E-waste as a challenge for public and ecosystem health

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5.1 The composition, fate, and toxic compounds in E-waste

Recently, the use of electrical and electronic items has been escalated rapidly with the growing importance of information and communication technology to the world economy. However, simultaneously, the life span of those items was reduced along with the drastic changes in features and the capabilities of the electronic and electrical items (Nnorom and Osibanjo, 2008). As a cumulative result of these occurrences the amount of end-of-life electronics and electrical items known as E-waste has been increased steadily. The approximate estimates highlight the average annual global E-waste volume is about 65.4 million tons in 2017 (Alabi and Bakare, 2017). Most of the world's E-waste is from Asian region and during 2014 and it was about 16 metric ton with representing 3.7 kg/inhabitant. However, in the means of waste quantity per inhabitant, the Europe is in the climax with 15.6 kg/inhabitant while in total with 11.6 metric tons (Bob et al., 2017). Developed countries play the leading role on production of E-waste compared to developing and poor countries. The studies show the United States and China are the leading E-waste producers in 2014 with approximately 32% from global E-waste production followed by Japan, Germany, and India. About 80% of E-waste from developed countries are been transported to the developing and poor countries as they have lesser labor cost and minimum legislations (Awasthi et al., 2016). China, India, Pakistan, Nigeria, and Ghana are the top most countries that receive E-waste from developed countries and it is important to note that most of those exports are illegal (Awasthi et al., 2016).

The major substances in the E-waste are ferrous metal, nonferrous metal, glass, plastic, and others (Link, 2014). Iron and steel accountable for most common substances in E-waste by weight and plastics score as second. Mobile phones, personal computers (PCs), entertainment items such as MP3 players, computer games and peripherals, refrigerators, televisions, washing machines, stereo systems, dryers, toys, toasters, kettles, and other household items are some of the common components that can be seen as E-waste and more of these products are ended up in landfills, rubbish dumps, and recycling centers creating several complications for waste management officials, policy makers, and residents (Bob et al., 2017). The figure becomes more problematic as the entering of E-waste into waste stream is accelerating continuously. Regarding PCs, about 20 million was expired and entered into the waste during 1994 and when it comes to 2004, the amount reached up to more than 100 million (Widmer et al., 2005). This fast growing nature of E-waste has obtained due to the global market for PCs is still away from saturation and the average life span of PCs is declining gradually. CPUs, for example, had 4−6 years of lifetime in 1997 and when in 2005, the lifetime has fallen to 2 years (Widmer et al., 2005). PCs mostly contain with plastic, Pb, Cd, and Hg and it has been calculated that 500 million PCs accommodate for about 2,872,000 ton of plastic, 718,000 ton of Pb, 1363 ton of Cd, and 287 ton of Hg (Widmer et al., 2005). However, mobile phones, calculators, PCs, printers, and other small information technology equipment only account for more or less 7% of E-waste in 2014 (Bob et al., 2017). These facts elaborate that the E-waste is one of the fastest growing and most complex types of solid wastes in this rapid growing economies (Bob et al., 2017).

The types of substances in E-waste can be categorized into two major categories according to their toxicity: hazardous and nonhazardous. Most of heavy metals, in particular, Cd, Cr, Pb and Hg, chlorofluorocarbon, polycyclic aromatic hydrocarbons (PAHs), polybrominated diphenyl ethers (PBDEs), polychlorinated biphenyls (PCBs), and polychlorinated dibenzo-*p*-dioxin furans (PCDD/Fs) are some of the groups that fall into hazardous category. All of these compounds are able to affect the quality of the ecosystem and the improper E-waste handling is the foremost reason to these detrimental effects. There are various techniques that is being used regarding informal E-waste recycling techniques including gold recovery from printed circuit boards with cyanide salt leaching or nitric acid and mercury amalgamation, open burning of printed circuit boards that cables for component separation or for solder recovery, heating and acid leaching of printed circuit boards, toner sweeping, plastic chipping, and melting, burning of wires to recover copper, and manual dismantling of cathode ray tubes, and open burning of plastics (Song and Li, 2014). All of these nonsafe methods are able to generate harmful consequences on environment and human community. During dismantling processes, for instance, dioxins, persistent organic pollutants, PAHs, PCBs, persistent halogenated compounds, hexavalent chromium, PBDEs, and heavy metals are been released and these pollutants persist in the environment for long period of time (Orlins and Guan, 2016).

5.2 Impacts of E-waste on ecosystem health

The impact of E-waste is not limited for a recycling or dumping site and it extends beyond the processing sites creating possible adverse impacts to the whole ecosystem: soil, water, air, and other biota. It is reported that the effluents from E-waste

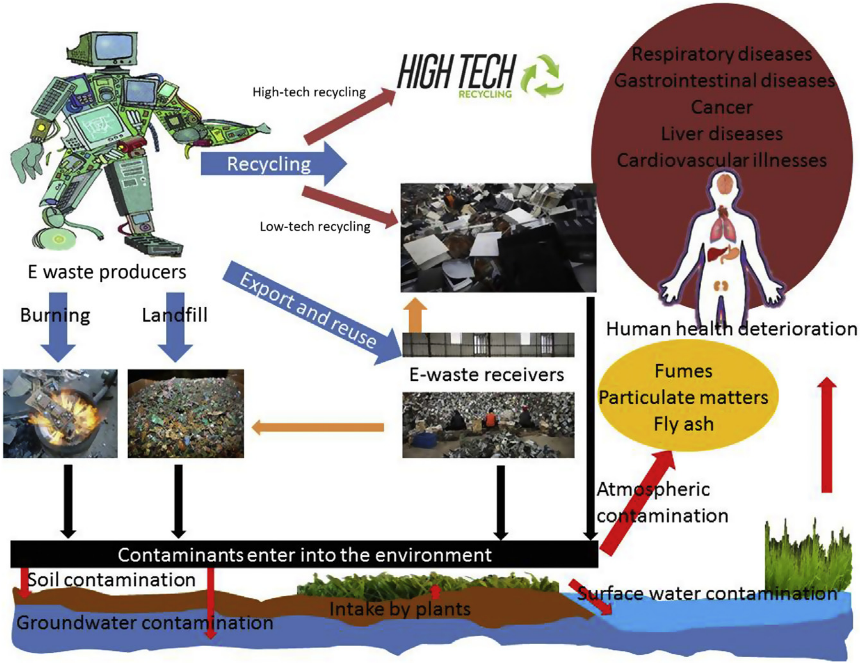

Figure 5.1 General cycling pathway of E-waste and their human and ecosystem impacts.

recycling centers and the dumping sites are rich with heavy metals and suspended particulate matters. The impact of E-waste is not same for all the time even for same E-waste product. The concentration of the contaminants in E-waste depends on the age of the particular E-waste product. Therefore composition of the E-waste is spatially and temporally heterogeneous. Fig. 5.1 shows the general cycling pathways and the ways that E-waste depletes the environment and the human health. Although the recycling is responsible to remove or delay the release of contaminants into the environment, large amount of contaminants may still accumulate in landfills and end up within the environment. It has been documented that the annual Cu production from E-waste is 820,000 and 5000 tons of Cu are annually release into the environment despite recycling (Robinson, 2009). PBDEs are mixed with plastics to form the flame retardants. However, there is no any chemical bond in between plastics and PBDEs and therefore, at the landfill sites and the recycling centers PBDEs may leach into the environment and it may create different human and ecosystem health impacts (Robinson, 2009). As such different contaminants from E-waste have the ability to deplete the quality of the ecosystems.

5.2.1 Impacts of E-waste on soil

Waste recycling centers are one of the most significant sources that affect soil quality as these sites are responsible to release metals and other contaminants with higher concentrations. However, the use of primitive methods to process E-waste is the major problematic reason to contaminate the soil due to E-waste (Awasthi et al., 2016). Most of E-waste dumping in landfills and the chemicals and toxic materials can easily harm to the nature of the natural soil (Dharini et al., 2017). The soil can be contaminated by either direct such as aerial contamination or indirect such as through irrigation processes and thereafter the plants will also be affected as the heavy metals like compounds are persisting for a longer time periods with their nonbiodegradable characteristics. Most of the times the waste from E-waste recycling centers release effluents to the open lands if there are no drain lines or open waters (Link, 2014). It is reported that most of these effluents are in acidic conditions and with having low acidic levels and higher contaminant content, these toxic pollutants become bioavailable state (Link, 2014). Moreover, the Ca contents of the water that coming from the E-waste recycling or dumping cites responsible for changing the pH of the natural soil. This may cause for nutrient depletion in the plants in the particular area (Dharini et al., 2017). Therefore not only creation of harmful health impacts but also the E-waste in soil can cause reduction of harvest in commercial agricultural systems. It may create long term impacts on country's economy. Except from the release of effluent into the open land, the recycling operations that are carried out on open soil also have significant impact for the deterioration of soil quality. It is important to note that Pb, Ba, and Cd have low or zero recycling efficiency and therefore, it is obvious to have higher metal concentrations in the discharges of the E-waste recycling centers which are able to contaminate the nearby soils with an unprecedented scale (Fu et al., 2008). For example, the soil samples that analyzed from nearby areas of E-waste recycling centers that located in Loni, India, has reported with extreme metal concentrations. Almost all the tested soil samples were above the safe concentrations and the highest Pb concentration was 174 times higher than the standards limits. Other than that Cd, Hg, Cr, and Zn have also found with exceeded concentrations in different percentages (Link, 2014). The containing of toxic elements in soil may create nutrient depletion in the plants. With the presence of toxic elements disturbs to the nitrogen absorption by plants. Nitrogen is an essential element for plants as it participates into the photosynthesis process and it is a major building block of the plant proteins. Therefore the contamination of soil by E-waste results the degradation of plant nutrient content (Dharini et al., 2017). Moreover, the studies have been showed that the soils that contaminated by E-waste are also in the deficiency of potassium which is an important component in plant growth and development (Dharini et al., 2017). Most of the E-waste recycling centers experiencing the same incidence as soil are the direct victim of releasing pollutants. In China, the former E-waste recycling centers are the places that have worst soil pollution status. It has been recorded that the metals in soil have greatly exceeded the standard levels and it has been recorded as 17.1 mg/kg of Cd, 11,140 mg/kg of Cu, 4500 mg/kg of Pb, and 3690 mg/kg of Pb. Most of the times the soil is receiving this much of metals due to burning of circuit boards or other metal chips (Luo et al., 2011). Notably, these contaminated statuses are also common to the agricultural lands that situated in nearby areas. Luo et al. (2011) show that the metal concentrations in agricultural soil have exceeded the maximum permissible levels and they warn that these situations are greatly affect agricultural crop production as well as the human population that consume those food items. Further, studies show that these metals are tending to fractionation within the soil and the highest percentages are reported with the residual fraction and the carbonate absorbed phases. The percentage of exchangeable fraction is comparatively low in E-waste contaminated soils. However, the percentage of this fraction in paddy and other agricultural soils are higher than that of the present and former E-waste recycling places (Luo et al., 2011). Therefore it poses higher threat to the whole ecosystem as the exchangeable fraction is responsible to pollute all other ecosystems especially aquatic environment and biota. As for Ni, Cd, and Zn specifically the exchangeable fraction is far higher than other metal fractions and therefore, the mobility of these metals are much greater than other metals and simultaneously their threat to the environment is also high (Luo et al., 2011).

5.2.2 Impacts of E-waste on aquatic ecosystems

Waste water is one of the major transport pathways regarding contamination of aquatic systems with E-waste (Brigden et al., 2005). It has been stated that the E-waste leachate contains several genotoxic and mutagenic substances (Alabi and Bakare, 2017) and most importantly, the underground water has received more mutagenic characters than raw leachate as the underground water table is the place where accumulation took place. Studies have shown that the quality of the water that coming from E-waste recycling and the processing centers do not meet the general water quality requirements in the means of pH, total dissolved solids, hardness, chlorides, and conductivity (Dharini et al., 2017). Apart from the direct contamination of aquatic ecosystems by E-waste leachate, deposition of dust particles that emitted from E-waste recycle or dumping sites also have the potential capability to contaminate the surface waters (Robinson, 2009). Studies show that the presence of dioxins, furans, PAHs, PCBs, and polybrominated diphenyls which are persistence toxins and heavy metals in E-waste have direct involvement with this mutagenesis nature and therefore aquatic organisms fall into a great danger. Moreover, studies show that considering the E-waste recycling cites the highest contamination next to the soil occurs at the pond or available aquatic ecosystems as most of the E-waste combustion processes are taken place at the presence of water source due to the requirement of continuous and easy supply of water for metal extraction processes (Luo et al., 2011). Therefore higher concentration of metals could be found from the water and the sediments. Other than that the most of the mismanaged E-waste recycling centers are tend to dump the waste near to water resources and eventually the pollutants from those E-wastes will be ended up in the aquatic environments (Luo et al., 2011). Nanyang River is one of the rivers that have contaminated with E-waste from different E-waste recycling centers in China and it has been revealed that the sediments have PBDE concentrations up to 16,000 ng/g (Luo et al., 2007b) and most importantly the carp fish from the river also have up to 766 ng/g of PBDE accumulation in fresh weight basis (Luo et al., 2007a). Pb, Ag, Cr, and Se like heavy metals also have been found in the water streams that located near to E-waste centers and the metal concentrations have been found with four or more times compared to drinking water (Pradhan and Kumar, 2014). This fact describes the contamination status of aquatic ecosystems and the whole ecosystem will be contaminated through these waters and the results would be more problematic for the community. Pradhan and Kumar (2014) have studied on heavy metal accumulation in water streams near to E-waste recycling and handling centers and reported that the elevated Cr, Cu, Cd, Fe, Pb, Zn, and Al concentrations as 0.60, 0.70, 0.05, 0.46, 0.04, 1.89, and 3.67 mg/L, respectively. It should be noted that the metal accumulation states are significantly different from these values in the residential area that 500 m away from the E-waste recycling center. The metal concentrations in the area of 500 m away to the E-waste site were reported as 0.02, 0.05, 0.002, 0.32, 0.002, 1.46, and 0.06 mg/L, respectively. Therefore the impact of E-waste is not a simple matter as these metals and all other toxic compounds eventually accumulate in bio systems and at the end the human community and all other ecosystems will be affected badly and irreversibly.

5.2.3 Impact of E-waste on atmosphere

It has been reported that the E-waste recycling centers and open burning sites are the major participants for release different contaminants from E-waste to atmosphere. Most importantly, the atmosphere is the major responsible media for contamination of human body through inhalation, ingestion, and dermal contact pathway. It has been reported that the workers in one of the E-waste recycling sites in China inhale dust containing air and those dust have reported with Cd, In, Sn, Sb, Pb, and Bi and their concentrations as 1.5, 1.3, 91, 13, 89, and 1 mg/m^3, respectively. Most of these heavy metals are carcinogenic and with the time the people may have to suffer with different types of health impacts. Several studies have revealed these point sources are responsible to release heavy metals, particulate matters, dioxines, and many of toxic compounds into the atmosphere that create different detrimental effects to the whole ecosystem (Chan and Wong, 2013). However, the type of contaminants in atmosphere will be different according to the types of work available in the area or near vicinity. For instance, the recycling centers and dumping sites that are mostly involved with circuit boards are tend to release massive amounts of Pb and Cu into the atmosphere, and in a site that located in New Delhi, India, has reported with Pb and Cu as 375,000 and 2670 mg/kg, respectively (Brigden et al., 2005). Also the battery workshops have reported with higher concentrations of Pb and Cd. For example, in an E-waste recycling center in India has reported Pb and Cd as 133,000 and 200,000 mg/kg, respectively, in dust samples (Brigden et al., 2005). As atmosphere is one of the major mediators for suspension of these metals, those contaminants are able to stay for a longer time, transport for a longer distances other than deposition on surfaces (Brigden et al., 2005). These metal particles are tend to adhere with particulate matters and this particulate matters are one of the major pollutants from E-waste, in particular, with open burning of E-waste. All of these metals that adhered to particulate matters tend to deposit on impermeable surfaces, open water bodies, and also intake by plants after deposit on soil surfaces. It has been found that the plants in nearby areas of the E-waste recycling centers are having higher metal concentrations and the weed species are found with the higher metals concentration than agricultural crops. Interestingly, the shoot area of those plants shows the highest metal accumulation (Luo et al., 2011). Therefore it has been suggested that apart from soil and irrigation water the contaminated atmosphere may be one of the major reasons for contamination of soil, aquatic environment, and human population. With the burning of E-waste for different processes, a heavy smoke is formed and the metallic and other compounds are released into the atmosphere. With this release the plants which are growing within the near vicinity are the first victims and with the deposition of metals on plants the folial uptake could take place (Luo et al., 2011). Bi et al. (2009) have found that there is a mechanism to folial uptake of Pb with atmospheric deposition with the presence of metal smelting factories in nearby area. Moreover, this fact could further elaborate the fact of having higher metal concentration in leafy edible parts than that of the root edible parts of a plant which grow near to E-waste recycling, processing, or dumping areas (Luo et al., 2011).

5.3 Impacts and associated risks of E-waste on public health

The improper handling, inadequate processing, and recycling methods are the foremost reasons that pose detrimental health impacts on human beings in particular for the immediate workers in those work lines in E-waste centers (Orlins and Guan, 2016). Almost all of these informal workers do not follow safety guidelines and use standard protective equipment due to their lack of knowledge about E-waste, the lack of knowledge about detrimental impacts, and because of financial issues. Identification of E-waste exposure is complex process as there are many of exposure routes, exposure sources, and different possible exposure time periods. Moreover, these different hazardous chemicals have same inhibitory, synergic, or additive effects (Alabi and Bakare, 2017) and at last a cumulative impact will be taken place. The exposure variability comes from different means: type of the E-waste, quantity of the E-waste, management processes of the E-wastes, age of the site, the human activities within the area, and the physical vulnerability such as pregnant women and children population (Alabi and Bakare, 2017).

However, the main route for heavy metal exposure to human is ingestion (90%), with the chain of soil—crop—food. Also the crop residuals use as foods for livestock and it also promotes the negative impacts on both human and animals and so that the soil contamination by electronic waste is a key start to pose a greater threat to the whole ecosystem (Fu et al., 2008). Table 5.1 depicts some of the studies conducted on human health impacts on E-waste and the pathways of contaminants that affect human health along with the concentrations of the contaminants. It is reported that in China, most of the E-waste recycling centers are located in rural regions and these rural areas are the hotspots for producing the most of food items

Table 5.1 Selected studies on E-waste and the human health impact by different E-waste contaminants.

Country	E-waste related site	Crop or food item/ intake	Contaminant	Concentration	Intake pathw
China	Taizhou, Zhejiang province	Rice	Cd	0.7 µg/kg/day	Dietary
China	Taizhou, Zhejiang province		Pb	3.7 µg/kg/day	Dietary
China	Taizhou, Zhejiang province	9 food groups	PBDE	44.7 ng/day/kg	Dietary
Indonesia	Astana Anyar district	PM 2.5 dust	Dust	186.75 $\mu g/m^3$	Inhalation
Indonesia	Parung Panjang district	PM 2.5 dust	Dust	229.9 $\mu g/m^3$	Inhalation
China	Taizhou, Zhejiang province	Brest milk	PBDE	572 ng/day/kg	Dietary
China	Taizhou, Zhejiang province	Duck eggs	PBDE	52.83 ng/day/kg	Dietary

China	Guiya	9 food items	PBDE	931 ng/day/kg	Dietary
China	Lin'an	9 food items	PBDE	1.94 ng/day/kg	Dietary
Ghana	Agbogbloshie, Accra	Soil	15 PAHs	390 ng/g	Dietary, inha dermal co
Philippines	Caloocan	Soil	15 PAHs	2900 ng/g	Dietary, inha dermal co
Vietnam	Bui Dau	Soil	15 PAHs	7200 ng/g	Dietary, inha dermal co
China	Wenling	Chicken meat	PBDE	1.8 ng/day/kg	Dietary
		Eggs		11.7 ng/day/kg	Dietary
China	San Men Country	Duck eggs	PBDE	0.54 ng/day/kg	Dietary
China	Qingyuan	Egg	PBDE	200.14 ng/day/kg	Dietary
China	Guiya	PM 2.5 dust	Heavy metals		Inhalation
South China	Guangdong province	Vegetables	Heavy metals	Cd: 0.4−4.22 mg/kg/DW Cu: 6.54−44.3 mg/kg/DW Pb: 1.21−14.4 mg/kg/DW Zn: 79.9−243 mg/kg/DW	Dietary
India	Varanasi district	Vegetables	Heavy metals	Cd: 1.1−4.5 mg/kg/DW Cu: 20.5−71.2 mg/kg/DW	Dietary

to the whole community, in particular rice (Fu et al., 2008). As rice is a staple food for most of the Asians including China and this can be the major source for heavy metal intake of human in the particular regions. Fu et al. (2008) showed that the rice samples received from the fields which are located near vicinity of a E-waste recycling centers exceeded the national standards for heavy metal contents in rice by 15.3%, 31%, and 100% for Hg, Cd, and Pb, respectively. It has been noted that the animal food sources are highly responsible for contamination of human body. For PBDE, the studies showed that the food items such as freshwater fish, seafood, chicken, and other meets and eggs have higher concentrations of PBDE (Song and Li, 2014; Chan and Wong, 2013). It was found that the nonherbivorous fish contain higher levels of PBDE and this fact could be true for most of other persistent pollutants as those could accumulate for a long time and thereafter, the humans who consume those fish species will get more pollutants into their body and finally contaminants will be accumulated in body tissues (Xing et al., 2009). Studies revealed that several food items in some of the countries have exceeded the US EPA reference dosages for dietary intake of PBDEs (100 ng/day/kg): the nine food items received from the Guiya, China, which is one of the popular E-waste recycling centers, have recorded with 931 ng/day/kg of PBDEs which is nine times more higher than the reference dosage (Chan et al., 2013). Moreover, duck eggs from Taizhou, China, and chicken eggs from Qingyuan, China, also have reported with increased PBDEs concentrations with the values of 104 and 200 ng/day/kg, respectively. These values are also exceeded the US EPA reference values (Labunska et al., 2013; Zheng et al., 2012). Both of these areas also have E-waste processing and recycling activities. Table 5.1 shows the records of different food items for different contaminants with their values which are collected from E-waste processing and recycling areas. Most importantly, it has been reported that the infants are also in great danger due to contaminated foods in mothers' diet. Studies conducted with breast feeding mothers in E-waste recycling and dumping areas have revealed that the breast milk which is the only food for 6-month-old infants has increased PBDE concentrations as 572 ng/day/kg. It should be noted that these values are 57 times higher than that of control areas (Song and Li, 2014).

Moreover, apart from dietary intake the inhalation pathway also one of the major reasons for the contamination of human body with E-waste contaminants especially for occupational workers. A study conducted in China has revealed that the mean concentration for PCBs through inhalation has showed fivefold higher than that of the control area (Xing et al., 2009). Not only from the direct exposure but also with the particulate matters that release form the different unsafe processes: grinding, melting, roasting, and open burning have considerable involvement for creating health impacts on the community. These particulates have the ability to create acute and chronic toxicological impacts when deposit on human respiratory track (Zheng et al., 2016). Most importantly the health risk that occurred due to inhalation of E-waste contaminant is severely affected on children rather than adults. This fact has been proved with a respiratory disease analysis done by Li et al. (2008) and it has been reported that 80% of children suffered from respiratory diseases due to bad air quality in the experimental area.

Although the dermal contact pathway has not received a significant research interest, it also serves as one of the pathways that is able to create adverse health impact on the human community. Studies have revealed that the adult people in Taizhou area which is one of the E-waste recycling cites in China has exposed to 0.363 pg/day/kg of toxic equivalents and for children this value was higher as 2.3 pg/day/kg and both have exceeded the value for the control site (Ma et al., 2008). At the same time the workers who are employed in E-waste collection, dumping, and incineration sites are kind of direct victims for the toxic contaminants that release from the E-waste. In China, for instance, there are higher number of incidences with skin damages, headache, vertigo, chronic gastritis, gastric ulcers, and duodenal ulcers on people who worked in a plant that do the incineration of circuit boards and separation of plastics from electrical waste (Alabi and Bakare, 2017). Contamination of groundwater with E-waste leachate reduces its quality and the palatability for human usage. These contaminants such as heavy metals, dioxins, furans, PAHs, PCBs, and polybrominated diphenyls are able to create human gastrointestinal irritation and laxative effects, abnormal sperm quality, chromosome aberration, DNA damage, reduced fecundity, and adverse birth effects (Alabi and Bakare, 2017).

Heavy metals are kind of dangerous compounds that can affect human health in several ways. Most of those heavy metals are potential carcinogens. Kidneys can be damaged by different heavy metals and Cd is one of those metals that creates an impact on the menacing proportion. It is important to note that Cd has long biological half-life in humans and therefore, both short- and long-term impacts can be expected. Pb is a metal that has a direct influence toward central nervous system as well as deterioration of intelligent quotient, and children are therefore one of the greater victims of Pb contamination. Mercury is a potential mutagenic compound and can greatly affect neurons (Fu et al., 2008).

Several studies have conducted experiment on analysis of different body parts for accumulation of contaminants which are common for E-waste recycling and dumping cites (Guo et al., 2010; Ni et al., 2014; Zhao et al., 2013). It is a great indicator for contaminants loading on human body, exposure levels, and human health risk due to E-waste contaminants. The placentas that collected after child birth have reported with different heavy metals such as Cd, Pb, Ni, PCDD, and PBDEs with elevated concentrations (Zhang et al., 2011). For example, placentas collected from mothers who live in Guiya town, China where a well-known E-waste collection center located, has reported 301.4 ng/g of Pb and it is as two times as higher than that of control site (165.8 ng/g). Moreover, in Taizhou, China the placental PBDE concentrations were reported as 19 times higher than that of control site (19.5 and 1.02 ng/g, respectively) (Leung et al., 2010). Similarly, the umbilical cord that collected from the people that live near to E-waste collection and recycling centers also showed increased pollutant concentrations such as heavy metals, PCDD, and PBDEs than that of control cites. Most importantly the Cd concentration in umbilical cords has exceeded even the WHO safety limits (5 μg/L) (Li et al., 2011). The foremost factors to these accumulation statuses could be the mother's involvements in E-waste recycling activities and living near to those E-waste collections and recycling centers during pregnancy and before the pregnancy and father's involvements with E-waste recycling and handling activities (Song and Li, 2014). Therefore the exposure of parents to the E-waste could create adverse health impacts on future generation and the continuous exposure therefore should be eliminated as much as possible even the lifestyles of those people are adhered with their occupation. Assessing of human blood and serum is one of the most common methods to detect the human body burden due to E-waste contaminants as human blood represents the body condition than any other specimen. Among several E-waste contaminants blood Pb level has gained considerable interest and those studies have reported that most of the people who are associated with E-waste are victims of escalated blood Pb levels, particularly, in children. According to US center for disease control, the blood Pb content higher than 100 μg/L, is considered as elevated blood Pb condition and most of the studies that conducted blood assessment for children in E-waste handling sites have found elevated blood Pb levels for children. Interestingly, with the increment of age the blood Pb level also has increased creating more detrimental health burdens on older children than younger ones (Zheng et al., 2008). Other than heavy metals PCB, PBDEs, and dechlorine also have found with elevated concentrations in human blood and among the different human groups, the occupational human group, who are integrated with E-waste recycling and handling are in greater danger (Ren et al., 2009). Other than blood, the human urinary fluids also show elevated contaminant concentrations as the urinary system is also responsible for detoxification and accumulation of contaminants. Zhang et al. (2016) have showed that the persons who are living near to the E-waste dismantling sites are having accumulated bisphenols in their urine and this has been interconnected with the elevated oxidative stress in those people. Overall study shows that 90% of people from affected area are having bisphenols in their urine and the concentrations are significantly higher than that of the urine samples from reference areas. Therefore these E-wastes have ability to disturb human health, living condition, and the physical fitness.

As a metabolic end product, human hair is gaining significant interest since it has the ability to represent contamination status of the human body. Several studies are there that focused on human hair to determine the E-waste contaminant levels in the human body (Zheng et al., 2011a,b; Leung et al., 2010). It has been found that the hair samples collected from workers and residents form E-waste recycling centers and nearby are having heavy metals such as Cd, Cu, Ni, Cr, Mn, As, PBDEs, and PCDD/Fs with increased concentrations than the control population (Leung et al., 2010; Zheng et al., 2011b; Ma et al., 2011). Children and neonates are the most sensitive group for the body burden due to E-waste exposure as they have number of intake pathways such as through breast milk and placental exposure, hand to mouth activities, and up taking of comparatively higher volume of air and lower toxic elimination rates. This fact has been showed clearly with the study conducted in Guiya E-waste recycling center in China. It shows, due to exposure of heavy metals in PM 2.5 particulate matters, the female adult population bears carcinogenic health risk as 59−60 cancer cases/million population and under the same conditions children under 10 years bear 90−91cancer cases/million population (Zheng et al., 2016).

The exposure to the toxic chemicals is not the only health problems that related with the E-waste. Studies have showed that suffering with hearing problems also a kind of detrimental health impact that is related to the E-waste handing, processing, and recycling workers (Carlson, 2016).

5.4 Safety measures for final disposal and future perspectives

At the end of a use of E-waste most of E-wastes do not recycle but reuse and dump in landfills. It has been noted that 80% of electrical and electronic items are transported to the poor and developing countries as illegal transfers or donations. However, after end of the use of electronic and electrical items the best method is recycling as that E-waste bulk contains numerous valuable metals and some other economically valuable components. Recycling have the ability to recover 95% of useful materials from a computer and therefore recycling has high positive impact on economic status of a country. However, the way in which the recycling is done have many of environmental impacts. E-waste recycling integrates with the disassembly and destruction of the equipment to recover new materials (Cui and Zhang, 2008). Most of the times the recycling is done without following a standard or safety procedure and therefore most of contaminants release from those E-wastes are subjected to create problems on different ecosystems. However, the recycling is always better than landfilling of E-waste and incinerated E-waste (Hischier et al., 2005).

Meanwhile, concerning the potential environmental and health issues, the management policies and legislations on E-waste have been raised as an important matter. Therefore from recent decades, the policies and legislations have been extended where they applied throughout the product lifetime: design, manufacture, consumption, and end-of-life, focusing a major responsibility on producers based on extended producer responsibility (Nnorom and Osibanjo, 2008). The government involvement of a particular country is a basic need in E-waste recycling sector in order to avoid the illegal E-waste transportation and handling. For example, since several decades, China has stated as one of the major country that receives illegal E-waste and therefore they have implemented number of E-waste recycling centers that do not follow basic safeguard techniques and so that the human exposure is critical in China. However, the Chinese government has involved into some extent on this issue and as a result of their management practices and the legislations, they could achieve the positive results. The percentage of children that has increased blood Pb levels, than WHO recommended levels was reduced with above government action (Huo et al., 2007; Zheng et al., 2008; Liu et al., 2011). Apart from the government responsibility to increase the effectiveness of the recycling, reuse, and disposal mechanisms of E-waste it is needed to have strong interactions among electrical and electronic item producers of the particular country. Because most of production processers are located out of the countries and for the recycling process the connection and the integration with the producers is highly required. It is true that some of large companies such as Apple, Philips, and Samsung have their own reverse logistic processes and however, this independence makes disadvantages at the point of reuse of those electrical and electronic items (Azevedo et al., 2017). Most importantly the public awareness is a basic need in order to mitigate the health risks that is created by E-waste exposure.

The future of the E-waste will be more complicated with the present procedures of recycling and the disposal. The global production of the E-waste will be changed along with the economic developments of the countries. It is strongly accepted that the total number of electrical and electronic waste production is highly correlated with the country's GDP (Robinson, 2009). Therefore the economic growth will be supported for more E-waste production. With the presence of this growing trend, the high tech mechanisms and more safeguards for the E-waste handling and management are required to establish the stability of ecosystems and human health quality despite of detrimental impacts from E-wastes.

References

Alabi, A.O., Bakare, A.A., 2017. Genetic damage induced by electronic waste leachates and contaminated underground water in two prokaryotic systems. Toxicol. Mech. Methods 27, 657–665.

Awasthi, A.K., Zeng, X., Li, J., 2016. Environmental pollution of electronic waste recycling in India: a critical review. Environ. Pollut. 211, 259–270.

Azevedo, L.P., Da Silva Araújo, F.G., Lagarinhos, C.A.F., Tenório, J.A.S. & Espinosa, D.C. R. 2017. E-waste management and sustainability: a case study in Brazil. Environ. Sci. Pollut. Res., 1–12.

Bi, X., Feng, X., Yang, Y., Li, X., Shin, G.P., Li, F., et al., 2009. Allocation and source attribution of lead and cadmium in maize (*Zea mays* L.) impacted by smelting emissions. Environ. Pollut. 157, 834–839.

Bob, U., Padayachee, A., Gordon, M., Moutlana, I., 2017. Enhancing Innovation and technological capabilities in the management of e-waste: case study of South African government sector. Sci. Technol. Soc. 22, 332–349.

Brigden, K., Labunska, I., Santillo, D., Allsopp, M., 2005. Recycling of Electronic Wastes China and India: Work Place & Environmental Contamination Amsterdam. Greenpeace Research Laboratories, UK, The Netherlands, pp. 1–56.

Carlson, K., 2016. Electronic waste worker health: studying complex problems in the real world. Proceedings of the Eighth International Conference on Information and Communication Technologies and Development. ACM, p. 35.

Chan, J.K.Y., Wong, M.H., 2013. A review of environmental fate, body burdens, and human health risk assessment of PCDD/Fs at two typical electronic waste recycling sites in China. Sci. Total Environ. 463, 1111–1123.

Chan, J., Man, Y., Wu, S., Wong, M., 2013. Dietary intake of PBDEs of residents at two major electronic waste recycling sites in China. Sci. Total Environ. 463, 1138–1146.

Cui, J., Zhang, L., 2008. Metallurgical recovery of metals from electronic waste: a review. J. Hazard. Mater. 158, 228–256.

Dharini, K., Cynthia, J.B., Kamalambikai, B., Celestina, J.A.S., Muthu, D., 2017. Hazardous E-waste and its impact on soil structure, IOP Conf. Ser.: Earth Environ. Sci., 80. p. 012057.

Fu, J., Zhou, Q., Liu, J., Liu, W., Wang, T., Zhang, Q., et al., 2008. High levels of heavy metals in rice (*Oryza sativa* L.) from a typical e-waste recycling area in southeast China and its potential risk to human health. Chemosphere 71, 1269−1275.

Guo, Y., Huo, X., Li, Y., Wu, K., Liu, J., Huang, J., et al., 2010. Monitoring of lead, cadmium, chromium and nickel in placenta from an e-waste recycling town in China. Sci. Total Environ. 408, 3113−3117.

Hischier, R., Wäger, P., Gauglhofer, J., 2005. Does WEEE recycling make sense from an environmental perspective? The environmental impacts of the Swiss take-back and recycling systems for waste electrical and electronic equipment (WEEE). Environ. Impact Assess. Rev. 25, 525−539.

Huo, X., Peng, L., Xu, X., Zheng, L., Qiu, B., Qi, Z., et al., 2007. Elevated blood lead levels of children in Guiyu, an electronic waste recycling town in China. Environ. Health Perspect. 115, 1113.

Labunska, I., Harrad, S., Santillo, D., Johnston, P., Yun, L., 2013. Domestic duck eggs: an important pathway of human exposure to PBDEs around e-waste and scrap metal processing areas in Eastern China. Environ. Sci. Technol. 47, 9258−9266.

Leung, A.O., Chan, J.K., Xing, G.H., Xu, Y., Wu, S.C., Wong, C.K., et al., 2010. Body burdens of polybrominated diphenyl ethers in childbearing-aged women at an intensive electronic-waste recycling site in China. Environ. Sci. Pollut. Res. 17, 1300−1313.

Li, Y., Xu, X., Wu, K., Chen, G., Liu, J., Chen, S., et al., 2008. Monitoring of lead load and its effect on neonatal behavioral neurological assessment scores in Guiyu, an electronic waste recycling town in China. J. Environ. Monit. 10, 1233−1238.

Li, Y., Huo, X., Liu, J., Peng, L., Li, W., Xu, X., 2011. Assessment of cadmium exposure for neonates in Guiyu, an electronic waste pollution site of China. Environ. Monit. Assess. 177, 343−351.

T Link, 2014. Impact of E-Waste Recycling on Water and Soil. New Delhi, India.

Liu, J., Xu, X., Wu, K., Piao, Z., Huang, J., Guo, Y., et al., 2011. Association between lead exposure from electronic waste recycling and child temperament alterations. Neurotoxicology 32, 458−464.

Luo, Q., Cai, Z.W., Wong, M.H., 2007a. Polybrominated diphenyl ethers in fish and sediment from river polluted by electronic waste. Sci. Total Environ. 383, 115−127.

Luo, Q., Wong, M., Cai, Z., 2007b. Determination of polybrominated diphenyl ethers in freshwater fishes from a river polluted by e-wastes. Talanta 72, 1644−1649.

Luo, C., Liu, C., Wang, Y., Liu, X., Li, F., Zhang, G., et al., 2011. Heavy metal contamination in soils and vegetables near an e-waste processing site, south China. J. Hazard. Mater. 186, 481−490.

Ma, J., Kannan, K., Cheng, J., Horii, Y., Wu, Q., Wang, W., 2008. Concentrations, profiles, and estimated human exposures for polychlorinated dibenzo-*p*-dioxins and dibenzofurans from electronic waste recycling facilities and a chemical industrial complex in Eastern China. Environ. Sci. Technol. 42, 8252−8259.

Ma, J., Cheng, J., Wang, W., Kunisue, T., Wu, M., Kannan, K., 2011. Elevated concentrations of polychlorinated dibenzo-*p*-dioxins and polychlorinated dibenzofurans and polybrominated diphenyl ethers in hair from workers at an electronic waste recycling facility in Eastern China. J. Hazard. Mater. 186, 1966−1971.

Marselina, M., Roosmini, D., Salami, I., Cahyadi, W., 2016. Analysis of respirable particulate exposure and its effect to public health around lead smelter and e-waste processing industry in West Java, Indonesia. J. Phys. Conf. Ser. IOP Publishing, p. 012071.

Ni, W., Huang, Y., Wang, X., Zhang, J., Wu, K., 2014. Associations of neonatal lead, cadmium, chromium and nickel co-exposure with DNA oxidative damage in an electronic waste recycling town. Sci. Total Environ. 472, 354–362.

Nishimura, C., Horii, Y., Tanaka, S., Asante, K.A., Ballesteros Jr, F., Viet, P.H., et al., 2017. Occurrence, profiles, and toxic equivalents of chlorinated and brominated polycyclic aromatic hydrocarbons in E-waste open burning soils. Environ. Pollut. 225, 252–260.

Nnorom, I.C., Osibanjo, O., 2008. Overview of electronic waste (e-waste) management practices and legislations, and their poor applications in the developing countries. Resour. Conserv. Recycl. 52, 843–858.

Orlins, S., Guan, D., 2016. China's toxic informal e-waste recycling: local approaches to a global environmental problem. J. Clean. Prod. 114, 71–80.

Pradhan, J.K., Kumar, S., 2014. Informal e-waste recycling: environmental risk assessment of heavy metal contamination in Mandoli industrial area, Delhi, India. Environ. Sci. Pollut. Res. 21, 7913–7928.

Qin, X., Qin, Z., Li, Y., Zhao, Y., Xia, X., Yan, S., et al., 2011. Polybrominated diphenyl ethers in chicken tissues and eggs from an electronic waste recycling area in southeast China. J. Environ. Sci. 23, 133–138.

Ren, G., Yu, Z., Ma, S., Li, H., Peng, P., Sheng, G., et al., 2009. Determination of dechlorane plus in serum from electronics dismantling workers in South China. Environ. Sci. Technol. 43, 9453–9457.

Robinson, B.H., 2009. E-waste: an assessment of global production and environmental impacts. Sci. Total Environ. 408, 183–191.

Singh, A., Sharma, R.K., Agrawal, M., Marshall, F.M., 2010. Risk assessment of heavy metal toxicity through contaminated vegetables from waste water irrigated area of Varanasi, India. Trop. Ecol. 51, 375–387.

Song, Q., Li, J., 2014. A systematic review of the human body burden of e-waste exposure in China. Environ. Int. 68, 82–93.

Widmer, R., Oswald-Krapf, H., Sinha-Khetriwal, D., Schnellmann, M., Böni, H., 2005. Global perspectives on E-waste. Environ. Impact Assess. Rev. 25, 436–458.

Xing, G.H., Chan, J.K.Y., Leung, A.O.W., Wu, S.C., Wong, M., 2009. Environmental impact and human exposure to PCBs in Guiyu, an electronic waste recycling site in China. Environ. Int. 35, 76–82.

Zhang, X., Ruan, X., Yan, M., Zhao, Y., Wei, W., Qin, Z., et al., 2011. Polybrominated diphenyl ether (PBDE) in blood from children (age 9–12) in Taizhou, China. J. Environ. Sci. 23, 1199–1204.

Zhang, T., Xue, J., Gao, C.-Z., Qiu, R.-L., Li, Y.-X., Li, X., et al., 2016. Urinary concentrations of bisphenols and their association with biomarkers of oxidative stress in people living near e-waste recycling facilities in China. Environ. Sci. Technol. 50, 4045–4053.

Zhao, Y., Ruan, X., Li, Y., Yan, M., Qin, Z., 2013. Polybrominated diphenyl ethers (PBDEs) in aborted human fetuses and placental transfer during the first trimester of pregnancy. Environ. Sci. Technol. 47, 5939–5946.

Zheng, L., Wu, K., Li, Y., Qi, Z., Han, D., Zhang, B., et al., 2008. Blood lead and cadmium levels and relevant factors among children from an e-waste recycling town in China. Environ. Res. 108, 15–20.

Zheng, J., Luo, X.-J., Yuan, J.-G., He, L.-Y., Zhou, Y.-H., Luo, Y., et al., 2011a. Heavy metals in hair of residents in an E-waste recycling area, South China: contents and assessment of bodily state. Arch. Environ. Contamin. Toxicol. 61, 696−703.

Zheng, J., Luo, X.-J., Yuan, J.-G., Wang, J., Wang, Y.-T., Chen, S.-J., et al., 2011b. Levels and sources of brominated flame retardants in human hair from urban, e-waste, and rural areas in South China. Environ. Pollut. 159, 3706−3713.

Zheng, X.-B., Wu, J.-P., Luo, X.-J., Zeng, Y.-H., She, Y.-Z., Mai, B.-X., 2012. Halogenated flame retardants in home-produced eggs from an electronic waste recycling region in South China: levels, composition profiles, and human dietary exposure assessment. Environ. Int. 45, 122−128.

Zheng, X., Xu, X., Yekeen, T.A., Zhang, Y., Chen, A., Kim, S.S., et al., 2016. Ambient air heavy metals in PM2. 5 and potential human health risk assessment in an informal electronic-waste recycling site of China. Aerosol Air Qual. Res. 16, 388−397.