REVIEW *Toxicology*

Current Levels of Heavy Metal Pollution in Africa

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ABSTRACT. Studies of environmental pollution in Africa indicate that toxic metal pollution has reached unprecedented levels over the past decade. Human exposure to toxic metals has become a major health risk on the continent and is the subject of increasing attention from national and international environmentalists. This paper reviews data from the past decade on environmental pollution in Africa and highlights countries where most heavy metal pollutions have been reported. Characteristics of heavy metal pollution in North, West, East and Southern regions of Africa have been described, as have major sources of pollution in the different regions. This review summarizes the sites where most of the heavy metal pollution has been reported in Africa and, where applicable, presents reported levels of pollution in different environmental compartments in the context of internationally acceptable limits. Contaminations in fish and food animals as well as impacts of heavy metal pollution on humans are also described.

KEY WORDS: Africa, environment, heavy metals, pollution.

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For many years, Africa was considered safe from heavy metal pollution [6]. However, rapid population growth and high urbanization rates have resulted in a recent expansion of cities in the absence of proper planning and without adequate waste disposal facilities [25]. Consequently, solid waste management has become a major challenge in many African countries, as waste production exceeds capacities for collection and disposal by local authorities [49]. As observed by the United Nations Centre for Human Settlements (UNCHS) [56], only one-third of the solid waste generated in urban areas across Africa is collected, and of that, only 2% is recovered and recycled. Furthermore, use of leaded gasoline [36], fugitive dusts [13], indiscriminate dumping and burning of toxic waste, including nickel/cadmium-based batteries, due to weak pollution legislation has worsened heavy metal pollution on the continent [22].

Recently, the United Nations Environment Program (UNEP) Global Environment Outlook (GEO) 4 [58] noted that Africa continues to be at risk from hazardous and electronic waste dumping due to inadequate monitoring capabilities and institutional mechanisms for managing such waste. There are limited resources for environmental management in most African countries, as most developmental programs are focused on economic growth and industrialization [52]. As a result, industrial expansion and increased extraction of natural resources have resulted in widespread heavy metal pollution [3, 59].

According to a comprehensive study on the environmental burden of disease by the World Health Organization (WHO) [62], environmental risk factors account for a quarter of the total burden of disease and 2.97 million human deaths every year in Africa. Since toxic metals constitute serious health hazards, the extent of toxic metal contamination of the African environment has been the subject of considerable interest. Although improvements in analytical techniques for measuring heavy metals have facilitated the generation of more reliable data, reviews of the current status of heavy metal pollution in Africa are rare. The objectives of this paper are to determine the current status of heavy metal pollution in Africa, to describe the characteristics and sources of pollution in the different regions of Africa, namely the North, West, East and Southern regions, and to provide a comprehensive assessment of impacts of heavy metals on the environment and human health in Africa. Although Arsenic (As) is not considered to be heavy metal, it is categorized as a toxic metal and has been included in this review. We limit our discussion to data generated over the past decade on heavy metals in different environmental compartments and their impact on animals and humans in Africa. Moreover, recommended values of heavy metals in the environment by international organizations and European Commission were used for reference, as guideline values are lacking in African countries.

CURRENT STATUS AND EXTENT OF HEAVY METAL POLLUTION IN AFRICA

As shown in Fig. 1, heavy metal pollution of water, sediment and/or soil has been reported in many African countries (marked 1–14). Notable heavy metals that have been reported include lead (Pb), cadmium (Cd), mercury (Hg), copper (Cu), cobalt (Co), zinc (Zn), chromium (Cr), nickel (Ni), manganese (Mn), iron (Fe), arsenic (As) and vanadium (V). Data on heavy metal pollution in countries that are not marked in Fig. 1, which are for the most part relatively less developed African countries, is scarce. However, current

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levels of pollution in these countries are likely to be comparable to those in the highlighted countries as sources of pollution are similar in Africa. Overall, while the dynamics of heavy metal pollution on the continent are similar, specific differences exist among the North, West, East and Southern regions of Africa.

North Africa

Studies of heavy metal pollution in North Africa have focused mainly on coastal environments (Fig. 1). In Egypt (3 in Fig. 1), El-Mex Bay and Eastern Harbour along the Mediterranean coast are polluted by municipal and industrial waste, as several industries located close to the coast discharge their effluents directly into the bay [1]. Moreover, the Omoum Drain, which flows directly into El-Mex Bay contributes to Cd contamination from phosphate fertilizers carried in agricultural wastes as well as other metals including Cu and Zn carried in industrial wastes [15]. In a comprehensive study by Abdallah [1] during the winter season, a total of 24 water samples were collected from various sites of the bay, including the western and middle parts, Omoum Drain mouth, the entrance of Alexandria Western harbour and a of chloroalkali plant and petroleum refinery. The concentrations (mean ± SD, mg/*l*) of Pb (14.19 ± 7.5), Cd (3.12 ± 2.1), Cu (4.29 ± 0.46), Zn (33.58 ± 12.7) and Cr (3.68 ± 1.7) exceeded the recommended values (Table 1).

On the Tunisian side of the Mediterranean Coast (2 in Fig. 1), contamination of El Melah Lagoon sediments with Pb (30.0 mg/kg) and Cd (1.5 mg/kg) has been attributed to industrial effluent [50]. Recently in Morocco (1 in Fig. 1), concentrations of Pb and Cd of up to 297.0 and 4.0 mg/kg, respectively, were recorded in Nador Lagoon sediment [8]. Along the Atlantic Coast of Morocco, the contribution of agricultural (phosphate fertilizers and pesticides) and industrial waste to coastal pollution was noted by Cheggour *et al.* [10], who reported contamination (mg/kg) of Sebou Estuary sediments by Cd (2.3 ± 0.7), Ni (101 ± 24), Zn (179 ± 24) and Cu (51.5 ± 12).

West Africa

Petroleum extraction is one of the major causes of pollution in West Africa. Corrosion of oil pipelines, discharges from oil industries and frequent acts of sabotage to oil facilities in the Niger Delta region of Nigeria (5 in Fig. 1) result in discharge of crude oil into the environment [11, 44]. Records of oil spill in Nigeria estimate that over 4,000 spill incidents have occurred since 1960, resulting in loss of over 2 million barrels of crude oil into the environment [44],

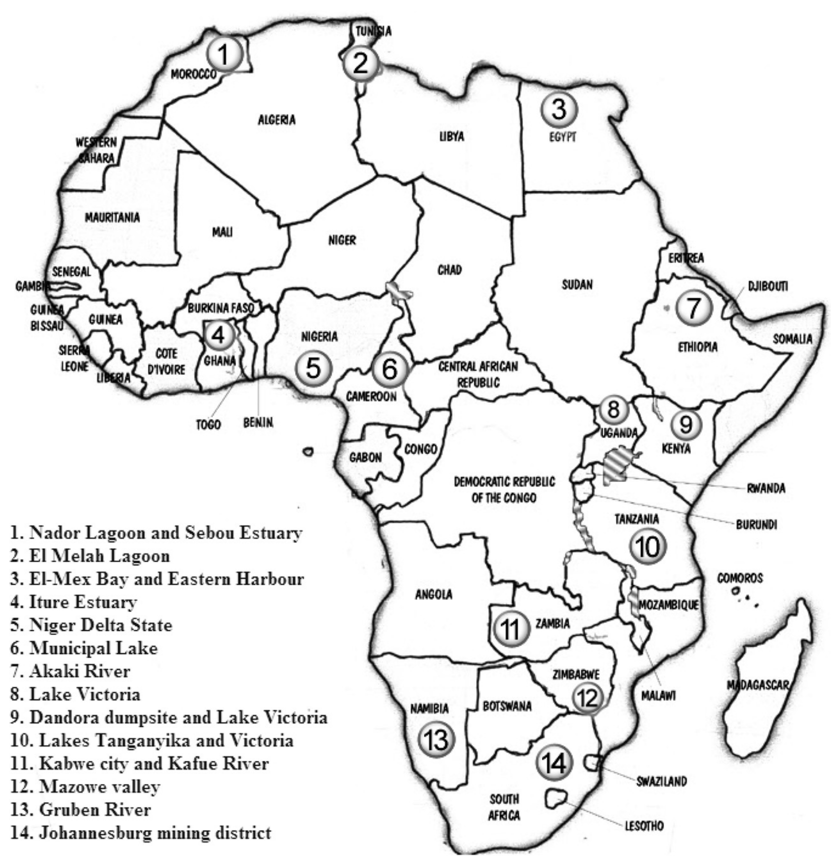

Fig. 1. Map of Africa showing sites where heavy metal pollution exceeding maximum limits in water, sediments or soils has been reported.

Table 1. Recommended values for heavy metal concentrations in the environment

	Pb	Cd	Hg	Cu	Co	Zn	Cr	Ni	Reference
Water (mg/*l*)	0.01	0.003	0.001	2		3	0.05	0.07	[61]
Sediments (μg/g)	20	0.3		45	19	95	90	68	[23]
Soils (mg/kg)	150	5		100	50	500	250	100	[20]
Vegetables mg/kg)	0.3	0.2		40		60	0.2		[21]
Fish (mg/kg)	0.2	0.05	0.5						[17]
Cattle offal (mg/kg)	0.5	0.5							[18]

[61] – World Health Organization (WHO), 1994.
[23] – Foerstner and Wittman, 1979.
[20] – Food and Agriculture Organization (FAO) and International Soil Reference and Information Centre (ISRIC), 2004.
[21] – Food and Agriculture Organization (FAO) and World Health Organization (WHO), 2003.
[17] – European Commission (2005).
[18] – European Commission (2001).

Contamination of the Bonny/New Calabar River Estuary in the Niger Delta by Pb, Cd, Cu, Zn, V and Cr has been attributed primarily to oil refineries, as the rivers receive effluents from Port Harcourt Refinery and other oil related activities [11]. Elevated levels (mg/*l*) of Pb (0.025–0.064), Cd (0.01–0.11), Cr (0.03–0.081) and Ni (0.03–0.09) recorded in the Ijana River were mainly attributed to Warri oil refinery discharges [16]. In a separate study, high concentrations (mg/l) of Pb (2.57) and Cd (0.39) were recorded in the Warri River following dredging of an oil well access canal as compared to the trace levels recorded prior to dredging [42]. In other regions of Nigeria, Oze *et al.* [45] reported concentrations (mg/*l*) of Pb (0.3 ± 0.1), Cd (0.03 ± 0.01), Cr (0.53 ± 0.01) and Ni (0.21 ± 0.01) in the Qua-Iboe River, which they attributed to effluent from crude oil processing and treatment activities.

Adekola and Eletta [4], in a study examining the relationship between industrial activities and pollution, attributed elevated levels of Zn, Fe, Cr, Cu and Mn in Asa River sediments in Nigeria to tannery, bottling, detergent and other industries that discharge into the river. Moreover, widespread contamination (mg/kg) of soils with Pb (67.5–426) and Cd (1.61–5.34) recorded during the rainy season in Lagos around The Ikeja Industrial Estate were attributed to activities of the paint, textile, steel/metal works, pharmaceutical and other industries located in the area [19]. In Ghana (4 in Fig. 1), contamination (mg/*l*) of water in the Iture Estuary with Pb (0.020–0.075) and Cd (0.011–0.041) has been attributed to waste carried by the Sorowie and Kakum Rivers, which flow through a rapidly urbanized and industrialized central region [22]. Additionally, Kwandwo [28] recorded contamination (mg/kg) of Hg (up to 2.3 ± 0.5) and As (up to 1.3 ± 1.1) in streams and rivers in Tarkwa, a gold mining town in Ghana. Alarming levels of sediment contamination (mg/kg) in the Municipal Lake have been recorded in Cameroon (6 in Fig. 1), with levels of 20.3–249 (mean value of 113) of Pb, 2.80–15.6 (13.7) of Cd, 42.8–142 (73.0) of Cu, 26.8–341 (164) of Zn, 94.7–199 (13.7) of Cr, and 2.68–32.7 (10.7) of Ni [14]. The authors attributed the contamination to various industrial activities, including automobile service stations and battery recycling that discharge effluents into the lake.

Cultivation of food crops in contaminated environments is common in West Africa, as small scale farmers cultivate food crops at dumpsites to maximize yields due to the seemingly high organic contents of waste dumpsite soils. Odai *et al.* [41] reported high levels (mg/kg) of Pb (54.6), Cd (2.87), Cu (1631.67) and Zn (2606.0) in soils used for vegetable cultivation at Kumasi waste dumpsites in Ghana. Soil contamination correlated with high concentrations of Pb (13.50) in onions, Cd (1.78) in cabbages and Cu (90.33) in lettuce grown at the dumpsites. Similarly, alarming concentrations (mg/kg) of Pb (13.19 ± 1.27), Cd (0.735 ± 0.16) and Cr (12.89 ± 1.27) recorded in tomatoes grown along the Challawa River bank in Nigeria were attributed to untreated effluents from tannery industries located in Challawa Industrial Estate [2].

East Africa

In East Africa, the Dandora solid waste dump site that occupies about 30 acres of land in Nairobi City, Kenya (9 in Fig. 1), highlights the environmental pollution in the region. Over 2,000 tons of solid waste, including industrial, agricultural, domestic and medical waste, generated per day in Nairobi is indiscriminately deposited into the dumping site [57]. Levels (mg/kg) of toxic metals such as Pb (264.0), Cd (40.0) Hg (18.6), and other heavy metals (Cr, Mn, Fe, Cu, Zn and Co) recorded in soil near the dump site and the Nairobi River bank exceeded the recommended limits (Table 1) [57].

Lake Victoria has been similarly polluted by industrial and domestic waste as well as small-scale gold mining activities that use Hg around the lake [24, 27]. On the Tanzanian coast (10 in Fig. 1), contamination (mg/kg) of sediment with Pb (54.6 ± 11.1), Cd (7.0 ± 2.1) and Hg (2.8 ± 0.8) has been reported [27]. Water contamination (mg/*l*) with Pb (1.4), Cd (0.02) and Ni (0.13), as well as Hg (0.03–0.1081 mg/kg) in sediments, was recorded on the Ugandan side of the lake (8 in Fig. 1) [35]. Similarly, contamination (mg/*l*) of Pb (0.496 ± 0.159), Cd (0.01 ± 0.002) and Cr (1.935 ± 0.258) has been recorded in water on the Kenyan coast [33].

Indiscriminate disposal of industrial, agricultural and domestic waste in urban rivers and use of leaded gasoline have led to toxic metal pollution in several cities in East Africa. Elevated mean levels (mg/kg) of Pb (4.9 ± 0.02) and Cd (0.3 ± 0.001) were reported in vegetables, including cowpeas, African spinach, lettuce and Chinese cabbage, cultivated along the Sinza River in Tanzania, further increasing the exposure of local communities to toxic metals [5]. In a related study, levels (mg/kg) of Cd (0.345 ± 0.18) in lettuce, Cr (24.11 ± 2.4) in lettuce and Zn (130.1 ± 6.4) in spinach exceeding recommended limits (Table 1) were recorded in Ethiopia (7 in Fig. 1). This was attributed to irrigation of vegetables with water from Akaki River, which is polluted with untreated sewage and industrial effluent [47]. In Uganda, the concentrations (mg/kg) of Pb (18.7) and Cd (1.87) in edible vegetables, including amaranthus and cauliflower, grown in polluted roadside soils exceeded the recommended limits (Table 1) and were attributed to vehicular emissions [36].

Southern Africa

Mining is the major source of environmental pollution in Southern Africa, as South Africa is the largest producer of gold in the world, while Zambia holds huge Cu and Co deposits. Contamination of transboundary water systems like Mazowe River in Zimbabwe that flows into the Zambezi River in Mozambique has been reported [48]. In South Africa (14 in Fig. 1), contamination of water with Pb, Cr, Zn, Cu, Mn, Co, As and Ni in the Natalspruit stream in Johannesburg is attributed to gold mining, as the stream's headwaters lie in an area in which tailings dumps abound [37]. In an extensive study by Meck *et al.* [32] in Zimbabwe, levels (mg/*l*) of Pb (1.02 ± 0.25), Cd (0.12 ± 0.00), Ni (2.37 ± 0.26) and Cr (2.48 ± 0.10) contamination of water in streams that exceeded recommended limits (Table 1) were attributed to gold mining activities in stream/river catchment areas.

Similarly, extremely high levels (mg/kg) of Cu (12,855 ± 1459) and Co (1,030 ± 58) were recorded during the rainy season in sediments from the Kafue River, which receives discharge from extensive Cu and Co mines in the entire Copperbelt Province in Zambia (11 in Fig. 1) [46]. Contamination (mg/kg) of Pb (9–75), Cd (<0.1–0.8), Ni (3–220), Cr (9–130) and Zn (1–125) has also been recorded in wetland sediments in the Copperbelt mining region [59]. The high concentration of Pb (0.36 ± 1.0 mg/*l*) recorded in Kafue River basin water was attributed to possible long distance transport of metals by the river and the use of Pb bullets during annual commercial hunting that is carried out in the basin to control the population of wildlife [53]. In Namibia (13 in Fig. 1), widespread contamination of Cu (up to 10,500 mg/kg), Zn (205 mg/kg) and Ni (1,950 mg/kg) in sediments of the Gruben River were attributed to the Khan copper mines [54].

Apart from mining, the contribution of industrial, agricultural and domestic wastes have also been highlighted in a few reports. In a study by Okonkwo *et al.* [43] in South Africa, Pb, Cd, Cu and Zn pollution in Thohoyandou rivers was attributed to the sewage treatment plant, waste dumping and the use of fertilizers and pesticides that contain Pb and Cd on surrounding farms. Similarly, Hg (trace –0.013 mg/*l*) contamination in groundwater across Lusaka City in Zambia was attributed to urban waste [60]. Of particular concern is a recent report by Muchuweti *et al.* [34] in Harare (Zimbabwe), in which high concentrations (mg/kg) of Pb (6.77), Cd (3.68), Hg (0.05), Zn (221.0), Cr (16.1) and Cu (111.0) were found in a locally consumed vegetable (Tsunga) due to the use of sewage sludge in agricultural soils. Contamination of other food crops including green beans, cabbages, peppers and maize also exceeded acceptable limits.

HEAVY METAL POLLUTION IN FISH, FOOD ANIMALS AND HUMANS

Impact of pollution in fish

Despite the evidence of extensive pollution of water bodies in Africa, few studies have examined the impact of heavy metal pollution in freshwater fish over the past decade (Table 2). Existing studies indicate that Pb and Cd contamination in fish is widespread and exceeds recommended limits (Table 1). Alarming concentrations (mg/kg) of Pb (33.0 ± 2.5) in *Brycinus lateralis* and Cd (4.4 ± 0.8) in tilapia fish were recorded in the Kafue River in Zambia by Syakalima *et al.* [53] and Norrgren *et al.* [38], respectively. From the analysis of Pb levels, Syakalima *et al.* [53] suggested possible chronic exposure and likely existence of widespread subclinical toxicity of *B. lateralis* fish in the river as the fish Pb levels were slightly higher than the water Pb levels (0.29–0.36). When pollution levels in fish over the past decade in Africa (Table 2) are compared to recommended limits (Table 1), Pb and Cd contamination exceed the limits.

Nonspecific conditions such as stunted growth and changes in the taste of fish from polluted streams in the Copperbelt mining region in Zambia are attributed to heavy metal pollution [39]. In addition to increased fish mortality, Norrgren *et al.* [38] reported multiple pathological changes in tilapia fish in the Kafue River, including excessive mucus production, epithelial sloughing, lamellar edema and telengiectasia in the gills of tilapia fish. Furthermore, transmission electron microscopic images of hepatocytes revealed electron-dense precipitates of heavy metals in these fish.

Heavy metals in livestock and other food animals in Africa

Although the general awareness of health risks associated with consumption of contaminated food has increased, comprehensive reports of contamination in food animals are few, and regulation of heavy metal content in meat products is lacking in many African countries [51]. In Kafue Lechwe, Syakalima *et al.* [53] reported Pb levels of up to 46.0 mg/kg in livers of the semi-aquatic antelopes inhabiting the Kafue River Basin in Zambia. This was attributed to mining and annual hunting activities in the river basin, as Pb contamination was also recorded in water and vegetation.

Table 2. Levels (Mean ± SD) of heavy metal pollution (mg/kg) reported in fish in Africa

Location	Sources of pollution	Pb	Cd	Hg	Cu	Zn	Cr	Ni	Reference
Egypt: El-Mex Bay & Eastern Harbour	Municipal, industrial and agricultural wastes	4.7 ± 1.9	2.8 ± 0.8		8.3 ± 1.2	43.9 ± 13.6	20.1 ± 9.3		[1]
Egypt: Lake Qarun	Industrial and domestic wastes	24.3 ± 8.6	0.79 ± 0.5		6.76 ± 0.7	48.7 ± 22.3	1.50 ± 0.3	3.99 ± 3.9	[31]
Nigeria: Ogba River	Municipal and industrial wastes	4.0	0.19		19.71	15.28	2.97	0.10	[40]
Nigeria: Qua-Iboe River	Oil Industry	25.6 ± 1.2	0.38 ± 0.1		6.65 ± 0.45			1.9 ± 0.1	[45]
Uganda: Lake George	Kilembe copper mines				2.5 ± 1.6	64 ± 10.9		2.5 ± 0.4	[30]
Tanzania: Lake Tanganyika	Unspecified	4.9 ± 3.1	0.39 ± 0.1		5.90 ± 3.4	101 ± 15			[9]
Tanzania: Lake Victoria	Gold mines			0.063					[24]
Zambia: Kafue River	Mines and possibly spent Pb pellets	33 ± 2.5							[53]
Zambia: Kafue River	Copperbelt mines	3.8 ± 1.0	4.4 ± 0.8		9,700 ± 800	300 ± 23	0.7 ± 0.4	1.5 ± 0.3	[38]

This may reflect a more general pattern of pollution in cattle that share the basin for nutrition. Similar studies done in waterbucks in Lake Nakuru National Park in Kenya revealed toxic levels of Pb (58.3 mg/kg) in liver tissue and Cd (16.24 mg/kg) in kidney tissue [26]. Contamination was attributed to the sewage treatment plant and the old municipal dumping site located inside the park, which also served as a dumping site for the nearby dry battery manufacturing plant [26].

In Marrakech City in Morocco, Sedki *et al.* [51] investigated Cd, Cu and Zn pollution in cattle grazing on a municipal wastewater spreading field and found Cd concentrations of up to 10.3 ± 2.5 and 0.6 ± 0.2 mg/kg in kidney and muscle tissues, respectively. In another extensive study, Abou-Arab [3] identified high concentrations (mg/kg) of Pb (0.72) in cattle kidneys and Cd (0.91) in goat livers in Egypt, which were attributed to industrial pollution, as the animals were reared in commercial cities.

Impact of heavy metal pollution on humans in Africa

Based on environmental studies over the past decade, it is clear that there is widespread exposure of humans in the African continent to heavy metals through water, fish, soil, food crops and food animals. In Tanzania, Harada *et al.* [24] recorded elevated concentrations (mg/kg) of Hg (1.00–3.79) in head hair of fishermen around Lake Victoria, which receives Hg pollution from small-scale gold mines. Similarly, Hg (trace to 0.012) and As (0.034–0.7) contamination (mg/kg) were recorded in human urine in Tarkwa, a gold mining town in Ghana [28].

Moreover, the Blacksmith Institute [7] has listed the Dandora dumpsite in Kenya as one of the 30 most polluted places on earth, while Kabwe City in Zambia ranks among the top ten. The UNEP [57] observed that the Dandora dumpsite exposes residents to unacceptable levels of pollutants, resulting in poor health. Of the 328 examined children and adolescents attending school and living adjacent to the dumpsite, 50% had blood Pb levels equal to or exceeding toxic levels of 10 μg/d*l*.

In Kabwe City, high soil concentrations (mg/kg) of Pb (759), Cd (22.3) and Zn (106), which are attributed to the closed lead and zinc mine [55], have been reported. The Pb concentrations of soil covering approximately 21 km^2 of the city exceed the threshold of 1,000 mg/kg that defines areas warranting soil clean-up [12]. Atmospheric Pb concentrations of more than 0.5 $\mu g/m^3$ were recorded in dusty residential areas, and blood Pb levels were related to patterns of environmental Pb contamination, with average blood Pb levels in children aged 0–7 years ranging from 31.3 to 38.2 μg/d*l* [12]. In a number of individuals, Pb levels exceeding 65 μg/d*l* were recorded, and it was estimated that there could be 650 cases of subacute toxicological Pb poisoning in the surrounding townships. In Morocco, heavy metal contamination in humans was linked to consumption of contaminated vegetables and meat produced on a wastewater spreading field in Marrakech [51, 29]. In that study, the concentrations of Pb and Cd in head hair from local residents were 16.5 and 2.9 mg/kg, respectively [29].

CONCLUSIONS

In the past decade, there has been a steady accumulation of heavy metals in the African environment. Pollution levels in many African countries are at critical points, as the current levels of many metals in water, fish, soils, edible vegetables and food animals exceed international limits. Toxic metals such as Pb and Cd are widespread, while Hg and As are reported in limited places. Regular monitoring is essential to prevent excessive build up in the food chain as well as widespread metal toxicity in animals and humans.

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