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A review on the toxic E-waste killing health and environment – Today's global scenario

D. Beula [a,b], M. Sureshkumar [a,*]

[a] Vels Institute of Science, Technology and Advanced Studies (VISTAS), Pallavaram, Chennai 600117, India
[b] NPSB Arts and Science College, Patel Road, Medavakkam, Chennai 600100, India

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ABSTRACT

Electronic waste or e-waste is one of the fastest growing problems globally. E-waste comprises of many number of components, that includes toxic substances too which can cause an intense impact on human health and the environment if not handled properly. Waste electrical and electronic equipment (WEEE) is becoming serious threat to the whole world. Toxic substances present in the e-waste when mixed in air and soil, leads to harmful effects to the environment either directly or in directly. There is an evidence that when the groundwater and soil gets contaminated due to e-waste, may cause harmful effects in some agricultural or manufactured products. Risk assessments has predicted that, Lead (Pb) and Copper (Cu) originating/extracted from circuit boards during recycling process have the potential to pose serious health risks to the workers and local residents of Guiyu, especially children who involves in this process. Series health issues were faced by the peoples in Guiyu, due to the consequences of uncontrolled e-waste recycling, and it has been reported as a specimen study to other countries. This review focuses on stating the serious issues on e-waste, and its impact on humans' health, environment, and soil globally. Further, the current progress on e-waste management and serious care needed to protect the soil and environment worldwide for the next generation is strongly registered.

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1. Introduction

E-waste broadly covers the waste from all electrical and electronic appliances such as computers, mobile phones, digital music players, refrigerators, washing machines, Televisions, etc. [1–3]. E-waste generated from discarded EEE (Electrical & Electronic equipment) are commonly divided into 3 main categories: large household appliances, IT, and telecom (personal computers, monitors and laptops) and consumer equipment [4–6]. Nowadays miniaturization and efficient cloud computing networks, from remote locations, increases e-waste production from global economic growth and the development of pervasive new technologies. Components of electrical and electronic equipment such as batteries, circuit board, plastic casings CRTs, activated glass and lead capacitors are classified as e-waste. E-waste contains valuable metals as well as potential environmental contaminants [7–10]. Dismantling does not involve only unscrewing but also shredding, tearing, and burning [11–13]. Rapid growth of industries in India has resulted in increasing the volume of hazardous wastes production. Generation of E-wastes is increasing at the rate of 2 to 5% per year [14–16]. During last few decades, one special type of waste had raised a great concern in most of the developed and in developing countries, which is named as electronic waste.

The e-waste is treated as a global environmental problem. Because of generation/production of 20 million to 50 million metric tons of e-waste annually, it has been estimated that 75 to 80% of the e-wastes were shipped to developing countries especially in Asia and Africa for recycling and disposal [17–20]. The e-waste has raised great concerns in these countries, as it contains many components which are hazardous, toxic, and non– biodegradable [17].

The generic name for E-waste is technological waste. E-waste scenarios may affect the environment thereby affecting food chain, thus leading to exposure of the general population to mixtures of toxicants, like toxic chemical elements, polycyclic aromatic hydrocarbons, and persistent organic pollutants [21–23]. Once the electrical or electronic devices are discarded as waste, E-waste volume

* Corresponding author.
E-mail address: mskumar.sbs@velsuniv.ac.in (M. Sureshkumar).

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increases. And this, releases traces of various toxic, carcinogenic gases and metals which leads a threat to human health and has chance to contaminate the environment [24–27]. The countries which are mostly affected by informal recycling are China, India, and some African countries, where e-waste has been recycled or disposed with no regulation, using less advanced technology [28–31]. E-waste are hazardous wastes when they exhibit one or more of the following characteristics: toxicity, ignitibility, corrosivity or reactivity. The main concerns about electronic wastes are, when worn out or discarded; the hazardous materials present in it such as -CFC, PCBs, lead (pb), mercury (Hg), tin (Sn), cadmium (Cd), hexavalent chromium (Cr) in circuit boards, plastics, BFRs, will occupy the volume or space in landfill [32–35]. There are 10 states in the country that contribute to the generation of 70% of the total e- waste, whereas 65 cities have generated more than 60% of the total e-waste in India. According to a report of the United Nations, e-waste from old computers would jump by 400% in the year 2020 in China and by 500% in India compared to 2007. Also, in China e-waste from discarded mobile phones would be seven times higher in 2020 compared to 2007 and in India, 18 times higher [36–39]. In this context, we would like to highlight the situation which currently exist today that spoil the earth nature with respect to the tons and tons of e-waste production from the obsolete electrical and electronic devices globally. Moreover, the burden imposed on the workers exposed to toxic metals from these e-wastes must be considered. In order to overcome this impact on health and environment, we have to analyze, understand and make certain principles for the development of better future generation.

2. Generation of E-waste

The expectation of generation of waste (e-waste) from the obsolete or broken down electronic and electrical equipment in India was 1,46,000 tones in the year 2005 [40–43]. According to Green Peace Report, 3,80,000 tons of e-waste was generated by India in 2007. The Basel Action Network (BAN) have reported that 50–80% of e-waste from United States of America (USA) has been exported to countries like India, China, Pakistan, Taiwan and still more [40–42]. So, for studies on the generation of total e-waste by/from India, have revealed that, it was approximately 1,46,000 tons to 3,30,000 tons in a year; and was predicted to touch 4.7 million tons in 2011. This serious issue projected the growth of E-waste to be about 34%. Further it has been noticed that 30,000 computers from the IT industry in Bangalore alone will be obsolete every year. E-waste of 1000 tons of plastics, 300 tons of lead, 0.23 tons of mercury, 43 tons of nickel, and 350 tons of copper are generated in Bangalore every year [1]. This problem was found to increase in the National Capital Region (NCR) for nearly 25,000 workers, who are dealing with e-waste and involved at various levels and processing about 10,000–20,000 tons of e-waste every year. In addition to these, traces of harmful gases and toxic substances like heavy metals have been identified in the ground water, soil samples which contaminate the whole environment in the study area [24]. Municipal solid waste is the fastest growing stream of E- waste. It is estimated that 20–50 million tons of e-waste are produced annually worldwide; among which the United States, Western Europe, China, Japan, and Australia are the major producers [43–46]. Each electronic items participation in the annual e-waste production, E (kg / year), depends on each electronic items mass (M) kg, N its average life cycle, L (year) $E = MN/L$ [7,47]. Through recycling process, 95% of a computer parts are made as useful materials and 45% of a CRTs material can be retrieved [47–49]. Hazardous wastes in India can be categorized broadly in two categories viz (1) hazardous wastes generated in India from various industries (II) hazardous wastes imported in to or exported to India [14].

If and when obsolete computers, color CRTs and other electronic appliances are e-waste, the hazardous substances such as lead, mercury, cadmium etc., present in these can be recycled sometimes for their resource value and reprocessed for recovery from e-waste. Moreover, in India, used oil, battery wastes and other non-ferrous wastes such as Zinc, lead are commonly recycled [14]. This must be done to protect the soil resources and water resources from the e-waste. It is estimated that one gallon of used oil is sufficient to contaminate one million gallons of ground water. USA turns out 1.4 billion gallons of used oil every year, of which only 12% is recycled back into high quality

products and the rest is either burnt or disposed illegally [14]. It should be noted that, globally the production of e-waste will turn out at least 13.9 million tons per year, except Latin America, Africa, Canada, or Russia [7]. The global production of e-waste might change as economic crisis grows when new technologies are developed. Changes in technology may also affect the production of e-waste globally [7].

3. Burden of E-waste

Electrical & electronic waste contains multiple toxic metals of large variety of materials, some of which contain a range of toxic substances that can contaminate the environment and threaten human. To evaluate workers exposure to metals, a survey has been taken. The next problem is related to the disposal of dismantled material which may contain traces of harmful gases and other toxic substances like heavy metals as lead, cadmium, mercury etc. which are leached into groundwater through soil and thus pollute air, water, and soil of the area where they are disposed of [24]. Due to unsafe e-waste disposal methods, considerable contamination risks have been found. Landfill leachates can potentially transport toxic substances into groundwater, whilst combustion in an incinerator can emit toxic gases into the atmosphere [25]. Leaching from dumpsites, can make e-waste contaminants to enter aquatic system [7]. In Sweden, a study was assessed among 55 recycling workers and 10 office workers at three formal recycling plants. It is found that they were exposed to 20 potentially toxic metals in their whole blood plasma, urine and air filters using inductively coupled plasma – mass spectrometry following acid digestion analysis [50–53]. The city of Guiyu and its surrounding towns in the Guangdong region of China is the largest e-waste recycling site in the world [1,2].

Environmentally friendly recycling process/method has not been widely used though it is a promising approach to tackle the e-waste problem [44]. Most of the waste from electronic products include toxic substances such as cadmium, & lead in circuit boards; lead oxide and cadmium in computer batteries, monitor (CRTs), mercury in switches and monitors. Many of these substances are toxic and carcinogenic [36]. The smoke and dust particles from these toxic substances consist of carcinogens and other hazardous chemicals which cause severe inflammations and lesions including many respiratory and skin diseases [11]. Even though the circuits are burnt to hunt the valuable metals such as gold, platinum, cadmium, the wire coat of those consists of Poly Vinyl Chloride. Printed circuit boards may produce erotic smoke and the carbon particles from the toners are carcinogens, they may lead to lung and skin cancer [11]. A prolong exposure of these toxic constituents in the environment might cause a long-term crisis for both human and ecosystem health. We can dispose electronic wastes safely by the following ways.

- Give back to your electronic companies and drop off points
- Visit civic Institutions

- Donating your outdated technology
- Sell off your outdated electronic waste to a certified e-waste recycler [54].

The chemical composition of e-waste varies depending on the type of the discarded items. Most of the e-waste is composed of a mixture of metals particularly copper (Cu), aluminum (Al), and iron (Fe) attached to or covered with or mixed with various types of plastics and ceramic materials. A discarded PC with a CRT monitor typically weighs 25 kg, which consists of 43% metal, 23.3% plastic, 17.3% electronic components and 15% of glass [7]. Due to lead (Pb) and Copper (Cu) originating from circuit boards may cause serious health risks to workers and local residents of Guiyu, especially children [55–58]. Moreover, Endocrine disruption and neurotoxicity are considered as examples of main health burden issues [21].

4. Impact on health and environment

Electronic wastes contain numerous dangerous metallic contaminants, for example, lead, cadmium, beryllium and Brominated fire - retardants of numerous poisonous substantial metals. Lead goes into organic frameworks through food, water, air and soil. Kids are more helpless against lead harming than grown-up, so their sensory system and blood gets influenced [24]. According to WHO, aerial defilement with dioxins has brough about degrees of human introduction 15–56 times more, due to which dioxins were found in human milk, placentas and hair, demonstrating that dioxins are being taken by people from the air, water or food stuffs at adequate levels to represent a genuine wellbeing hazard. E-squander laborers and different occupants from Guiyu had middle blood serum BPDE centralizations of 126 ng/L and 35 ng/L individually, contrasted with referents from a close by town who had only 10 ng/L. Tests of human hair from towns close Taizhou contained PBBs, PBDEs, and PCBs at focuses up to 58 ng/g, 30 ng/g, and 182 ng/g individually [7]. Youngsters in Guiyu had essentially higher blood Pb and Cd levels and lower psychological capacities than kids from a close by control town. Revealed raised degrees of Cr focuses in umbilical string blood from newborn children in Guiyu, umbilical line Cr fixations were corresponded with DNA harm and were associated also with the mother's introduction to E-squander reusing. The creators infer that E-squander is an expected wellspring of hereditary change and may actuate cytogenetic harm [7].

Youngsters are viewed as more powerless to risky metal substances, and have higher basal metabolic rate contrasted with grown-ups. The sorts and portions of weighty metal introductions can prompt differing impacts on human wellbeing, particularly kid wellbeing. Lead introduction can bring about the creation of autoantibodies against neural proteins, including myelin fundamental protein and glial fibrillary corrosive protein, reasoning that lead can increase neurological illness, by expanding the immunogenicity of sensory system proteins. Because of Cd exposure, renal injury happens, which is generally a cylindrical brokenness which progress to move extreme kidney harm, diminished glomerular filtration rate (GPR). The harmfulness of methyl mercury to the creating cerebrum is perceived [28]. Health hazards like brain disorders, kidney, renal and neurological damage, mental retardation, behavioral problems, hearing impairment, lung disease, fragility of bones, are observed among the people of Bangladesh [59].

Heavy metals from e-squander introduction may involve hindering respiratory outcomes in kids. Side effects or maladies, for example, nose and throat aggravation followed by hack, wheezing and dyspnea or asthma happens after presentation to expanded degrees of certain weighty metals, for example, lead, cadmium, chromium, magnesium, nickel, chromium, mercury cobalt or vanadium [28]. Hazardous materials like lead, mercury, chromium from e-wastes leads to many diseases, particularly nickel causes skin damage, asthma, antimony causes skin irritation, hair loss, lung and heart damage, fertility problems. .Barium causes muscle weakeness, changes heart beat rate, paralysis and also affect aquatic system [60]. Exposure to the hazardous components of e-waste can occur through three ways: Inhalation from air, dietary, dust ingestion and skin contact. In order to know the amount of heavy metals, transferred in to the human body, it is necessary to find out the exposure sources and average daily doses of heavy metals from e-waste. In Jiangsu province (Xue et al.,2012) the workers' non-cancerous effects might be possible for pb. The study reveals an obvious cancer risk of pb, from these sites [61–63]. Also the human body burden and health effects of heavy metals includes 5 types of human tissues: placenta, umblical chord blood, blood and serum, hair and urine [61]. Dust and dermal samples of workers in informal e-waste recycling centers of chandigarh an Ludhiana, Punjab, India, were collected and presence of heavy metals like As, Cu, Cd, Cr, Ni, Fe, Zn, Pb, Ba were observed [64–66]. Reported adverse effects of chemical exposure to e-waste and e-waste recycling include: fetal loss, prematurity, low birth, and congenital malfunctions; abnormal thyroid function and thyroid development: neuro behavioral disturbances and genotoxicity [67].

5. Human body burden of heavy metals

The human body presentation to e-squander in placentas gathered after labor in Guiyu, demonstrated Cd levels in placentas. The pollutant levels in umbilical line blood because of e-squander presentation were higher. As per the symptomatic blood lead level rules for youngsters characterized by the U.S communities for illness control, kids with a blood lead level > or equivalent to 100 Â μg/L are at high risk because,5 Âμg per deciliter was adopted by CDC in 2012 as the upper reference range value for BLLs in children. Substantial metal level in human hair is found in the order Zn > Pb > Cu > Cd > Ni with the most elevated levels found in occupationally exposed workers. Pregnant ladies' presentation to hefty metals from e-squander has brought about different negative impacts, with increment in unconstrained premature births, actually births, untimely births, decreased birth loads and newborn child lengths, Apgar scores, neonatal conduct neurological appraisal scores and so forth [61] Unless appropriate security measures are taken, these harmful substances can fundamentally influence the strength of workers and others in the region - who physically sort and treat the waste – by entering the body:

- Through respiratory tracts
- Through the skin or
- Through the mucous membrane of the mouth and the digestive tract [32].

There are odds of mishaps like cuts and consumes during the destroying, corrosive showers, and cremation measure. Phthalates, for example, DEHPs in hex monomer structure impacts the improvement of testis, Butyl benzyl phthalate (BBP) and dibutyl phthalate (DBP) likewise perilous to generation and presentation to phthalates in pregnancy diminishes ano–genital file in male youngster, DINP and DIDP impacts liver and kidneys. Lead harms the circulatory framework and kidneys. Mercury can harm the kidneys and presentation to pregnant mother might influence fatal turn of events. When in contact with water it changes over into the more deadly methyl mercury, would turn into a piece of natural pecking order [32]. During the dismantling, shredding, acid baths and incineration process can meet accidents like cuts and burns. Phthalates such as DEHPs in hex monomer form effects the development of testis, Butyl benzyl phthalate (BBP) and dibutyl

phthalate (DBP) also hazardous to reproduction and exposure to phthalates in pregnancy reduces ano-genital index in male child, DINP and DIDP effects liver and kidneys.

6. Developmental neurotoxins in E-waste

The developing central nervous system is often more vulnerable to injury than the adult one. Of the almost 200 chemicals known to be neurotoxic, many are developmental neurotoxicants. Exposure to these compounds in utero or during childhood contributes to a variety of neurodevelopmental and neurological disorders [68]. The metals in e-waste include Cu, Al, Pb, Sn, Ni, Ag, Au, Ar, Cd, Cr, Hg, Indium, Ruthenium, Selenium, Vanadium and Zinc. Developmental neurotoxicity is due to certain chemicals, which in turn affect infants and young children leading to relatively low body weight. Developing fetuses and young children are at critical of neuronal growth, differentiation, migration, synaptogenesis, and myelination. The commonly assessed neurodevelopment end points include IQ, memory, language, gross and fine motor skills, attention, executive functions, and behaviour [32]. Lifelong disabilities will be caused due to neurodevelopmental diseases such as autism, attention deficit disorder, mental retardation and cerebral palsy . Glutamate is the major excitatory neurotransmitter in the brain tissues and is associated with learning and memory by the establishment of long – term potentiation (LTP) [44].

6.1. Neurotransmission and calcium homeostasis

Many heavy metals can affect neurotransmission and disrupt the calcium signaling pathway and thus interfere with synaptic functions. Calcium homeostasis refers to the maintenance of a constant concentration of calcium ions in the extracellular fluid of a human. Maintaining calcium at its set point includes many processes, which is important for

- Nerve transmission
- Nerve conduction
- Muscle contraction
- Cardiac contractibilit00y
- Blood clotting
- Bone formation
- Cell- to cell adhesion [44]

6.2. Neuroendocrine disruption

Thyroid – stimulating hormone (TSH), T4 and Triiodo thyroxine (T3) could have unique effects on the initiation and modulation of gene expressions for brain development [44]. In brain development process, thyroid – stimulating harmone and triiodo thyronine would have specific effects. Toxic metals like lead, mercury, or cadmium causes potential disruption of transthyretin levels in the brain and cerebrospinal fluid. Pregnant women and children in turn have reduced levels of FT4, due to lead exposure [44].

Apparently several toxicologic mechanisms may be involved in this (Fig. 1) mixture of known and suspected neurotoxicants. Heavy metals can induce oxidative stress by increasing the production of reactive oxygen species (ROS) and depletion of antioxidant reserves.Neurons have limited capacity to detoxify ROS and are particularly vulnerable to oxidative stress. Pb exposure increases the formation of superoxide anion ($\bullet O2^-$) and hydrogen peroxide ($H2O2$) in the central nervous system (CNS), which may interact with proteins, lipids, and DNA to induce apoptosis [44].

Potential developmental neurotoxicants in e-waste (Tables 1 and 2) and their adverse effects on neurodevelopment in children.

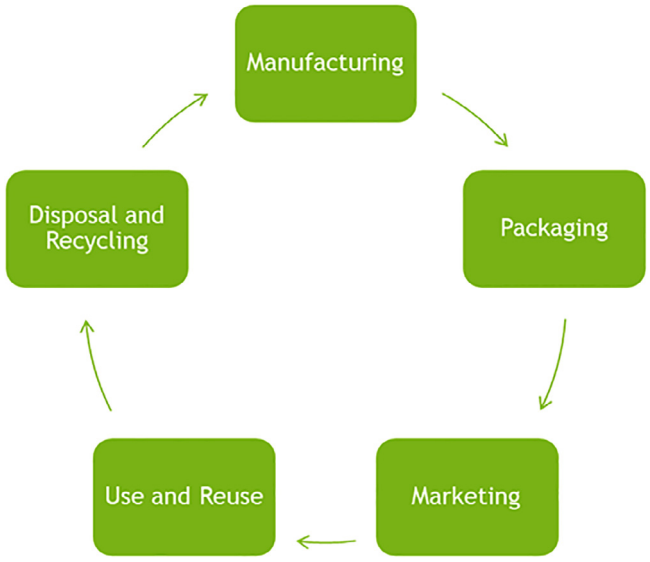

Fig. 1. Lifecycle of electronic products.

Table 1
Various e-waste sources and their constituents.

E-waste sources	Constituents
Solder in printed circuit boards, glass panels, and gaskets in computer monitors	Lead
Chip resistors and semi-conductors	Cadmium
Relays and switches, and printed circuit boards	Mercury
Galvanized steel plates and decorator or hardener for steel housing	Chromium
Cabling and computer housing	Plastics and PVC
Electronic equipment and circuit boards	Brominated flame-retardants
Front panels of CRTs	Barium, phosphorus, and heavy metals
Copper wires, Printed circuit board tracks.	Copper
Nickel–cadmium rechargeable batteries	Nickel
Lithium-ion battery	Lithium
Motherboard	Beryllium

Solid lines represent more – studied links; dashed lines indicates possible links in Fig. 2

7. Impact on the environment

Ba, Cu, Pb and Zn were identified as major pollutants, which contains e- waste dismantling sites. Lead was the chief metal of concern which possesses health risk to adults and children through ingestion of soil and dust. Hazardous index value for Pb and Cu from exposure to contaminated dust in adults was 0.73 and 0.57 respectively. High concentration of Ba, Cu, Pb and Zn was observed in the soil and dust samples, also in adults risk of cancer from exposure to Cr [69]. High potential e-wastes can also cause death or serious injury. They affect flora and fauna, due to their chemical active, Hazardous characteristics of e-wastes can damage the surroundings by fire hazards, at high temperature and pressure. Also, these wastes lead to combustion of other materials by oxidizing process. Micro-organisms and their toxins from e-wastes are responsible for diseases in animals and human [28].

Inappropriate disposal causes environmental pollution, threatening the soil contents and reduces crop production .In Bangladesh, 15% of the child worker die due to the effect of e-waste recycling, every year [59]..

Table 2
Disposal processes of e-waste and their environmental and health hazards.

Computer/e-waste component	Process	Potential occupational hazard	Potential environmental hazard
Cathode ray tubes	Breaking, removal of copper yoke and dumping	• Silicosis • Cuts from CRT glass • Inhalation or contact with phosphor containing cadmium or other metals	Lead, barium and other heavy metals leaching into ground water and release of toxic phosphor
Printed circuit boards	De soldering and removing computer chips	• Tin and lead inhalation • Possible brominates dioxin, beryllium, cadmium, and mercury inhalation	Air emission of the same substances
Dismantled printed circuit board processing	Open burning of waste boards	Toxicity of workers and nearby residents rom tin, lead, brominates dioxin, beryllium, cadmium, and mercury inhalation	Tin and lead contamination of immediate environment, including surface and ground waters, brominates dioxins, beryllium, cadmium, and mercury inhalation
Chips and other gold-plated compounds	Chemical stripping using nitric and hydrochloric acid along riverbanks	• Acid contact with eyes, skin may result in permanent injury • Inhalation if mists and fumes of acids, chlorine and sulfur dioxide gases can cause respiratory irritation to severe effects, including pulmonary edema, circulatory failure and death	• Hydrocarbons, heavy metals, brominates substances etc. discharged directly into river and banks. • Acidifies the river destroying fish and flora
Plastics from the computer and peripherals	Shredding and low-temperature melting	Probable hydrocarbon, brominates dioxin and PAH exposure to workers living in the burning works area	Emission of brominates dioxins and heavy metals and hydrocarbons
Secondary steel or copper and precious metal smelting	Furnace recovers steel or copper from waste	Exposure to dioxins and heavy metals	Emission of dioxins and heavy metals
Wires	Open burning to recover copper	Brominated and chlorinated dioxin and PAH exposure to workers living in the burning works area	Hydrocarbon and ashes, including PAHs discharged into air, water and soil

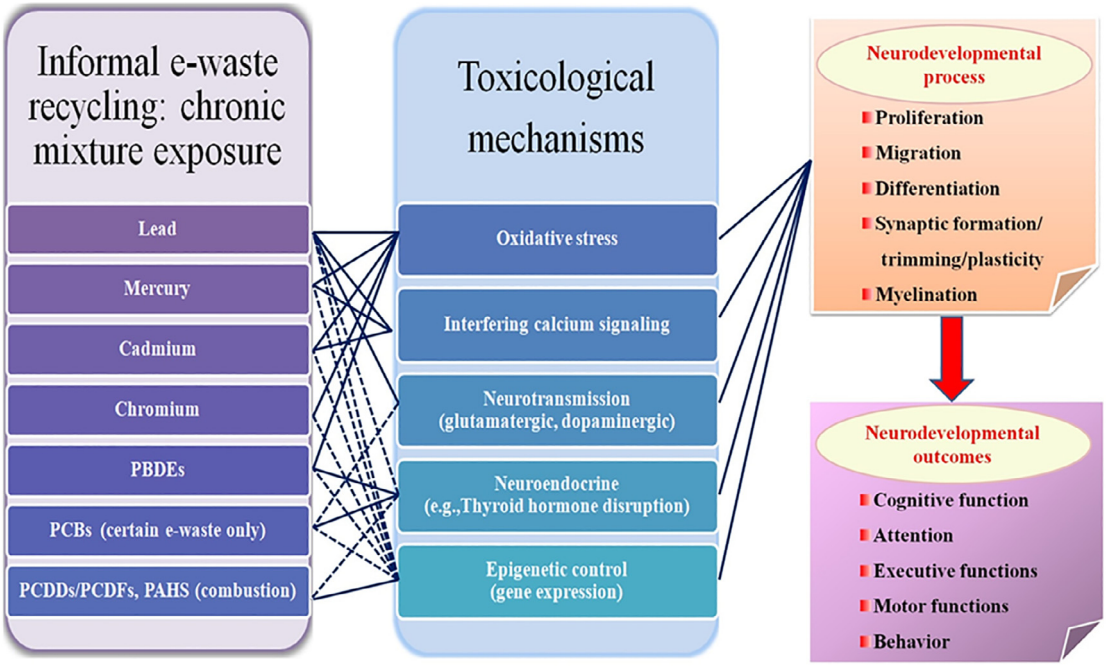

Fig. 2. Various electronic waste and their health impacts.

If non-biodegradable e-waste remains untreated for a long time, then it becomes a source of contaminated leachate, there by polluting the ground water and drinking water supply. Acidification of the soil also takes place from melting computer chips. The pollutant being a non-degradable and toxic may enter the biological food chain by absorption from plant roots via soil and ground water contamination. Incineration of E-waste can emit toxic fumes and gases, there by polluting the surrounding air. City of Guiyu, Hongkong is facing acute water shortages due to contamination of water resources. This is due to the disposal of recycling waste such as acids, sludge, etc. in rivers.

Some of the impacts of the current informal sector recycling are, release of toxins into the environment, loss of natural resources due to low recovery of metals and health impacts to workers [32].

PCBs accumulated in fishes and other organisms undergo bioaccumulation which result in high value in top level carnivore such as humans, PCB also absorbable via skin and inhaled or ingested causing neurotoxicity, liver damage, tumors, immune suppression

and behavioral changes and reproductive disorders, abnormal sperms [11]. Many e-waste contaminants are spread into the air via dust. Combustion of E-waste containing flame retardants has resulted in concentrations of the total PBDEs of up to 16.575 mg /m3 in material samples in Guiyu [7].

8. Conclusion

E-waste is omnipresent [7,17]. It is characterized by its unusual chemical compositions. Contamination associated with e-waste has already caused environmental degradation in the developing countries and adversely affected the health of the people, who live in and around e-waste facilities. Developing countries are targeted for e-waste disposal by rich countries. The hidden flow of E-waste results, environmental damage in the backyards and scrap yards of the developing countries. A major challenge is ahead in achieving, sustainable of e-waste management and to establish better understanding on human health impact [17]. Contamination associated with E-waste has already caused considerable environmental degradation in poor countries and negatively affected the health of the people who live there. However, the negative effects of the contaminants at these sites maybe reduced using standard remediation technologies. Some of the remediation technologies are

- Thermal desorption
- Excavation or dredging
- Surfactant enhanced aquifer remediation {SEAR}
- Pump and treat
- Solidification and stabilization. An environmental friendly affordable technological solution called phytoremediation will be an effective one [70].

CRediT authorship contribution statement

D. Beula: Conceptualization, Writing - original draft.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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