Electronic Waste and its Negative Impact on Human Health and the Environment

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Abstract—**This paper reviews electronic waste and its disposal methods. It also explores hazardous effects that e-waste have on human health, animals and the environment; it contains, for example, toxic metals. The ever-increasing growth of e-waste is one of the biggest threats of the 21st century; it is therefore a priority worldwide. There is no single best method to eradicate e-waste and related problems. Lack of suitable education, resulting in low levels of awareness, drives improper management of e-waste. This study therefore concludes that awareness and suitable education is the most important aspect that influences appropriate and proper management of e-waste, i.e. good ("green") information technology practices.**

Keywords—Electronic waste, 21st century, toxic metal, human health, environmen, recycling

I. INTRODUCTION

Electronic waste [1] is rapidly becoming a worldwide threat—it negatively impacts on earth, our only non-renewable commodity [2]. E-waste gradually poisons the environment [3-7]. Planet earth has been "captured" by it and still, approximately 300 million computers and 1 billion mobile phones are produced yearly, as reported by TheWorldCounts [8]. According to Reyes, et al. [9] the escalating volume of e-waste has become matter of urgency globally. E-waste contaminates air and water; it has devastating consequences for the environment, human health and livestock [10].

Electronic equipment, such as information and communication technology [11] products, are developing and evolving at an unpresented rate; consumers want to own the latest ICT products, whilst manufacturers attempt to keep up with these demands [11]. ICT products, that are still in good working condition, are discarded by owners that rush to obtain new and improved products [12]. Also, high demand for these products lured in new market players; new manufacturers, for example from China, manufacture and produce imitation, low quality products that eventually has short life spans [13]. Discarding of unwanted ICT products results in e-waste, which must be appropriately managed and disposed of; it also increases the risk that humans, and the environment, will be harmed.

Various studies showed that toxins from e-waste, released into the air or water, increase the probability that disorders will negatively impact on people's health; it causes, for example, skin diseases and under-development of the brain in children [14, 15]. Literature put forward that there is limited awareness on the negative effects of e-waste on peoples' health and the environment [2, 16]. Freeman [17] argue that low levels of awareness about the negative impacts of e-waste lead to unsuccessful efforts to adopt and practice green information technology. Education is often advocated as a precursor to awareness about GIT practices; however, only a few studies have dealt with this matter to date [18]. So, perceived limited knowledge about the harmful effects of e-waste on health and environment motivates this study. The researchers aim to give a concise overview of e-waste and its harmful effects, as well as recycling and disposal of e-waste.

This paper is structured as follows: the magnitude of e-waste and its major categories are discussed in Section II. In Section III e-waste recycling and disposal methods are discussed. Health and environmental dangers of e-waste are discussed in Section IV, and a conclusion is provided in Section V.

II. ELECTRONIC WASTE

There is no comprehensive definition of e-waste. Each country came up with its own definition thereof [19]. E-waste is often used interchangeably with WEEE, i.e. Waste from Electrical and Electronic Equipment [20]. The following definitions are given in the literature: Grant, et al. [21] define e-waste as any end of life "equipment which is dependent on electric current or electromagnetic fields in order to work properly." Puckett, et al. [22] define e-waste as "a broad and growing range of electronic devices ranging from large household devices such as refrigerators, air conditions, cell phones, personal stereos, and consumer electronics to computers which have been discarded by their users." Sinha-Khetriwal [23] say that "e-waste can be classified as any electrical powered appliance that has reached its end-of-life." So, as there is no standard definition of e-waste. For this study, e-waste is defined as all electric and electronic equipment

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discarded or unwanted by the owner, regardless of working state or not, that contains both toxic and valuable materials.

There were roughly six billion mobile phones in existence worldwide in 2013 [24]. As a result, the volume of discarded equipment is staggering; the United Nations Environmental Programme and United Nations University [25] predict that e-waste, from discarded personal computers alone, will escalate from 200% to 400% in South Africa and China, and to 500% in India in the years 2007 to 2020. In India e-waste, from mobile phones, is expected to increase 18 fold by the year 2020 [26]. In the European Union more than 3.8 billion units of electronic equipment were placed on the market in 2009—it includes 250 million personal computers [27]. Statista [28] predicts that nearly 180 million tablet computers will have been sold globally by 2019. 44.7 million metric tons of e-waste was generated worldwide in 2016 [29]. Apart from the sheer volume of e-waste, the more concerning problem with e-waste is the rate at which it is increasing [30]. It is projected to increase by a further 33% per year from 2017 onwards.

Perkins, et al. [30] divide e-waste into the following three categories: household applications, e.g. washing machines and refrigerators; ICT equipment, e.g. personal computers and laptops; and consumer equipment, e.g. televisions, portable music players and mobile phones. Gaidajis, et al. [31] provide a broader and more encompassing classification of e-waste—it entails ten main categories, as shown in Table 1. The classification is according to the European Union directives on WEEE [32]. This paper focuses on the third category, i.e. information technology and telecommunications equipment.

Table 1: Electronic waste ten main categories [33]

Item	Category
1	Large household appliances
2	Small household appliances
3	Information technology and telecommunications equipment
4	Consumer equipment
5	Lighting equipment
6	Electric and electronic tools, but excluding large scale stationary industrial tools
7	Toys, leisure and sports equipment
8	Medical devices
9	Monitoring and control instruments
10	Automatic dispenses

III. ELECTRONIC WASTE RECYCLING AND DISPOSAL METHODS

Nearly 75% to 80% of e-waste generated in first world countries are shipped to Africa and Asia; it is done under the disguise of "recycling", "disposal" and even "donation" [30]. Fig.1 illustrates common methods then used to deal with the e-waste. Firstly, it is recycled in both the formal and informal sectors. Secondly, current disposal methods include: thermal treatment disposal and dumping disposal [34]. Two methods are applied to dispose through dumping, i.e. open dumping and sanitary landfilling.

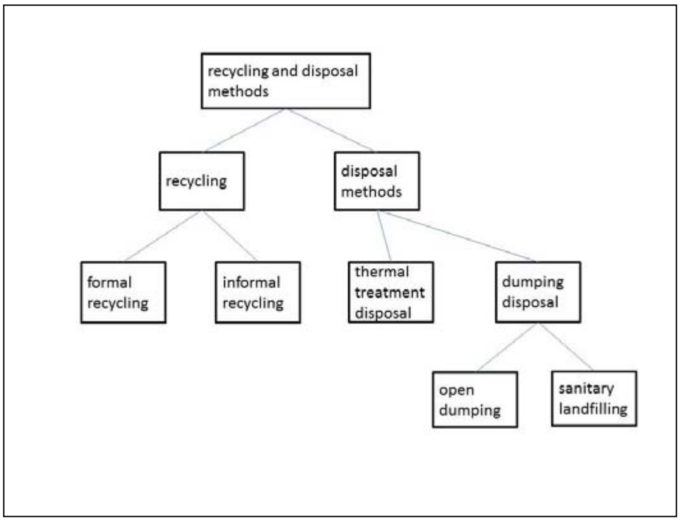

Fig. 1. Electronic waste recycling and disposal methods

A. *Recycling Techniques of Electronic Waste*

About 12.5% of the world's e-waste are properly recycled; the remaining 87.5% end up in landfills, are burned in the open, or shipped to underdeveloped or developing countries [10]. Gupta [35] states that about 95% of e-waste is processed and recycled by the informal sector—it is characterized by labor intensive work, lack of essential (or not any) technology, unregulated and unregistered processes, as well as lack of protective clothing and gear for the workers. Workers apply dangerous methods, such as acid baths to remove or strip metals from the components [2, 36, 37]. Kiddee, et al. [38] found that, in Nigeria, metals of value are extracted from e-waste components, such as computers' motherboards, using (dangerous) acid; leftovers/residue are dumped on the ground or into the streams. According to Perkins, et al. [30] only the informal sector's workers are exposed to toxic materials; workers in state of the art recycling facilities are properly protected from undue exposure. Workers in the informal sector may inhale toxins and/or contaminated dust [39]. Unwillingness of informal recyclers to be regulated can be a barrier to safe practices [39].

Onwughara, et al. [40] suggest that governments fail to recognize and regulate informal recycling, and so amplify poor health and working conditions of workers. Informal recycling is a booming business, due to a number of reasons. For example, informal systems influence e-waste collection systems; recyclers usually go door to door to collect/buy e-waste from consumers of electronic products. Consumers are often remunerated better by informal recyclers, than by formal recycling collectors. This could be attributed to the high cost associated with treatment of e-waste through formal streams. A number of formal recycling businesses even closed down due to lack of e-waste material to recycle in countries such as Beijing [39]. According to Onwughara, et al. [40] the primary objective of informal recycling is financial gain.

Typical informal methods to recover valuables from e-waste include manual disassembling and recovery of valuable materials; acid extraction of metals; shredding; melting and extrusion of plastics; burning plastics and residual materials; and tonner sweeping [41]. Formal recycling currently lack available techniques to recycle some of the components in an environmentally friendly manner [31]. Formal recycling is characterized by state of the art facilities; semi/highly skilled workers; and strict regulatory laws. It is found mainly in rich and developed countries; they have access to requisite technology as well as workers, and are able to equip employees with the necessary protective gear [18, 21].

The objectives of formal recycling are: firstly to minimise the quantity of e-waste that needs treatment and limit release of toxic emissions into the environment; and secondly to also maximise the recovery of valuable metals such as copper, aluminum and gold [40, 42]. Roughly 95% of valuable metals can be recovered through formal recycling procedures and techniques [43]. Mouton and Wichers [44] say that recycling efforts are purely for financial gains and recyclers fail to address environmental problems. Even after treatment of e-waste, a portion thereof still remains as residue—this needs disposal in the form of either landfilling or incineration [42]. Neither of these is environmentally friendly [27, 31].

Formal recycling typically entails two types of facilities, depending upon the nature of the method involved. In the first instance, e-waste is dismantled and mechanically processed for material separation and further processing. The second instance involves a facility with metallurgical processes that are applied to recover plastic and other materials [41]. Metallurgical processes can be used to refine and upgrade metal containing fractions. The dominant metallurgical method in recovering non-ferrous metals and other valuable materials involves a combination of pyro metallurgical processing copper smelters, followed by electrolytic refining. According to Cui and Zhang [45] the pyro metallurgical processing technique has been applied in the market for at least 20 years. In this process the crushed scraps are burned in a furnace or a molten bath to remove plastics. There are only a few industries in the world that recycle copper containing materials. The so-called "integrated" smelters, which recycle many different kinds of copper containing materials, include Boliden in Sweden, Umicore in Belgium, Noranda in Canada, and Norddeutsche Affinerie AG in Germany [46].

B. Disposal Methods of Electronic Waste

Sanitary landfill dumping and dumping on open dumps are usually used as dumping disposal methods to dispose of waste on a large scale. Tam [47] says that a landfill "is a waste disposal site for the deposit of waste onto or into land, including internal waste disposal sites, and a permanent site used for temporary storage of waste, but excluding transfer facilities." Thermal treatment disposal can be done by open burning or through incineration. Open burning releases all the emissions directly into the air [48]. These open fires burn at relatively low temperatures. The advantages of incineration, over open burning, are that the toxicity in materials are reduced to the level that is legible for landfilling dumping; and the heat from incineration can be used to produce energy [42]. Incineration is usually employed in countries such as Japan, where land is a scarce resource. It reduces the volume of e-waste considerably prior to landfilling of the ashes [47]. It is likely to eradicate organic flammable e-waste materials [38]. It also releases heavy metals into the atmosphere [27, 31]. Incineration simply reduces waste to between 30% and 50% of its original size; it does not solve the problem of e-waste [10].

Sanitary landfilling is used as an alternative to open dumping, even though it leads to emissions of carbon dioxide [49]. Raghab, et al. [50] define sanitary landfilling as "a method of disposing of refuse on land without creating nuisances or hazards to public health or safety, by utilizing the principles of engineering to confine the refuse to the smallest practical area, to reduce it to the smallest practical volume, and to cover it with a layer of earth at the conclusion of each day's operation or at such more frequent intervals as may be necessary." The downside is leachate [51]. According to Koda [52] leachate forms as a result of a biochemical process that takes place when rainwater filters through waste in a sanitary landfill. Sanitary landfills, as modern landfills, replace conventional landfills and solve leachate problems to a large extent [42]. Fig. 2 shows a basic sanitary landfill.

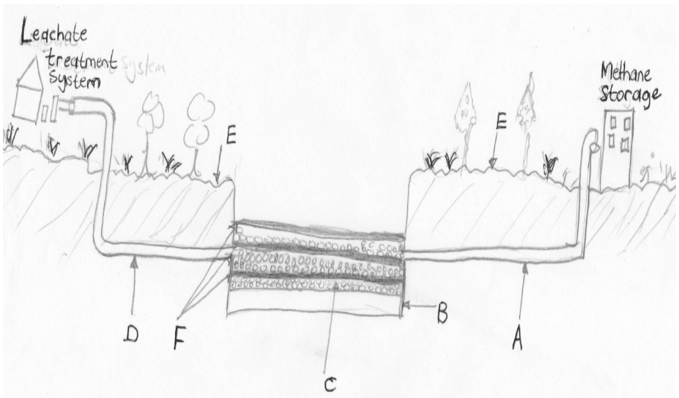

Fig. 2 The basic sanitary landfill

In Fig. 2, A represents a methane gas recovery point; B is a barrier of clay to prevent water and soil contamination and C is a daily cover; a landfill must be covered daily and protected from, for example, pests, mosquitos and rodents. D depicts leachate collection, and E a ground surface. F is a refuse cell that compact waste covered from daily activities.

Yasin and Usman [53] define open dumping as a land discarding location where solid wastes are thrown away in a way that does not safeguard or shield the territory or domain; they are receptive to open burning, and visible to the nearby community and scroungers. In this study open dumping is defined as the worst e-waste management method; it exposes the environment, humans' health and livestock to possible emissions of toxic fumes from the e-waste components. According to Xakalashe [33] nearly 15% of thrown away computers end up in landfills in Hong Kong. 92% of unwanted laptops end up in landfills; a mere 8% are recycled in the United States of America (USA). Approximately 133,000 personal computers are discarded daily in the USA [54]. The different methods used to dispose of e-waste fail to solve the problems associated with e-waste and none of the methods discussed solve the problem of e-waste.

IV. Health and Environmental Dangers of Electronic Waste

In this section the environmental and health-related problems caused by e-waste, specifically in light of the methods and techniques mentioned in the previous section, are discussed. Sources of exposure to e-waste are categorized as follows: informal recycling, formal recycling and exposure from toxic compounds remaining in the environment, i.e. environmental exposure [21]. People often do not have sufficient knowledge in this regard; they are unaware of the potential dangers that e-waste pose to the environment and their health [27].

A. Environmental Problems Presented by Electronic Waste

The Oxford Dictionary [11] defines an environment as “surroundings, especially as they affect people’s lives, the natural world of the land, sea and air.” And so, environmental dangers of e-waste can be classified under land dangers, air (aerial) dangers and water dangers [21].

According to Deng [55] activities involved in the recovery of precious metals form e-waste can cause severe pollution when highly toxic heavy metals are released into the water, land and atmosphere. Soil contamination from aerial deposition or irrigation is likely to pollute crops [56]. A study conducted in China revealed that soil contamination from aerial deposition is the main source of toxic metals contamination, such as cadmium lead and mercury, in rice [57]. Crops in or close to areas that are contaminated with e-waste are likely to absorb and accumulate toxic metals from e-waste and then pose potential health risks to humans and animals [58].

Open burning, to recover copper from wires, releases hydrocarbons in the air; it causes air pollution. Ha, et al. [59] showed that e-waste workers in Bangalore, India breath dust laden air containing cadmium, lead and other toxic metals. Many e-waste contaminants are spread into the air and via dust. This is a major source of exposure to humans and affects them through ingestion, inhalation and skin absorption [60].

Water pollution refers to toxic metals that could leach through the soil into underground water streams of local communities. Luo, et al. [61] found that land farm soil as far as two kilometers from e-waste sites were found to be contaminated with dioxins and dibenzofurans. Gupta [62] found that dumping of acid “leftovers” and sludge into the rivers, after informal treatments of waste, lead to water scarcity for households; the water became contaminated. Water then had to be transported from afar towns to cater for the Guiyu population in Hong Kong. Contamination such as this endangers not only people, but also wildlife that relies on the water for sustenance.

Summary of the negative environmental impacts presented by electronics; refer to Table 2. Humans (and animals) cannot live outside of the environment, and without food produced in the environment. It supports all living beings with life. It is therefore crucial that we all work together to protect our planet. For this we must be equipped with the right knowledge and become aware.

Table 2 Environmental effects of electronic waste [35]

Source of E-waste	**Process Followed**	**Environmental Hazard**
Cathode Ray Tubes	Breaking, removal of copper yoke and dumping.	Heavy metals like lead, barium leach into ground water and release toxic phosphor.
Chips and other gold plated compounds	Chemical stripping using nitric and hydrochloric acids along river banks.	Hydrocarbons discharged directly into water acidify the river destroying fish and flora.
Printed circuit boards	De-soldering and removing chips	Brominated dioxins, beryllium, cadmium and mercury are emitted in the atmosphere
Plastics from computer and peripherals	Shredding and low temperature melting	Emissions of brominated dioxins, heavy metals and hydrocarbons in the air.
Dismantled printed circuit boards processing	Open burning of waste boards	Tin and lead contamination of immediate environment
Wires	Open burning to recover copper	Hydrocarbons and ashes including PAHs discharged into air, water and soil.

B. Electronic Waste Effects on Humans and Livestock

Literature indicates that some of the hazardous elements of e-waste, i.e. mercury, cadmium, lead and phosphorous, can leach into the soil; it contaminate water and soil [21, 63]. Also, uncontrolled burning and disassembly of e-waste may negatively affect those involved in the processing thereof, and also people in surrounding communities. When e-waste is disposed of in or onto landfills, or burned, it poses health risks to humans and livestock; this is due to the hazardous materials it contains. When e-waste lands in/on landfills it exposes all to ecological toxins, resulting in elevated chances of developing chronic diseases e.g. cancer and neurological disorders [64].

According to Fu, et al. [57] ingestion of relatively low doses of toxic metals can result in development of malfunctioning organs and chronic syndromes over a long period of time. Grant, et al. [21] argue that people can be affected by toxic materials from e-waste through contact with contaminated soil, water or dust, or through pre-exposed food sources including meat. Generally, and most likely, exposure to hazardous components occur through inhalation, ingestion and dermal contact [65]. Fig.3 presents some of the health hazards caused by e-waste.

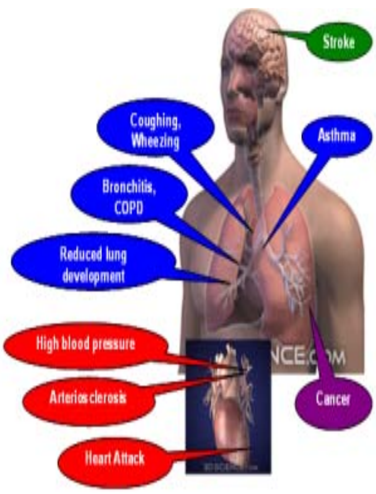

Fig. 3. Effects of heavy metals form electronic waste on human health [34]

Landfills containing e-waste will contaminate underground water [48]. Eventually, it will contaminate fresh waterways and will ultimately be consumed by humans and livestock [27]. Poly-halogenated aromatic hydrocarbons were found in food produced nearby e-waste treatment sites in the Zhejiang province in China [66]. Liu, et al. [67] reported evidence of polybrominated diphenyl ether and polychlorinated biphenyl in soil, plants and snails from town of Guiyu and the surrounding area. Organic material in landfills decomposes and percolates through soil as landfill leachate—it results in liquid that drains from the landfill [38]. A preliminary study showed that lead levels in homes of e-waste workers were between 4 and 23 times higher than families that do not have contact with an e-waste worker. So, e-waste workers unintentionally transport toxic metals contamination with them from work to home, and this increases exposure to their family members. Table 3, shows the source of health dangers to humans caused by e-waste.

Table 3 Sources of health effects caused by electronic waste [35]

Source of E-waste	**Constituent**	**Health effects**
Solder in printed circuit boards, glass panels and gasket in computer monitors.	Lead	Damage to central and peripheral nervous systems, blood systems and kidney damage. Affects brain development in children.
Chip resistors and semi-conductors	Cadmium	Accumulates in kidney and liver, causes neural damage, teratogenic and toxic irreversible effects on human health.
Relays and switches , printed circuit boards	Mercury	Chronic damage to the brain, respiratory and skin disorders due to bioaccumulation in fish
Plastic housing of electronic	Brominated flame	Disrupts endocrine system functions.
Corrosion protection of untreated and galvanized steel plates, decorator or hardener for steel housing.	Hexavalent chromium	Asthmatic bronchitis and DNA damage
Cabling and computer housing	Plastics including PVC	Burning produces dioxin. Dioxin causes: reproductive developmental problems, immune system damage and interfere with regulatory hormones.
Front panel of cathode ray tubes	Barium	Short term exposures causes: muscle weakness, damage to heart, liver and spleen.
Motherboard	Beryllium	Lung cancer, inhalation of fumes and dust causes chronic beryllium disease.

V. CONCLUSION

There is no single method that can eradicate the e-waste problem. Recycling and e-waste workers suffer from exposure to toxins, regardless of whether they work in the formal or informal sector. It is just the level of exposure that differs. Formal (relatively safer) recycling/disposal cannot compete with informal ones. Underdeveloped and developing countries may benefit if both sectors can work together, rather than to try to put an end to the informal sector. For example, the informal sector may play a feeder role to the formal sector, with material or e-waste to process. This will be beneficial if, and only if, the informal sector is sufficiently rewarded through government incentives, for instance. Otherwise, the formal sector may fold, given the profitability of informal sector. On the other hand, formal recycling/disposal methods are not a panacea, they also run the risk of exposing e-waste toxins into air, soil and water. Combinations of e-waste management methods can be used to mitigate the e-waste impact on the environment, human health and animals. E-waste is here to stay given the growing population of the world, and the demand for new products and technological developments. People must therefore be suitably educated in this regard. Education, as precursor to awareness, is therefore recommended; for example governments must encourage the introduction of modules aimed at educating students at tertiary institutions about the harmful effects of e-waste, e-waste management and green information technology practices.

Education is most important in the underdeveloped and developing countries; they are too unaware of the existence of the problem, and they are home to most of the world's e-waste. Because of the prevalence of ICT equipment, tools and platforms, such as mobile learning and social media, people with digital and mobile literacy can take advantage of these mediums to educate themselves. However, this cannot replace traditional means of transferring knowledge, such as radios. Society is segmented in terms of literacy in this regard and not all have access to digital platforms. In addition, we should become aware of and seek new ways to "green" all life stages of electronic products. Education on the negative impact of e-waste on the environment, humans and animals should be made part of the curriculums in schools and institutions of higher learning. Investments must also be made to develop new and better practices to manage of e-waste, such as innovative product design, extended producer responsibility, standards and labelling. Manufacturers and producers must ensure greening of equipment throughout their life stages.

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