Guiding Principles for Development of E-waste Management using Biological Systems for Indian Scenario

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***Abstract*— The information and communication revolution has brought enormous changes in the way we organise our lives, our economies, industries and institution. Electronic waste (e-waste) is one of the fastest-growing pollution problems worldwide given the presence if a variety of toxic substances which can contaminate the environment and threaten human health, if disposal protocols are not meticulously managed. It constitutes a serious challenge to the modern societies and requires coordinated effects to address it for achieving sustainable development. E-waste constitutes multiple components some of which are toxic that can cause serious health and environmental issues if not handled properly. The problem of E-waste has forced Environmental agencies of many countries to innovate, develop and adopt environmentally sound options and strategies for E-waste management, with a view to mitigate and control the ever growing threat of E-waste to the environment and human health. In rapid developing countries like India, it is difficult to completely adopt or replicate the E-waste management system used in developed countries due to many country specific issues viz. socio-economic conditions, lack of infrastructure, absence of appropriate legislations for E-waste, approach and commitments of the concerned, etc. This article provides the associated impacts and possible management of E-waste using Biological systems. Physical incineration and chemical processes using strong acids are hazardous as well as expensive for treatment, therefore biological approaches using microorganisms, earthworms and plants are valuable alternatives to traditional methods.**

***Keywords*:— Electronic waste, Microremediation, Phytoremediation, Vermiremediation**

I. Introduction

In the 20th Century, the information and communication revolution has brought enormous changes in the way we organize our lives, our economies, industries and institution. At the same time, these have led to manifold problems including the problem of massive amount of hazardous waste and other wastes generated from electric products. It constitutes a serious challenge to the modern societies and require coordinated effects to address it for achieving sustainable development. Every day, enormous quantity of waste is generated, which is at present in need of attention [48]. The spectacular developments in modern times have undoubtedly enhanced the quality of our lives. U.S. residents produce about 7 kilograms of e-waste/person/year[20]. The total broken down and obsolete e-waste generated in India reckoned to be about 1, 46,000 tonnes yearly[38].

Therefore, it has become paramount in the world to take adequate measures to control the rise in electronic waste as they could rise by 50% in the next decade consequently increasing environmental pollution and health hazards [25, 27]. The electronics industry is where outsourcing of manufactured products is practiced by most of the companies. Most original equipment manufacturers have disintegrated their vertical manufacturing chains and labour-intensive activities. Their main activity is now focused on product design, branding and supply chain management and manufacturing is partly or entirely outsourced to contract manufacturers or component suppliers, who have adequate know, how and technological capabilities and are able to reduce production costs by utilizing the economics of scale. The majority of labour-intensive production activities, such as sheet metal processing, machining, injection moulding, printed circuit board fabrication and assembly, have moved to developing countries or economies in transition, where labour cost is lower. As a result most of the electronic manufacturing companies are today concentrated mainly in the Pacific Rim countries such as Singapore, South Korea, Malaysia and other Asian countries, such as India, Taiwan-China and Mainland China.

A. *What is e-waste?*

Rapid growth of technology, up-gradation of technical innovations, and a high rate of obsolescence in the electronics industry have led to one of the fastest growing waste streams in the world which consist of end of life electrical and electronic equipment product such as :

- Refrigerator, Washing machines, Computers and Printers, Televisions, Mobiles, I-pods etc.
- Many of which contain toxic materials.

B. *Composition of E-waste*

It Consists of Ferrous & Non-ferrous Metals Plastics, Glass, Wood etc.

- Iron & Steel -50%
- Plastics -21%
- Non-ferrous metal -13%
- Mercury, Arsenic, Lead etc.

II. E-WASTE GENERATION IN INDIA

Projection by International Association of Electronic Recycler (IAER).

- 3 billion electronic and electrical appliances became WEEE in 2010.
- Globally about to 20 – 50 million tons of E-Waste are disposed of each year.
- Which accounts for 5% of all Municipal Solid Waste.

According to Comptroller and Auditor-General's (CAG) Report, over 7.2 MT of Industrial Hazardous Waste, 4 lakh Tonnes of electronic waste, 1.5 MT of Plastic waste, 1.7 MT of medical waste and 48 MT of municipal waste are generated in the country annually.

- CPCB has estimated that E-Waste exceeded 8 lakh tonnes mark in 2012.
- There are 10 states that contribute to 70% of the total E-Waste generated in the country.
- 65 cities generate more than 60% of the total E-Waste in India.
- Among the top ten cities generating E-Waste, Mumbai ranks first followed by: Delhi, Bengaluru, Chennai, Kolkata, Ahmedabad, Hyderabad, Pune, Surat & Nagpur.
- Main source of electronic waste in India are the government, public and private (Industrial) sectors is 70%
- Contribution of individual house hold is 15%
- Rest being contributed by manufacturers.

Out of total E-Waste volume in India :–

Television	-	68%
Desktop, Server	-	27%
Imports	-	2%
Mobile	-	1%

Despite 23 units currently registered with Govt. of India, Ministry of Environment and Forest/Central Pollution Control Board, as E-Waste recyclers/ preprocessors the entire recycling process more or less still exists in the un-organized sector.

A. Electronic waste in global context

- It is estimated that more than 50MT E-Waste is generated globally every year.
- A report of the United Nations predicted that by 2020, E-Waste from old computers would jump by 400% on 2007 levels in China and by 500% in India.
- -Additionally E-Waste from discarded mobile phones would be about seven times higher than 2007 levels in China and in India 18 timers higher by 2020.

-China already produces about 2.3 million tonnes of E-Waste domestically second only to the US with about 3 million tonnes.

-Such predictions highlight the urgent need to address the problem of E-Waste in developing countries like India where the collection and management of E-Waste and the recycling process is yet to be properly regulated.

-It may cause rising environmental damage and health problems of E-Waste recycling if left to the vagaries of the informal sector.

B. Growth of electrical and electronic industry in India

- The electronic market in India jumped from US $ 11.5 billion in 2004 to US $ 32 billion in 2009 making it one of the fastest growing electronic market worldwide with US $ 150 billion in 2010.
- India's low manufacturing costs, skilled labour, raw materials, availability of engineering skill and opportunity to meet demand in the populous Indian Market have contributed significantly.
- India's large and growing middle class of 320 – 340 million has disposable income for consumer goods.

C. Impact of Harardous Substances on health and environment

- Many of these substances are toxic and carcinogenic
- The materials are complex and have been found to be difficult to recycle in an environmentally sustainable manner causing health hazard.
- The impacts is found to be worse in developing countries like India where people engaged in recycling E-Waste are mostly in the un-organized sector, living in close proximity to dumps or landfills of untreated E-Waste and working without any protection or safe guards.

D. Dealing with E-waste

Currently, around the world, the volume of obsolete computers and other E-Wastes temporarily stored for recycling or disposal is growing at an alarming rate causing enormous environmental and health hazard to any community.

How much waste is in 500 million computers:-

Plastic	-	6.32 Billion Pounds
Lead	-	1.58 Billion Pounds
Cadmium	-	3 Million Pounds
Chromium	-	1.9 Million Pounds
Mercury	-	0.632 Million Pounds

Storing of E-Waste in landfills: Environmental & health hazard

Incineration: Environmental & health hazard

Reusing and recycling: Limited life span, hazardous in un-organized sector

E. Import of hazardous E-waste in India

- India is one of the largest waste importing countries in the world.
- It generates about 350000 tonnes of electronic waste every year and imports another 50000 tonnes.

F. Waste economy in the un-organised sector

- More than 90% of the E-Waste generated in the country end up in the un-organized market for recycling and disposal.
- The un-organized sector mainly consists of the urban slums of the metros and mini metros where recycling operations are carried out by the unskilled employees using the most rudimentary methods to reduce cost.
- Workers face dangerous working conditions as they may be without protection like gloves or masks.
- Very often child labour is employed to separate the parts from the circuit board utilizing wire cutters pliers.
- Nitric acid is used on the circuit board to remove gold and platinum.
- It is estimated that about half of the circuit boards used in the appliances in India end up in Moradabad (Uttar Pradesh) also called Peetal Nagri or the brass city.
- Private and Public Sector prefer auctioning their E-Waste to informal dismantlers and get good price of it.
- Strict regulation is necessary to process E-Waste through organized sector.

In July 2009, E-Waste Recyclers Association was formed. Problem facing the organized sector:

- Lack of proper collection and disposal mechanism
- Stiff resistance from large informal sector
- TIC Group India Pvt. Ltd. in Noida (UP) has capacity 500 tonnes of E-Waste annually but processing only 200 tonnes per year
- Attero recycling unit in Roorkee (Uttarakhand) is a 35 crore plant can process 36000 tonnes per year although getting 600 tonnes currently.
- License to import may be necessary to sustain formal business.

The national laws of China, India and the Philippines have for several years now forbidden the importation of hazardous waste. The Basel Convention also bans the export of toxic waste from Organization for Economic Cooperation and Development (OECD) to Non-OECD countries, even for recycling purposes. Despite these prohibitions, however, electronic waste continues to arrive into these nations. It was observed that despite significant attention from the media and enactment of some national level trade bans (most notably, China and India), the problem is apparently worsening.

High-tech Trashing of Asia' – showcases the Chinese town of Guiyu as an example of several environmental impacts that can be caused by informal recycling of electronics (BAN/SVTC 2002). Toxics Link, an Indian NGO, also published a report in 2003 arguing that similar problems are occurring in Delhi and other areas of India (Toxic Links 2004).In 1992, the Basel Convention banned the export of hazardous electronic wastes and in 1994, parties in the Basel Convention agreed to an immediate ban on exports of electrical and electronic scrap, including computers for final disposal in non-OECD countries. China also has other legislation banning the importation of waste electric and electronic appliances such as computers, television sets, monitors and CRTs (ECOFLASH 2003). Studies by the BAN, Greenpeace, and other environmental groups and NGOs are indicatives of very damaging toxic trades that the global community sought to prohibit in the late 1980s with the adoption of the Basel Convention.

G. Challenges

Difficulties specific to developing and industrializing countries in WEEE management after assessing management issues from China, India, and South Africa. These difficulties are summarized below:

• Although the quantity of indigenous e-waste per capita is still relatively small (estimated to be less than 1 kg e-waste per capita per year), populous countries such as China and India are already huge producers of e-waste in absolute terms;
• These countries also display the fastest growing market for EEE;
• Some developing and transition countries are importing considerable quantities of e-waste. Some of them arrive as donations to help 'the poor' while others are mislabeled.

The challenges facing EoL management of e-waste in developing countries are enormous and include the following items:

1. The increasing volume of e-waste imported illegally into the developing countries. Second-hand EEE imported into the developing countries are rarely tested for functionality. Thus significant quantities of used EEE imports estimated at between 25–75% are unusable junk (e-scrap)
2. Ignorance of the toxicity or hazardous nature of e-waste. There is lack of awareness in government and public circles of the potential hazards of the present EoL management of WEEE in the developing countries to human health and the environment. Those involved in the dangerous crude recycling activities are also ignorant of the implications of these activities and/or are forced to choose between 'poverty and poison'.
3. There is absence of infrastructure for the recycling or appropriate management of e-waste following the principles of sustainable consumption/development. In Africa formal recycling facilities for e-waste exists only in South Africa.
4. Lack of funds and investment to finance profitable improvements in e-scrap recycling. There is loss of resources, energy wastages and environmental pollution as a result of the crude 'backyard' recycling activities. There should be economic incentives for environmentally sound practices and technologies. Recycling and treatment facilities require a high initial investment, particularly those fitted with technologically advanced equipments and processes.
5. Absence of legislation dealing specifically with e-waste. There is also a near absence or ineffective implementation of existing regulations/legislation relating to the control of trans-boundary movement of hazardous wastes and recyclables.
6. Absence of mandated or effective voluntary take-back programmes (EPR) for end-of-life EEE in the developing countries. There is also the unwillingness of consumers and enterprises to hand out their obsolete EEE or pay for WEEE recycling.

III. E- WASTE MANAGEMENT AND CONTROL

Waste management refers to all measures taken to protect human and environmental from the dangers of constituents of electronic and other wastes. It is generally undertaken to reduce their effects on health and the environment and possible to recover valuable resources from them[30]. Management of electronic wastes unlike non-hazardous wastes is the responsibility of the producing industries, marketers, users and government. The industries should adopt measures that will reduce, the sizes of their products and quantities of hazardous materials used in their production.

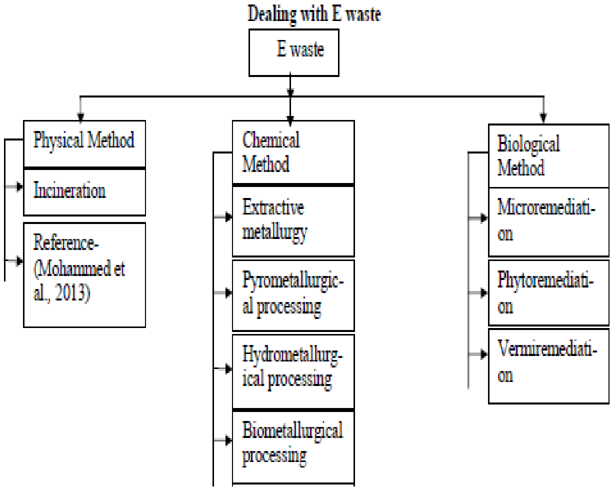

Fig.1. Dealing with E-Waste

The hazardous materials could, if possible, be replaced with non-hazardous ones. Governments on the other hand, should adopt proper regulatory policies, consider privatization of electronic waste and create public awareness[1, 2, 3, 27].

A. *Microremediation of E-Waste*

Microremediation is defined as the use of the microorganisms to eliminate, contain or transform the contaminants to nonhazardous or less-hazardous form in the environment through the metabolisms of microorganisms[28].

There are 6 major mechanisms in micro-remediation of toxic metals which are:
(1)Bioleaching; (2)Bio-sorption; (3)Bioaccumulation; (4)Bio-transformation; (5)Bio-mineralization; and (6)Microbiallyenhanced chemisorption of metals.

a) Bioleaching

Bioleaching uses a natural ability of the microorganisms to transform metals present in the waste in a solid form in a dissolved form. There are two forms of bio-leaching: direct leaching and indirect leaching. Direct leaching makes use of the organic acids produced by the microbes, to oxidize the insoluble toxic metals, turning them into ions which they become soluble. In Indirect leaching metal oxidizing bacteria are used that oxidize the metal surrounding the microbe. In most cases, the anion of the target metal compounds is oxidized, giving out free metal ions in aqueous medium[44].

b) Biosoprtion

Biosorption refers to the concentrating and binding of soluble contaminants to the surface of cellular structure [4, 6, 7], it does not requires active metabolism, in this case the soluble contaminants are ionized toxic metals[46].

d) Bioaccumulation

It is defined as the absorption of contaminants within the organism, which are transferred into a biomass cell within the cellular structure and concentrated there, this process requires active metabolism[33]. For organic contaminants[10, 13, 14], there are sometimes chemical reactions in the cell cytoplasm to convert them to other compounds; however, the metals entering the cell cytoplasm will not undergo any reaction but sequestered instead[18].

e) Biotransformation

Biotransformation refers to the process in which a substance is changed from one chemical form to another chemical form by chemical reactions; in the case of toxic metals, the oxidation state is changed by the addition or removal of electrons, thus their chemical properties are also changed[33].
There are 2 ways for biotransformation process[23-28]. Direct enzymatic reduction, in which multivalent toxic metal ions are reduced by accepting electrons from the enzymes in the exterior of the cell. Indirect reduction, can be used to reduce and immobilize multivalent toxic metal ions in sedimentary and subsurface environment by actions of metal-reducing or sulfate reducing bacteria[43].

f) Biomineralization

Biomineralization describes the process in which toxic metal ions combine with anions or ligands produced from the microbes to form precipitation[26, 37, 41].

g) Microbially-enhanced chemisorption of metals

Chemisorption is similar to adsorption except there is a chemical reaction between the surface and the adsorbate[46]. In microbially-enhanced chemisorption of metals a series of chemical reactions in which microbes first precipitate a bio-mineral of a non-target metal known as priming deposits, the priming deposits, then act as a nucleation focus for the subsequent deposition of the target metal[43].

B. *Phytoremediation for Electronic Waste*

The act of removing toxic metals from the environment by the use of metal accumulating plants is termed phytoremediation[45]. There are four basic methods employed in remediation using plants 1)Phytoextraction,
2)Phytovolatilization,
3)Phytostablization and
4)Rhizofilteration[27].

a) Phytoextraction

Phytoextraction refers to the uptake of toxic metals from the soil or polluted water by plant roots and translocating and accumulating them in plant tissues [16-19]. After the metals are mobilized, and captured by root cells, they bind to the cell wall, followed by slow diffusion through different cell walls and enter the xylem to transport to other parts of the plant[21]. The plants are later harvested and destroyed by burning in landfills or the metals could be recycled by a process called phytomining [45].

b) Phytovolatilization

Phytovolatilization 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[30, 31].

c) Phytostabilization

Phytostabilization refers to the stabilizing process for contaminated soils by immobilizing toxic metals using plants so their availability to the environment is reduced[35]. It is achieved by absorption and accumulation by the roots, adsorption onto roots, or precipitation within the root zone of plants[9].

d) Rhizofiltration

Rhizofiltration, refers to the use of plant root to absorb, adsorb, or precipitate toxic metal contaminants from aqueous medium[5]. For absorption, toxic metals are absorbed to the root surface by the actions of chemisorption, ion exchange, and complexation [28, 21, 16]. For adsorption, some toxic metals adsorb to the surface of the plant root [5]. For precipitation, some plants release negative charged ions which combine with some toxic metal species to form precipitants on their surface while some plants alter the pH near their root systems to allow enough hydroxide ions for toxic metal hydroxides to precipitate on their root surfaces, immobilizing their movement in water bodies thus reducing their concentration[5].

e) Vermiremediation Technology

Earthworms have been reported to bio-accumulate chemical contaminants in their tissues and either biodegrade or bio-transform them into harmless products with the aid of enzymes [39]. Hartenstein et al [15], studied that earthworms can bio-accumulate high concentrations of heavy metals like cadmium (Cd), mercury (Hg), lead (Pb) copper (Cu), manganese (Mn), calcium (Ca), iron (Fe) and zinc (Zn) in their tissues.

IV. CONCLUSIONS

E-waste is a serious problem at both local and global scales. E-waste problems appeared initially in developed countries and now extend widely to other developing countries like India and around the world. The volume of e-waste is growing fast because consumer technology is rapidly changing and the innovation of technology results in rapid obsolescence, thus generating massive amounts of e-waste. E-waste consists of many different materials, some of which contain a variety of toxic substances that can contaminate the environment and threaten human health, if the end-of-life management is not meticulously managed. Many case study from e-waste recycling plants confirmed that the toxic chemicals such as heavy metals and POPs have and continue to contaminate the surrounding environment. Landfill leachates from disposal sites demonstrate the release of toxic substances from e-wastes with the concentration varying significantly between field and laboratory based studies.

The paper proposed technique for bio-decomposition of E-waste and a national uniform E-waste management system for India based on the current, social, economical, occupational and environmental scenario, needs and requirements analysis in light of various successful practices, approaches followed in various countries, especially the best practice of Switzerland. The proposed system may lead to more formal and rigorous control of the regulatory authority over the E-waste collectors, traders, recyclers, manufactures and importers–exporters of electronic appliances. It may intensify the E-waste collection and lead to more appropriate use of resources including technical expertise and technologies for better E-waste management. The Indian E-waste system requires several reforms for the environmentally sound and regulated scientific processing of E-waste. Further, studies, considerations and research are required for reforming the policies, legislature and laws related to E-waste to suit the Indian scenario. Also there exists a need for finding out the most environmental friendly recycling/disposal processes and treatment options for handling the E-waste containing the various toxic and hazardous materials. Management of E-waste, if properly carried out, is an opportunity as it is often called as "urban mining." The role of public private partnership (PPP) plays a key role in developing and organizing a sound E-waste management strategy in India. Although very few private enterprises have established the facilities for the waste treatment in few cities like Bangalore, Chennai, and Noida which are handling and treating the E-waste in more scientific and environmental friendly manner.

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