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# 2. Chemical Hazards of Soil Pollution Due To E-Waste

**Komal Jakhar**

Department of Chemistry,
M. D. University,
Rohtak, India.

## Abstract

Accelerated growth in the digital industry in the last few years has revolutionized today's world and led to enormous changes in our life style, society and economy. Substantial increase in the production, utilization and subsequent disposal of electric and electronic items leads to global environmental problem of e-waste. Soil is the most important and dynamic biogeochemical resource supporting numerous life forms and is the main receptor of e-waste. Severe soil pollution due to e-waste treatment, recycling and disposal causes manifold problems of environmental degradation, ecological imbalance, loss of biodiversity and risk to mankind. E-waste causes soil contamination due to a number of toxic chemicals such as polychlorinated biphenyls, dioxins, dibenzofurans, brominated flame retardants, polyaromatic hydrocarbons, mercury, lead, arsenic, cadmium, nickel and chromium etc. The toxic pollutants of e-waste causes a number of adverse health effects such on neurological complications, kidney damage, endocrine disorders, allergies, anaemia, genetic mutations, birth defects, lung disorders, digestive problems and skeletal deformations etc. This section deals with the different types of pollution caused by the hazardous chemicals during e-waste processing activities and the chemical toxicology of these pollutants.

**Keywords:** Soil contamination, e-waste, toxic chemicals, health hazards

## 2.1 Introduction:

Soil is a vital and versatile natural resource composed of inorganic minerals, organic matter, air, water and living organisms. Soil acts as a complex biogeochemical system and its dynamic composition in a particular area is a resultant sum of many factors such as parent rock materials, topography, climate, time and the living organisms inhabiting it. In ecological systems, soil serves many important functions such as water absorption, storage and purification; as a medium for plant growth; habitat to numerous micro and macro-organisms; nutrients storage and recycling; breakdown of organic matter; atmospheric alternations by absorption and emission of gases and water vapours and as a strata for construction and mining (Cachada et al., 2018)

Several natural and anthropogenic factors are responsible for soil pollution such as forest fire, volcanic eruptions, industrialization, acid rain, urbanization, mining, use of agrochemicals, metallurgical operations, disposal of waste, nuclear discharge, landfilling, discharge of sewage and accidental leakage etc. (Koul and Taak, 2018).

Soil pollution due to e-waste treatment and disposal is emerging as a crucial problem at global scale since potential accumulation of hazardous chemicals of e-waste in soil has a direct impact on food chains resulting in bio toxicity, bioaccumulation and bio magnification of toxic chemicals in living beings (Tang et al., 2010).

E-waste is the fastest growing problem of developed and developing economies as several metric tonnes of e-waste is generated globally every year. Use of electric and electronic items is exponentially increased in the last few years due to rapid advances in digital industry, urbanization, economic reforms, changed life style, numerous design options, low cost and high demand of electronics.

Proper and scientific treatment and recycling of e-waste has both environmental and economic significance as on one side e-waste contains numerous toxic chemicals that need treatment and disposal and on other side it contains some valuable and non-renewable metals such as platinum, gold, copper, silver and palladium which should be recovered and reused again (Pinto, 2008).

Unfortunately only one third of e-waste is systematically and scientifically treated and almost two third is treated in informal and unscientific setting imposing multiple problems of environmental pollution, ecological imbalance, loss of biodiversity and human health concerns.

E-waste is generally recycled by primitive techniques in poorly protected, unauthorized and informal settings especially in developing economies due to lesser scientific awareness, low labour cost, and greater Tran's boundary movement of electronic waste and less stringent environmental regulations (Perkins et al., 2014).

## 2.2 Complex Composition of E-Waste:

Various electric and electronic devices which are defective, outdated, discarded and requires disposal and recycling are termed as e-waste. All the type of house hold appliances, telecommunication devices, information technology gadgets, medical equipment's and electronic toys which are rejected are included in e-waste such as air conditioners, televisions, remotes, refrigerators, washing machines, microwaves, mobile phones, chargers, telephones, fax machine, computers, laptops, i-pods, DVD players, VCRs, typewriters, printers, copiers, compact discs, cameras, X-ray machines, thermometers, oximeters etc.

Due to rapid scientific growth in design and development of electric and electronic items, the chemical composition of e-waste is ever changing and complex (Tsydenova and Bengtsson, 2011). Chemically e-waste contain hazardous heavy metals, metalloids, plastics, glass, brominated flame retardants (BFRs), polychlorinated biphenyls (PCBs), ceramics, polymers, polychlorinated dibenzodioxins (PCDDs), polychlorinated dibenzofurans (PCDFs) and polyaromatic hydrocarbons (PAHs) (Oguchi et al., 2013). Details of varied toxic chemicals present in e-waste is shown in Table 2.1.

**Table 2.1: Various chemicals in e-waste**

| **Chemicals** | **Electric and electronic waste** |
|---|---|
| BFRs | Plastic covering of electronics, printed circuit boards, electric wire and cables |
| PCBs | Electric motors, capacitors, transformers, generators, ceiling fans, fluorescent lightning, dishwashers |
| PCDDs and PCDFs | Combustion by products of electric and electronic devices |
| PAHs | Combustion by products of electric and electronic devices |
| Mercury | LCD panels (gas discharge lamps) used in televisions, computers, projectors, photocopiers, cameras, calculators, fax machine, sensors, printed circuit boards, batteries, switches, ovens, heaters |
| Lead | Batteries, printed circuit boards, cathode ray tubes, light bulbs, plastic materials, switches, mobile phones, televisions, lasers |
| Cadmium | Batteries, cathode ray tubes, printed circuit boards, semiconductor chips, photocopier, switches, mobile phones, alloys, plastic materials |
| Arsenic | Semiconductor diodes, LCD panels, solar cells, cell phones, CD players, printed circuit boards, cameras, plastic materials |
| Chromium | Magnetic tapes, anticorrosion coating, plastic paint and pigments, cathode ray tubes, cell phones, solar cells, LCD panels, switches, wires, disk, CD players |
| Antimony | Cathode ray tubes, printed circuit boards, LCD panels, fax machine |
| Nickel | Batteries, cell phones, alloys, LCD panels |
| Beryllium | X-ray machine, ceramic component of electronics, power supply boxes |
| Lithium | Batteries, laptops, clocks, cell phones, cameras, toys |
| Aluminium | Air conditioners, cathode ray tubes, LCD panels, digital cameras |
| Barium | Microwave ovens, fluorescent lamps, cathode ray tubes, printed circuit boards |

| Chemicals | Electric and electronic waste |
|---|---|
| Iron | Microwave oven, LCD TV, printers, telephone, washing machine |
| Copper | Alloys, printed circuit boards, electrical and communication wirings |
| Zinc | Batteries, metal coatings, alloys, cathode ray tubes |

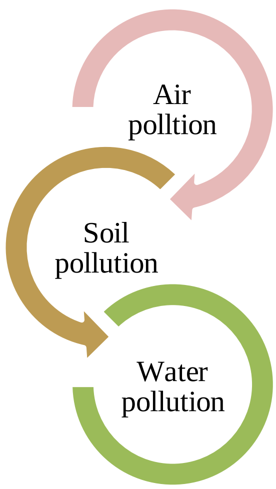
Note. Modified from Oguchi, M., Sakanakura, H., Terazono, A., 2013. Toxic metals in WEEE: characterization and substance flow analysis in waste treatment processes. Sci. Total Environ. 463–464, 1124–1132.

## 2.3 General Methodology of E-Waste Treatment and Associated Pollution Problems:

E-waste treatment causes release or emission of hazardous chemicals in aerial, aquatic or terrestrial systems which results in "correlated" contamination of air, water and land. Sometimes initial aerial emission of toxic chemicals causes air pollution, but settlement of these pollutants on surface soil and water bodies through dry and wet deposition causes water and soil pollution also. Similarly many pollutants from e-waste possess volatile to semi volatile nature and leaching tendencies.

Therefore release of toxic chemicals in soil initially causes soil pollution, but eventual vaporization or leaching of pollutants to ground water results in air and water pollution respectively. Moreover contaminated soil can widely translocated to other areas through winds, floods and by ground water transport which further intensify the contamination effects. (Moeckel et al., 2020). The general methodology of e-waste treatment and the associated pollution hazards is discussed here.

**Figure 2.1: Correlated air, water and soil pollution due to e-waste**



## a. Open burning and incineration:

Open burning of electronic and electric items is a common practice during informal e-waste treatment causing release of numerous toxic and carcinogenic chemicals. Burning of printed circuit boards, wires and cables in order to recover important metals results in severe contamination of air and soil by toxic heavy metals and organic pollutants (Zhou et al., 2013).

Plastic and polymer components of electronics are invariably associated with polychlorinated biphenyl and brominated flame retardants which on open burning causes heavy release of hazardous polychlorinated and polybrominated dibenzodioxins and dibenzofurans (Chen etal. 2012; Chan and Ming, 2013).

Incomplete combustion of e-waste results in emission of a large number of toxic persistent aromatic hydrocatrbons (PAHs) such as anthracene, chrysene, pyrene, naphthalene, fluoranthene, phenanthrene, benzo(a)anthracene, benzo(b)fluoranthene, acenaphthylene, benzo(a) pyrene and fluorine etc. In addition to air contamination, the soil samples near open burning sites of e-waste treatment areas also shows high concentration of persistent aromatic hydrocarbons (Moeckel et al., 2020).

Incineration is also most widely used thermo decomposition technique for electronic waste employing high temperature conditions in specially designed incineration chambers for complete combustion of waste materials along with subsequent release of ash, flue gas and heat. Incineration helps in significant reduction of volume of e-waste, utilization of generated heat for energy production and partial detoxification of hazardous chemicals, but generation of large amount of fly ash and bottom ash impose serious health risk though inhalation, dermal exposure and ingestion. Occurrence of various toxic heavy metals in fly ash in bio accessible forms is reported indicating toxic emissions through incineration (Tao et al., 2015).

## b. Landfilling:

Waste electric and electronic items are generally discarded in landfill sites on a large scale which leads to the problem of leaching and evaporation of hazardous chemicals (Ikhlayel, 2017). Landfilling causes formation of leachate i.e. liquid waste product containing diverse mixture of toxic chemicals which can percolate and cause severe contamination of soil and water resources (Li et al., 2009).

Leaching of dangerous chemicals such as Be, Cd, Co, Pb, Ni, Cr, Cu, B, Al and brominated flame retardants is reported due to disposal of e-waste through landfilling (Kiddee et al., 2013). Evaporation of volatile and semi volatile toxic chemicals from landfilling cause ambient air pollution in the surrounding areas (Lindberg et al., 2001).

## c. Dismantling, Shredding and Crushing:

Dismantling or disassembly includes manual or mechanical sorting of various part of discarded devices into valuable, reusable and waste items.

Several health risk and pollution problems are associated with these activities such as explosion of cathode ray tubes, accidental release of toxic chemicals, dermal exposures, spill of dangerous chemicals, inhalation of toxic fumes, burns and cuts (Tsydenova and Bengtsson, 2011). Breaking of cathode ray tubes, fluorescent tubes and de-soldering of printed circuit boards causes an exceptionally high release of toxic chemicals such as mercury, lead, barium, yttrium, cadmium, nickel, zinc, copper, antimony and sliver etc. (Bi et al., 2010; Lecler et al., 2015; Aucott et al., 2003; Zimmermann et al., 2014). High concentration of zinc, copper, arsenic, lead, cadmium and selenium is reported in surface soil and ground water near electronic recycling units (Pradhan and Kumar, 2014). Shredding of plastic materials of electronics causes ambient aerial emission of brominated flame retardants (Ceballos and Dong, 2016). Large particles released during crushing and shredding gets deposited on surface soil affecting soil aeration and functions (Zhang et al., 2012).

### d. Metallurgical Operations:

Metallurgical operations focuses on purification and refining of recovered metallic elements. Pyrometallurgical techniques employs incineration and smelting for obtaining target metals and results in emission of metal fumes, dioxins and other pollutants (Zhang et al., 2012; Priya and Hait, 2017). Hydrometallurgy involves dissolution and recovery of target metals by employing various acids, bases, halides, cyanides and thiosulphates and results in contamination of soil and water with used additives and heavy metals. (Zhang et al., 2012; Iannicelli-Zubiani etal., 2017). Acid leaching is the most common form of hydrometallurgy causes generation of acid waste and waste water which is normally discharged in open areas or in nearby streams causing contamination of soil, water and deep sediments. Lower pH causes increased solubility and phytoavailability of heavy metals which further intensifies the contamination risk (Quan et al., 2014).

## 2.4 Consequences of Soil Contamination:

Although soil has a natural capacity to store, degrade and detoxify a number of chemicals but extensive and unjudicial use of electronics and their subsequent treatment and disposal causes soil contamination, soil burdens, transportation of soil pollutants to different biological systems including human beings and numerous acute to chronic health hazards.

#### a. Altered Soil Composition:

The contamination of soil by e-waste alters its original composition and physical, chemical and biological properties which results in acidification, loss of soil organic matter, nutrient deficiency, desertification, salinization, loss of soil biodiversity and habitats (Cachada et al., 2018). A significantly lower pH and total organic count (TOM) is reported is soils contaminated due to e-waste recycling operations (Wu et al., 2015). The bio toxicity of a pollutant in the soil does not merely depend upon its concentration, in fact the physiochemical properties of soil greatly influence the bioavailability and potential mobility of pollutants (Tang et al., 2010).

Complex association of numerous microorganism in soil is associated with several key functions such as breakdown of organic matter, nutrient recycling, soil formation, and degradation of some pollutants. Significant alternation in variety, composition and function of soil microorganisms is reported in the highly polluted soils due to e-waste recycling (Liu et al., 2015).

## b. Soil Burdens:

Contamination of agricultural lands and vegetables with toxic metals is observed in vicinity of e-waste treatment sites (Lou et al., 2011). Critical level of heavy metals such as Pb, Cd, Ni, Cr and organic pollutants such as polychlorinated biphenyls and persistent aromatic hydrocarbons is reported in agricultural soils near e-waste recycling sites (Tang et al., 2010). Prersence of toxic polychlorinated dibenzo-p-dioxins and dibenzofurans is reported in contaminated soils of e-waste (Ma et al., 2008).

Relatively high concentration of brominated flame retardants (BFRs) such as polybrominated biphenyl ethers (PBDEs) and tetrabromobisphenol-A (TBBPA) and heavy metals like Hg, As, Pb, Cu, Zn, Ni, Cd is reported in sediments, soil and herb plants near e-waste dismantling sites (Wang et al., 2015).

## c. Transport Pathway of Soil Pollutants to Biological Systems:

Pollutant present in the soil can follow different routes such as leaching to the ground water, volatilization to atmosphere, degradation by chemical and microbial reactions within soil, conversion into less toxic form i.e. sequestration or assimilation in biological systems and food chains. Thus potential bio toxicity of a soil pollutant depends on many factors such as its bioavailability, uptake by living organisms and its metabolism, detoxification, excretion or accumulation in their bodies. (Cachada et al., 2018).

Plants grown in contaminated soil absorb toxic chemicals by their roots and transport and accumulate them in different tissues. Another plausible mechanism of toxin uptake by plants is direct foliar absorption from polluted atmosphere (Lou et al., 2011). Generally most of the toxic pollutants enters in different food chains through plants and shows bioaccumulation, bio amplification and enhanced bio toxicity at different tropic levels.

### d. Routes of Exposure in Human Beings:

The toxic chemicals from e-waste causes several health complications in human being through contaminated air, water and soil. Human exposure to the hazardous chemicals occur through inhalation, skin contact or dermal absorption and oral intake of contaminated water and food (Perkins et al., 2014).

Massive and critical exposure of populations mainly takes place through intake of contaminated plant products grown in polluted soil and water. Another potential route of indirect exposure is intake of contaminated animal food such as dairy products, poultry products and fishes (Lou et al., 2011; Moeckel et al., 2020).

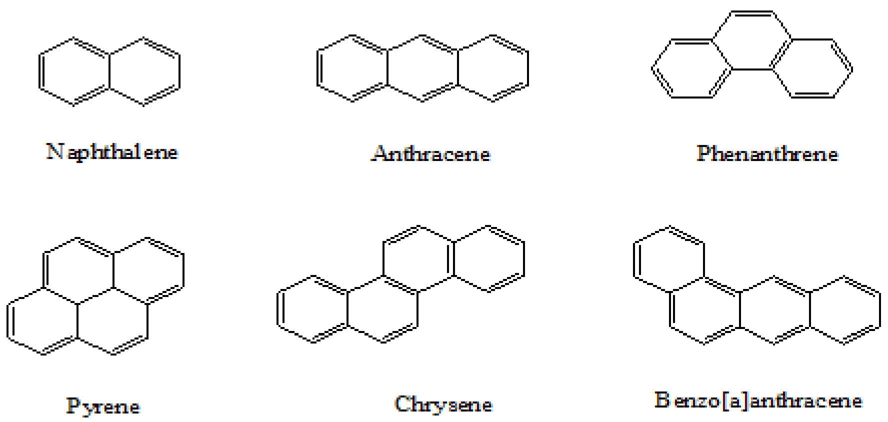
## 2.5 Chemical Toxicology of Dangerous Pollutants:

Chemical toxins of e-waste causes numerous health complications through genetic mutations, immune disorders, cellular malfunctioning's, enzyme inhibition, hormonal imbalance, damage to vital organs and systems, neonatal outcomes (Grant et al., 2013). Toxicology of some potentially hazardous pollutants from e-waste is discussed in this section in order to get a comprehensive idea about chemical hazards of e-waste.

### a. Polyaromatic Hydrocarbons:

Polyaromatic hydrocarbons (PAHs) represents a group of highly lipophilic aromatic compounds with longer half-lives, and are known to resist degradation. PAHs shows tendency to persist, bio accumulate and bio amplify in food chains and shows carcinogenic, mutagenic and teratogenic potential (Cachada et al., 2018). PAHs are known to cause a number of health hazards such as nausea, vomiting, breathing problems, skin allergies, diarrhoea, kidney damage, immune disorders and liver problems. (Abdel-Shafy and Mansour, 2016).

**Figure 2.2: Hazardous polyaromatic hydrocarbons**



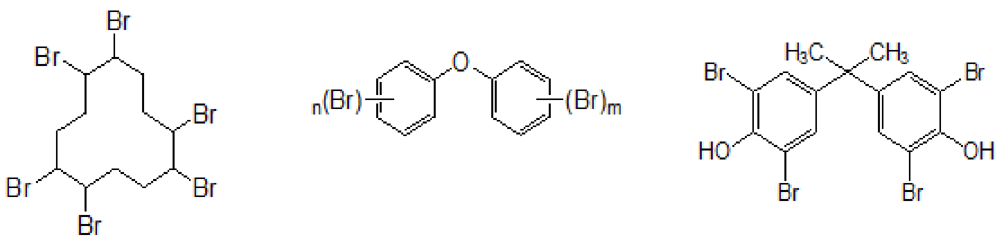

### b. Brominated Flame Retardants:

Brominated flame retardants (BFRs) are the bromoorganic compounds invariably added to plastic components of electronic and electric items to reduce their flammability. BFRs belongs to the group of persistent organic compounds and shows toxicity through bioaccumulation and bio persistence.

A number of different BFRs are present in e-waste such as hexabromocyclododecane (HBCD), polybrominated diphenyl ethers (PBDE), polybrominated biphenyls (PBBs), bisphenol-A ethers, and tetrabromobisphenol-A (TBBP-A) etc. (Wang et al., 2015).

BFRs can causes cancer, diabetes, malfunctioning of thyroid and estrogen, impaired memory and learning, reproductive disorders and abortions (Kim et al., 2014).

**Figure 2.3: Brominated flame retardants**



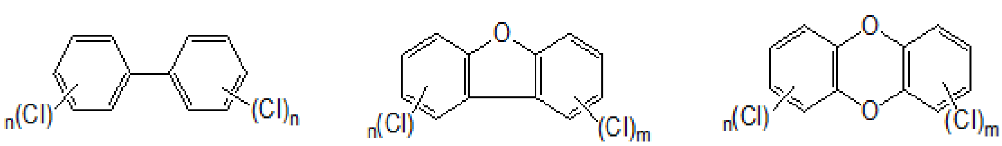

HBCD PBDEs TBBPA

**c. Polychlorinated Biphenyls and Dioxins:**

Polychlorinated biphenyls (PCBs), polychlorinated dibenzo dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) are extremely dangerous highly lipophilic group of chlorine containing organic compounds with marked tendency of persistence and bioaccumulation across food chains.

These polychlorinated pollutants are carcinogenic in nature and can cause mental retardation, neurobehavioral disorders, thyroid dysfunction, diabetes, immune disorders, endometriosis and developmental disorders (Arisawa et al., 2005).

**Figure 2.4: Polychlorinated biphenyls, dioxins and dibenzofurans**




PCBs PCDFs PCDDs

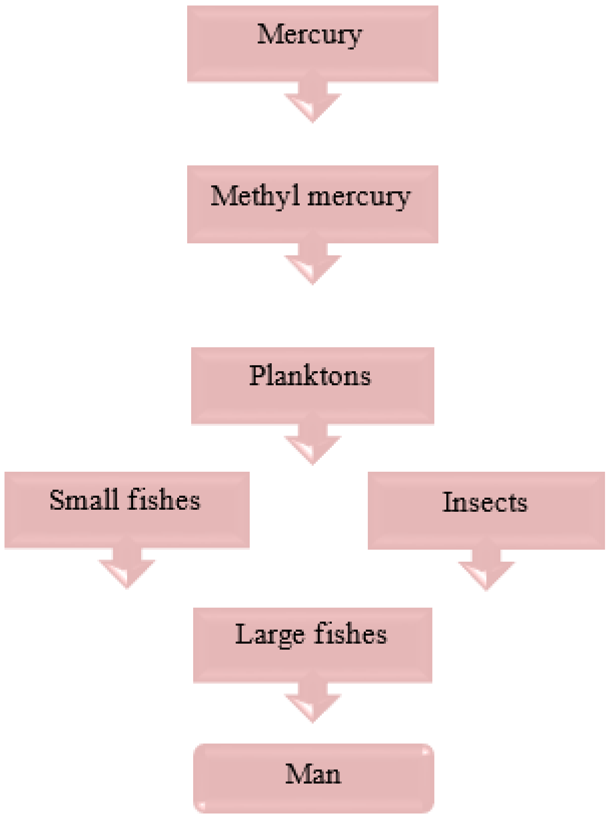
## d. Lead:

Lead shows several adverse health effects such as nervous disorders, anaemia, birth defects, sterility, cancer, high blood pressure, interference in metabolism of calcium and vitamin D, abortions and kidney malfunction. (Pinto, 2008; Goyer, 1993).

## e. Mercury:

Mercury is extremely toxic in nature and can cause convolutions, tremors, headaches, speech and visual impairments, cognitive and motor dysfunction, memory loss, insomnia, neuromuscular effects, mental retardation, behavioural disorders, genetic disorders and kidney damage (Rice et al., 2014). Extreme toxicity of mercury is reported in Japan as Minimata disease affecting thousands of people. Main cause of massive contamination was the bioaccumulation and bio amplification of toxic methyl mercury through food chains. Dietary intake of fishes contaminated with methyl mercury causes nervous and brain disorders, permanent paralysis, metabolic malfunctioning and genetic disorders (Kudo et al., 1991).

**Figure 2.5: Propagation of hazardous mercury in a food chain**




## f. Arsenic

Arsenic shows potent toxicity in humans and affects vital metabolic pathways. Pentavalent arsenic called arsenate shows resemblance with phosphate and interfere in ATP generation and energy production through citric acid cycle. Trivalent arsenic called arsenite is more toxic form of arsenic as it reacts with thiol and sulfhydryl group present in enzymes and proteins resulting in enzyme inhibition and metabolic disorders (Hughes, 2002). Arsenic can also cause nervous disorders, skin cancer, renal malfunction, diabetes mellitus, cardiovascular problems and liver damage (Singh et al., 2011).

### g. Cadmium:

Cadmium shows bioaccumulation in kidney, liver and bones and causes metabolic disorders, enzyme inhibition, DNA damage, birth defects, cancer, kidney, liver and bone deteriorations, lungs dysfunction and nervous disorders. (Rani et al., 2014; Perkins et al., 2014). Most severe cadmium poisoning is reported in Japan as itai-itai or brittle bone disease and is associated with painful symptoms of extremely fragile bones, joints weakening, kidney failure and skeletal deformations (Aoshima, 2016).

### h. Chromium:

Hexavalent chromium compounds shows high bio toxic potentials and can cause inhibition of respiratory enzymes, dermatitis, allergies, ulceration, perforation of nasal septum, kidney damage, lung cancer, bronchial asthma, liver and stomach disorders (Costa and Klein, 2006).

### i. Beryllium:

Toxic effects of beryllium are skin allergies, damage to mucous membrane, conjunctivitis, respiratory disorders, cancer, heart problems and fatal lung disease. Acute beryllium disorder caused by short term exposure results in severe cough, sore throat and pneumonia like symptoms. Berylliosis or chronic beryllium disease caused by prolonged exposure results in shortness of breath, inflammation of lungs, chest pain, heart disease and weight loss (Wambach and Laul, 2008).

### j. Antimony:

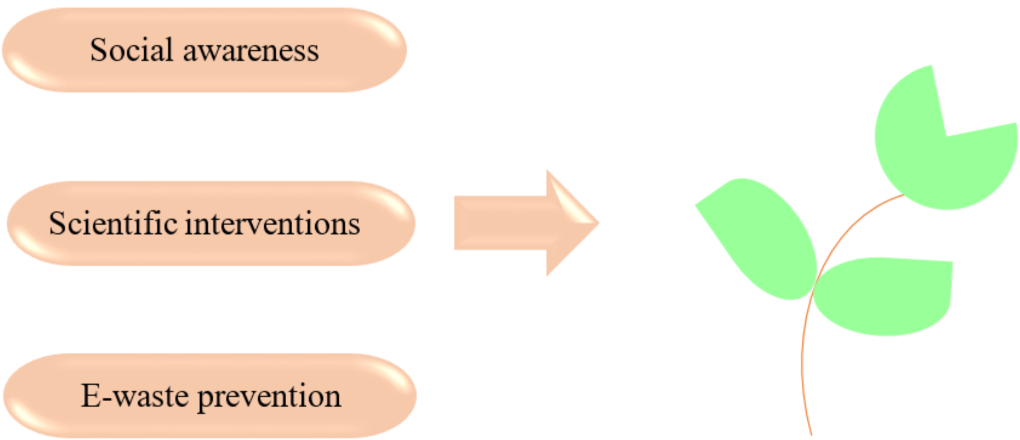
Antimony shows district toxicological profile and causes dermatitis in the form of pustules and eruptions called ‘antimony spots’. Antimony also causes diarrhoea, loss of appetite, muscle weakness, vomiting, chronic bronchitis, genetic defects, respiratory irritations, kidney damage, pneumoconiosis and myocardial degeneration (Sundar and Chakravarty, 2010).

## 2.6 Conclusion:

Generation of e-waste, its improper recycling and disposal has become an emerging environmental problem in today’s world endangering our natural resources, delicate ecological associations, biodiversity and human health.

Comprehensive and dedicated planning, monitoring and regulation of e-waste is urgently required particularly in poor and developing economies. In order to reduce the rate of e-waste generation, the prime focus should be on pollution prevention by enlightening social awareness against detrimental effects of e-waste on both abiotic and biotic systems. In parallel combination, high-tech and environmentally benign methods should be developed both for e-waste treatment as well as for environmental protection and remediation in order to protect our mother nature.

**Figure 2.6: Prevention of E-Waste for a Better Tomorrow**

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