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The Impact of Electronic Waste Disposal and Possible Microbial and Plant Control

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---ABSTRACT---

Technological advancement and increased awareness on the importance of information technology have caused enormous generation of electronic wastes throughout the world. This has been prominent particularly in developing countries where the importation of used electronic gadgets is on the increase in recent times without proper methods of recycling. These wastes contain toxic metals such as cadmium, arsenic, antimony, chromium, lead, mercury, selenium, beryllium and brominated flame retardants which pose threats to health and environment. The effects of these recalcitrant metals on the brain, kidney, respiratory tracts and skin of adults and children are of major concern .While plants and microorganisms are employed in controlling the menace of electronic wastes, governments should promulgate laws, create public awareness, privatize wastes management and import proper waste recycling technologies into developing countries where electronic wastes are enormous. Electronic companies also have to minimize hazardous wastes by making portable products that use minimum amounts of these toxic metals or completely use their alternatives which are of less toxic nature than these heavy metals and retardants.

KEY WORDS: *electronic waste, phytoremediation, toxic metals, recycling, microbial remediation*

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I. INTRODUCTION

Electronic waste refers to used and exhausted electronic products that require recycling or other proper forms of disposal. These include electrical appliances and automobile machines like computers, television, cell phones, refrigerators, air conditioners, toasters and washing machines that are basically information technology equipment and home appliances (Susan, 2008). The European Union categorizes such equipment into large and small home appliances, information technology equipment, consumer equipment, lighting equipment, electrical/electronic tools, toy/leisure/sport equipment, medical devices, monitoring and control instruments and automatic dispensers. Technological advancement, increasing awareness on the importance of information technology and continuous improvement in lifestyle have necessitated increased usage of electronic equipment (Mandada, *et al*, 2004). This has caused enormous generation of such wastes throughout the world particularly in Africa where the importation of used electronic gadgets is on the increase in recent times but the proper methods of recycling the wastes are insufficient.

These electronic wastes contain recalcitrant and toxic materials which pose distinct challenges that differ from other types of wastes to the environment (Lincoln *et al*, 2007). The hazardous materials contained in electronic wastes include; cadmium, arsenic, antimony, chromium, cobalt, lead, mercury, selenium, beryllium and brominated flame retardants among others (Musson*et al*, 2006). The improper methods of recycling (disposition on land fields, handpicking of parts and burning) electronic wastes and natural decomposition of these wastes on our environment are associated with emission of toxic chemicals that contaminate environmental air and water bodies.

Thus, such poor methods of disposal that are particularly practiced in African countries where obsolete electronic equipment are dumped coupled with continuous generation of the wastes have become an issue of concern to environmental safety and waste management (Cui and Forssberg, 2003). According to World Health Organization (WHO), about 2 million people die prematurely every year throughout the world from illnesses caused by indoor air pollution. About 44% of this population are children under five that die due to pneumonia, while 54% from chronic obstructive pulmonary disease (COPD), and 2% from lung cancer (WHO, 2011). Unless proper measures are put in place globally and particularly in developing countries against frequent dumping of electronic wastes these health hazards mentioned above, will be difficult to control.

II. UNPRECEDENTED ADVANCEMENT AND GROWTH IN GLOBAL USAGE OF ELECTRONIC EQUIPMENT

The world experienced a sudden boost in electronic manufacturing industries in recent times due to technological innovations geared towards replacement of preexisting technology in an attempt to bridge digital gap(Nnorom and Osibanjo, 2008).This development has brought us to the era of rapid changes in equipment features and capabilities, decrease in price and growth in internet usage. These reasons coupled with changes in lifestyle and increased awareness on the importance of information dissemination have succeeded in growing markets for such equipment globally (Martin*et al*, 2008).This unprecedented growth of electronic equipment in developed countries has resulted in the influx of worn-out electronic equipment into developing countries in an attempt to compete with other developed countries of the world (Christopher, 2007). This has however, resulted in environmental and health hazards since these near obsolete electronics do not last long before they develop faults and eventually end up in dumps. For example, mobile phones have been the predominant communication gadgets in Nigeria and by the end of 2009, she had about 73 million active mobile subscribers (a country with a total population of 155 million) making it the fastest growing mobile market in Africa (NCC, 2010). This, in no small measure, makes Nigeria one of the greatest contributors to this global problem. Furthermore, the total broken down and obsolete electrical/electronic wastes generated in India reckoned to be about 1, 46,000 tonnes yearly (Sharma *et al*, 2012) while that generated in Uganda and Senegal are said to be enormous (Mathias *et al.*, 2009). In fact, it is estimated that developing countries are likely going to receive about 20-50 million tonnes or even more of the electronic wastes produced annually by developed countries most of which are illegally shipped to developing countries in dire need of these technologies without considering the adverse health and environmental impacts (Agyeman and Carmin, 2008). Therefore, it has become paramount for the world to take adequate measures to curb the rise in electronic waste as they could raise by 50% in the next decade consequently increasing environmental pollution and health hazards (Martin *et al.*, 2008).

III. THE HEALTH EFFECT OF TOXIC CHEMICALS IN ELECTRONIC WASTES

Electronic devices are sophisticated electrical appliances that are built up with different materials like plastics, metals and chemicals that work together to produce the desired effects. These chemicals include: polyvinyl chloride, copper, lead, mercury, arsenic, cadmium, manganese, cobalt, gold and iron (USEPA, 2007). Between 1994 and 2003, disposal of Personal Computers resulted in the discharge of 718,000, 287 and 1,363 tonnes of lead, mercury and cadmium respectively into the environment (Widmer, 2005).

Mercury

Mercury is an important component of batteries, display screens and switches of electronic equipment. The elemental form of mercury evaporates into the atmosphere and precipitates into ground water through rain (Qianrui*et al.,* 2004).Bacteria convert mercury to methyl-mercury in soils which goes to the bottom of aquatic food chain and accumulates in animal fatty-tissues (Clarkson and Magos, 2006).WHO states that the tolerable intake of methyl mercury is 1.6μg/kg body weight of a pregnant woman per week in order to protect the developing foetus against neurotoxic effects (JECFA, 2004).Exposure to methyl mercury could be mild or severe depending on the level and this could occur through eating contaminated foods. Foetuses and young children are more susceptible to mercury toxins which affect the nervous system and cause neurological disorder, cognitive debilities, skin irritation, memory disorder, language, fine motor as well as spatial skills losses (Richard, 2009). Other symptoms are tumors, emotional changes, insomnia, headaches and disturbances in sensations while high exposures cause kidney effects, respiratory failure and death (Robin, 2012). Some of the signs of mild exposure are tremor, impaired memory and coordination while high level of exposure may produce symptoms like coughing, chest discomfort, difficult breathing, nausea, vomiting, diarrhoea, sore gums, eye irritation and changes in behavior or vision (WHO, 2012).

Lead: Lead is used as solder to anchor computer and television screens as well as various circuit board components. It is the most studied chemical component of electronic equipment that has recorded many hazardous human health effects particularly in children (Rossi, 2008). Exposure to lead could occur through drinking contaminated water which may result in several damages to the brain and nervous system, growth, hearing, behaviour and learning problems. It can also cause high blood pressure, reproductive and memory problems in adults (Elizabeth, 2009). This chemical can remain in bones and blood streams for years. Short time exposure to high level causes vomiting, diarrhoea, convulsion, coma and even death (Elizabeth, 2009).

Chromium : Chromium is used for decorative and protective plating of aerospace, vehicle, heavy equipment, oil field applications (Bor-Shong*et al.,* 2006).People can be exposed to chromium through breathing, eating or drinking and through skin contact with chromium compounds. When chromium gets into human system, it binds to protein and triggers a reaction that has damaging effect on the body (Irwin, 1997).Health effects associated with chromium exposure include skin irritation and ulceration, asthma and respiratory irritation, perforated eardrums, kidney and liver damage. Others include pulmonary congestion, oedema, epigastria and discoloration of the teeth. Lungs, kidneys, and intestines are the most vulnerable organs of the body and long term presence of this metal in tissues may lead to cancerous growths (Stephen, 2013).

Brominated Flame Retardants: These are chemicals that are added to home appliances like television, computers, furniture, carpets, textiles, foam and plastics to prevent or reduce risks of fire disasters. Brominated flame retardants (BFR) are released into the environment through landfill leachates obtained from the incineration of these materials. Thus these retardants accumulate in fatty tissues through foods taken by man and other animals (Janssen, 2005).Concerns have been shown about the persistence of these chemicals in water, air and soil across the globe (Elizabeth, 2009). These chemicals may disrupt endocrine system and increase the risk of cancer to digestive and lymphatic systems (Janssen, 2005). Risks analysts are concerned about the causes, bioaccumulation and persistence of this chemicals in humans, although, the major pathway for human exposure is still unknown (Brown, 2004).

Cadmium: Cadmium is predominantly used in rechargeable batteries, plastic cadmium plated steels, solders and television picture tubes. It is also found in printed Circuit Boards, cadmium chip resistors, infrared detectors and semiconductors (MECAZ, 2013). The toxicities of this element can lead to kidney, bone and pulmonary damages. Long time accumulation can occur in kidney. Acute toxicity can lead to nausea, vomiting, weakness, shortness of breath and lung oedema. Chronic exposure has been linked to kidney and bone damages as well as hypertension (Elizabeth, 2009).

Beryllium: Beryllium is a component of motherboard of computers that serve as electrical connector or insulators of microprocessors. People mostly exposed to harmful level of barium effect are those working in the industries and those living close to electronic waste sites. However, these effects are acquired through inhaling dust, eating plants or drinking water that is polluted with barium.(Elizabeth, 2009).Barium poisoning is much more severe when consumed in contaminated water as small amount could cause breathing difficulties, increased blood pressures, heart rhythm changes, stomach irritation, muscle weakness, changes in nerve reflexes, swelling of brains and liver, kidney and heart damage depending of the level of exposure(Lim and Schoenung, 2010). Other trace chemicals in electronic wastes that may cause damage to human systems include Arsenic and selenium. However, the growth of electronic products can directly be linked to growing demands for energy globally and corresponding growth in air pollution and greenhouse gas production.

IV. MANAGEMENT AND CONTROL OF ELECTRONIC WASTES

Wastes management refers to all measures taken to protect human and environment from the dangers of constituents of electronic and other wastes. It is generally undertaken to reduce their effects on health and environment and possibly to recover valuable resources from them (Ogbuene*et al.,* 2013). Management of electronic wastes unlike non-hazardous wastes is the responsibility of the producing industries, marketers, users and government who are the major stakeholders but this should begin with the producing industries. The industries should adopt measures that will reduce the sizes of their products and quantities of hazardous materials used in their production (UNEP, 2010). The hazardous materials could, if possible, be replaced with non-hazardous ones. Also the avoidance of the purchase of excess production materials will, in no small measure, aid the control of these hazardous materials. In addition, manufacturers of electronic products should recover and reuse worn-out electronic equipment as this will reduce the cost of raw materials and serve as job opportunity to the unemployed.

Furthermore, proper training of all industrial personnel of every sector on the proper handling of electronic wastes will reduce the effects of these chemical substances (Soraj, 2013). The use of environmentally friendly policies by manufacturing industries such as the continuous standardization of products for easy disassembling and use of readily biodegradable materials will tremendously help in the reduction of the risks posed by the use of these products and their wastes (Ramachandra *et al.*, 2004). Furthermore, users can reduce the effects of electronic wastes on the environment by donating the used electronic equipment to schools and nonprofitable organizations that require their services in order to extend their life span rather than disposing of them. In addition, users should always buy certified products that are energy efficient with few toxic constituents (USEA, 2001).Governments on the other hand, are saddled with regulatory policies and setting up of agencies that will enforce the regulatory functions regarding hazardous substances. Therefore, governments should provide adequate policies that are easy to enforce but adequately control and check hazardous wastes disposal into the environment. In this way, government should consider privatization of electronic waste management as an option for proper control (USEA, 2001).This cannot however, be achieved without the acquisition of the required technology most especially that these developing countries continue to experience influx of such wastes without proper management strategies. Therefore, in the importation of a particular recycling technology, its viability and practicability should properly be considered before committing the scarce resources to forestall failure. Since high electronic waste generation linked to consumption and quality of life has become a challenge particularly in developing countries, there is the need by the government to create greater public awareness on the risks associated with electronic wastes generation (CCK, 2010).

V. ELECTRONIC WASTES TREATMENT TECHNIQUES

There are several techniques employed in the treatment of electronic wastes to clean up the environment of their hazards. These techniques include:

Incineration: This treatment involves subjecting the electronic wastes to thermal treatment in special incinerators under high temperature to turn the wastes into gas, steam or ash. It is a practical method of treatment that reduces the volume of the original wastes to at least 20% (DEGA,2012). The disadvantage associated with incineration is emission of gaseous pollutants such as dioxins and furans which persist in the environment and may have serious environmental consequences. Due to the hazards associated with this method, it is considered as a bad and unacceptable method of electronic wastes disposal and it is the commonest method employed in Japan and other developing countries (Sharma *et al*, 2012).

Recycling: This method involves processing electronic wastes into new products by dismantling, sorting and collecting different materials before they are used in subsequent productions. Unrecovered materials are left for environmental degradation and the refurbished materials are sold as secondhand goods (John *et al.,* 2010). The dismantling of the equipment can be done either with automated machines or manually. There are some disadvantages associated with manual method of dismantling as the workers may be exposed to the risks of the chemical constituents of the waste during work. Recycling has been described as the best remedy to the growing electronic waste problems as it recovers metals for future use and conserves natural resources when these metals are reused. It also reduces the amount of greenhouse gas emissions caused by the manufacturing of new products (Linda, 2010).

MICROBIAL REMEDIATION OF TOXIC METALS IN THE ENVIRONMENT

Many microorganisms have the potential to degrade and detoxify metals in the environment through different processes such as adsorption, methylation, demethylation and oxidation/reduction reactions which are important in controlling the distribution of metal toxicants (Bruins *et al.*, 2000). This is because metal ions are essential requirements for the physiological and metabolic process of the organisms (Nies, 1999). Metal ions serve as ionic carriers that take part in electron transport systems of organisms transporting materials across the cell membrane. Bacteria precipitate metals within their cells into ions (Podda*et al.*, 2000). They also degrade metals to produce chemical substances called siderophore in the form of phenols and catechol as their process of ion uptake (Renshaw*et al.*, 2002). Others transform metal toxicants by binding proteins that can subsequently bind the metal ion. Microorganisms can also degrade metals such as chromium, mercury and selenium by subjecting them to oxidation/reduction reactions (Ross, 1994). This process is categorized into two: assimilatory and dessimilatory reactions. Microbial assimilation involves the transformation of metals to obtain proteins (Brock and Madigan, 1991). In this wise the metal enhances the physiological and metabolic functions of the microbes by acting as a terminal electron acceptor while in dessimilatory reaction, the metal does not play any role in the species responsible for the reaction.An oxidation/reduction reaction of a microorganism is associated with cytochrome system in someof the organisms (Christopher *et al.*, 1995). In this case, enzymes produced by microorganisms take part in the oxidation/reduction of metals. For example, arsenate reductase is a microbial enzyme that consists of genes that are resistant to arsenic and can reduce As^{V} to As^{III} (Xu*et al.*, 1998). Plastic eating fungi (*Pestalotiopsismicrospora*) has been recently discovered and the enzymes (serine hydrolase) have been isolated for large scale production to breakdown plastics in landfills.

This endophytic fungus found in Ecuador cans completely digestpolymer, polyester polyurethane aerobically and anaerobically without any other source of energy except the plastics (Jonathan *et al.*, 2011). So also mediated reduction of As has been reported by membrane – bound genes in *Desulfomicrobium* strain (Macy *et al.*, 2000). These genes are wide spread in gram +ve and –ve bacteria and are located in plasmids, chromosomes and transposon (Gladysheva*et al.*, 1994; Carlin, 1995; Summer, 1997). Examples of microorganisms involved in this activity are *Alcaligenesfeacalis, Pseudomonas arsentoxidans,Chlorella* and *Chlorococcus*. Metal toxicants can also be detoxified through biomethylation activities of microbes by converting the metal to volatile derivatives that are less toxic to the environment. This is a major process of volatilization of As, Hg and Se in soils and sediments and it is carried out by trans or cis – methylation to reduce the metal to methyl group. Bacteria, fungi and algae were reported to be involved in this reaction and they utilize organic matter as their source of methyl donor in the entire process (Gadd,2004). In aquatic environment, benthic microbes are capable of methylating metals under aerobic and anaerobic conditions to produce volatile compounds that are easily lost to the atmosphere (Wood, 1975; Maher, 1995).Biosorption is another process employed by microbes (bacteria, fungi, algae and yeast) to metabolically or physicochemically pick up heavy metals from their environment because of the negative charges in their cell walls that have affinity for positively charged cationic metals. This biosorbent characteristic is as a result of the presence of negatively charged carboxyl, amines, hydroxyl phosphate, sulfhydryl groups and teichoic acids that bind and regulate the movement of the toxic cations across the membrane (Shruti*et al.*, 2012). The efficiency of biosorbent ability of microbes is influenced by factors such as pH, temperature, environment, physiochemical properties of the target metal and interaction with other metals. Experimental research has shown that about 84% biosorption of 300mg/L of Pb in water using *Bacillus cereus* revealing the potential of *Bacillus cereus* in remediation of lead in waste water (Shruti*et al.*, 2012).

VI. THE USE OF PLANTS TO REMOVE TOXIC METALS FROM THE ENVIRONMENT

The act of removing toxic metals from the environment by the use of metal accumulating plants is termed phytoremediation. The plant root has the ability to absorb, translocate, bioacccumulate and store the toxicant in the entire plant body (Vinita, 2007). This method has advantages over other methods because it is cheaper in terms of practice and solar driven and the plants possess certain chelating agents that enhance metal uptake without emitting the metals to the environment. Phytoremediation has advantages over microbial remediation due to the fact that it is effective in removal of some inorganic metals that cannot be degraded by microbes particularly in the soil (llya*et al.*, 1997). While microbial bioremediation leads to accumulation of some toxic metals in aquatic food chain, phytoremediation helps to remove the metals completely from the water body by absorbing the toxic metals into parts of its body. Phytoremediation has been effective in the removal of radioactive metal (Cr) and non-reactive metals (Pb,Zn,Cd,Cr, As and Hg) from soil and water (Cosio*et al.*, 2004; Turgut*et al*, 2004). Several plants have been used to remove toxic metals from soil and water and these include; *Arabidopsis thaliana* (Zn, Cu, Pb, Mn, P) (Lasat, 2002), *Sedum alfredii*(Pb, Zn) (Li *et al.*, 2005) and *Salsola kali* (Cd) (de la Rosa *et al.*, 2004). There are four basic methods employed in remediation of soil or water using plants and these are: phytoextraction, phytovolatilization, phytostablization and rhizofilteration.

Phytoextraction: Plants with high metal absorbing ability are used for phytoextraction. The plants can take up high amounts of the toxic metalsfrom the soil through the roots and accumulate them on their shoot systems (stem or leaves) due to high tolerance, high biomass and fast growth. The plants are later harvested and destroyed by burning in landfills or the metals could be recycled by a process called phytomining(Chaney *et al*., 2000).It is preferable to use non-edible plantsfor phytoremediation, but in a situation where edible plants are used because of high toxic metal retention ability, they are harvested and subsequently used for nonfood purposes such as wood or cardboard or disposed in landfills after burning to ashes (Vinita, 2007). Plants of Brassicaceae family including *Arabidopsis* species (*A. halleri*)have been reported to have shown hyper accumulative ability for As, Cu, Co, Cd, Mn, Ni, Se, Pb and Zn (up to 100 to 1000 levels) better than Indian mustard and sunflower that are initially used for phytoextraction(Ma *et al*., 2001). However, due to their slow growing ability, only *Alyssum bertolonii*(Ni hyper accumulator) has been used for large scale remediation of metals in the field (Li *et al*., 2003).It is reported that the future is promising on cloning of genes from effective phytoextraction plants to other plants to explore their characteristics in order to improve the technology and enhance the viability of the plants (Clístenes and Baoshan, 2006).

Phytovolatilization: Volatilization is the act of transpiration of organic and inorganic metals and evaporation of the metals to the atmosphere through the stem and leaves of plants. This method is much more effective for organic metals but can be used for few inorganic metals that can exist in volatile forms(Hansen *et al*., 1998).It is also used in transformation of metals (like Se) to organic volatile forms through assimilation and methylation (Terry *et al*., 2000). While in another way, the metals (As and Hg), are dispersed or diluted to forms that do not pose threat to the environment (Lin *et al*., 2000).Phytovolatilization is more of an advantage to phytoextraction due to the fact that it completely disperses the metal as a gas and there is no need for harvesting the plants after the activity.

However, the method can be improved by the use of plants with high transpiration capability and can produce certain enzymes that can mediate volatilization and by gene transfer to impact nano accumulation ability to other plants (Le Duc*et al*., 2004).

Phytostabilization: This method employs plants to stabilize or transform metals into less bioavailable forms that cannot be moved to water bodies or further pollute the soil environment (Kramer and Chardonnens, 2001).The plant uses its root and exudate to prevent leaching and erosion of the metals by stabilizing them in the soil. It is experimentally observed that combining trees and grasses in this method is much more effective. The use of fast-transpiring trees prevents downward leaching of metals and grasses prevent wind erosion and lateral runoff with their thin dense root systems. However, grasses that are known to be feeds to animals do not accumulate metals in their shoots thereby minimizing exposure of animals to heavy metals (Pilon-Smith, 2005).

Rhizofiltration: In rhizofiltration, plant roots grown in water absorb metals through the roots and precipitate them to the atmosphere (Schmoger*et al*., 2000). Plants, sediments and microbe (*rhizobium*) act as biogeochemical filters that efficiently remove contaminants from water (Horne, 2000). Constructed wetlands have been widely used for filtering large volumes of wastewater containing toxic inorganics like Se, nitrate and phosphate (Nzengung and McCutcheon, 2003). Several aquatic plants have affinity for different toxic metals in wastewater. These plants include *Polygonumamphibium* L. (sharp dock), *Lemna minor* L. (duck weed), *Eichhorniacrassipes*(water hyacinth), *P. stratiotes*(water lettuce), *Lepironia articulate*(calamus) and *Hydrocotyle umbellate* L. (Pennywort). For instance, it has been experimentally found that the roots of Indian mustard is effective in the phytoremediation of Cd, Cr, Cu, Ni, Pb and Zn while sunflower can remove Pb, U, Cs-137 and Sr-90 from hydroponic solutions (Mohammed *et al*., 2008). This method can be used in *in-situ* or *ex-situ* bioremediation of wastewater. Other species apart from hyper accumulators can also be used in rhizofiltration and this technology has advantages over other methods because it has proven field effective with the removal of 21 - 874µg/L of Uranium in water (Hosh and Singh, 2005).

VII. CONCLUSION

Electronic wastes have globally been on the increase due to technological advancement, increased awareness on the importance of information technology and continuous improvement in lifestyle. These have necessitated increased usage of electronic equipment particularly in developing countries where the importation of used electronic gadgets is on the increase in recent times without proper methods of recycling the wastes. These electronic wastes contain recalcitrant and toxic materials which pose distinct challenges that differ from other types of wastes to the environment. The improper disposal of these wastes on land fields, handpicking of parts and burning in our environment are associated with emission of toxic chemicals that contaminate the soil, air and water bodies. Government should therefore, regulate the abundance of these wastes and consider privatization of electronic wastes management and create awareness on dangers associated with them. Electronics manufacturing companies should also employ means of minimizing wastes by making portable products that will reduce the amounts of hazardous metals in them. The use of microorganisms and plants to remediate these metals discharged into the environment as a result of the disposal of these wastes should be strongly recommended and employed by government at all levels.

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