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Chapter

E-Waste and Metal Contamination in the Environment: Health Effects

Mark E.C. Dockrell, Diane Purchase and Robert G. Price

Abstract

It is predicted that electronic waste (e-waste) derived principally from discarded electronic equipment will reach 74 million metric tonnes by 2030. In addition, urbanization and industrialization have contributed to metal contamination in the environments. E-waste is often deposited in low-income countries adversely affecting the health of the working population. The main sources of e-contamination are soil, dust, and food matrices. Drinking water can also be contaminated with heavy metals such as arsenic (As), cadmium (Cd), mercury (Hg), and lead (Pb) causing a major health concern. Exposure to pollutants present in waste has a significant detrimental impact on human health; children in developing countries are often particularly susceptible. Sensitive monitoring procedures are needed to improve the rate of detection and monitoring of the possible adverse effects on the population exposed to significant quantities of e-waste.

Keywords: air quality, biomarkers, contamination pathways, biomarkers of effect, biomarkers of exposure, metals, electronic waste

1. Introduction

Electronic and electrical waste (e-waste) is the fastest growing domestic waste stream in the world [1]. E-waste is a broad category; the term is used to cover all items of electrical and electronic equipment and its parts that have been discarded as waste without the intention of reuse. It particularly affects impoverished city dwellers who work in or near informal dumps and landfills. Many of these sites are in low- and middle-income countries. E-waste can contain valuable material, for example, gold but it can also be harmful to human health if it is not disposed of correctly or preferably recycled under the correct conditions and procedures. Workers often use primitive recycling techniques such as acid leaching and cable burning to recover, gold, copper, and other valuable metals and are, therefore, directly exposed to contaminants arising from these processes [2]. Other hazardous by-products are also released into the environment with unknown effects. According to the global e-waste statistics partnership (GESp), 53.6 million tonnes of e-waste are produced worldwide, but only 17.4% of this was recorded as collected and appropriately recycled [3]. In addition to the risk from exposure to the original constituents of, for example, electronic equipment, substances added in the recovery process, as well as those resulting from the recycling process is also health threats. The residents of the local area, as well as those working,

are likely to be exposed to a complex mixture with currently unknown toxicity [4]. Airborne contaminants had an immediate effect on the respiratory system but have longer-term effects on the kidney and liver function of Chinese e-waste dismantling workers exposed to high levels of heavy metals [5]. Biomarkers of kidney and liver function should, therefore, provide valuable indicators of early damage to these organs. The waste stream of obsolete electronic equipment grows exponentially with the result that the ecological impact of e-waste is growing exponentially [6].

2. E-waste chemical composition and exposure pathways

The nature of e-waste is highly heterogeneous (from temperature exchange equipment to small IT and telecommunication equipment with external dimensions less than 50 cm); the chemical composition of e-wastes is extremely complex, featuring a mix of metals (e.g., precious, ferrous, and nonferrous metals), metalloids, rare earth elements, glass, plastics, flame retardants, and other additives. Heavy metals are naturally occurring elements that have a high atomic weight and a density at least five times greater than that of water. **Table 1** presents the key transition metals, and metalloids found in e-waste and their usage in electrical and electronic equipment. Many of the raw materials in e-waste are valuable commodities, for example, copper (Cu) and gold (Au), they exist in high purity and quality that can be recovered. The recoverable value of e-waste was estimated to be US\$ 57 billion [7]. E-waste is a valuable resource; many formal and informal activities have evolved to reclaim these materials around the world. Such activities have a direct impact on human health and the environment.

Many developed countries have strict regulations for recycling their e-waste. For example, in the EU, the WEEE Directive 2012/19/EU stipulated the requirements for e-waste disposal and require the producers to manage their product's life cycle, from cradle to grave including end-of-life recycling. In the formal sector, the recycling process mainly involves four key stages: collection, sorting, mechanical size reduction and physical separation, and metal recovery (**Figure 1**). The mechanical process entails dismantling, shredding, or crushing the e-waste, and a number of techniques are available to separate the particles after size reduction such as sieving, gravity, magnetic and electrostatic separation, and particle flotation. Metal recovery can be achieved by pyrometallurgy involving high-temperature smelters, hydrometallurgy (using various aqueous solutions and solvents), and bio metallurgy (employing microorganisms to leach or extract metals). The size reduction stage has the highest potential in releasing dust particles containing toxic metals into the environment. Workers can be exposed to these compounds *via* inhalation and skin contact. Studies carried out in formal recycling factory around the world have shown the high levels of metal present in the dust (**Table 2**). For example, a study in five sheltered e-waste facilities disassembling flat-screen and tube displays showed the presence of Al, As, Be, Cd, Cr, Co, Ni, and Hg in the inhalable fraction of air samples, although the level was below German and international occupational limit [12]. Another study of three e-waste recycling companies in Sweden of varying sizes showed that recycling workers are exposed to elevated levels of metals and rare earth elements, around 10–30 times higher than the control of office workers [13].

It was estimated 80% of the e-waste worldwide is processed by the informal sector in low or lower-middle income countries [7, 18] where legislations on environmental protection and workers' right are less strong than in developed countries, and they

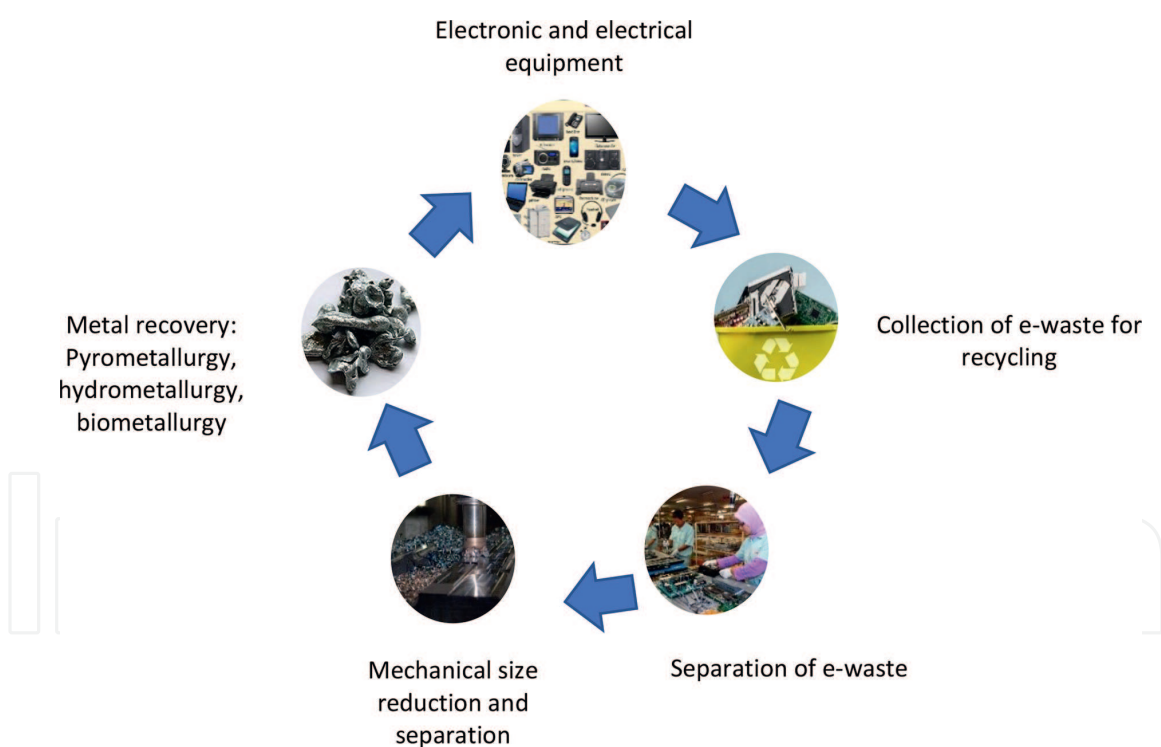
	Usage
V	Used in rechargeable flow battery. VO ₂ is used as semiconductors and in transistors.
Cr*	Cr ⁶⁺ is widely used as a corrosion inhibitor in corrosion protection in metal housing. Cr is a crucial component of stainless steel (where it is present at least at 10.5%) which is widely employed for EEE production. It can be also used in form of NiCr alloy, in multilayer metallisations in printed circuit boards, smart card chips and microdevices for ensuring adherence between metallic layers and between Au finishing and the device surface.
Mn	As an alloy with steel, Al or Cu, it has important metallurgical applications. As manganese oxides, they are used as a depolarizer in batteries, sensors and super capacitors.
Fe	There are numerous uses <i>e.g.</i> , as electrical steel used in magnetic cores for transformers, generators and motors. AsFe ₂ O ₃ it is used in hard drive and printed circuit boards. Widely recycled.
Co	As a magnetic alloy with Fe, Ni, Al, Nd, Sm (<i>e.g.</i> , AlNiCo, SmCo, etc. magnets). It is widely used in Li-ion batteries. Often found in CRT, printed circuit boards and hard drives. It is often recovered due to its economic value.
Ni	As an alloy with steel, Cr, Mn or Fe for corrosion protection in housing. Ni is widely used in batteries and CRT. It is employed as a coating in preserving NdFeB magnets from oxidation. It is often recovered due to its economic value.
Cu	Commonly used in electrical wiring. Copper wire is found in most electrical equipment and electronic circuitry. It is used for printed circuit board pathways and as bulky material in multilayer connections where Au is the external finishing (<i>e.g.</i> , smart card chips, printer cartridge connections and pathways). It represents the most abundant non-ferrous metal in de-manufactured printed circuit boards and small electronic equipment. Also forms important alloy with Al and Ti. It is often recovered due to its economic value.
Zn	Used in die-castings in electrical industries. As alloys such as Ni, Ag and Al solder. ZnO is widely used in the manufacture of rubber, plastics, inks, batteries and electrical equipment. ZnS is used in making luminous paints, fluorescent lights and x-ray screens. It is often recovered due to its economic value.
Ga	High-purity Ga is used in the manufacturing of semiconductors. GaAs and GaN are used in electronic components <i>e.g.</i> , integrated circuit, high-speed logic chips, diode lasers and light-emitting diodes (LEDs)
Ge	Commonly used in fluorescent lamps, LEDs, and transistors (historically). Si-Ge alloy, it is used in the manufacturing of semiconductors for high-speed integrated circuits.
As	As alloys with Pb or Ga. GaAs is a semiconductor material used in printed circuit boards and laser diodes.
Se	Used in Li-Se battery and ZnSe has been used in the manufacturing of LEDs and laser diodes.
Sr	Primarily used in the manufacturing of glass for CRT.
Pd	Often used as soldering materials and as electrodes in multilayer ceramic capacitors in laptops and mobile phones. It is often recovered due to its economic value.
Ag	Widely used in membrane switches and pathways, it is often present in printed circuit boards, plasma display panels and photovoltaic panels (PVPs). Powdered Ag and its alloys are used in paste preparations for conductor layers and electrodes, ceramic capacitors, and other ceramic components. It is often recovered due to its economic value.
Cd**	Commonly used in contacts, switches and rechargeable Ni-Cd batteries. CdS is used in CRT.
In	Extensively used in liquid crystal display (LCD) as transparent electrodes (indium tin oxide) and thin-film transistors in the production of flat screen monitors, TVs and solar panels. GaInN and GaInP are used in LEDs and laser diodes.
Sn	Used in alloys with Pb as solder for electric circuits in historic electric and electronic equipment. Nb ₃ Sn is used in coils of superconducting magnets. Also used as electrode in Li-ion batteries. Stannate aqueous solutions are used to produce electrically conductive and corrosion-resistant coatings on glass by electroplating and Zn ₂ SnO ₄ is a fire-retardant used in plastics housing.

	Usage
Sb	Used in antifriction alloys in electrical cable sheathing, as lead-free solder as well as fining agent in glass for TV screens. As semiconductor material, it is used in infrared detectors and diodes.
Te	Used in the manufacturing of solar panels. It is often doped with Ag, Au, Cu or Sn in semiconductor applications.
Pt	It is a component of the Co-Cr-Pt alloy used for hard drive platters coating; also found in fiberglass, liquid-crystal and flat-panel displays, and CRT. It is often recovered due to its economic value.
Au	Widely used in the production of corrosion-free connectors in electronic devices, cables and integrated circuits. It is often recovered due to its economic value.
Hg*	Historically used in mercury-vapor lamps and cold-cathode fluorescent lamps. It has also been used in switches, relays of older mainframe computers, LCD and batteries.
Tl	Used by the electronic industry in photoelectric cells.
Pb*	Historically used in electrical solder with Sn on printed circuit boards and PbO is used in CRTs.

*EU Restriction of Hazardous Substances (RoHS) regulation restricted concentration in new equipment since 2006: *:
 $\leq 0.1\%$ by weight; ** $\leq 0.01\%$ by weight.*

Table 1.

Key transition metals and metalloids and their use in electric and electronic equipment. (adapted from Purchase [6] et al., 2020).

**Figure 1.**

Different stages of formal recycle of e-waste and its potential in circular economy.

are also difficult to enforce due to the informal nature of the operation. The recycling practice generally uses simple and crude methods to recover the precious metals in an informal environment where the workers and their kin have little protection against the hazardous materials generated. In comparison to the highly automated processes in the formal sector, informal recycling of e-waste normally involves three stages: (i) manual dismantling, (ii) recovery of valuable materials via open burning and/or acid stripping, and (iii) disposal of unsalvageable waste. E-waste is dismantled with

Region & Country	Comments	References
North America:		
US	Lead and Cd in electronics recycling facilities.	Ceballos [8]
	Hg detected in a battery recovery facility.	Reh [9]
Europe:		
France	Inhalation exposure to Pb, Cd, Y in CRT processing plant	Lecler [10]
	Pb and Y were detected in dust and skin of workers in fluorescent lamp recycling facilities	Zimmermann [11]
Germany	Al, As, Be, Cd, Cr, Co, Ni and Hg detected in an inhalable fraction of air samples in flat screen and tube display dismantling area	Gerding [12]
Sweden	High levels of Cr, Pb, In and Hg in CRT recycling facilities.	Julander [13]
Asia:		
China	Pb, Ni, Fe, Mn, Zn, Cu and Cd were detected from formal e-waste dismantling parks from 18 cities are distributed in indoor workshops	Wu [14]
	Pb and Cu detected in waste electronic and electrical equipment recycling plants	Deng [15]; Lau [16]

Table 2.

Examples of metal exposure of e-waste recycling workers in air samples.

rudimentary tools such as hammers, chisels, and screwdrivers into smaller fragments or valuable components, which can then be melted down on open fires. For example, valuable metals and chips can be recovered after burning waste printed circuit boards; similarly, cable wires are burnt to extract copper and resell (**Figure 2**). Hazardous solvents or acids may also be used to strip and clean the metals. Any residual materials of no immediate economic value will be discarded on land or burnt.

As a result of the proximity of the workers, their kin, and livestock to the informal recycling activities, they are exposed to high levels of hazardous chemicals from e-waste combustion and acid and waste disposed on the site through different routes (**Figure 3**). Metals and metalloids are among some of the chemicals released into the air from manual dismantling in dust particles, which can be deposited to the ground or water body *via* dry and wet deposition, soil particle transport, or runoffs. As air borne particles, they can be inhaled and as deposit, they can be taken up by direct human contact e.g., by children who live in the vicinity. This can be by drinking contaminated water or by consumption of crops and local livestock. A number of studies have reported elevated levels of metals in the dismantling area compared to other areas in an informal recycling site [19, 20]. Disposal of the acid from metal stripping into a water body or directly into the soil also affects the soil health and may leach into groundwater. Elevated levels of metals in e-waste recycling sites have been reported to impact soil microbial diversity, population, and functional activities of the microbial communities [17, 21]. A systematic review carried out by [22] on electronic waste recycling activities between 2005 and 2017 around the world showed that the levels of As, Cd, Cr, Hg, and Cd in soil, water, and sediments are generally higher than international standards, and the risk associated with their exposure for both human health

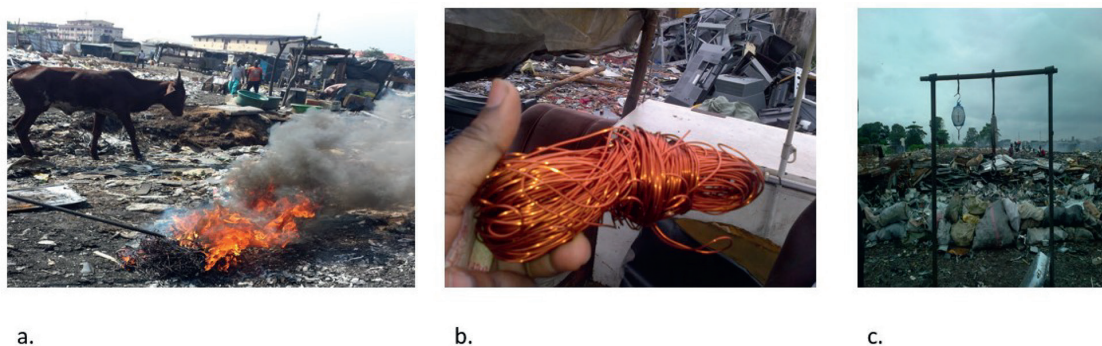


Figure 2. Scenes from an e-waste informal recycling site in Alaba Lagos, Nigeria: A – E-waste was burned to recover the metal in the site where livestock and workers also resided; b – Copper wires were recovered from burnt cables; and c – Scales used to measure the weight of the recovered metals to be resold. (photos source: Khadijah Isimekhai©).

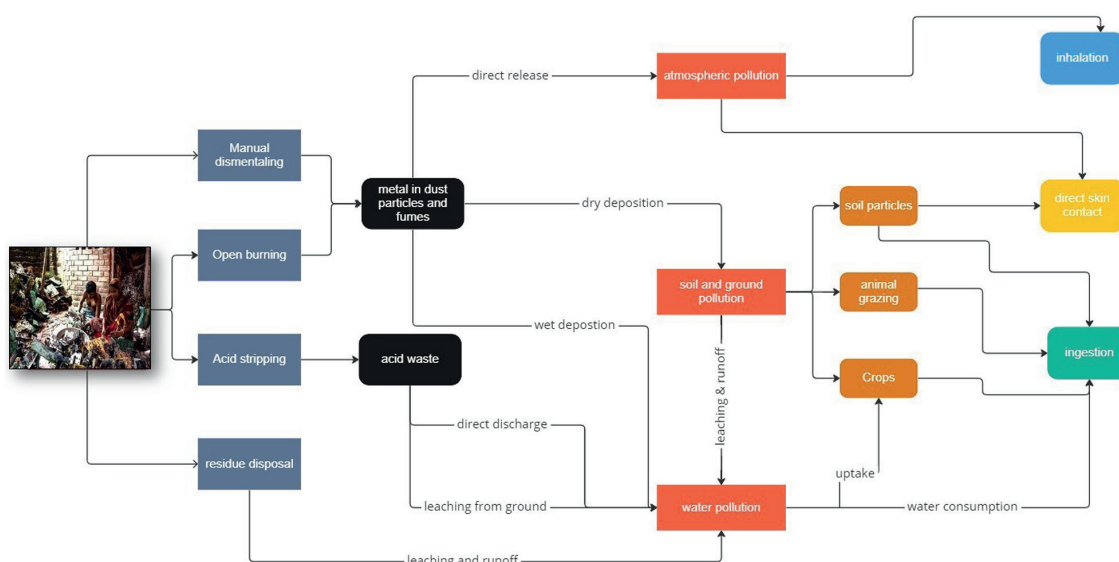


Figure 3. Different pathways of metal exposure from informal e-waste recycling. (photo source: Debashish Chatterjee).

and the environment are not well characterized. The latter is not surprising given the complexity of the living conditions and varying practices and traditions in dietary intake.

3. Biomarkers

A study of biomarkers for disease caused by all the chemical composites of e-waste would be of great value for monitoring people who may be exposed in formal or informal recycling environments. However, this would be a substantial piece of work and is beyond the remit of this chapter. The following focuses specifically on some of the important potentially toxic metals present in e-waste.

Biomarkers can be subcategorized into biomarkers of effect and biomarkers of exposure. A biomarker of effect is used in the assessment of health risk and can give an assessment of absorbed dose in industrial workers and populations exposed to waste recycling. Both have their uses. Biomarkers of effect can directly relate a

potentially harmful substance to a pathological process, demonstrating cause and effect. As such, it can also indicate possible remedial treatment. Biomarkers of exposure give an assessment of a worker's current exposure to a hazard. However, when there is pathological damage caused by chronic exposure to the hazard this type of biomarker may be less useful. This is not always the case. Deciduous teeth have been shown to provide retrospective information on timing of early-life metals exposure [23]. In addition, chronic lead exposure affects bone turnover and, consequently, can be identified by studying markers of bone formation and bone turnover [24]. Some biomarkers of exposure may also be predictors of subsequent adverse health effects.

4. Biomarkers of effect

4.1 Arsenic

Arsenic (As) is a common component of e-waste found in circuit boards, semiconductors, LCD displays, and computer chips. When dumped in landfill, As can leach into the soil and the groundwater, and when recycled, As can be released exposing workers by inhalation [25].

Serum matrix metalloproteinase-9 (MMP-9) has been suggested as a biomarker for As inhalation. Serum MMP-9 is associated with chronic respiratory disease and lung inflammation [26]. Although it did correlate with estimated exposure levels, it was not significantly associated with urinary As levels. Serum MMP-9 is also a potential biomarker for other conditions including tick-borne encephalitis [27], brain tumors [28], and alcohol intoxication in adolescents [29]. The specificity of these biomarkers needs to be considered.

As can cause both liver and kidney damage. Peripheral blood mitochondrial DNA copy number (mtDNAcn) is a potential biomarker of arsenic-induced liver damage [30]. As exposure has been shown to be associated with renal tubular injury [31]. Studies of As nephrotoxicity have used a combination of biomarkers of tubular toxicity including N-acetyl-beta-D-glucosaminidase (NAG), β 2-microglobulin (β 2-MG), α 1-microglobulin (α 1-MG), as well as retinol-binding protein (RBP) [32]. Urinary levels of four putative cancer-related proteins, FASLG, SEZ6L, LYPD3, and TFPI2, were associated with blood As levels in a study of Bolivian women [33].

4.2 Cadmium

Cadmium (Cd) is stored in the kidney and liver with a biological half-life of 10–30 years [34]. Cd is primarily toxic to the kidney. Prolonged or high exposure to Cd may result in a reduced glomerular filtration rate (GFR) and ultimately in renal failure. Prolonged urinary levels of $>4 \mu\text{g Cd/g creatinine}$ are associated with renal tubular dysfunction. Biomarkers of tubule function, such as RBP, β 2MG, and NAG, have been used in the identification of Cd induce tubular function [34].

Cd can also cause bone demineralization in children [35, 36] and increase the risk of osteoporosis and fracture in pregnant, postmenopausal women, and the elderly. [37, 38]. Urinary calcium (uCa) excretion is a determinant of bone mineral density. Deoxypyridinoline (DPD) represents a specific degradation product of mature collagen found in bones. It is excreted unmetabolized in urine and is a specific marker of bone resorption and osteoclastic activity. Two studies found urinary Cd

concentrations associated with β 2-MG, U-Ca, and DPD levels [36, 39]. Bone mass density has also been proposed as a marker of Cd exposure [40].

4.3 Chromium

Hexavalent chromium [Cr(VI)] is a known carcinogen and is increasingly being recognized as a neurotoxicant. 8-hydroxy-2'-deoxyguanosine is a marker of DNA damage, and urinary 8-hydroxy-2'-deoxyguanosine/creatinine ratio has been shown to correlate with Cr(VI) exposure [41]. Positive dose-response associations were also found between chromium levels in erythrocytes and olive tail movement, tail length, and tail DNA%. The comet is a very widely used assay to microscopically detect DNA damage at the level of a single cell. In exposed workers, Cr(VI) markers of genotoxicity and oxidative stress have been measured. These included micronucleus analysis in lymphocytes and reticulocytes, the comet assay in whole blood, and malondialdehyde and 8-oxo-2'-deoxyguanosine in urine. [42].

Exposure to Cr and Cr compounds through dermal contact mainly induces DNA damage, metastasis, and immune system disorders. mRNA expression of IL-4, IL-6, and IFN- γ was increased in skin tissues exposed to chromate [43]. A correlation was reported between urinary levels of Cr(III) and the renal damage biomarker KIM-1 in tannery workers [44].

4.4 Copper

In a 2001, paper copper (Cu) was said to make up 20% of “typical electronic scrap,” which was more than any other metal [45]. An occupational exposure study of workers in e-waste recycling in Sweden found that dismantling workers had a significantly higher exposure to copper by inhalation than outdoor workers [13]. However, there is little evidence of long-term Cu-induced toxicity due to inhalation, possibly due to the tightly regulated homeostasis that prevents Cu toxicity. The development of chronic Cu toxicity is dependent on Cu homeostasis and its tissue retention. This homeostatic control is disturbed in Wilson’s disease. Wilson disease is a rare genetic condition typified by Cu retention in the liver. There is some evidence from animal studies that Cu ions are involved in the development of type 2 diabetes [46], this needs further investigation.

4.5 Mercury

The main adverse health effects of Mercury (Hg) include neurotoxicity, teratogenicity, nephrotoxicity, and immunotoxicity [47]. After consumption of methylmercury (MeHg)-contaminated food, the gastrointestinal tract absorbs approximately 95% of ingested MeHg, although it should be noted that MeHg can also be readily absorbed through the skin and lungs. Once absorbed into the bloodstream, the majority of MeHg enters the red blood cells or is transported by plasma proteins. Serum albumin (Alb) is the most abundant plasma protein to which MeHg covalently binds through sulfhydryl groups, forming a reversible MeHg-Alb conjugate. Circulatory distribution of MeHg conjugates to several organs, mainly to kidneys and the brain. All mercurial forms have known deleterious effects on human health at high doses; recent evidence indicates an association between chronic low doses of MeHg and cytotoxic effects, mainly in the central nervous system [48]. Neuron-specific enolase (NSE), a pro-inflammatory cytokine secreted by astrocytes S100B, and glutamate receptor

(GRIA 1) levels were increased with mercury exposure. GRIA 1 and S100B levels discriminated between neurological symptoms in positive and negative groups [49].

The majority of plasmatic MeHg-Alb is transferred to the kidneys through a non-filtrating peritubular mechanism. [48]. Several markers of tubule damage and dysfunction have been used to identify Hg-induced renal damage including RBP and NAG [47]. These, however, would not be able to discriminate between Hg- and Cd-induced renal damage. A more recent study offers the potential of greater discrimination. Medina Perez and colleagues identified single nucleotide polymorphisms (SNPs) in glutathione-related genes that could modulate the pathogenesis of Hg nephrotoxicity [50].

4.6 Lead

Lead (Pb) is an important component of e-waste due to its well-known toxicity. The nervous system is the mostly affected target in lead toxicity. Positive correlations between blood lead and ADHD scores (inattentive, hyperactive/impulsive, and total scores, $\beta = 0.22-0.28$; $p < 0.001$) have been demonstrated [51]. However, a score of behavioral abnormalities may not prove a useful biomarker. In a study looking at plasma metabolite in two groups of adults, those with low plasma Pb level and high cognition vs. those with high plasma Pb level and low cognition, a significant reduction in docosahexaenoic acid, glycocholic acid, and arachidonic acid, and significant induction of p-cresol sulfate and phenyl acetyl-L-glutamine were observed [52]. Markers of tubule dysfunction, such as NAG [53] and kidney injury molecule 1 (KIM-1) [54], have been associated with Pb-induced nephrotoxicity.

Biomarkers of Exposure.

4.7 Arsenic

Levels of both As and Pb in the hair, fingernails, and urine of shallow groundwater-consuming residents were greater than those in the hair, fingernails, and urine of tap water-consuming residents. Interestingly, the As level in urine showed a linear relationship with the As concentration in groundwater ($R^2 = 0.91$) [55]. Urinary porphyrins have also been proposed as an arsenic biomarker of exposure. After chronic ingestion of As, dermatologic lesions have been used as a long-term biomarker of cumulative arsenic exposure [56] (Hughes FM, 2006). A study investigating novel biomarker sampling methods found a significant association between groundwater and fingernail arsenic concentration [57].

4.8 Cadmium

Blood cadmium levels are indicative of recent exposure rather than whole-body burdens. Urine cadmium levels primarily reflect total body burden. A biokinetic model can estimate intake based on urinary levels.

4.9 Chromium

Cr exposure determined by blood and hair analysis correlated with calculated exposure. [58]. Exposure to Cr(VI) can cause serious adverse health effects such as lung cancer and irritation of the skin and airways. Although assessment of Cr in urine

is not specific for Cr(VI) exposure, the total amount of Cr in urine is the most used marker of exposure for biomonitoring of Cr(VI). [59]. The half-life of Cr in the body is approximately 2 days; however, incomplete reduction of Cr (VI) to Cr (III) may cause longer Cr (VI) retention in tissues. For biomonitoring, urinary chromium has been widely used to assess recent total chromium exposure in the general population, whereas blood chromium is measured to assess Cr (VI) exposure, and hair chromium is used to assess chronic occupational exposure [60]. Specific exposure to Cr(VI) can be determined in erythrocytes [41]. Cr(VI) induced renal damage was found to correlate with Interleukin 18 (IL-18) in animal studies [60] (Tsai T-L 2017). A study by Hegazy [61] revealed that lactoferrin protected against Cr-induced acute renal failure in rats and significantly showed antioxidant, anti-inflammatory and antiproliferative properties, and down-regulated IL-18 and IGF-1.

4.10 Copper

Copper can be measured in blood, urine, hair, and nails to indicate exposure. [62].

4.11 Mercury

The most common biomarkers of exposure to mercurials are internal dose markers that encompass measurements of total Hg levels in hair, urine, and blood [47]. Hair MeHg and Tissue Hg (THg) correlations are reported to be high. [63]. Urinary total Hg levels are suitable to assess long-term exposure to both elemental and inorganic Hg [64].

4.12 Lead

Humans are exposed to Pb through inhalation, ingestion, and skin contact *via* food, water, tobacco smoke, air, dust, and soil. Pb accumulates in bones, brain, liver, and kidney. [65]. For example, lead inhaled in dust could be retained in the lungs, removed from the lungs by protective mechanisms and ingested, stored in bone, or eliminated from the body *via* the kidneys. Toxicity can be observed in the kidneys, blood, nervous system, or other organs and tissues. At any step after exposure, biological markers of exposure to lead can be detected.

Blood lead (Pb-B), mainly red cell lead, is a representative of soft tissue lead, and most widely used as a measure of body burden and absorbed doses of lead. Urine lead (Pb-U), as well as plasma lead (Pb-P), increases exponentially with increasing Pb-B under a steady-state situation and reflects recent exposure [66]. Pb-B can not differentiate between low-level chronic Pb exposure and a high-level short Pb exposure when based on a single B-Pb measurement. The toxicokinetic of Pb within various body compartments (i.e., cycling of Pb between bone, blood, and soft tissues) is complex. The determination of Pb in urine (U-Pb) is considered to reflect Pb that has diffused from plasma and is excreted through the kidneys. Nail-Pb is considered to reflect long-term exposure because this compartment remains isolated from other metabolic activities in the body. However, high variability in Pb levels measured in the same fingernails and toenails of various subjects, even after rigorous washing procedures have been reported; such lack of reproducibility suggests that nail specimens offer only limited scope in assessing exposure to Pb but teeth accumulate Pb over the long term and may provide a better source [67].

5. Conclusion

The world demand for electronic equipment has increased exponentially in the last decade resulting in a significant problem of how the resulting waste is handled. During the same period, the supply of key metals has been compromised by the limitation of the world supply. As a result, the requirement for recycling has become apparent. The policy of sending waste materials to poorer countries with few facilities has led to the realization that there is considerable health risks in the methods currently used to recycle waste materials. The need for monitoring increased with the realization that chronic exposure is as serious as acute exposure. There is a requirement for simple-to-use monitoring tests, which could be used on-site and checked if required in the nearest laboratory. This would require the use biomarkers of exposure and effect. Exposure should include air monitoring. Most biomarkers of effect are excreted in the urine, which provides a readily available source for monitoring. A prior requirement would be to establish normal ranges and acceptable limits for the biomarkers in the nonexposed population. If possible, these should be point-of-care tests, which could be utilized on-site. The current guidelines would need to be reviewed in the light of these findings. Only about 20% of the world's electronic waste is currently recycled and this needs to be increased for both economic and health reasons. More local recycling plants need to be set up and recycling procedures standardized. The supervision of the recovery of metals from dump needs to improve and formalized, particularly in sites located in the developing world. Increasing pressure on the producers of electronic equipment to demonstrate tracking the waste could help facilitate appropriate testing.

Methodology used for data searching

The data included in this review was obtained from searches of a number of resources including but not exclusively, The National Library of Medicine, PubMed; The World Health Organization, www.who.int; The European Commission, www.environment.ec.europa.eu; Web of Science, and The UN environment programme, www.UNEP.org/ietc. The search terms included e-waste, e-waste plus biomarker, and e-waste plus metal biomarker.”

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