pleurotus* (*Pleurotus ostreatus*) widely consumed by the population in southeastern Nigeria, which accumulates small quantities of Hg and whose consumption has no impact on the health of the population. Therefore, these champions can be useful for monitoring air pollution by Hg. Ali et al. (2018) showed mercury contamination of soils in the gold mining area and areas near the locality of Dar-Mali, Nile State of Sudan. The highest concentrations were observed in the soils of the mining area. In addition, the further one is from the mining areas, the lower the mercury levels. The same observations were also made by Okang' Odumo et al. (2014) and Ikingura et al. (1997) who have worked in mining areas in Kenya and Tanzania. Okang' Odumo et al. (2014) reported that the high presence of Hg in the soils around this gold mining area is due to the technology used to extract the gold throughout the amalgamation processes, which causes a significant release of mercury. The contamination of the soils of this mining area and the nearby soils is due to the direct spillage during the amalgamation, the wet and dry deposition of the atmosphere, and the runoff of the residues. Again the work of Donkor et al. (2006), who also worked in a mining area in Ghana, did not fully confirm the findings made by Okang' Odumo et al. (2014), Ali et al. (2018) and Ikingura et al. (1997); but the presence of Hg was reported in the soils of areas near the mine site, and large concentrations of THg (4.876 $mg.kg^{-1}$ dw) and MeHg (0.162 $mg.kg^{-1}$ dw) were found during the wet season in the soils of the mine site. MeHg was undetectable in soil samples during the dry season, which would be due to the low water content of these soils during the dry season, thus limiting the microbial activities that allow the production of MeHg (Donkor et al., 2006). Therefore, the presence of Hg in the areas close to the artisanal gold mining site would be due to the dry deposition process (Ali et al., 2018). However, the concentration of Hg in the sites studied is above the average global concentrations in soils, and this does not exclude the closure of this area to carry out decontamination work (Ali et al., 2018). Podolský et al. (2015) measured mercury in the soils of the extraction and smelting zones of certain metals in Namibia and Zambia. Mercury levels in soils from mining and/or smelting areas were higher in northern Namibia than in the Zambian Copper belt due to higher levels of Hg observed in mine tailings materials as well as in foundry feed and waste in Namibia (particularly at Berg Aukas and Tsumeb). In addition, the highest Hg levels were observed near the mining and smelting operations and in the upper layers of the soil (the topsoil). A strong correlation between Hg and total carbon or total sulfur was also observed. Similarly, the work of Campbell et al. (2003) showed that Hg concentrations in agricultural surface soil samples were also correlated with organic carbon, total phosphorus, and percent clay. A study by Malehase et al. (2016) conducted in South Africa showed that dam tailings had the highest Hg concentrations compared to other environmental samples (0.890-6.755 $\mu g.g^{-1}$). Therefore, the old amalgam tailings dams are sources of mercury contamination in the study area. In addition, a dominance of elemental Hg and sulfur-bound Hg was observed in most of the dam tailings. On the other hand, we note a dominance of organic mercury in the soil. Kiefer et al. (2014) evaluated mercury content in amalgams from the Munhena mine in Mozambique. The percentages of mercury in these amalgams varied from 38.55 to 64.16%. The results of this research reveal that all of the amalgams from these miners generally contained an excess of mercury. The differences in the mass percentage of mercury in each artisanal amalgam are indicative of the techniques used by individual miners to form their amalgam. Therefore, removing excess mercury before the combustion process could significantly reduce the amount of mercury released into the environment during gold mining processes. The research of Noubissié et al. (2016) reported the presence of Hg in the soils of vegetable gardens and the leaves of three plant species (*Amaranthus hybridus, Corchorus olitorius,* and *Lactuca sativa*) in Cameroon at N'Gaoundéré. However, the highest Hg concentrations were found in amended soils (15.03 ± 0.53 $mg.kg^{-1}$) in which household waste combustion debris (containing batteries, low-consumption lamps, plastics, and others) is used as fertilizer. Regarding plants, the species *L. sativa* is the one that accumulates the most Hg (3.12 ± 1.18 mg.kg^{-1}) and the results of the risk index show the existence of a real risk of ingestion of Hg by consumers of vegetables grown on these soils. As a result, the presence of mercury in these soils is due to the use of household waste as fertilizer. Gardeners must change this practice by using chemical or biological fertilizers. These plants could also be used for the decontamination of agricultural soils, given their capacity to accumulate Hg. Youssao Abdou Karim et al. (2018) also detected Hg in beef fodder found around cotton crop fields, in okra leaves (*Abelmosehus eseulentus* (L.) Moench) in intercropping with cotton and intended for human consumption, in cow's milk, and in the soils of cotton crops in the 2KP communes in North Benin, at various concentrations. Okra leaves accumulate more Hg (15.7 µg.kg^{-1}) compared to fodder, which can present an enormous risk for the consuming population. These plants of *A. eseulentus* (L.) Moench, whose leaves have a high capacity for accumulating Hg, can be used for soil decontamination work while avoiding their consumption. However, the presence of Hg in cow's milk would be due to an agricultural source starting from the soil and passing through fodder to the cow's milk. Indeed, the upper layers of these agricultural soils have high Hg levels compared to the lower layers. The literature review conducted by Degila et al. (2019) showed that batteries containing mercury, artisanal gold mining, and informal general waste deposition are the main anthropogenic sources of mercury in Benin. From all this research, we can conclude that, in general, the concentrations of mercury in the upper layers of soils are always higher than those of the lower layers, which would be due to the presence of oxy-hydroxides in the soils limiting the movement of mercury (van Straaten, 2000), according to a study that was conducted in Tanzania. Overall, Hg contamination of soils is largely due to mining activities and certain agricultural practices, not to mention the natural sources of gaseous mercury from biomass burning (Brunke et al., 2001).

MERCURY IN THE ATMOSPHERE AND IN AQUATIC ECOSYSTEMS

Most of the research works carried out in the aquatic environment show the conversion of Hg^{2+} into MeHg, elemental Hg, or in the form of a bound particle (Berzas et al., 2010). Mercury, in particular MeHg, has caught the attention of researchers since it was recognized as a very potent neurotoxin with its great ability to bio-accumulate along the food chain and preferentially in certain organs. In addition to meat and poultry, some aquatic animals have become the main dishes because of their high protein content. Therefore, the feeding mode of aquatic species and their environment has been the subject of several studies (Ugbiye et al., 2013). Indeed, several studies have been carried out to evaluate the level of THg or MeHg in the various organs of these aquatic animals.

Ugbidye et al. (2013) measured Hg in edible frog (*Rana esculenta*) samples from the river Guma, Benue in Nigeria. The results of this research showed that the level of Hg is always higher in the liver compared to the intestines and the muscles. In addition, mercury concentrations in all water and sediment samples were generally below the detection limit. However, according to Ugbidye et al. (2013), all the Hg found in the frog could result from bio-accumulation. Hg preferentially accumulates in certain tissues such as adipose tissue and the liver, the main target of this chemical pollutant. Given its strong ability to accumulate large amounts of Hg, the edible frog could be used as an excellent bio-indicator of mercury pollution (Ugbidye et al., 2013). The consumption of these edible frogs presents a great health risk for its consumers. The presence of mercury in this environment is due to anthropogenic activities. On the other hand, Voegborlo et al. (2010) carried out work on different fish species from the Atlantic coast of Ghana; they showed that mercury concentrations were generally elevated in predatory fish that were at the top of the food chain. Research by Ouédraogo and Amyot (2013) in sub-Saharan semi-arid freshwater reservoirs in Burkina Faso showed that piscivorous fish (0.17 µg.g^{-1}) were more contaminated than fish omnivores (0.13 µg/g) and non-piscivorous fish (0.06 µg/g). This would be due to the feeding habits of these fish. The Hg concentrations found during this research are similar to those reported in previous work carried out in Africa and other tropical regions. Therefore, Burkina Faso's freshwater systems are not threatened by gold mining activities. Degila et al. (2020) measured mercury on samples of two species of fish in Benin, *Sarotherodon melanotheron* and *Chrysischthys nigrodigitatus* from Lake Nokoué and the lagoon of Porto Novo. *C. nigrodigitatus* fish had the highest rate of mercury accumulation, which is thought to be due to their difference in diet. In addition, the highest concentrations were obtained at the Porto-Novo bridge but well below the standard set by decree No. 425 (2003) in Benin (0.5 mg/kg wet weight), which would be due to the presence of an underground source supplying the ecosystem with mercury (Chouti et al., 2011) but probably also to the intense manual dredging activity which would contribute to the remobilization of sedimented metals. Donkor et al. (2006) conducted research on mercury in different environmental compartments of the Pra Bassin River in Ghana. This study reveals that, in addition to the obvious point sources of Hg along the Pra and its tributaries, the levels of Hg and its speciation in the studied aquatic system are controlled by precipitation, which determines the hydrology and the differences in water regimes flow according to the seasons. The seasonal difference in the speciation of Hg suggests that the methyl-mercury

(MeHg) found in the aqueous phase and river sediments is probably of terrestrial origin where its production is favored during the rainy season by the high mercury content of the water soil organic. According to the enrichment factor (EF), the surface sediments are slightly polluted during the rainy season and unpolluted during the dry season. Therefore, the introduction of Hg into the river system would probably come from the delta river and the Gulf of Guinea. Arinaitwe et al. (2020) measured mercury in the Tilapia and Perch samples from Lake Victoria. This research showed that the THg concentration in open Lake Nile perch samples was generally more than 2 to 3 times higher than that of near-shore Nile perch. In the majority of fish analyzed, a weak Pearson correlation with fish length and weight was observed (r = 0.389 and 0.354, respectively), so age is not the main influencing factor. In addition, the samples analyzed seemed to indicate a general abundance of THg in the liver than in the muscle, which could be explained by the existence of several Hg-binding proteins in the liver (Vieira et al., 2017). Total mercury was dominated by methyl and inorganic mercury at the Nile perch. The work of Erasmus et al. (2018) measured mercury in a long-lived predatory fish species (*Lophius vomerinus*) in Nambia. This work made it possible to find total mercury levels lower than the WHO guideline for fish (0.5 mg/kg). The results of this study made it possible to find the existence of a strong positive correlation between the total concentration of Hg in the muscle tissues and the size of the animal. Ntow et al. (1989) analyzed mercury in ten (10) species of commercial fish from the coastal zone of Ghana. The concentrations of total mercury were below the value recommended by the WHO (0.5 $\mu g g^{-1}$). It emerges from this research that the consumption of these species of fish does not present a great danger to the consuming population. Williams et al. (2010) measured mercury in samples of water, sediment, fish, and some invertebrates in the Mpumalanga area in South Africa. 38% of the water samples showed total mercury concentrations above the world average (5.0 ng/L) and 19% were above the concentration that could cause chronic effects on aquatic life (12 ng/L). Concentrations of total mercury and methyl-mercury during the wet season period were higher than those during the dry season. Methyl-mercury accounted for, on average, 24% of the concentrations in sediments. The Inkomati WMA area had the highest MeHg concentration in invertebrates and fish; therefore, coal-fired power plants and artisanal gold mining activities would seem to have an impact on this mercury pollution. Lusilao-Makiese et al. (2016) undertook mercury speciation work in water and sediment samples collected near a gold mine in South Africa. These different samples were collected during the dry season. The majority of the samples had methyl-mercury proportions of at least 90% of the total mercury, which proves that the mine's watersheds are a potential source of mercury methylation. High concentrations of mercury had been found in mine tailings (up to 867 $\mu g.kg^{-1}$) and also in mine sediments (up to 837 $\mu g\ kg^{-1}$). The same observation was made with the samples taken near the mine tailings storage facilities and inside a receiving dam. An increase in mercury and methyl-mercury concentrations with sediment depth was observed. This proves that the anoxic conditions of the sediments are among the main factors favoring the methylation of mercury on the site. Campbell et al. (2003) during research on Lake Victoria in East Africa also observed an increase in mercury concentration in sediment profiles. Moreover, the mercury concentrations in these sediments were low suggesting important sources of Hg other than liquid Hg used in gold mining activities. However, the levels of precipitation ranged from 7.6 and 30.9 $ng.L^{-1}$, is slightly higher than those observed in water samples, suggesting that Lake Victoria's mercury sources are primarily atmospheric, with some contributions due to erosion. The works of Kassegne et al. (2018) conducted in the Akaki River and Aba Samuel Reservoir watershed of Ethiopia, in sediments and African catfish (*Clarias gariepinus*), yielded several results. During this study, mercury was measured in sediment and fish samples collected during the rainy season and the dry season. The average concentration of mercury in the sediments in the rainy season was higher than that in the dry season. This is thought to be due to increased runoff deposition from natural and anthropogenic sources of mercury. In addition, mercury concentrations also increased from upstream to downstream, which could be attributed to localized and diffuse inputs of mercury emissions from agricultural, industrial, and urban effluents from the city of Addis Ababa and, to a lesser extent from natural sources. In addition, an established correlation between mercury concentrations and fish size indicates that mercury concentrations tend to increase over time as fish grow. However, THg concentrations in all sediment samples were below US EPA standards (200 mg/kg dry weight). Mercury concentrations found in *C. gariepinus* were consistent with FAO/WHO guidelines. Brunke et al. (2016) measured gaseous elemental mercury (GEM) in air and total mercury THg in rainwater, over seven years (2007–2013) at Cape Point, South Africa, during the rainy season (May-October). This research has shown that wetter years have higher levels of GEM and THg. Annual averages of GEM and THg are positively correlated with total annual rainfall (May to October). Meteorological factors are behind this observed positive correlation between GEM and THg, such meteorological factors would be for example sea surface temperature changes or large-scale droughts causing increased biomass burning (Monks et al., 2012). The research of Gichuki and Mason (2013) carried out in rainwater in South Africa showed that the average Hg concentration at Cape Point was 10.6 $ng.L^{-1}$ and that at Pretoria was 15.8 $ng.L^{-1}$. By comparing the values of the Hg concentrations in these samples, it appears that the existence of a significant regional anthropogenic source of contamination for the two sites. The work of Malehase et al. (2016) in Randfontein, South Africa, showed that dam tailings had the highest Hg concentrations compared to other environmental samples. A dominance of elemental Hg and sulfur-bound Hg was observed in the dam tailings. The dominance of sulfate-bound Hg is the result of the existence of a high potential for Hg methylation by sulfate-reducing bacteria; therefore, the old dams where amalgam residues are discharged are sources of mercury contamination in the study area. Finally, a strong seasonal correlation was observed in the sediment and water samples. McKinney et al. (2016) measured mercury in sharks off the east coast of South Africa. Elevated values of mercury concentration have been observed in finmako sharks (*Isurus oxyrinchus*), scalloped hammerhead sharks (*Sphyrna lewini*), white sharks (*Carcharodon carcharias*), and jagged tooth sharks (*Carcharias taurus*). In 88 and 70% of species, mercury levels were above regulatory standards which could have effects on fish health and human consumption. Poste et al. (2015) analyzed mercury in water, plankton, and fish samples in African lakes. Low levels of mercury were observed in fish, and mercury trophic growth factors (TMFs, representing the average increase in contaminant concentrations from one trophic level to another) ranged from 1.9 to 5, 6. Very low TMF values were observed in hypereutrophic lakes than in meso- and eutro-phic lakes. A negative correlation was observed between TMF values and chlorophyll concentration in the study lakes. This is thought to be due to a strong influence of THg concentrations by trophic state with high phytoplankton biomass throughout the year potentially reducing the potential for elevated mercury in fish. Black et al. (2011) measured mercury in 27 species of fish in tropical Africa. This work was carried out on the Okavango Delta in Botswana, Southern Africa. Mercury concentrations in non-piscivorous fish (19 ± 19 ng) were lower than in piscivorous fish (59 ± 53 $ng.g^{-1}$). This difference in concentration observed between these two species of fish results from their food habits. In general, mercury concentrations in fish throughout tropical Africa were well below those found in freshwater ecosystems elsewhere in the world. The causes of this apparent "African mercury anomaly" are unidentified and further research is needed to improve understanding of the biogeochemical cycle of mercury in the environment. Joiris et al. (1998) measured mercury in Anadara bivalves (*Senilia senilis*) from Ghana and Nigeria. The median concentrations of Hg obtained during the dry season were higher than those obtained during the rainy season at the level of the lagoons; on the other hand, these concentrations were lower in the dry season in the estuary. The concentrations of Hg obtained at the level of the Ghanaian lagoons are also higher than those obtained at the level of the estuary of the Bonny River in Nigeria. This would be due to the degree of urbanization and population density around Nigerian estuaries, but other biotic and abiotic factors should not be neglected as well. Diankha et al. (2020) analyzed mercury on mussel (*Perna perna*) and sea urchin (*Echinometra lucunter*) from the Bay of Soumbédioune in Senegal. Irrespective of the species considered, the concentration of mercury in the grilled products was twice that of the raw products. The concentrations found in these species are well below the standard set by the US Environmental Protection Agency (USEPA) for seafood products in 2008, which is 0.5 $mg.kg^{-1}$. Therefore, the consumption of these species by the population does not present a health risk. However, these species should be consumed in moderation because mercury can bio-accumulate in the body following regular consumption of these species. Nianne et al. (2019) analyzed mercury in sediment samples and water in pristine and artisanal small-scale gold mining (ASGM) sites in the Gambia River (Kédougou region, Eastern Senegal). In the Gambia River, high concentrations of total Hg (1.16 ± 0.80 $mg. kg^{-1}$) and methyl-mercury (3.2 ± 2.3 $ng.g^{-1}$) were also observed in samples of sediments collected from ASGM sites. Along the river, THg concentrations in sediments decrease with distance from ASGM sites, while those of methyl-mercury increase downstream. The sedimentation of Hg-enriched fine particles downstream of mine sites (ASGM) probably promotes the production and accumulation of MeHg in the sediments. Surface soil erosion can also provide significant and long-term inputs of Hg to downstream aquatic ecosystems, where it can be converted to its methylated form. The recent and rapid development of ASGM mining activities in Kédougou in the Senegal region has led to dramatic Hg contaminations of soil, sediments, and water due to a large input of Hg during the processing of ore 'gold. This activity can constitute a long-term source of contamination and can have a large-scale impact on the aquatic ecosystem through bio-magnification. Diop and Amara (2016) measured Hg in green algae (*Ulva lactuca*), the brown mussel (*Perna perna*), the Caramot shrimp (*Penaeus kerathurus*); liver and muscle of fish *Solea senegalensis*, *Mugil cephalus*, *S. melanotheron* and *Sardinella aurita* along the Senegalese coast. Among the different species, the highest concentration of mercury was observed in fish and the lowest in algae. In fish species, Hg concentration in the liver was higher than in muscle. In shrimp, mussels and sardine, and sole muscle, Hg concentrations were below safe limits for human consumption, according to the European Union directive. The results of this research indicate that the concentrations of mercury in fish and other organisms (algae, mussels, and shrimps) from the Senegalese coasts are lower or in the same order as those observed in other African countries and more generally in the seawater of coastal areas. Benson et al. (2007) analyzed mercury on several species of fish such as *C.*

nigrodigitatus, *Brycinus nurse, Hemichromis fasciatus, Lutianus ava, Oreochromis nilotica, Pomadasys jubelini, Stellifer stellifer* and *Tilapia guinensis* from the Niger Delta in Nigeria. In general, mercury concentrations in various fish species behaved like this, *P. jubelini* > *O. nilotica* > *H. faciatus* > *L. ava* > *S. stellifer* > *B. nurse* > *C. nigrodigitatus* > *Tragogomphus guinensis*. So *P. jubelini* accumulate more mercury than other fish species. This would be due to the eating habits and way of life of this species. This species of fish could pose a greater risk to consumers, especially in environments contaminated by mercury residues. Kakulu and Osibanjo (1986) measured mercury in fish and sediments from the Niger Delta region of Nigeria. It appears that the species *Papyrocranus afar* had the highest concentrations of Hg. In general, most fish species analyzed contained less than 65 $\mu g.kg^{-1}$ wet weight. Except for sediments from the Asa River near Uzère, mercury concentrations in the sediments were related to organic carbon content. Mercury pollution in the Niger Delta area of Nigeria is of little concern. El Mahmoud-Hamed et al. (2019) measured mercury in freshwater fish *C. gariepinus* (African catfish) and *O. niloticus* (tilapia fish) from the right bank of the Senegal River in Mauritania (Rosso, Boghé, and Kaédi). Hg concentrations were higher in muscle than in liver and gills for both species studied (muscle > liver > gills); which can be caused by the presence of methyl-mercury. Overall, the mercury concentration observed in fish in the Senegal River was high compared to that observed in other rivers in Africa. Koffi et al. (2006) measured mercury in certain species of fish (carp, sardine, sea bream, sole, grouper, captain, ombrine and crayfish) in certain sites (East, Abidjan, Center and West) in Ivory Coast. It shows that carp concentrate more mercury (192 $\mu g.kg^{-1}$) than all other fish, which would be due to their lifestyle. No concentration is above or equal to the maximum authorized threshold for fishery products (500 $\mu g.kg^{-1}$). Whatever the species of fish, the mercury concentration is higher in Abidjan, this would be due to the industrial activities that take place in this city. Mahjoub et al. (2021) measured certain metals, including mercury, in the muscles of five fish (*Esox lucius, Sander lucioperca, Micropterus salmoides, Lepomis macrochirus,* and *Scardinius erythrophthalmus*) species from the Mechraâ-Hammadi dam in Morocco. The results show that demersal fish living near sediments and piscivorous fish with a higher trophic level were likely to accumulate more Hg. The concentration of Hg in the different fish species follows the following order: *E. lucius* > *S. lucioperca* > *M. salmoides* > *L. macrochirus* > *S. erythrophthalmus*. In addition, Hg concentrations in summer were higher than those in winter, this may be due to the increase in the volume of water in the dam caused by the contribution of rainwater in winter, leading to a dilution of the Hg higher metabolic rates, which could cause an intensification of fish feeding activity, which will cause an increase in metal levels in fish (Mahjoub et al., 2020; Shinn et al., 2009; Kassegne et al., 2019).

Concentrations of Hg in muscle tissue of different fish species were below European Union (EC) Directive No. 1881/2006. According to the THQ (Target Risk Quotient) results, consumption of certain species of fish, namely, *E. lucius* and S. *lucioperca* may cause more harm to humans. Therefore, for a healthier diet, it is recommended to consume less carnivorous fish. Chahid et al. (2014) analyzed Hg in fish (*Sardina pilchardus, Scomber scombrus, Plectorhinchus mediterraneus, Trachurus trachurus, Octopus vulgaris, Boop boops, Sarda sarda, Trisopterus capelanus,* and *Conger conger*) from the Atlantic Sea, in different fishing ports in the southern Kingdom of Morocco. However, the concentrations of Hg found in these different species of fish were below the maximum levels set by Commission Regulation (EC) No. 629/2008 (0.5 $mg.kg^{-1}$ for muscle fish flesh). The lowest Hg levels were found in horse mackerel, octopus, and conger. This can be explained by the feeding habits of these fish. It appears that the consumption of fish from this region does not present a danger to human health. Banana et al. (2016) measured mercury in fish samples (*Serranus scriba, Oedalechilus labeo, Diplodus vulgaris, Dicentrarchus labrax, Lithognathus mormyrus, Epinephelus marginatus, Sarpa salpa, Sciaena umbra, Pagrus pagrus, Caranx crysos, Pinctada radiate* and *Sepia officinalis*) oysters, cuttlefish, magnoliophyte plants and sediments around Farwa Island in Libya. It emerges from this study that *Serranus scriba* had a high rate of Hg^{2+} during the study period from January to July, followed by *Epinephelus marginatus*. In general, the samples taken near the industrial area have a high level of mercury. It can be said that the high contamination of fish, oysters, and cuttlefish in the marine environment around the industrial zone of the General Society of Chemical Industries (GCCI) represents a potential source of contamination for the resident populations. Therefore, this area must be treated to prevent cases of mercury contamination. Abolghait and Garbajm (2015) investigated mercury in the meat of canned light tuna (*Katsuwonus pelamis* and *Thunnus albacares*) and small fresh tuna (*Euthynnus alletteratus*) in Libya. The average mercury concentration found in small fresh tuna (1.185 ± 0.968 $mg\ kg^{-1}$ wet weight) was often above the standard allowable limit. This same research showed that canned skipjack and yellowfin tuna sold commercially in Tripoli had Hg levels below European thresholds. However, large consumption of small Mediterranean tunas can lead to Hg poisoning problems. Al-Asadi (2018) measured the mercury in the sediments and some fish (*Sarpa salpa, Spondyliosoma cantharus, Mullus surmuletus, Diplodusannularis, Scorpaena elongate, Pagellus erythrinus, Labrus* species, *Lithognathus mormyrus, Dipoldus vulgaris, Sciaena umbra, Euscarus cretensis, Epinephelus costae, Umbrina cirrosa, Trygon pastinaca, Epinephelus guaza, Dentex dentex, Pagrus pagrus*) west of Libya. The scorpion fish and *Sarpa salpa* species had the highest and lowest Hg concentrations, respectively (3.586 and 0.1765 µg/g, respectively). It emerges from this research that the fish sampled in the area located 110 km and more from the petrochemical complex (considered an unpolluted area) have low contamination compared to those taken near the petrochemical complex. The probable source of mercury pollution in this region would be the Chlor-Alkali plant. Almli et al. (2005) analyzed mercury in the livers and kidneys of male and female crocodiles (*Crocodylus niloticus*) 2.0-4.0 m in length from the Kafue and Luangwa rivers in Zambia. In general, mercury concentrations in the Kafue River are slightly higher than those in the Luangwa River. This is believed to be due to mining activity carried out around the Kafue River drainage area. However, this mining activity did not significantly influence mercury concentrations in the tissues of crocodiles in Kafue National Park. Ikingura and Akagi (2003) measured THg and MeHg in fish (*Tilapia urolepis, Hydrocynus vittatus, Bagrus orientalis, Synodontis maculipinna, Clarias mossambicus* and *Alestes affinis*) hydroelectric reservoirs (Mtera, Kidatu, Hale-Pangani, Nyumba ya Mungu) of Tanzania. It appears from this research that approximately 56 to 100% of the total mercury in fish was methyl-mercury. THg levels in herbivorous fish were lower than in piscivorous fish. In general, mercury concentrations in fish from reservoirs in Tanzania were very low and markedly different from those in fish from hydroelectric reservoirs of similar age in temperate and other regions (which contained high concentrations of mercury). Lower levels of mercury in fish were correlated with low background concentrations of THg in sediments and flooded soil (mean 2-8 µg/kg dry weight) in the vicinity of the reservoir. Odumo et al. (2014) assessed mercury in sediments and wetlands (around and at the bottom of leaching ponds) in Kenya in an artisanal gold mining area. The results of this study reveal that mercury is present at very high levels in sediment residues, followed by river sediments and ores. So mercury is transported to the terrestrial ecosystem by wet and dry deposition. The Migori-Transmara region can be considered a highly polluted environment with high mercury concentrations. The artisanal technology used to extract gold is not appropriate, it is necessary to put in place other methods of gold extraction, to reduce the levels of mercury that can be released into the environment. Rasoazanany et al. (2018) measured mercury in marine fish (*Gazza minuta* (Toothpony), *Gymnosarda unicolor* (Dogtooth tuna), *Upeneus taeniopterus* (Finstripe goatfish), *Sphyraena fosteri* (Bigeye barracuda), *Polydactylus sextarius* (Blackspot threadfin), *Herklotsichthys quadrimaculatus* (Bluestripe herring), *Chirocentrus dorab* (Dorab wolf-herring), *Euthynnus affinis* (Kawakawa) from Morondava on the west coast of Madagascar. This study reveals that mercury concentrations in *Sphyraena forsteri* and *Polydactylus sextarius* exceeded the WHO guideline/ FAO (0.5 $mg.kg^{-1}$). The bronchia of all fish species had high mercury levels, and *Sphyraena forsteri* had maximum mercury levels (3.2 $mg.kg^{-1}$). Kidd et al. (2003) measured mercury in selected species of fish and invertebrates in the Lake Malawi food web. The results of this study showed that pelagic fish had significantly higher Hg levels than benthic species. In addition, Hg levels were high in the largest fish of each species, which would be due to a phenomenon of biomagnification. So regular consumption of these large fish can lead to mercury poisoning. Gnandi et al. (2011) measured THg and MeHg in the lagoons of Lomé in Togo. The results of this study reveal that the sediments of the Lomé lagoons contain high levels (above normal) of total mercury and methylmercury. Concentrations of THg and MeHg are similarly higher for the western lagoon compared to the eastern lagoon, and particularly higher for the southern shores compared to the northern shores. This phenomenon is due to more significant sources of pollution on the southern shores of the lagoon, but also to chelation by organic carbon. The increase in the percentage of MeHg compared to THg in the dredged sediments of the eastern lagoon reveals that the clean-up dredging activity carried out in the past would be responsible for the increase in the production of MeHg because it decreases the amount of carbon thus increasing the trapping capacity of the lagoon. Pascal et al. (2020) assessed mercury in sediments from rivers draining gold panning sites in Fizi territory, eastern Democratic Republic of the Congo. The results thus obtained revealed that the sediments of these studied rivers are considerably polluted by mercury according to the values relating to their total mercury content and the calculated mercury pollution indices, which are above the standards recommended by the Canadian Council of Environment ministers. Compared to the sediments of other rivers, mercury concentrations are higher in the sediments of the Kimbi River. These high concentrations observed in the Kimbi River are due to gold panning activities that generate effluents and elemental mercury that pollute the waterways. Thus, it is necessary to regularly strengthen the capacity of artisanal gold miners by organizing workshops on extraction methods that do not pollute the environment and also showing them the impact that mercury has on aquatic ecosystems. Coelho et al. (2016) measured mercury in sediments and biological samples (*Senilia senilis* and *Tagelus adansoni*) from the Bijagós Archipelago in Guinea-Bissau. The sediments contained very low concentrations, suggesting that anthropogenic sources of Hg are negligible in this region. But the Hg is well correlated with the fine fraction, the aluminium and the loss on ignition. An almost insignificant variation in mercury concentration is observed in the bivalves *Tagelus adansoni* and *Senilia senilis*. This slight difference in Hg concentration between these two biological species would be due to divergent food preferences. Nsabimana et al. (2020) assessed mercury in water samples from Lake Kivu, Rwanda. In addition, one out of six samples at Rusizi and four out of six at Rubavu were above the EPA (Environmental Protection Agency of the United States) maximum allowable limit of 0.025 μg.L^{-1} for Class III surface water intended for fish consumption and recreation. Mambou Ngueyep et al. (2021) measured mercury in water in Batouri, Cameroon. The results of this research reveal that the mercury concentrations in the waters studied were above the standard established by the WHO (0.01 mg.L^{-1}). The presence of mercury in these waters would be due to the mining activity that takes place in this locality and which is likely to release mercury during the gold smelting process. Youssao Abdou Karim et al. (2018) measured THg in the sediments and the water of the Mekrou River and its derivatives, in the communes of Kérou, Kouandé, and Pehunco, in northern Benin. The results of this research show that watercourses (Mekrou River and its tributaries) have relatively higher Hg levels (181.2 to 616.9 μg.L^{-1}) compared to pond and dam waters (0.5 to 1.3 μg.L^{-1}). This would be due to a re-dissolution of bottom sediments. Conversely ponds and dams are characterized by low levels of mercury in water and relatively higher levels in sediments compared to streams. This shows that most of the mercury is more concentrated in the sediments because in these environments (ponds and dams) there is an absence of water current, therefore, resuspension of the bottom sediments. The presence of mercury in these environments would be due to anthropogenic activities including artisanal gold mining which was practiced on the bed of the Mékrou river in the commune of Péhunco, more precisely in the village of Kouyagou, and agricultural activities. Donkor et al. (2016) analyzed THg in fish, waters, and sediments from the Ankobra and Tano basins in southwestern Ghana. It appears from this research that the sediments of Heman Prestea have the highest concentrations of Hg, which would be due to the interconnection of this river with the Ankobra river where extraction activities are carried out. So there would have been a movement of Hg-laden sediment from the Ankobra River to the Heman Prestea River. Thus the values of the Mullers geochemical index (Igeo) varied from 8.02 to 9.67 and from 7.32 to 7.90 for the Ankobra and Tano basins, respectively. This indicates that these environments are very heavily polluted. The International Atomic Energy Agency (IAEA) (Kwaansa-Ansah et al. 2011) far from the allowable limit of 0.81 μg.g-1 suggests the sediment Hg concentrations determined during this research. On the other hand, the mercury concentrations in the waters were very low and were below the WHO guideline value of 1.00 μg.L^{-1} for drinking water (WHO, 1985). This would be explained by the pH range of 6.0 to 8.0 observed in waters, the presence of suspended solids, and the processes of adsorption and co-precipitation that can remove metals such as Hg from solutions as sulphides under anoxic conditions (Hamilton, 1971) cited by Donkor et al. (2016). The Hg concentrations found in most fish species were greater than 0.2 μg.g^{-1} and were below the WHO guideline value <0.500 μg.g^{-1} (wet weight). These results suggest that mining activities contribute significantly to environmental degradation through mercury contamination of the Ankobra and Tano basins. Nianne et al. (2015) measured mercury in eight species of fish and two species of crustaceans and the human hair of 111 volunteers of different ages and sexes, living in urban areas (Kedougou and Samekouta) or mining areas (Tinkoto and Bantako) of the River Gambia. THg concentrations in fish were below the WHO safety standard of 0.5 mg kg^{-1} ww, while 100% of crustaceans had concentrations that were above this safety standard. Generally, the difference in mercury concentration between different species of fish is often linked either to their eating habits or to their lifestyles. In addition, the pollution of aquatic environments in Africa results from human activities such as artisanal mining activities for certain precious metals, certain industrial activities, and poor management of household waste and agricultural activities.

The work of Niane et al. (2015) showed that THg concentrations in the hair of local people with a diet of fish from the Gambia River in two artisanal gold mining areas were higher (1.45 and 1.5 mg kg^{-1} in Bantako and Tinkoto, respectively) than those of the other localities (0.42 and 0.32 mg kg^{-1} in Kédougou and Samekouta, respectively) which have diversified diets. Additionally, at gold mining sites, approximately 30% of the Aboriginal populations have hair Hg concentrations greater than 1 mg kg^{-1} defined as a hair Hg guideline by the US EPA. Higher exposure of women to Hg in the Tinkoto gold mining site was observed due to their involvement in amalgam combustion. It appears from this study that the consumption of fish is not the main source of exposure to Hg, further research would prove necessary to determine other possible sources of exposure to elemental Hg of the inhabitants. Black et al. (2011) measured mercury in the hair of people eating fish products and in 27 species of fish in tropical Africa. This work was carried out on the Okavango Delta in Botswana, Southern Africa. Total mercury concentrations in hair from Okavango Delta subsistence fishing communities ranged from 0.003 to 0.97-μg g^{-1} with a median of 0.10 μg g^{-1} and a mean of 0.21 ± 0.22 μg g^{-1}. It appears from this study that no hair sample exceeded the US National Research Council recommended level for mercury in hair of 1 μg g^{-1} (National Research Council, 2000) cited by Black et al. (2011). In addition, individuals with high fish consumption had elevated mercury levels in their hair. So regular consumption of fish from this zone can lead to short- or long-term mercury-related health problems. Black et al. (2017) conducted a study on occupational mercury exposures and behaviors of artisanal and small-scale gold miners in Burkina Faso. The results showed that 82% of the burners and 24% of the inspectors of these miners were exposed to concentrations above the authorized limit (100 $\mu g/m^{-3}$) and 11% of the burners exceeded the level considered very harmful to life and health (10,000 $\mu g/m^{-3}$). The exposure of the controllers would be due to atmospheric contamination during the combustion of the amalgams by the burners (Harada et al., 1999). Bose-O'Reilly et al. (2020) measured mercury in breast milk, urine, and hair among mother-child pairs in an artisanal and small-scale gold mining area in the Kadoma region of Zimbabwe. The mean concentrations of THg in breast milk, in the control, moderately exposed and highly exposed groups were 0.5 $\mu g.L^{-1}$, respectively; 1.10 and 1.20 $\mu g.L^{-1}$ with a maximum concentration of 24.80 $\mu g.L^{-1}$. 26.2, 76.5, and 85.2%, respectively in the control group, the moderately exposed group, and the highly exposed group had mean concentrations of THg in the babies' urine that exceeded the reference value (0.70 $\mu g.L^{-1}$). In general, Hg concentrations are elevated in individuals from the highly exposed group. Babies were exposed to Hg either by inhalation during fusion processes and also by consumption of breast milk. Mambrey et al. (2020) analyzed mercury in urine and blood in an artisanal and small-scale gold mining area in Kadoma and Shurugwi, Zimbabwe. Overall, 52% of samples had Hg concentrations that were above the Human Bio-monitoring cutoff values (Human-Biomonitoring Commission of the German Environmental Agency, 1999). This indicates that at Kadoma and Shurugwi, men were exposed to occupational and environmental pathways. The Hg concentrations in the different samples were higher in all samples at Shurugwi compared to those at Kadoma. This can be attributed to several factors, such as lower autoclave usage, variabilities in gold extraction methods, and recurrent use of Hg. Elhamri et al. (2007), assessed mercury levels in hair and different fish species, namely Sardina *(Pilchardus W*., Clupeidae), common mudulet (*Mugil cephalus L.,* Mugilidae), and hake (*Merluccius merluccius* L., Merluucciidae)*,* in the Moroccan Mediterranean coastal community. However, the Hg concentrations in the various fish species analyzed are below 0.50 $\mu g.g^{-1}$, which is the maximum limit established by European Union regulations. It shows that fishermen and their families are more exposed because of their regular consumption of fish (three to five times a week). High concentrations of mercury were found (3.08 to 7.88 $\mu g.g^{-1}$) in the hair of women of childbearing age (50%). In general, the Hg concentrations from this study indicate a certain margin of safety for the majority of the adult population including a significant portion of women of childbearing age. Banana et al. (2017) assessed mercury levels in human blood and hair (whose ages ranged from 18 to 47 years) in an industrial area in Libya. These blood and hair samples were taken from people working and residing around the General Society of Chemical Industries (GCCI) for different periods ranging from 10 to 20 years. Among the blood samples analyzed, 13% of the samples have a Hg level above the guideline of the World Health Organization (WHO) (200 $\mu g\ L^{-1}$). Similarly, 20.83% of the hair samples had Hg concentrations above the standard WHO limits (4.4 gg^{-1}). The highest concentrations of Hg were found in the blood (849 $\mu g.g^{-1}$) and the hair (10.3 $\mu g.g^{-1}$) of a 47-year-old person. Hg concentrations in blood and hair correlated with the age of the people sampled. It appears that the concentrations of Hg in human blood depended on age and the duration of exposure. The infertility of some of these workers could be due to the high exposure to Hg. Moreover, it can be said that the high presence of Hg in human blood and hair is the cause of the high level of mercury pollution in the adjacent environment of the petrochemical industry zone in Libya. Attiya et al. (2020) conducted a survey on the state of health of dentists in Morocco following daily occupational exposure to mercury in two regions of Morocco. The results of this research showed a significant difference in the age and seniority variables in the exercise of the profession between the two regions. 32.50% of the participants claimed to feel a gradual deterioration in their state of health since the start of their function and 46.35% claimed to have neuropsychological dysfunctions. Obi et al. (2015) measured mercury in the umbilical cord blood of mother-newborn couples at hospitals in Nnewi, Nigeria. The results of this research showed a significant correlation was observed between maternal blood and umbilical cord (r = 0.471). A slight increase in mercury was observed in the blood of mothers who claimed to have consumed fish at least once a day. A positive and significant correlation of mercury concentrations in cord blood was observed with weight, height at birth, as well as head and chest circumference. Mercury levels in 36% of participants were above the bio-monitoring guideline associated with the United States Environmental Protection Agency (US EPA) reference dose for mercury. Channa et al. (2013) assessed mercury in maternal and cord blood in the population at three sites along the South African coast. In umbilical cord blood, Hg concentrations for site 1 (1.45 $\mu g.\ L^{-1}$) were more than double that of Hg in site 2 (0.70 $\mu g.L^{-1}$) and site 3 (0. 73 $\mu g.L^{-1}$). The elevated concentrations of Hg observed in maternal blood and umbilical cord blood in site 1 are thought to be due to the use of wood and gas for cooking, borehole water as a source of drink, and daily consumption of fish fresh, canned fish, fruit, or dairy products. It appears from this study that 2% of the population studied were above the reference value of the EPA (5.8 $\mu g.L^{-1}$), which does not cause great concern because we are in front of low mercury exposure in pregnant women and the developing fetus in South Africa.

MERCURY MANAGEMENT POLICIES IN THE ECOWAS REGION

Here, several authors have proposed some solutions for the effective management of wastes and activities that generate mercury in the environment. In general, the most determining factor in the success of the mission to eradicate mercury-related pathologies is poverty. The strategies implemented by the states for the application of the Minamata convention are identical and derive from the Minamata Initial Assessment (MIA). As part of the implementation of the Minamata convention on the use of dental amalgam, several research works have been carried out. In their research in Tanzania, MoHCDEC (2020), claimed that dental amalgam is one of many products that contain mercury, therefore there is a need to drastically reduce its use, and release to the environment to minimize human exposure to all forms of mercury as much as possible. During this work several solutions were proposed such as: carrying out recycling activities with mercury-free dental materials, encouraging the use of cost-effective, and clinically effective mercury-free alternatives for dental restoration; encourage research and development of quality mercury-free materials. Spiegel (2009) has shown that the burden of poverty on artisanal miners in Africa does not allow them to use appropriate technologies to reduce mercury pollution. This research shows that to reduce mercury pollution, donors must put in place effective strategies such as access to microfinance, access to fair gold sales markets, the organization of technical training, and awareness of these minors to the risks they incur by practicing this activity in an artisanal way. According to the Minamata Initial Assessment of Benin (MIA, 2018a), mercury releases/emissions in 2017 are estimated at 44,500 kg. Mercury releases to air, water, and soil in 2017 are 16892.5, 5051.6, and 14007.9 kg Hg/year, respectively. Benin signed the Minamata Convention on October 10, 2013, and ratified it on April 28, 2016, with the approval of the United Nations Treaty Headquarters on November 7, 2016. The main sources of mercury inputs in Benin are batteries containing mercury, artisanal gold mining, informal dumping of general waste, open burning of waste, wastewater disposal/treatment system, skin lightening creams and soaps, paints with mercury preservatives, electrical switches and relays containing mercury, cement production, and electricity and thermal production by burning biomass (MIA, 2018a). However, certain shortcomings should be noted concerning the inventory of mercury in Benin. Among these shortcomings is the lack of traceability of import and export products and the porous characteristics of borders. To reduce or eliminate the use of mercury in Beninese territory, it will be necessary to: raise awareness among target groups (health workers and gold miners) on the dangers of mercury, and encourage them to gradually use products and equipment that do not contain mercury. The authorities must also review the method of waste and wastewater management, and improve the national legal framework for better implementation of the Minamata Convention. According to the Initial Assessment of Minamata Mali (MIA, 2018b), Mali signed the Minamata Convention on Mercury on October 10, 2013, then ratified it on May 25, 2016. In Mali, the mining sector consumes a lot of mercury, particularly artisanal gold mining (MIA, 2018b). In addition to mining, other sources of mercury are electrical switches and relays containing mercury, thermometers, mercury light sources, creams and soaps containing mercury, and cemetery industries. Mining activities are the main sources of mercury contamination of air, water, and soil and followed by general waste deposits. Exposed persons are minors (women, men, and children), women of childbearing age, health workers, and waste management, workers. This highlights the need to raise awareness among civil society to reduce the consumption of products containing mercury. In addition, there is a need to improve the policy, legal and institutional frameworks for mercury management, reduce the use of mercury in practices in the artisanal and small-scale gold mining (gold panning) sector, implement put in place a policy for the ecological and rational management of waste containing mercury. It should be noted that there are some gaps in the management of mercury in Mali. Among these gaps is the lack of appropriate tools and resources for customs officers and professionals in the control sector to track the flow of mercury entering Mali. Added to this is the lack of reliable data on products and devices containing mercury. The Minamata Initial Assessment missions of Togo (MIA, 2018c) and Senegal (MIA, 2018d) also noted the anthropogenic sources of mercury cited in Benin (MIA, 2018a) and Mali (MIA, 2018b), but pesticides used in agriculture have been mentioned as an anthropogenic source of mercury in Senegal (MIA, 2018d). In addition, the deficiencies reported in the implementation of the mercury inventory in Benin and Mali was observed in Senegal and Togo (MIA, 2018c, d). According to work by UNIDO (2018) carried out in member states of the Economic Community of West African States (ECOWAS), the amount of mercury imported, traded, and used by miners in the Artisanal gold mining in West Africa is well above official figures. Some of the mercury that illegally arrives in this region is believed to be of Chinese origin. A significant quantity of mercury illegally enters the ECOWAS region from Ghana via Togo and Burkina Faso and Burkina Faso is a hub for illegal entry of mercury into ECOWAS. The informal nature of the economy in this region and the high cost of gold make the sector very attractive. The permeability of borders in the region and gold and mercury exchanges allowing local miners to continue their work are all factors that favor the intensive use of mercury. Reducing mercury use and trade in West Africa requires not only an understanding of mercury flows but also the regulation of mercury trade. Reducing the use of mercury in the ECOWAS region will require: greater cooperation and harmonization of regulatory frameworks, thus regional and national coordination of relevant public institutions must be established, strengthening regulatory oversight of gold imports in countries of destination, encouraging miners to extract mercury-free gold or helping them to use techniques that are more respectful of the environment, through tax incentives and other commercial advantages.

Conclusion

Many studies have been carried out in Africa and around the world on the knowledge of mercury, its distributions, its impact on food and environmental matrices as well as its effects on human health and that of the ecosystem. However, faced with the immensity of areas not yet explored, such as the trade in mercury and its flows, its quantification in cosmetics, and in certain professional circles, researchers and other scientists still have major challenges to meet to enlighten decision-makers. In many African countries, mercury is still a major problem because it is used in gold mining sites, in ointments for depigmentation, and dental amalgams. Because of all this, it is necessary to respond appropriately for the protection of the environment but also the health of the population and also of health professionals, and minors. These appropriate measures must be taken to reduce its use or the outright elimination of these anthropogenic sources. In addition, awareness workshops must also be organized to show the environmental and health effects of mercury to prevent and reduce cases of mercury contamination. In addition to these actions, studies should be extended to the level of major consumer food crops grown in Africa to see their levels of mercury contamination.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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