Internal medicine

Silent threat: the presence of heavy metals from anthropogenic and natural sources. Implications for public health: A narrative review.

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Abstract

Introduction: Soil contamination by heavy metals is a growing concern worldwide. These toxic elements, derived from various anthropogenic and natural sources, accumulate in crops and enter the food chain.

Review objective: This article is a narrative review that aims to show the wide availability of heavy metals as potential risks to human health. We searched for articles from systematic reviews and clinical studies that used PUBMED to compile possible sources of poisoning.

Essential points of the review:
The most important sources of heavy metal poisoning are related mainly to soil contamination and its subsequent transfer to food.
Seleniferous areas: These areas contain high natural concentrations of heavy metals, which pollute the soils and, therefore, the crops that grow in them.
Industrial pollution: Industrial activity is an essential source of soil contamination by heavy metals since these metals can be released into the environment through various industrial processes.
Biomass: Different animal samples indicate the biomass is contaminated with heavy metals.

Conclusion: Heavy metals are present in different forms and within populations. Soil contamination is highlighted as the primary source of heavy metal poisoning through food intake, especially rice, wheat, and meat.

Keywords:

Heavy metals, lead, mercury, and sources of poisoning.

Abbreviations

As: arsenic.
Ba: barium.
Cd: cadmium.
Co: Cobalt.
Cr: Chromium.
Cu: Copper.
HG: mercury.
Mn: manganese.
Ni: nickel.
PB: lead.
Se: selenium.
Zn: zinc.

Supplementary information

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Authors' contributions

Jorge Luis Gaibor Carpio: Conceptualization, data curation, formal analysis, acquisition of funds, research, writing - original draft.

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Introduction

Heavy metals are chemical elements that have a high density and, in general, are toxic to living beings, even at low concentrations. Unlike other pollutants, heavy metals do not break down in the environment but instead accumulate in soils, water, and living organisms through a process known as bioaccumulation [1]. Some examples in this category are lead (PB), mercury (Hg), cadmium (Cd), arsenic (As), chromium (Cr), and thallium (Tl), which are compounds that naturally form part of the Earth's crust as a result of geological processes that involve many minerals and cannot be degraded or destroyed [2].

A 2014 study on the coast of Ecuador determined the presence of the heavy metals cadmium and lead in the estuary of the Chone River; 66 samples were obtained. The cadmium concentration in water was relatively high in isolated areas (0.129 mg/L). The cadmium accumulation level was relatively high in the sediment (0.0033 mg/g). High-concentration mul sites were also found for lead from 0.18 to 0.21 mg/L. In places with a greater flow of water from the estuary of the Chone River, the concentrations were 8 UPSs (practical units of salinity) and less influence on the currents of the seawater (30 UPSs). Compared with Ecuadorian legislation, these results reveal high concentrations of cadmium in the ecosystem of the estuary under study, which could affect the health of organisms that live at the level of the water column, such as fish, as well as the recreational activities of local bathers, of the cantons Sucre and San Vicente Manabí [3].

Evaluating heavy metals in milk can be considered an indicator of environmental contamination. A study in Ecuador aimed to determine the presence of lead, mercury, and arsenic in raw milk from Machachi, Province of Pichincha, Ecuador. Fifty-eight samples were collected from 29 dairy farms with extensive grazing systems located up to a maximum of one kilometer around the Municipality of Machachi, where there is industrial activity and which is close to Panamericana Sur. The samples were analyzed via atomic absorption spectrophotometry with a hydride generator (mercury and arsenic) and a graphite furnace (lead). All the samples analyzed presented lead levels, with an average of 0.208 mg/kg (ranging between 0.0016 and 0.719 mg/kg), 98.28% (57/58) of which contained levels higher than the maximum allowed by the NTE INEN 9 of 0.02 mg/kg. Mercury was also detected in four samples (mean of 0.00009 mg/kg, range between 0.00 and 0.002 mg/kg), and arsenic was detected in two samples (mean of 0.00003 mg/kg, range 0.00 to 0.001 mg/kg); however, these values were below the limit allowed by the Codex Alimentarius (0.01 mg/kg) in foods in general. With these results, the authors concluded that there could be an area contaminated with Pb, so continuous monitoring should be carried out in milk, and the investigation should be extended to possible sources of contamination, such as drinking water, irrigation water, forages and food received by dairy cows in the area [4]. It has also been shown that contamination with heavy metals occurs in protected areas of Ecuador, such as the Manglares Cayapas Mataje Ecological Reserve in the province of Esmeraldas. The element with the highest contamination value was cadmium (Cd). The study concludes by highlighting the need to adopt substantial changes in agricultural uses and practices and to reform legal regulations and management programs to provide, in an integrated and inclusive way, the basic guidelines of action for conservation. of natural and cultural heritage, the provision of ecosystem and cultural services that contribute to the sustainability of the area, the excellent living of its local populations and the strengthening of the management of the protected area [5].

Differences between microminerals and heavy metals

The classification of a metal as "heavy" is not based solely on its atomic weight or density but rather on its toxicity to living things and its persistence in the environment. The metals considered heavy and toxic are as follows:

- Chromium: In particular, hexavalent chromium (Cr(VI)) is highly toxic and carcinogenic.
- Nickel: At high concentrations, it can be toxic and cause allergies.
- Selenium: Although it is an essential element in small amounts, it can be toxic at high concentrations.

Metals that are not considered toxic heavy metals but essential for life are called microminerals.

- Copper: This is essential for many biological processes but can be toxic to some aquatic organisms at high concentrations.
- Iron: This iron is essential for transporting oxygen in the blood and other biological processes.
- Manganese: Essential for metabolism and neuronal function.
- Molybdenum: Essential as a cofactor in many enzymes.
- Zinc: Essential for the growth, development, and function of many cells [6].

Aluminum, mercury, and lead are the most common causes of heavy metal poisoning in our environment; however, these elements are so toxic to life that they are considered the most poisonous metals: thallium.

Thallium, a chemical element with the symbol TI, has an atomic number of 81 on the periodic table. Thallium sulfate was once used as a poison for ants and rats. The occupational limit of exposure to thallium is 0.1 mg/m3 on the skin for eight hours a day. Levels of 15 mg/m3 are considered immediately dangerous to health. Thallium is readily absorbed through the skin and during inhalation. Because thallium is tasteless, odorless, and soluble in water, accidental and criminal poisoning has been reported [7].

Sources of heavy metal contamination

Rice

Heavy metals are rich in seleniferous areas, and soil contamination by heavy metals causes excess heavy metals in rice and other food crops [8 -10]. A study in a seleniferous area in Enshi, China, investigated the bioaccumulation of heavy metals. The soils were contaminated by Mo, Cu, As, Sb, Zn, Cd, Tl, and Hg caused by the erosion of Se-rich shales. Among these heavy metals, Cd and Mo had the highest bioavailabilities in soils. The bioavailable fractions of Cd and Mo represented 41.84% and 10.75% of the total Cd and Mo in the soils, respectively. Consequently, much higher bioaccumulation factors (BAFs) of Cd (0.34) and Mo (0.46) were found in rice than those of other heavy metals (Zn 0.16, Cu 0.05, Hg 0, 04 and Sb 0.0002) [9].

Another study [10] of 137 soil samples from agricultural land around a lead/zinc smelter in an area of 64 km2 was conducted. The concentrations, spatial distributions, and potential sources of nine heavy metals (As, Cd, Co, Cr, Cu, Ni, Pb, V, and Zn) in soils and their possible ecological risks were investigated in detail. The results revealed that the average concentrations of Cd, Pb, Cr, and Zn in these soils were higher than their background values in Henan Province, and the average Cd content was 2.83 times greater than the hazard detection values in the standard. Chinese nationals determine that agricultural areas near industrial areas have a high risk of contamination.

Wheat

With the increasing industrialization of agriculture, sewage sludge production increases yearly. A greenhouse experiment was performed to investigate the accumulation of heavy metals in wheat (*Triticum aestivum* L.) grown in 30 calcareous soils. Wheat grown on soils treated with sewage sludge had the highest average dry matter content, which was 2.11 and 1.25 times greater than wheat grown on control soils and those treated with sewage sludge, respectively. In all the treatments, the wheat roots presented higher levels of heavy metals than the wheat shoots. Among all the heavy metals examined, Pb and Cu had the highest bioconcentration factors for roots and shoots (BCFRoots and BCFShoots) in the control soils and those treated with sewage sludge, followed by Cd in the soils treated with spiked sewage sludge. Co and Ni had the lowest BCFRoots and BCFShoots among all the treatments. Given that a wide range of calcareous soils were used in this study and that calcareous soils constitute the majority of soils in the Middle East, the findings are relevant to all countries in this region [11].

In fresh and frozen meats

In one study, 13 heavy metals were analyzed in representative samples of cattle meat, poultry meat, cattle offal, and poultry offal (20 per category) from markets and retail stores in 16 cities in Shandong Province, China. The heavy metals investigated were Cu, Cr, V, Ni, As, Se, Sn, Cd, Pb, Sb, Mn, Ba and Hg. The results revealed that the mean levels of total heavy metals in the meat and offal were 1.56 mg/kg and 39.8 mg/kg, respectively. Cu, Cr, Mn, Ni, Se, Ba, and Pb were found in all the samples (100%), followed by Hg (95.0%), V (91.3%), Sn (73.8%), Cd (51.3%), As (21.3%) and Sb (11.3%) [12]. In another study, 30 samples, 15 from chilled beef and 15 from frozen meat were collected from various merchandising stores in Sharkia. The chilled meat samples' average Pb level (mg/kg) was 0.64 ± 0.14, undetectable for Hg, 0.02 ± 0.14 for Cd, and 4.66 ± 0.57 for As. In the frozen samples, the average concentrations were 0.89 ± 0.21 for Pb, 0.08 ± 0.03 for Hg, 0.02 ± 0.004 for Cd and 5.32 ± 0.59 for As. In general, the levels of MH in frozen meat samples were more significant than those in refrigerated samples [13].

In oysters and clams

Oysters and clams are abundant and widespread seafood. These bivalves have proven to be suitable bioindicators for evaluating the accumulation of heavy metals in aquatic environments. In one study, the presence of heavy metals such as As, Cd, Hg, and Pb was investigated in cultured Saccostrea glomerata oysters and Meretrix lyrata clams collected from VanDon - Quang Ninh and CatBa - Hai Phong. The results revealed that the concentrations of heavy metals in the oysters Saccostrea glomerata and clam Meretrix lyrata were in the order of As> Cd> Pb> Hg. Among the four heavy metals studied at the six sampling sites, the concentrations most contaminated with As were 2.81 ± 1.07 and 1.6 ± 0.62 mg/kg wet weight for clams and oysters, respectively [14].

In the banana shrimp

A study was carried out to analyze the level of contamination by the heavy metals nickel (Ni), zinc (Zn), and lead (Pb) in shrimp (Penaeus merguiensis) caught in the northern Persian Gulf. The concentrations of heavy metals in the shrimp muscle followed the order Zn> Ni> Pb. The Zn and Ni contents were higher than the standard limits recommended by the WHO. The combined impact of all the metals was less than the acceptable limit of 1 in shrimp. The carcinogenic risk of Ni was more significant than the unacceptable value. The findings did not indicate any potential health risks from daily consumption of this species. However, prolonged shrimp consumption can pose a risk of carcinogenic effects from nickel. Monitoring these trace metals in seafood is necessary to ensure the quality of seafood and food safety [15].

Crayfish

One study evaluated the concentrations of metals in the abdominal muscle and exoskeleton of 3- and 4-year-old crayfish (Orconectes limosus) collected from Lake Gopło. In autumn (October 2014), 93 males and 35 females were collected. The analyses revealed that heavy metals accumulated in the muscle and exoskeleton in the following sequence: Zn> Cu> Pb> Mn> Ni> Hg and Mn> Pb> Zn> Ni> Cu> Hg. Compared with studies conducted two years ago, significantly higher Pb concentrations were detected in the muscle, and higher contents of Zn, Pb, Mn, and Ni were detected in the exoskeleton [16].

In sea cucumbers

A study evaluated the contents of heavy metals (Cu, Zn, Cr, Pb, Cd, As, and Hg) in young sea cucumbers (Apostichopus japonicus) from the Bohai and Yellow Seas coastal areas in northern China. Sea cucumber hatchlings were collected from twenty commercial hatcheries distributed in five coastal cities. The mean concentrations of heavy metals in mg/kg were as follows: Cu (0.179), Zn (2.634), Cr (0.108), Pb (0.065), Cd (0.161), As (0.372), and Hg (0.034). All the mean concentrations were below the maximum residual limits established by Chinese legislation, but the As concentration in 10% of the samples exceeded the safety threshold. Significant differences were found in the contents of Cr, Pb, and Hg among the five investigated areas. In general, the levels of heavy metals in sea cucumber juveniles are relatively low, and more attention should be paid to the toxic metals Pb, Cd, As, and Hg in future routine monitoring programs [17].

Salty fish

In Zagazig, Egypt, four types of locally produced salted fish (salted sardines, fetish, dahlia, and herring) were tested for lead (Pb), cadmium (Cd), arsenic (As), and mercury (Hg) contents. The recorded results revealed that all the analyzed metals were present in the evaluated samples except for mercury, which was not found in the salted herring. Herring contained the highest residual Pb and Cd contents, followed by sardines, feseikh and sahlia, in that order. After sardines, herring and sahlia, the feseikh had the highest concentration. In that order, sardines, feseikh, and sahlia had the highest amounts of mercury. Several samples were found to be above the maximum allowable levels. There were no apparent hazards associated with the consumption of such conventional seafood, based on the HQ and HI values calculated for the heavy metals under investigation based on daily intake [18]; 3 additional studies did not determine the toxic levels of heavy metals in local carp or fish [19-22].

Cow milk

A systematic review [23] presented the potential toxicity of heavy metals such as lead (Pb), mercury (Hg), cadmium (Cd), iron (Fe), nickel (Ni), aluminum (Al), and copper (Cu) in raw cow milk. A total of 60 original articles published since 2010 that reported the levels of these metals in raw cow milk worldwide were reviewed. The data revealed that the highest levels of Ni (833 mg/L), Pb (60 mg/L), and Cu (36 mg/L) were detected in raw cow milk collected from an area composed of granites and gneisses from granite in India. In contrast, the highest level of Cd (12 mg/L) was detected in the barite mining area of India. The Fe values in the raw cow milk samples were above the WHO maximum limit (0.37 mg/L), and the highest values (37.02 mg/L) were recorded in India. The highest level of Al was recorded (22.50 mg/L) in raw cow milk collected near the food-producing plant region in Turkey. The target hazard ratio (THQ) values for Hg were less than 1, suggesting that milk consumers are not at noncancer risk, except in Faisalabad Province (Pakistan), where THQ values = 7.7. For the other heavy metals, the THQ values were > 1 for Pb (10 regions of 70), Cd (6 regions of 59), Ni (3 of 29), and Cu (3 of 54).

In a second systematic review [24] of 48 articles with data from 981 milk samples, the initial evaluation revealed that Cu, Cd, Zn, and Pb were the most common contaminants, which exceeded the maximum permissible criteria in 94%, 67%, 62% and 46% of the samples, respectively. Based on the target hazard ratio and carcinogenic risk results, milk consumers in 33 (68.75%) and 7 (14.5%) studies were exposed to moderate to high carcinogenic and noncarcinogenic risk levels, respectively. The highest level of risk is due to the consumption of pasteurized and sterilized milk, which is detected in Pakistan, Brazil, Egypt, Slovakia, and Turkey.

In a third systematic review in China [24], 16 studies were included that analyzed the levels of metals in milk and dairy products in 20 provincial administrative regions. Most of these studies detected toxic heavy metals, including mercury, lead, cadmium, chromium, and arsenic, in samples of milk and dairy products. The lead concentration in milk from these studies did not exceed the Chinese standard for milk. However, three studies reported relatively high lead levels in commercial and raw milk, surpassing the European Commission standard. The contaminated environment surrounding the farm, feed, and packaging materials are likely sources of metals in milk and dairy products. The hazard index for the 11 metal elements tested in milk and dairy products was less than 1, indicating negligible noncarcinogenic health risks from exposure to these metals. Children are at greater risk than adults. This review illustrates that research in this field is limited to China.

In a fourth systematic review of 66 published articles [26] between 2000 and 2021, arsenic (As), mercury (Hg), lead (Pb), and cadmium (Cd) were examined. Pb was the most studied (43%). The As concentration was 12.71 μg/kg (95% CI 0.16–25.26), the Hg concentration was 16.09 μg/kg (95% CI 4.31–27.70), the Pb concentration was 197.04 μg/kg (95% CI 75.28–318.18), and the Cd concentration was 31.67 μg/kg (95% CI 20.14–43.20). The concentrations of metalloids in the milk were within the different threshold limits for Pb and Cd. Some studies in America, Africa, and Asia have reported elevated concentrations of Pb and Cd. The simulated hazard ratio (RQ) and integrated hazard ratio (IRQ) values generally remain above one, indicating potential risks to human health. In particular, the IRQ value increases when more metals (loids) are considered. Subgroup analysis showed that low-fat milk contains relatively high concentrations of metals (loids). Although the concentrations of metals (loids) in milk largely comply with safety limits, some regions present concentrations of concern.

In poultry for human consumption

Bird tissues are bioindicators for research on the relationships between environmental levels of heavy metal accumulation. Heavy metal concentrations in the internal organs (heart, liver, and kidney), feathers (primary and mammary), and bones (sternum and femur) of two focal species, Amaurornis phoenicurus and Gallinula chlorpus, were analyzed. The accumulation of heavy metals varies depending on the target tissue, the variables associated with the species of birds, and the type of heavy metal. Although Zn and Cu had the highest concentrations among the two species, Cu accumulated mainly in internal organs, As in feathers, and Pb in bones. The concentrations of As, Ni, and Pb in the feathers of both focal species were lower than those reported in the literature, whereas the concentrations of Cd and Cr were above the toxic levels. The results also revealed that the spatial correlation for heavy metal concentrations between bird tissues was weaker than the nonspatial correlation, suggesting low spatial autocorrelations and variability. Furthermore, the multiple regression analysis revealed a significant correlation for the estimates of Cr, As, and Pb in the heart, sternum, and kidney of A. phoenicurus, respectively, and potentially Cr in G. chlorpus femur through the use of feathers. These results support the feasibility of using feathers as indicators of contamination by the heavy metals As, Cr, and Pb [27].

Canned tuna

Human consumption of fish protein, including canned tuna, constantly increases worldwide. However, there are some concerns about possible exposure to high concentrations of metals in canned tuna. In a systematic review [28], from 23 articles, 1295 tuna samples were taken, and the concentrations of the metals copper (Cu), selenium (Se), iron (Fe), zinc (Zn), mercury (Hg), lead (Pb) and chromium (Cr) were determined. , arsenic (As), nickel (Ni), tin (Sn), and cadmium (Cd) in canned tuna. The order of classification of the metals based on the mean concentrations (μg/g wet weight) was Fe (13.17)> Zn (9.31)> Se (2.23)> Al (1.8)> Cr (1.63)> Cu (1.52) > As (0.38). > Ni (0.33)> Pb (0.24)> Cd (0.14)> Hg (0.11)> Sn (0.1). Except for Cd and Se, the concentrations of other metals in canned tuna were below the limits recommended by the United States Environmental Protection Agency (USEPA), the World Health Organization (WHO), the Organization of the United Nations for Food and Agriculture (FAO) and the National Standards of Iran. Organization (INSO). The minimum and maximum target hazard ratios (THQs) for adults were 5.55E-5 for Al and 2.23E-08 for Cr. For children, they were 7.23E-05 for Al and 2.91E-08 for Cr. The THQ and total objective hazard ratio (TTHQ) were ≤1.0 for adult and child users. As's incremental lifetime cancer risk (ILCR) was 3.21E-5 in adults and 4.18E-5 in children. Adults and children who consume canned tuna in Iran do not face a noncarcinogenic risk but rather a carcinogenic risk due to As.

In wild birds

In one study [29], mercury, iron, copper, and zinc levels were measured in 18 great cormorants (Phalacrocorax carbo) collected from the Anzali and Gomishan wetlands in the southern Caspian Sea. The mean levels of metals in the dry muscle, liver, and kidney tissues were 2.26, 5.71, and 3.79-Hg; 943.54, 379.97, and 348.05-Fe; 42.64, 14.78, and 60.79-Cu; and 71.97, 134.63, and 77.82-Zn, respectively (mg/kg). The results of the Pearson correlation analysis revealed a positive and robust relationship between liver fat and mercury ($r = 0.95$, $R^2 = 0.90$). In addition, there was a significant difference between the values of all metals and the allowed limits presented in the EPA, the WHO, and the CCME, where all the values were above the standard levels. Therefore, since humans sometimes eat the muscles of a bird, this result is a severe warning. However, the relatively high levels of heavy metals that accumulated in different tissues of the great cormorant at that time resulted from the high weight and nutrition they had in their migration's terminal days owing to a lack of natural physical activity.

Wild sparrows

Passerine birds such as sparrows have been used as effective sentinels of ecosystem pollution. They can provide direct evidence of the environment's bioavailability and accumulation of heavy metals. In a study [30] of the bioaccumulation of heavy metals (Cu, Zn, Pb and Cd) and Ca in different organs and tissues (feathers, internal organs, skeletons and muscles) of an urban bird, a tree sparrow (Passer montanus) was collected from a contaminated site [Baiyin (BY)] and a relatively uncontaminated site [Liujiaxia (LJX)], and their associations were investigated. Significantly higher and lower concentrations of heavy metals and Ca were found in different organs and tissues of sparrows in BY than in LJX. However, except for Pb, the heavy metal concentrations were below the threshold for sublethal effects. Age-dependent variations in metals were quantified, and it was found that adult birds contained higher concentrations of different metal organs and tissues, except feathers than chicks and juveniles did. The tissue distributions of heavy metals in sparrows of various ages and sexes were similar at the two study sites, and heavy metal elements accumulated mainly in feathers. This study investigated the correlations between heavy metals in different organs and tissues. It revealed that their correlations were strong in chicks and adults but weak in juveniles. Furthermore, Pb and Cd in young sparrows' internal organs, skeletons, and muscles can be estimated from feathers, whereas Cu and Zn are found in adult sparrows.

Sea turtle hatchlings

Anthropogenic sources can cause the accumulation of heavy metals in marine organisms through ingestion, absorption, or inhalation. In the case of sea turtle embryos, heavy metals can be absorbed by the egg from the incubation environment or transferred maternally to offspring, causing neurological, reproductive, and developmental problems. In a previous study [31], deceased pups were collected from two beaches near a cement factory in Ras Baridi, and the concentrations of heavy metals (chromium (Cr), manganese (Mn), iron (Fe), cobalt (Co), nickel (Ni), copper (Cu), zinc (Zn), arsenic (As), selenium (Se), cadmium (Cd) and lead (Pb)) in the liver, muscle and residual yolk of the pups were measured. Heavy metal concentrations were significantly different between the sampled tissues.

Migratory animals

Heavy metal pollution in Indian wetlands is increasing due to industrial, agricultural, and urban development activities. Shorebirds occupy relatively high trophic levels and are especially vulnerable to heavy metal contamination. In one study [32], the concentrations of heavy metals (zinc, copper, cobalt, chromium, lead, and cadmium) were measured in 22 common species of migratory shorebirds (220 samples of shorebird droppings). Hazardous concentrations of Zn were determined: 84.72–224.74 mg/kg; Cu: 26.63–170.36 mg/kg; Co: 13.98–14.42 mg/kg; Cr: 14.78–98.16 mg/kg; Pb: 18.95–157.29 mg/kg; and Cd: 9.33–60.56 mg/kg. This study revealed trophic transfer from soils to prey and from these to birds.

Marine sediments

In the coastal city of Hong Kong, which experiences substantially different metal loads from anthropogenic activities, a previous study [33] evaluated the contamination of coastal sediments with ten heavy metals (As, Cd, Cr, Cu, Pb, Hg, Ni, Zn, Fe, V). The results revealed that the contamination trend with these metals decreased from the interior to the exterior of the coast of the studied area. The order of contamination was Cu> Cr> Cd> Zn> Pb> Hg> Ni> Fe> As> V, of which Cd, Hg, and Cu were the most significant potential ecological risk factors compared with the other metals. It was also shown that Cr, Cu, Hg, and Ni could originate from industrial discharge and transportation activities. V, As, and Fe were derived mainly from natural sources, whereas Cd, Pb, and Zn were identified in municipal discharges and industrial wastewater.

In acid rain near mining areas

The leaching of heavy metals from abandoned mines can seriously threaten surrounding areas, especially in regions influenced by acid rain with high frequency. One study [34] evaluated the potential risks of heavy metals in tailings collected from a small-scale abandoned multimetal mine. The results suggested that the Zn, Cu, Pb, and Cd in the tailings could cause very high risks. Both the batch and semi-dynamic leaching tests consistently confirmed that the leaching of heavy metals (particularly Cd) could lead to severe contamination of the surrounding environment. Heavy metal leaching rates are pH-dependent and related to their chemical speciation in mine tailings. The leaching behavior of Cu and Cd was dominated by surface washing, and that of Zn was controlled initially by diffusion and then by surface washing. The leaching mechanisms of Pb and As varied with pH. It was estimated that acid rain could considerably increase the release fluxes of Zn (20.8%), Cu (36.7%), Pb (49.9%) and Cd (35.3%) in the study area.

In dust storms

In one study [35], the potential hazards of heavy metals in dust storms were investigated by collecting samples. The heavy metals in the dust storms were contaminated by anthropogenic sources, leading to higher concentrations than the initial values. The enrichment factors and geo-accumulation indices revealed that heavy metals come from natural and anthropogenic sources and that anthropogenic sources strongly influence Cu, Ni, Zn, and Pb. The heavy metals in the dust storms were divided into four sources: Cu and Ni were attributed to industrial sources, mainly from local mining and metal processing; Cr was contributed primarily by industrial sources related to industrial production, such as coal combustion; Pb and Zn were contributed mainly by sources of transport; and Ti, V, Mn, Fe and As came from natural and agricultural sources. The level of comprehensive ecological risk from heavy metals in dust storms was low, but there were moderate and high risks at individual sites. Both adults and children had the highest carcinogenic and noncarcinogenic risks from ingestion, and the risk to children was more significant than that to adults.

Fly ash from garbage incineration furnaces

Fly ash from municipal solid waste (MSW) incineration is a hazardous waste that contains heavy metals. Secondary aluminum slag (SAD) is a dangerous waste dumped during aluminum smelting and contains active aluminum nitride (AlN). In a previous study [36], aluminum nitride reduced heavy metals in MSWI fly ash to an alloy. The final result was transparent for the construction, and iron and zinc were reduced in 67 and 100% of the ashes, respectively. This work provided a novel idea of recycling solid waste into alloys and clear glass for construction.

Road dust

Heavy metals are persistent and bioaccumulative in road dust. In a previous study [37], the contamination by heavy metals reported in the dust of the urban roads of several cities on different continents (Asia, Europe, Africa, America, and Australia) was reviewed. Pb, Zn, Cu, Ni, Cd, Cr, Mn, and Fe concentrations were higher than their initial values in the soil. Heavy metal pollution levels vary widely among cities, countries, continents, and periods. High levels of Pb and Cd contamination are observed in road dust because of the operation of leaded gasoline and the population of older vehicles. The highest level of Zn contamination was observed in road dust in Europe, followed by Asia, Africa, Australia, and America (North America and South America). Cu pollution and the pollutant load index (PLI) are the highest in Europe and the lowest in Africa, with intermediate PLI values in American and African cities. The potential ecological risk on different continents was most significant in Asia, Europe, Australia, America, and Africa. A comparative assessment of the noncancer risk to children indicated that Australia is the most susceptible country due to high exposure to heavy metals in road dust, followed by Asia. However, there is no susceptibility risk in European, African, or American cities. No potential hazard was observed for adults due to noncarcinogenic metals. The carcinogenic risk for all age groups was within the threshold limit range for all world regions.

Car drivers in urban areas

In a study [38] in Yazd-Iran, urban taxi drivers were evaluated for seven heavy metals, including arsenic, cadmium, cobalt, chromium, lead, manganese, and nickel. The exposure concentrations were determined via air sampling in the breathing zones of 40 randomly selected intercity taxi drivers, 20 in winter and 20 in summer 2019. Arsenic and lead had the highest exposure concentrations among the seven heavy metals, whereas cobalt and chromium had the lowest concentrations. Arsenic, cadmium, manganese, and nickel will likely cause some adverse noncarcinogenic health problems (THQ> 1) in drivers throughout their working lives. The 95% ECR percentile of the heavy metals measured was 1.3E - 03, much higher than the value of 1E - 06. The concentrations of arsenic and nickel were higher in the winter than in the summer. Taxi drivers in the city of Yazd were shown to be at considerable risk to their health.

In auto workers

In a previous study [39], the concentrations of heavy metals such as lead (Pb), cadmium (Cd), and chromium (Cr) were evaluated among automobile workers who were occupationally exposed in the city of Mingora, Khyber Pakhtunkhwa, Pakistan. Three automobile service groups were studied: battery recyclers, spray painters, and mechanics. A total of 40 blood samples were collected from groups of automobile workers, while ten blood samples were collected from control individuals from different locations in the study area. The battery recycling group presented the highest Pb level (5.45 ± 2.11 µg/dL), surpassing both the aerosol painter group (5.12 ± 1.98 µg/dL) and the mechanical group (3.79 ± 2.21 µg)./dL). This can be attributed to their increased exposure to Pb contamination resulting from the deterioration, dismantling, crushing, or shredding old batteries. In the context of chromium (Cr) exposure, a similar trend was observed among the battery recycling groups and painters and mechanics groups. However, for cadmium (Cd), the mechanical group presented the highest level of exposure (4.45 ± 0.65 µg/dL), which surpassed those of the battery recycling group (1.17 ± 0.45 µg/dL) and the painter group with aerosol (1.35 ± 0.69 µg/dL), which was attributed to his increased exposure to welding fumes and other activities in his workplace.

In incinerator workers

Exposure to chemicals released during municipal waste disposal and treatment is increasingly considered a potential occupational health problem. Several toxic metals emitted by an incinerator, including As, Be, Cd, Cr, Pb, Mn, Hg, Ni, and V, have potentially poisonous properties; therefore, their exposure may concern workers' health. In a systematic review [40], from studies investigating toxic metals measured in incinerator workers' main biological matrices (blood, urine, hair), the metals measured in incinerator workers are generally low, with some notable exceptions for Cd and Pb. However, these results may be affected by several confounding factors related to nonoccupational exposure, including diet, area of residence, and others, as well as by several methodological limitations, as we found in the studies reported.

Thermometers

The health sector contributes significantly to mercury (Hg) contamination because of the possible presence of mercury in thermometers, blood pressure cuffs, amalgams, etc. Other potential sources of mercury in this sector are used frequently and in large volumes, where the presence of the metal is not obvious and could collectively contribute to contamination; for example, some chemicals used for the clinical diagnosis of diseases may contain mercury [41, 42].

Dental amalgams

A lead source in Ecuador is dental amalgams, also known as silver fillings, which are mixtures of mercury, silver, copper, tin, and zinc used to fill dental cavities. Mercury in dental fillings is in a metallic form, which is not very toxic, but it evaporates at 25 °C and becomes mercury vapor, which is very harmful. Dental amalgam fillings can release small amounts of mercury in vapor form, which can enter the body via inhalation [43].

Medicines

Among the medicines outside the primary table, one of the common uses stands out: algae-based products such as Spirulina, which are widely promoted for their vitamin B12 content. Knowledge about contamination with cyanotoxins, heavy metals, pesticides, or polycyclic aromatic hydrocarbons (PAHs) is scarce, although some studies have reported high contaminants in spirulina products. Regular intake of spirulina, and most likely other products derived from algae, as a dietary supplement in grams, requires closer monitoring of potentially harmful components [44]. There have also been reports of traditional Chinese herbal medicines contaminated with heavy metals [45], as well as conventional herbs with marshmallow roots (*Althaea officinalis* L., radix) from Polish pharmacies [46]. The reporting of heavy metal levels in "Ayurvedic" medicine from the Indian medical system to cleanse the body and restore the mind–spiritual balance has repeatedly reported alarming levels of cases of heavy metal poisoning [47].

In medicinal plants

Heavy metals can be found in medicines of plant origin. In February 2022, 28 drug samples (solid and liquid) were collected from Texas pharmacies to investigate heavy metals such as zinc, iron, and lead. The levels of zinc, iron, and lead (mg/kg) in the solid samples were 1.95--51.43, 29.09--2055.92, and ND-26.68, respectively, whereas they were 0.043--4.267, 0.100--5.25, and ND-1.434, respectively, in the liquid samples. The average values of total noncancer risk (TNCR or HII) and total risk of cancer (TCCR) associated with the intake of heavy metals from solid samples were 4.54E - 03 ± 1.1E - 03 and 2.11E - 06 ± 6.0E - 07, whereas those related to the intake of heavy metals from liquid samples were 1.98E - 04 ± 4.1E - 05 and 9.44E - 09 ± 2.3E - 09, respectively. Compared with liquid samples, solid samples have higher concentrations of heavy metals. The concentrations of zinc, iron, and lead in the liquid samples were lower than the acceptable standards recommended by the WHO of 50, 20, and 10 mg/kg, respectively. On the other hand, few solid sample results are more than acceptable. However, the TNCR and TCCR results for all the samples were within the limits globally recommended by the US EPA. Finally, the heavy metal results revealed no health risks associated with the use of the investigated drugs [48].

Ingestion of contaminated animal products

When one of these heavy metals is released into the air, water, or soil, it can be absorbed by plants and crops, consumed by livestock and fish, and eventually ingested by humans unintentionally by closing the food chain [49, 50].

Donor blood

The risk of heavy metal poisoning from donor blood has been the subject of numerous scientific investigations. The evidence from scientific studies highlights the risk of heavy metal poisoning in donors with high blood concentrations of heavy metals. The risk of toxicity is exceptionally high in vulnerable populations such as newborns and premature babies, as well as in pregnant women and other people with conditions that require multiple blood transfusions. This is worse in developing countries where some population members participate in illegal refining and artisanal mining [51].

Retained bullets

Lead toxicity secondary to retained bullets after a penetrating gunshot wound is rare but probably underdiagnosed, given the substantial number of firearm injuries. In a systematic review of 142 articles on systemic lead toxicity secondary to retained bullets in patients, several factors appeared to increase the risk of developing lead toxicity, including the location of the bullet, the presence of a recent fracture or trauma, the number of fragments, hypermetabolic states and the duration of retention of the bullet. In particular, bullets located within a body fluid compartment, such as an intra-articular space, appear to have a substantially greater risk of developing lead toxicity. Although patients with lead toxicity from retained bullets have symptoms similar to those of patients with lead toxicity from other sources, the diagnosis of lead poisoning can occur months or years after a gunshot wound. Symptomatic patients with elevated blood lead levels tend to improve with a combination of chelation and surgical removal of the retained bullets [52].

Pollution by industrial effluents and mining

Some methods are available to remove heavy metals from industrial wastewater [53]; however, informal, illegal mining industries are limited in developing countries [54].

Residual oil produced from the automobile crankshaft

In a meta-analysis of the toxicological implications associated with the exposure of humans and laboratory animals to spent crankcase oil, 28 studies were analyzed, and 14 were used for the meta-analysis, which included 1,243 subjects. The meta-analysis revealed that exposure to residual crankcase oil caused a significant reduction in the body weight of the animals (n = 5, SMD; - 1.2; 95% CI; (- 1.78, - 0.67), *P* = 0.0001, I2 = 22%) and in the red blood cell count (n = 5, SMD; - 1.28; 95% CI; (- 2.18, - 0.38, *P* = 0.02); I2 = 78%) and hemoglobin (n = 4, SMD; - 1.12, 95% CI (- 2.71, 0.46); *P* = 0.16; I2 = 89%) in the animal models. However, there was a significant increase in aspartate aminotransferase (AST) (n = 6, SMD; 0.76; 95% CI; (0.41, 1.11), *P* = 0.0001, I2 = 89%), alkaline phosphatase (ALP) (n = 5, SMD; 1.92; 95% CI; (0.02, 3.83), *P* = 0.05, I2 = 92%), and creatinine (n = 4, SMD = 1.56; 95% CI; (0.05, 3.07), *P* = 0.04, I2 = 90%) compared with those of the control. On the other hand, there was a nonsignificant effect on alanine aminotransferase (ALT) (n = 5, SMD; 1.13; 95% CI; (- 0.37, 2.62); *P* = 0.14; I2 = 92%), urea (n = 4, SMD; 1.23; 95% CI; (- 1.18, 3.65), *P* = 0.32, I2 = 94%), concentrated cell volume (PCV) (n = 5, SMD; 0.10, 95% CI; (- 0.36, 0.56), *P* = 0.67; I2 = 47%), and hemoglobin concentrations (n = 6; SMD; - 0.74; 95% CI; (- 1.73, 0.26), *P* = 0.15; I2 = 89%). Other findings include oxidative stress, the bioaccumulation of heavy metals, and immunotoxic, genotoxic, and carcinogenic effects [55].

E-waste recycling

E-waste recycling can release heavy metals into the environment and cause adverse health effects. A nested case-control study of 51 pairs of subjects with and without asthma evaluated the associations between exposure to heavy metals from electronic waste recycling and the prevalence of asthma. House dust, airborne dust, blood, and urine were collected from residents of two neighboring sites in Ubon Ratchathani Province, Thailand. Multiple e-waste management activities are carried out at the first site, while the second site is primarily agricultural. Chromium, mercury, nickel, and lead concentrations in household dust and air were higher at the electronic waste handling site (P <0.05). Still, exposure levels were similar in subjects with and without asthma [56]. Twenty Chinese studies conducted in e-waste recycling areas were included in this systematic review. The included studies were conducted with an exposed group versus a control group. Most of the included studies reported that blood Pb levels were ≥5 µg/dl and that exposure to Pb from e-waste affects children's health as a result of informal recycling of e-waste, such as a decrease in serum cortisol levels, inhibition of hemoglobin synthesis, impact on neurobehavioral development, and physical development effects [57].

In children's paintings

Due to their physical and chemical properties, heavy metals are still used in producing various commercial products. Using such products increases the possibility of exposure to heavy metals; some of them are classified as probable human carcinogens (Group 1) by the International Agency for Research on Cancer. The exposure of schoolchildren to heavy metals at an early age can lead to serious health problems throughout life and a high probability of developing cancer. In one study [58], the presence of heavy metals was determined in acrylic paints commonly used by schoolchildren. Acrylic paints of different colors were analyzed to detect seven possible heavy metals: manganese (Mn), cobalt (Co), nickel (Ni), zinc (Zn), arsenic (As), cadmium (Cd), and lead (Pb). The elements identified in all the samples analyzed had concentrations ranging between 0.05 and 372.59 µg/g. Cd constituted the lowest percentage (0.05%), whereas Zn constituted the highest percentage, which was tremendously high (68.33%). Furthermore, the contamination of the paints was also color-specific, with considerable concentrations of heavy metals found in the dark brown color (526.57 µg/g). In contrast, the scarlet color (12.62 µg/g) contained lower amounts.

Cosmetics

Toxic elements have been reported in traditional Kohl-based eye cosmetics in the Spanish and German markets. The levels recommended by the European Union are Pb <20 ppm, As <5 ppm, Cd <5 ppm, Sb <100 ppm, and Ni <200 ppm. In Germany, the levels are more restrictive: Pb <2 ppm, As <0.5 ppm, Cd <0.1 ppm, Sb <0.5 ppm, and Ni <10 ppm. Pb levels ranged from 1.7 to 410,000 ppm in six study samples, four above the recommended limit for at least two heavy metals [59].

Another study in Saudi Arabia tested 31 commonly used cosmetic products (hair cream, beauty cream, skin cream, hair nutritional formula, hair gel, daily whitening scrub, shampoo, and hair gel), shower, body care, body lotion, hand washing, daily use, beauty products, shaving cream, toothpaste, beauty and germ soap and cream soap). According to the maximum concentrations, the heavy metal contents were arranged in the following decreasing order: Al> Cu> Mn> Pb> Cr> Ni> Hg> Co> As> Cd in cream products; Al> Pb> Cu> Cr> Mn> Ni> Hg> As> Co> Cd in shampoo products; Al> Cu> Pb> Cr> Mn> Ni> As> Co> Hg> Cd in soap products; and Al> Cu> Mn> Pb> Cr > Co> Ni> Cd> As> Hg in toothpaste products [60].

The Palestinian cosmetics market is also contaminated with products that exceed the limits for cadmium (9.5 ± 2.3 ppm), Cu (33.8 ± 9.2 ppm), and Zn (151.0 ± 7.4 ppm) [61]. A systematic review [62] revealed 16 publications published between 2012 and 2020 that measured the levels of heavy metals such as lead, cadmium, iron, nickel, chromium, and mercury in various cosmetic samples. The study findings support the existence of these metals as pollutants or cosmetic components, which pose substantial health risks; however, regulations and acceptable limits vary between different countries, representing a significant challenge for the cosmetic industry.

Skin-lightening products

The Minamata Convention on Mercury prohibits the manufacture, import, or export of skin-lightening products that contain mercury concentrations greater than 1 ppm; however, there is a lack of knowledge about the worldwide prevalence of mercury-added skin-lightening products. A systematic search included 41 articles from 22 countries published between 2000 and 2022. In total, mercury concentrations were captured from 787 samples of skin-lightening products, and the overall combined central mean mercury level was 0.49 µg/gram; the interquartile range (IQR) was 0.02–5.9. A total of 1,042 human biomarker measurements were compiled from 863 individuals. We also synthesized information on the use of 3,898 products and the self-reported health impacts associated with the use of mercury-added products by 832 people. This review suggests that mercury continues to be a widely active ingredient in many skin-lightening products worldwide and that users are at risk of varying and often high exposure [63].

In tattoo ink

Today, tattoos have become very popular worldwide. With the help of tiny needles, tattoo ink can be placed inside the skin's surface, and many unknown ingredients can be introduced. These ingredients include polycyclic aromatic hydrocarbons, heavy metals, and primary aromatic amines, which are unintentionally introduced along with the ink or produced inside the skin by different processes, such as cleavage, metabolism, and photodecomposition. These could pose toxicological risks to human health if present beyond permissible limits. Polycyclic aromatic hydrocarbons such as benzo(a) pyrene are present in carbon black ink. Primary aromatic amines can form within the skin due to the reductive cleavage of organic azo dyes. Environmental protection agencies report that they are highly carcinogenic. Heavy metals, namely cadmium, lead, mercury, antimony, beryllium, and arsenic, are responsible for cancer, neurodegenerative, cardiovascular, gastrointestinal, lung, kidney, liver, endocrine, and bone diseases. Mercury, cobalt sulfate, other soluble cobalt salts, and carbon black belong to Group 2B, meaning they can cause human cancer. On the other hand, cadmium and its compounds belong to Group 1 (carcinogenic to humans) [64].

On t-shirt prints

Heavy metals are often used in different textile processes, such as dyeing and printing. When toxic elements are present in amounts more significant than those recommended in textile materials, they can pose a potential risk to human health through absorption through the skin. In one study, the concentrations of several heavy metals (Co, Cu, Cr, Cd, and Pb) were analyzed in T-shirts discolored by skin contact and printed for a particular program in Mettu. High levels of Cu were detected in black, green, blue, and red t-shirts, ranging between 26,726 and 179,315 mg/kg. Cr exceeded the recommended limits in most T-shirt samples and was present mainly in yellow, black, and blue colors. Cd levels were found to be within normal ranges. However, all the T-shirt samples presented low levels of cobalt, ranging from 1.33 ± 2.13 to 3.94 ± 0.21. The maximum lead concentrations were 3.40 ± 0.19 mg/kg for the red samples and 2.71 ± 0.13 mg/kg for the blue samples. In this investigation, the Pb, Cu, and Cr concentrations in the red- and green-colored T-shirt samples were above the standard values suggested by OEKO Tex [65].

In disposable food containers

The use of disposable materials is booming with the rapid development of urbanization and industrialization, which can inevitably lead to the release of toxic and harmful substances during their use in daily life. In one study [66], large amounts of metals were released from disposable food containers in hot water, and the order of metal concentration was Zn> Ba> Fe> Mn> Ni> Cu> Sb> Cr> Se> Be> Pb> Co> V> CD. Furthermore, the hazard ratio (HQ) of the metals in young adults was less than 1 and decreased in the order of Sb> Fe> Cu> Be> Ni> Cr> Pb> Zn> Se> Cd> Ba> Mn> V. In addition, the excess lifetime cancer risk (ELCR) results for Ni and Be indicated that chronic exposure to Ni and Be may present a nonnegligible carcinogenic risk. These findings suggest that there may be potential metal-related health hazards for people who use disposable food containers in high-temperature environments [66].

In toys and children's jewelry

Heavy metal contamination in children's toys and jewelry is constantly challenging in different countries. These pollutants can enter the body of children through the oral, dermal, and respiratory routes. In a systematic review of studies of contamination in children's toys and jewelry in 15 countries, including the United Kingdom, Saudi Arabia, Cambodia, China, Kosovo, Nigeria, North America, Kazakhstan, the United Arab Emirates, Pakistan, Iraq, Israel, the West Bank/Palestine, the Czech Republic and Turkey. In conclusion, children's toys and jewelry made of plastic or metal continue to present the most severe contamination by toxic elements and the presence of lead (Pb), nickel (Ni), cadmium (Cd), arsenic (As), mercury (Hg), chromium (Cr), and copper. (Cu), selenium (Se), barium (Ba), zinc (Zn), cobalt (Co), manganese (Mn), bisphenol A, phthalates, parabens, azo dyes, and flame retardants are considered constant challenges [67].

Conclusions

Heavy metals are present in different forms and within the population's reach. Soil contamination is highlighted as the main source of heavy metal poisoning through food intake, especially rice, wheat, and meat.

References

1. Rahman Z, Singh VP. The relative impact of toxic heavy metals (THMs) (arsenic (As), cadmium (Cd), chromium (Cr) (VI), mercury (Hg), and lead (Pb)) on the total environment: an overview. Environ Monit Assess. 2019 Jun 8; 191 (7): 419. doi: 10.1007/s10661-019-7528-7. PMID: 31177337.https://link.springer.com/article/10.1007/s10661-019-7528-7

2. He Y, Men B, Yang X, Li Y, Xu H, Wang D. Investigation of heavy metals release from sediment with bioturbation/bioirrigation. Chemosphere. 2017 Oct;184:235-243. doi: 10.1016/j.chemosphere.2017.05.177. Epub 2017 Jun 2. PMID: 28599152. https://linkinghub.elsevier.com/retrieve/pii/S0045653517308299

3. Pozo-Miranda F. Presencia de metales pesados Cadmio y Plomo en estuario del río Chone Manabí, Ecuador. Revista Científica UNEMI 2017;10(24):123-130. https://dialnet.unirioja.es/servlet/articulo?codigo=6430728

4. De la Cueva F, Naranjo A, Puga B, Aragon E. Presencia de metales pesados en leche cruda bobina de Machachi, Ecuador. La Granja. Revista de Ciencias de la Vida, 2021;33(1):21-30. https://doi.org/10.17163/lgr.n33.2021.02 https://lagranja.ups.edu.ec/index.php/granja/article/view/33.2021.02

5. Muyulema-Allaica J, Canga-Castillo S, Pucha-Medina P, Espinosa-Ruiz C. Evaluación de la contaminación por metales pesados en suelos de la Reserva Ecológica de Manglares Cayapas Mataje (REMACAM)-Ecuador. Revista Internacional de Investigación e Innovación Tecnológica 2021;7(41):40-61. https://www.scielo.org.mx/pdf/riiit/v7n41/2007-9753-riiit-7-41-40.pdf

6. Domellöf M. Microminerals: Iron, Zinc, Copper, Selenium, Manganese, Iodine, Chromium and Molybdenum. World Rev Nutr Diet. 2021;122:140-148. doi: 10.1159/000514738. Epub 2021 Aug 5. PMID: 34352754. https://karger.com/books/book/128/chapter-abstract/5066488/Microminerals-Iron-Zinc-Copper-Selenium-Manganese?redirectedFrom=fulltext

7. Kemnic TR, Coleman M. Thallium Toxicity. 2023 Jul 10. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2024 Jan–. PMID: 30020612. https://www.ncbi.nlm.nih.gov/books/NBK513240/

8. Mao Y, Tan H, Wang M, Jiang T, Wei H, Xu W, Jiang Q, Bao H, Ding Y, Wang F, Zhu C. Research Progress of Soil Microorganisms in Response to Heavy Metals in Rice. J Agric Food Chem. 2022 Jul 20;70(28):8513-8522. doi: 10.1021/acs.jafc.2c01437. Epub 2022 Jul 11. PMID: 35816106. https://pubs.acs.org/doi/10.1021/acs.jafc.2c01437

9. Chang C, Yin R, Zhang H, Yao L. Bioaccumulation and Health Risk Assessment of Heavy Metals in the Soil–Rice System in a Typical Seleniferous Area in Central China. Environ Toxicol Chem. 2019 Jul;38(7):1577-1584. doi: 10.1002/etc.4443. Epub 2019 Jun 21. PMID: 30994945. https://setac.onlinelibrary.wiley.com/doi/10.1002/etc.4443

10. Deng Y, Jiang L, Xu L, Hao X, Zhang S, Xu M, Zhu P, Fu S, Liang Y, Yin H, Liu X, Bai L, Jiang H, Liu H. Spatial distribution and risk assessment of heavy metals in contaminated paddy fields - A case study in Xiangtan City, southern China. Ecotoxicol Environ Saf. 2019 Apr 30;171:281-289. doi: 10.1016/j.ecoenv.2018.12.060. Epub 2019 Jan 3. PMID: 30612016. https://doi.org/10.1016/j.ecoenv.2018.12.060

11. Jalali M, Imanifard A, Jalali M. Heavy metals accumulation in wheat (*Triticum aestivum* L.) roots and shoots grown in calcareous soils treated with nonspiked and spiked sewage sludge. Environ Sci Pollut Res Int. 2023 Feb;30(8):20862-20873. doi: 10.1007/s11356-022-23604-6. Epub 2022 Oct 19. PMID: 36260228. https://link.springer.com/article/10.1007/s11356-022-23604-6

12. Qin C, Wang X, Du L, Yang L, Jiao Y, Jiang D, Zhang X, Zhang T, Gao X. Heavy metals in meat products from Shandong, China and risk assessment. Food Addit Contam Part B Surveill. 2024 Mar;17(1):56-65. doi: 10.1080/19393210.2023.2286008. Epub 2024 Feb 12. PMID: 38093555. https://www.tandfonline.com/doi/full/10.1080/19393210.2023.2286008

13. Mohamed NH, Yahya G, El Bayoumi RM, Hussein MAM, Cavalu S, Dahshan H, Alsayeqh AF, Darwish WS, Nasr EAA. Detection and health risk assessment of toxic heavy metals in chilled and frozen meat collected from Sharkia province in Egypt. Open Vet J. 2023 Dec;13(12):1729-1737. doi: 10.5455/OVJ.2023.v13.i12.21. Epub 2023 Dec 31. PMID: 38292728; PMCID: PMC10824086. https://www.ejmanager.com/mnstemps/100/100-1703024877.pdf?t=1722121214

14. Dang TT, Vo TA, Duong MT, Pham TM, Van Nguyen Q, Nguyen TQ, Bui MQ, Syrbu NN, Van Do M. Heavy metals in cultured oysters (Saccostrea glomerata) and clams (Meretrix lyrata) from the northern coastal area of Vietnam. Mar Pollut Bull. 2022 Nov;184:114140. doi: 10.1016/j.marpolbul.2022.114140. Epub 2022 Sep 21. PMID: 36152497. https://www.sciencedirect.com/science/article/abs/pii/S0025326X22008220?via%3Dihub

15. Dehghani M, Sharifian S, Taherizadeh MR, Nabavi M. Tracing the heavy metals zinc, lead and nickel in banana shrimp (Penaeus merguiensis) from the Persian Gulf and human health risk assessment. Environ Sci Pollut Res Int. 2021 Aug;28(29):38817-38828. doi: 10.1007/s11356-021-13063-w. Epub 2021 Mar 20. PMID: 33745043. https://link.springer.com/article/10.1007/s11356-021-13063-w

16. Stanek M, Dąbrowski J, Różański S, Janicki B, Długosz J. Heavy Metals Bioaccumulation in Tissues of Spiny-Cheek Crayfish (Orconectes limosus) from Lake Gopło: Effect of Age and Sex. Bull Environ Contam Toxicol. 2017 Jun;98(6):740-746. doi: 10.1007/s00128-017-2098-2. Epub 2017 May 5. PMID: 28477051; PMCID: PMC5429899. https://link.springer.com/article/10.1007/s00128-017-2098-2

17. Jiang H, Tang S, Qin D, Chen Z, Wang J, Bai S, Mou Z. Heavy metals in sea cucumber juveniles from coastal areas of Bohai and Yellow seas, north China. Bull Environ Contam Toxicol. 2015 May;94(5):577-82. doi: 10.1007/s00128-014-1432-1. Epub 2014 Nov 25. PMID: 25421712. https://link.springer.com/article/10.1007/s00128-014-1432-1

18. Morshdy AEMA, Tharwat AE, Maarouf H, Moustafa M, Darwish WS, El-Ghareeb WR, Alsayeqh AF, Mustafa NA. Heavy metal contents in salted fish retailed in Egypt: Dietary intakes and health risk assessment. Open Vet J. 2023 Dec;13(12):1738-1743. doi: 10.5455/OVJ.2023.v13.i12.22. Epub 2023 Dec 31. PMID: 38292718; PMCID: PMC10824094. https://www.ejmanager.com/mnstemps/100/100-1703101871.pdf?t=1722336912

19. Aski MAH, Ghobadi S, Sari AA, Ardeshir RA, Arabi MHG, Manouchehri H. Health risk assessment of heavy metals (Zn, Pb, Cd, and Hg) in water and muscle tissue of farmed carp species in North Iran. Environ Sci Pollut Res Int. 2023 Mar;30(12):32464-32472. doi: 10.1007/s11356-022-24043-z. Epub 2022 Dec 3. Erratum in: Environ Sci Pollut Res Int. 2023 Mar;30(12):32473. doi: 10.1007/s11356-023-25425-7. PMID: 36462077. https://link.springer.com/article/10.1007/s11356-022-24043-z

20. Lin C, Chen J, Xu J, Li Y, Liu Y, Lin H. Distribution and risk assessment of heavy metals in the economic fish of the Southern Fujian Province. Environ Toxicol Pharmacol. 2022 May;92:103834. doi: 10.1016/j.etap.2022.103834. Epub 2022 Feb 26. PMID: 35227884. https://www.sciencedirect.com/science/article/abs/pii/S1382668922000278?via%3Dihub

21. Ansel MA, Benamar N. Accumulation of heavy metals in muscle, liver, and gonads of little tunny (Euthynnus alletteratus) from the western region of Algeria. Environ Sci Pollut Res Int. 2018 Nov;25(32):32640-32648. doi: 10.1007/s11356-018-3254-x. Epub 2018 Sep 21. PMID: 30242657. https://link.springer.com/article/10.1007/s11356-018-3254-x

22. Shuhaimi-Othman M, Yakub N, Ramle NA, Abas A. Comparative toxicity of eight metals on freshwater fish. Toxicol Ind Health. 2015 Sep;31(9):773-82. doi: 10.1177/0748233712472519. Epub 2013 Jan 9. PMID: 23302712. https://journals.sagepub.com/doi/abs/10.1177/0748233712472519

23. Boudebbouz A, Boudalia S, Bousbia A, Habila S, Boussadia MI, Gueroui Y. Heavy metals levels in raw cow milk and health risk assessment across the globe: A systematic review. Sci Total Environ. 2021 Jan 10;751:141830. doi: 10.1016/j.scitotenv.2020.141830. Epub 2020 Aug 21. PMID: 33182002. https://www.sciencedirect.com/science/article/abs/pii/S0048969720353596?via%3Dihub

24. Alinezhad Z, Hashemi M, Tavakoly Sany SB. Concentration of heavy metals in pasteurized and sterilized milk and health risk assessment across the globe: A systematic review. PLoS One. 2024 Feb 5;19(2):e0296649. doi: 10.1371/journal.pone.0296649. PMID:

38315713; PMCID: PMC10843077. https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0296649

25. Yan M, Niu C, Li X, Wang F, Jiang S, Li K, Yao Z. Heavy metal levels in milk and dairy products and health risk assessment: A systematic review of studies in China. Sci Total Environ. 2022 Dec 10;851(Pt 1):158161. doi: 10.1016/j.scitotenv.2022.158161. Epub 2022 Aug 19. PMID: 35988597. https://www.sciencedirect.com/science/article/abs/pii/S0048969722052603?via%3Dihub

26. Hasanvand S, Hashami Z, Zarei M, Merati S, Bashiry M, Nag R. Is the milk we drink safe from elevated concentrations of prioritized heavy metals/metalloids? - A global systematic review and meta-analysis followed by a cursory risk assessment reporting. Sci Total Environ. 2024 Jul 23;948:175011. doi: 10.1016/j.scitotenv.2024.175011. Epub ahead of print. PMID: 39053561. https://www.sciencedirect.com/science/article/pii/S0048969724051611?via%3Dihub

27. Mukhtar H, Chan CY, Lin YP, Lin CM. Assessing the association and predictability of heavy metals in avian organs, feathers, and bones using crowdsourced samples. Chemosphere. 2020 Aug;252:126583. doi: 10.1016/j.chemosphere.2020.126583. Epub 2020 Mar 23. PMID: 32443269. https://www.sciencedirect.com/science/article/abs/pii/S0045653520307761?via%3Dihub

28. Rahmani J, Fakhri Y, Shahsavani A, Bahmani Z, Urbina MA, Chirumbolo S, Keramati H, Moradi B, Bay A, Bjørklund G. A systematic review and meta-analysis of metal concentrations in canned tuna fish in Iran and human health risk assessment. Food Chem Toxicol. 2018 Aug;118:753-765. doi: 10.1016/j.fct.2018.06.023. Epub 2018 Jun 18. PMID: 29913231. https://www.sciencedirect.com/science/article/abs/pii/S0278691518303971?via%3Dihub

29. Aazami J, KianiMehr N. Survey of heavy metals in internal tissues of Great cormorant collected from southern wetlands of Caspian Sea, Iran. Environ Monit Assess. 2017 Dec 29;190(1):52. doi: 10.1007/s10661-017-6433-1. PMID: 29288418. https://link.springer.com/article/10.1007/s10661-017-6433-1

30. Ding J, Wang S, Yang W, Zhang H, Yu F, Zhang Y. Tissue distribution and association of heavy metal accumulation in a free-living resident passerine bird tree sparrow Passer montanus. Environ Pollut. 2023 Jan 1;316(Pt 1):120547. doi: 10.1016/j.envpol.2022.120547. Epub 2022 Nov 4. PMID: 36343853. https://doi.org/10.1016/j.envpol.2022.120547

31. Tanabe LK, Scott K, Dasari V, Berumen ML. An assessment of heavy metals in green sea turtle (*Chelonia mydas*) hatchlings from Saudi Arabia's largest rookery, Ras Baridi. PeerJ. 2022 Aug 23;10:e13928. doi: 10.7717/peerj.13928. PMID: 36032942; PMCID: PMC9415434. https://peerj.com/articles/13928/

32. Aarif KM, Rubeena KA, Nefla A, Musilova Z, Musil P, Shaju SS, Joseph J, Mullungal MN, Muzaffar SB. Heavy metals in wetlands of southwestern India: from sediments through invertebrates to migratory shorebirds. Chemosphere. 2023 Dec;345:140445. doi: 10.1016/j.chemosphere.2023.140445. Epub 2023 Oct 18. PMID: 37863211. https://www.sciencedirect.com/science/article/abs/pii/S0045653523027157?via%3Dihub

33. Huang F, Chen C. GIS-based approach and multivariate statistical analysis for identifying sources of heavy metals in marine sediments from the coast of Hong Kong. Environ Monit Assess. 2023 Mar 28;195(4):518. doi: 10.1007/s10661-023-11152-6. PMID: 36976384. https://link.springer.com/article/10.1007/s10661-023-11152-6

34. Li W, Deng Y, Wang H, Hu Y, Cheng H. Potential risk, leaching behavior and mechanism of heavy metals from mine tailings under acid rain. Chemosphere. 2024 Feb;350:140995. doi: 10.1016/j.chemosphere.2023.140995. Epub 2023 Dec 19. PMID: 38128738. https://doi.org/10.1016/j.chemosphere.2023.140995

35. Luo H, Wang Q, Guan Q, Ma Y, Ni F, Yang E, Zhang J. Heavy metal pollution levels, source apportionment and risk assessment in dust storms in key cities in Northwest China. J Hazard Mater. 2022 Jan 15;422:126878. doi: 10.1016/j.jhazmat.2021.126878. Epub 2021 Aug 11. PMID: 34418825. https://www.sciencedirect.com/science/article/abs/pii/S030438942101846X?via%3Dihub

36. Shen H, Lou B, Liu B, Zhang J, Zhang X, Liu J, Zhang R, Chen M, Zhang S. Reduction of heavy metals in municipal solid waste incineration fly ash followed by making transparent glass. Waste Manag. 2024 Jun 30;183:184-190. doi: 10.1016/j.wasman.2024.05.008. Epub 2024 May 17. PMID: 38759276. https://www.sciencedirect.com/science/article/abs/pii/S0956053X24002940?via%3Dihub

37. Roy S, Gupta SK, Prakash J, Habib G, Kumar P. A global perspective of the current state of heavy metal contamination in road dust. Environ Sci Pollut Res Int. 2022 May;29(22):33230-33251. doi: 10.1007/s11356-022-18583-7. Epub 2022 Jan 13. PMID: 35022986. https://link.springer.com/article/10.1007/s11356-022-18583-7

38. Sepahi Zoeram F, Ebrahimi AA, Mehrparvar AH, Sarsangi Aliabad A, Fallah Zadeh H, Mehri H, Zare Sakhvidi MJ. Health risk assessment of inhalational exposure to heavy metals in drivers working in an urban desert city in the Middle East. Environ Monit Assess. 2022 Jun 28;194(8):533. doi: 10.1007/s10661-022-10234-1. PMID: 35763174. https://link.springer.com/article/10.1007/s10661-022-10234-1

39. Khan K, Room SA, Bacha AU, Nabi I, Ahmad S, Younas M, Ullah Z, Iqbal A, Alrefaei AF, Almutairi MH, Chang JW, Chi KH. Assessment of heavy metals among auto workers in metropolitan city: a case study. Front Public Health. 2023 Nov 7;11:1277182. doi: 10.3389/fpubh.2023.1277182. PMID: 38026331; PMCID: PMC10662099. https://www.frontiersin.org/journals/public-health/articles/10.3389/fpubh.2023.1277182/full

40. Mauriello MC, Sbordone C, Montuori P, Alfano R, Triassi M, Iavicoli I, Manno M. Biomonitoring of toxic metals in incinerator workers: A systematic review. Toxicol Lett. 2017 Apr 15;272:8-28. doi: 10.1016/j.toxlet.2017.02.021. Epub 2017 Mar 1. PMID: 28257910. https://www.sciencedirect.com/science/article/abs/pii/S0378427417300802?via%3Dihub

41. Alvarez-Chavez CR, Federico-Perez RA, Gomez-Alvarez A, Velazquez-Contreras LE, Perez-Rios R. Hidden sources of mercury in clinical laboratories. Environ Monit Assess. 2014 Sep;186(9):5393-400. doi: 10.1007/s10661-014-3787-5. Epub 2014 May 11. PMID: 24816591. https://link.springer.com/article/10.1007/s10661-014-3787-5

42. Erfantalab P, Zamani N, Hassanian-Moghaddam H. Broken thermometer in foot: a source of mercury poisoning. Trop Doct. 2020 Jan;50(1):83-84. doi: 10.1177/0049475519884419. Epub 2019 Nov 6. PMID: 31694474. https://journals.sagepub.com/doi/10.1177/0049475519884419

43. Jirau-Colón H, González-Parrilla L, Martinez-Jiménez J, Adam W, Jiménez-Velez B. Rethinking the Dental Amalgam Dilemma: An Integrated Toxicological Approach. Int J Environ Res Public Health. 2019 Mar 22;16(6):1036. doi: 10.3390/ijerph16061036. PMID: 30909378; PMCID: PMC6466133. https://www.mdpi.com/1660-4601/16/6/1036

44. Grosshagauer S, Kraemer K, Somoza V. The True Value of Spirulina. J Agric Food Chem. 2020 Apr 8;68(14):4109-4115. doi: 10.1021/acs.jafc.9b08251. Epub 2020 Mar 25. PMID: 32133854. https://pubs.acs.org/doi/10.1021/acs.jafc.9b08251

45. Chui SH, Wong YH, Chio HI, Fong MY, Chiu YM, Szeto YT, Vong WT, Lam CW. Study of heavy metal poisoning in frequent users of Chinese medicines in Hong Kong and Macau. Phytother Res. 2013 Jun;27(6):859-63. doi: 10.1002/ptr.4816. Epub 2012 Aug 16. PMID: 22899484. https://onlinelibrary.wiley.com/doi/10.1002/ptr.4816

46. Jurowski K, Krośniak M. The Toxicological Assessment of Content and Exposure of Heavy Metals (Pb and Cd) in Traditional Herbal Medicinal Products with Marshmallow Root (*Althaea officinalis* L., radix) from Polish Pharmacies. Toxics. 2022 Apr 13;10(4):188. doi: 10.3390/toxics10040188. PMID: 35448449; PMCID: PMC9028009. https://www.mdpi.com/2305-6304/10/4/188

47. Sikder MM. Ayurvedic Medicine: A Traditional Medical System and Its Heavy Metal Poisoning. Chonnam Med J. 2024 May;60(2):97-104. doi: 10.4068/cmj.2024.60.2.97. Epub 2024 May 24. PMID: 38841605; PMCID: PMC11148304. https://cmj.ac.kr/DOIx.php?id=10.4068/cmj.2024.60.2.97

48. Lawi DJ, Abdulwhaab WS, Abojassim AA. Health Risk Study of Heavy Metals from Consumption of Drugs (Solid and Liquid) Samples Derived from Medicinal Plants in Iraq. Biol Trace Elem Res. 2023 Jul;201(7):3528-3540. doi: 10.1007/s12011-022-03408-y. Epub 2022 Sep 3. PMID: 36057033. https://link.springer.com/article/10.1007/s12011-022-03408-y

49. Anual ZF, Ahmad NI, Anak Robun C, Ahmad Suhaimi LR, Surawi NH, Sudin K, Mustaffa AF, Zainudeen AAH, Mohd Zaini S, Mamat NA. Heavy metals in offal and canned food sold in the Malaysian market. Food Addit Contam Part A Chem Anal Control Expo Risk Assess. 2023 Dec;40(12):1589-1599. doi: 10.1080/19440049.2023.2272726. Epub 2023 Dec 13. PMID: 37883683. https://www.tandfonline.com/doi/full/10.1080/19440049.2023.2272726

50. Kumar P, Dipti, Kumar S, Singh RP. Severe contamination of carcinogenic heavy metals and metalloid in agroecosystems and their associated health risk assessment. Environ Pollut. 2022 May 15;301:118953. doi: 10.1016/j.envpol.2022.118953. Epub 2022 Feb 16. PMID: 35182654. https://linkinghub.elsevier.com/retrieve/pii/S0269749122001671

51. Offor SJ, Orish CN, Chidi Eze E, Frazzoli C, Orisakwe OE. Blood donation and heavy metal poisoning in developing nations: Any link? Transfus Apher Sci. 2021 Apr;60(2):103067. doi: 10.1016/j.transci.2021.103067. Epub 2021 Jan 29. PMID: 33541762. https://linkinghub.elsevier.com/retrieve/pii/S1473050221000173

52. Kershner EK, Tobarran N, Chambers A, Wills BK, Cumpston KL. Retained bullets and lead toxicity: a systematic review. Clin Toxicol (Phila). 2022 Oct;60(10):1176-1186. doi: 10.1080/15563650.2022.2116336. Epub 2022 Sep 8. PMID: 36074021. https://www.tandfonline.com/doi/full/10.1080/15563650.2022.2116336

53. Al-Ansari MM, Benabdelkamel H, AlMalki RH, Abdel Rahman AM, Alnahmi E, Masood A, Ilavenil S, Choi KC. Effective removal of heavy metals from industrial effluent wastewater by a multi metal and drug resistant *Pseudomonas aeruginosa* strain RA-14 using integrated sequencing batch reactor. Environ Res. 2021 Aug;199:111240. doi: 10.1016/j.envres.2021.111240. Epub 2021 May 8. PMID: 33974838. https://linkinghub.elsevier.com/retrieve/pii/S001393512100534X

54. Marshall BG, Veiga MM, da Silva HAM, Guimarães JRD. Cyanide Contamination of the Puyango-Tumbes River Caused by Artisanal Gold Mining in Portovelo-Zaruma, Ecuador. Curr Environ Health Rep. 2020 Sep;7(3):303-310. doi: 10.1007/s40572-020-00276-3. PMID: 32506189. https://link.springer.com/article/10.1007/s40572-020-00276-3

55. Bekibele GE, Anacletus FC, Patrick-Iwuanyanwu KC. The toxic effects of spent crankcase oil exposures; systematic review and meta-analysis. Toxicol Res. 2021 Apr 20;38(2):113-135. doi: 10.1007/s43188-021-00093-2. PMID: 35419273; PMCID: PMC8960553. https://link.springer.com/article/10.1007/s43188-021-00093-2

56. Kuntawee C, Tantrakarnapa K, Limpanont Y, Lawpoolsri S, Phetrak A, Mingkhwan R, Worakhunpiset S. Exposure to Heavy Metals in Electronic Waste Recycling in Thailand. Int J Environ Res Public Health. 2020 Apr 26;17(9):2996. doi: 10.3390/ijerph17092996. PMID: 32357423; PMCID: PMC7246830. https://www.mdpi.com/1660-4601/17/9/2996

57. Desye B, Tesfaye AH, Berihun G, Ademas A, Sewunet B. A systematic review of the health effects of lead exposure from electronic waste in children. Front Public Health. 2023 Apr 12;11:1113561. doi: 10.3389/fpubh.2023.1113561. PMID: 37124790; PMCID: PMC10130399. https://www.frontiersin.org/journals/public-health/articles/10.3389/fpubh.2023.1113561/full

58. Khan MR, Ahmad N, Ouladsmane M, Azam M. Heavy Metals in Acrylic Color Paints Intended for the School Children Use: A Potential Threat to the Children of Early Age. Molecules. 2021 Apr 19;26(8):2375. doi: 10.3390/molecules26082375. PMID: 33921808; PMCID: PMC8073559. https://www.mdpi.com/1420-3049/26/8/2375

59. Navarro-Tapia E, Serra-Delgado M, Fernández-López L, Meseguer-Gilabert M, Falcón M, Sebastiani G, Sailer S, Garcia-Algar O, Andreu-Fernández V. Toxic Elements in Traditional Kohl-Based Eye Cosmetics in Spanish and German Markets. Int J Environ Res Public Health. 2021 Jun 5;18(11):6109. doi: 10.3390/ijerph18116109. PMID: 34198922; PMCID: PMC8201171. https://www.mdpi.com/1660-4601/18/11/6109

60. Salama AK. Assessment of metals in cosmetics commonly used in Saudi Arabia. Environ Monit Assess. 2015 Oct;188(10):553. doi: 10.1007/s10661-016-5550-6. Epub 2016 Sep 8. PMID: 27613289. https://link.springer.com/article/10.1007/s10661-016-5550-6

61. Abualhasan M, Naffa L, Alarda R, Zahi B, Amireh A, Al-Atrash M. Heavy metal and microbial testing of selected cosmetic products in the Palestinian market. J Environ Sci Health C Toxicol Carcinog.

2024;42(1):1-15. doi: 10.1080/26896583.2023.2281199. Epub 2024 Jan 19. PMID: 38060279. https://www.tandfonline.com/doi/full/10.1080/26896583.2023.2281199

62. Gyamfi O, Aboko J, Ankapong E, Marfo JT, Awuah-Boateng NY, Sarpong K, Dartey E. A systematic review of heavy metals contamination in cosmetics. Cutan Ocul Toxicol. 2024 Mar;43(1):5-12. doi: 10.1080/15569527.2023.2268197. Epub 2023 Nov 2. PMID: 37916307. https://www.tandfonline.com/doi/full/10.1080/15569527.2023.2268197

63. Bastiansz A, Ewald J, Rodríguez Saldaña V, Santa-Rios A, Basu N. A Systematic Review of Mercury Exposures from Skin-Lightening Products. Environ Health Perspect. 2022 Nov;130(11):116002. doi: 10.1289/EHP10808. Epub 2022 Nov 11. PMID: 36367779; PMCID: PMC9651181. https://ehp.niehs.nih.gov/doi/10.1289/EHP10808

64. Negi S, Bala L, Shukla S, Chopra D. Tattoo inks are toxicological risks to human health: A systematic review of their ingredients, fate inside skin, toxicity due to polycyclic aromatic hydrocarbons, primary aromatic amines, metals, and overview of regulatory frameworks. Toxicol Ind Health. 2022 Jul;38(7):417-434. doi: 10.1177/07482337221100870. Epub 2022 May 19. PMID: 35592919. https://journals.sagepub.com/doi/10.1177/07482337221100870

65. Sima MF. Determination of some heavy metals and their health risk in T-shirts printed for a special program. PLoS One. 2022 Sep 20;17(9):e0274952. doi: 10.1371/journal.pone.0274952. PMID: 36125988; PMCID: PMC9488751. https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0274952

66. Zeng X, Liu D, Wu Y, Zhang L, Chen R, Li R, Gu W, Zhang L, Liu C, Sun Q. Heavy metal risk of disposable food containers on human health. Ecotoxicol Environ Saf. 2023 Apr 15;255:114797. doi: 10.1016/j.ecoenv.2023.114797. Epub 2023 Mar 16. PMID: 36933486. https://www.sciencedirect.com/science/article/pii/S0147651323003019?via%3Dihub

67. Fadaei A. An investigation into the present levels of contamination in children's toys and jewelry in different countries: a systematic review. Rev Environ Health. 2022 Jul 4;38(4):601-611. doi: 10.1515/reveh-2022-0064. PMID: 35778924. https://www.degruyter.com/document/doi/10.1515/reveh-2022-0064/html

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The authors declare that they have no conflicts of interest.

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