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Review Article

An overview of E-waste, its management practices and legislations in present Indian context

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Abstract
E-waste coming out from the electronic sector of the entire world is harming the world's environment. There has been a pattern of a substantial increase in the production of E-waste worldwide. This is as a consequence of population increase, industrialization, urbanization and economic activity. Since the last decade, the rate of consumerism has been found to be very high due to higher economic growth, which has resulted in increased E-waste production. Almost all countries are recycling more and more E-waste, but a million tonnes of E-waste still coming out. Experts believe that the rise of E-waste is due to our rapidly changing lifestyles. We have started adopting new electronic devices coming into the market, trying to make life more convenient. In India, electronic waste is growing at 10% per annum. The trend of urbanization has played a significant role in the enhancement of E-waste generation. The population living in urban areas was 27.67% in 2000, 38.03% in 2018, and is expected to reach approximately 42% in 2025. As the population increases, the amount of E-waste will also rise to an alarming situation. This review paper provides the present scenario of E-waste and its management practices and legislation in the present Indian context. This would help all the stakeholders involved in the production of electrical equipment to gain better understanding of E-waste.

Keywords: Environmental pollution, E-waste, Human health, Legislation, Management

INTRODUCTION

E-waste is described as discarded electrical and electronic devices or parts . E-waste or Waste electrical and electronic equipment (WEEE) is the term used to describe old, end of life (Perkins *et al*., 2014) or discarded appliances using electricity. E-waste includes computers, consumer electronics, fridges etc. which are disposed-off by their original users. According to E-waste Rules (2016), E-waste means Electrical and electronic equipment (EEE), whole or in part discarded as waste by the buyer as well as rejects from manufacturing, refurbishment and repair processes *(www.cpcb.nic.in).*

Categories of E-waste (E-waste categories pursuant to the European Union-EU Directive 2002/96/EC)

1. Large household appliances (refrigerators/freezers, washing machines, dishwashers).
2. Small household appliances (toasters, coffee makers, irons, hairdryers).
3. Information technology (IT) and telecommunications equipment (personal computers, telephones, mobile phones, laptops, printers, scanners, photocopiers).
4. Consumer equipment (televisions, stereo equipment, electric toothbrushes).
5. Lighting equipment (fluorescent lamps).
6. Electrical and electronic tools (handheld drills, saws, screwdrivers).

7. Toys, leisure and sports equipment.
8. Medical equipment systems (with the exception of all implanted and infected products).
9. Monitoring and control instruments.
10. Automatic dispensers.

The rapid growth of technology, up-grading technical innovations, and a high rate of obsolescence in the electronics industry have led to an increase in E-waste volume. Studies by Bertram *et al*. (2002); and Cui and Zhang (2008) also affirm that wastes from electrical and electronic equipment are the fastest growing waste category. United Nation University (UNU) report showed that 44.7 million metric tonnes (Mt) E-waste was generated worldwide in 2016 and predicted that E-waste's total quantity to be increased up to 52.2 Mt by 2021. Out of the total E-waste generated, only 20% E-waste was officially collected and recycled formally (Baldé *et al*., 2017). According to Forti *et al*., (2020), the global E-waste generation in 2019 was 53.6 million metric tons (Mt), of which only 17.4 % was officially recorded as being properly collected and recycled. It has risen with 1.8 Mt since 2014, but the overall production of E-waste has increased by 9.2 Mt. This suggests that recycling efforts are not keeping track with E-waste's global growth. It is further estimated that the amount of E-waste generated will exceed 74 Mt in 2030. In India, a total of 3230 metric kiloton (kt) of E-waste was generated in 2019, which comes to 2.4 kg per capita of E-waste.

Globally 15-20 % of E-waste is recycled while the remainder is dumped into developing countries. E-waste from developed countries finds an easy way into developing countries within the name of trade which is further complicating the issues associated with waste management. Despite the existence of varied conventions, there is still a comparatively high flow (50-80 per cent) of WEEE from the USA, Canada, Europe, Japan, and Korea to developing countries like India, China, Taiwan, Pakistan, Bangladesh, Srilanka, Bhutan, Nepal and various African countries (Puckett *et al*., 2002; Terazono, 2006; Cobbing, 2008; Johri, 2008; Shamim *et al*., 2015). Some developing countries are becoming the fastest-growing markets for EEE and produce a significant WEEE volume (Widmer *et al*., 2005). In India few cities namely, Mumbai, Delhi, Madras, Hyderabad and Ahmedabad are notable regions, which receive a majority of E-waste as a charity (Imran *et al*., 2017; Arya *et al*., 2020). The European Union (EU) directive, the Basel Convention, the take-back scheme, the Extended Producer Responsibility (EPR), the Organization for Economic Co-operation and Development (OCED) became more common among the popular legislation. These guidelines and amendments aim to deal with massive volumes of E-waste in a proactive and environmentally sustainable manner, without altering the ecological parity (Gollakota *et al*., 2020). Solid waste management, which is already an enormous problem in India, has become more complicated due to E-waste. India receives the partially obsolete and scrap gadgets (Borthakur and Govind, 2017; Ashfaq and Khatoon 2014) from western countries due to the weak legislations over its handling and management (Agoramoorthy and Chakraborthy, 2012). Clear government policies and competent bureaucracies for solid waste management are urgently required, particularly in those countries where population growth in semi-urban areas is rapid by urbanization. Services and programs to provide adequate disposal of waste for the management of toxic biological and chemical wastes, minimization and recycling will be required (Rajput *et al*., 2009).

ENVIRONMENT AND HEALTH CONCERN

E-waste is considered as being highly contagious for the environment and its components (Rakib and Ali, 2014). The processing technologies such as smelting, cutting, crushing, incineration, and combustion release toxic emissions (Lee *et al*., 2007). Traditional E-waste processing through inappropriate networks in India has resulted in an immense quantity of heavy metals and other contaminants into the natural environment, which negatively affects natural environments such as soil, water, dust and plants (Awasthi *et al.,* 2016). The main environmental concerns are resource depletion due to the manufacturing of new electrical and electronic equipment and dangerous substances arising from waste. If electrical and electronic products are disposed -off in landfill sites, a million tonnes of materials that might be recovered and reused for new products are being lost. E-waste varies chemically and physically from municipal or industrial waste. E-waste is much more life-threatening than many other municipal wastes because electronic devices contain thousands of components manufactured from lethal chemicals and metals such as lead, cadmium, polyvinyl chlorides (PVCs), brominated flame retardants, beryllium, antimony, phthalates, chromium and mercury (Saoji, 2012). These wastes may have adverse effects on the environment and human health (Gaidajis *et al.,* 2010; Alabi *et al*., 2020). Although these dangerous substances are usually only contained in small amounts, they cause serious environmental damage. Improper handling of E-waste adds hazardous material to environmental cycles through particulate matter from dismantling activities, fly and bottom ash from burning activities, leachates from dumping sites and wastewater from dismantling and shredding facilities. Emissions due to burning of E-waste can give rise to greenhouse gases contributing to global warming. The human health impacts of E-waste recycling have been well studied by researchers around the world, especially in those countries where E-waste recycling is carried out by the informal sector (Herat, 2020). Reproductive and endocrine systems, kidney, bones and the nervous systems etc. may be damaged by long-term exposure to E-waste content (Islam *et al*., 2019). Once these harmful chemicals are released into the human body, they can be accumulated in the fatty tissues and affect the human population residing around the informal E-waste markets (Zeng *et al*., 2017; Zhang *et al*., 2017; Liu *et al*., 2018).

Several elements present in E-waste pose health hazards on human beings. The important ones are that chronic exposure to arsenic can lead to various skin diseases, decrease nerve conduction velocity, and cause lung cancer. Beryllium causes Chronic Beryllium Disease (beryllicosis), which primarily affects the lungs. Long-term exposure of cadmium causes Itai-itai disease. Lead is a neurotoxin that affects the kidneys and the reproductive system. Mercury affects the cardiovascular and central nervous system. Brominated Flame Retardant (BFR) can lead to severe hormonal disorders. The various health effects on human beings by different hazardous materials present in the E-waste are indicated in Table 1 (Adapted from Frazzoli *et al*., 2010; Kumar and Singh, 2014; Li and Achal, 2020).

TREATMENT OF E-WASTE

E-waste is a mixture of valuable material that is recoverable and recyclable with toxic substances that must be safely disposed of as its treatment is complicated. E -waste requires both labour-intensive technical processes for the separation of toxic waste. Handling of E-waste by beginning with manual dismantling has been recommended as the best starting process for its treatment. Recovery of the precious material is still not worth because of the heterogeneity of the material. Heterogeneity is causing a big problem in terms of proper recovery. The metal content is around 28-30% in which Copper is 10 to 20 %; Lead is 1 to 5 %; Nickel is 1 to 3% and precious metals like silver, platinum, and gold are 0.3 to 0.4%. Other materials are plastics (19%), bromine (4%), glass and ceramics (49%). In addition to these inorganic elements, other essential organic compounds are also present in circuit boards such as isocyanate phosgene acrylic and phenolic resins (Ludwig *et al*., 2003). The dismantled E-waste is separated into glass, copper, steel, aluminium, plastic, printed circuit boards etc. E-waste's overall PCB content is 3-5% by weight of E-waste, which requires environmentally safe recycling methods. The remaining 95-97% of metals, plastics, and glass can easily be dissembled separated manually without harming the environment (Chatterjee, 2012). The hazardous components like capacitors, CRT screens, CFC gases, light bulbs and batteries are also separated and removed at this stage. Mechanical processing which is typically a large-scale operation allows the increase in recyclable materials in a dedicated fraction and further isolates hazardous materials. Typical components of automated processing plants are the Crushing units, Shredders, Magnetic separators and Air separators.

Most of the fractions obtained here are refined to be sold as secondary raw materials. At the completion of refining and after extraction of valuable fractions, the contaminants which are typically unusable and toxic are disposed-off in specially built hazardous waste disposal facilities.

E-WASTE MANAGEMENT IN INDIA

The E-waste stream within the country is rising three times faster than the municipal waste stream. According to Global E-waste Monitor 2020, India is the third-largest electronic waste producer in the world after China and the USA. These three countries generate approximately 38 % of the total of 53.6 million tonnes (Mt) of E-waste (Times of India, July 4 2020). E-waste management in India has been largely based on the highly organized informal sector, including the collection, segregation, dismantling and recycling. The informal sector's recycling is done in a primitive way by using inefficient methods which cause damage to the health of the workers and environmental damage and loss of valuable materials. E-waste management in India differs from that in the world. E-waste disposal procedures are a significant concern as a result of informal recycling activities. The quantification of E-waste in India is thus challenging and there is no method for regulating the movement of E-waste in the system (Sankhla *et al*., 2016).

According to a study on Electricals and Electronics Manufacturing in India, conducted by the Associated Chambers of Commerce and Industry of India (ASSOCHAM-NEC) in 2018, Maharashtra produced 19.8% of E-waste but recycled only about 47,810 tonnes per annum (TPA), Tamil Nadu (13%) recycled about 52,427 TPA, Uttar Pradesh (10.1%) recycled about 86,130 TPA. West Bengal contributed 9.8%, Delhi 9.5%, Karnataka 8.9%, Gujarat 8.8%, and Madhya Pradesh 7.6% of E-waste. Among the top ten E-waste generating cities, Mumbai ranked first followed by Delhi, Bangalore, Chennai, Kolkata, Ahmadabad, Hyderabad, Pune, Surat and Nagpur. Chandigarh generates 17 kg of E-waste annually, resulting in 4100 tonnes of E-waste from Chandigarh's households (Ravindra and Mor, 2019). There is no large-scale organized E-waste recycling facility in India and the entire recycling exists in the unorganized sector (*https://cpcbbrms.nic.in*). Most of the activities, like collection, transportation, segregation, dismantling, recycling, disposal, etc., are carried out by the informal sector. The E-waste is mostly picked up by the rag pickers who pay a certain amount to the customer from whom the waste is col-

Table 1. Various health effects by different hazardous material present in the E-waste (Adapted from Frazzoli *et al*., 2010; Kumar and Singh, 2014; Li and Achal, 2020).

S.No.	Pollutant	Source of E-waste	Health effects
1	Arsenic	Semiconductors, microwaves, LEDs (Light-emitting diodes), solar cells	Chronic exposure to arsenic can lead to various diseases of the skin, decrease nerve conduction velocity and cause lung cancer.
2	Barium	Electron tubes, filler for plastic and rubber, lubricant additives	Cause brain swelling, muscle weakness, damage to the heart, liver and spleen.
3	Beryllium	Switchboards and printed circuit board	Carcinogenic; Chronic Beryllium Disease (Beryllicosis), a disease which primarily affects the lungs.
4	Brominated Flame Retardant	Casing, circuit boards (plastic), PVC cables	Combustion of halogenated case material and printed wiring boards at lower temperatures releases toxic emissions, including dioxins, leading to severe hormonal disorders.
5	Cadmium	Batteries, solder, alloys, circuit boards, computer batteries, cathode ray tubes (CRTs)	Carcinogen; Long-term exposure causes Itai-itai disease, which causes severe pain in the joints and spine. It affects the kidneys and softens bones.
6	Chrome	Dyes, switches, solar	Inhaling hexavalent chromium can damage liver and kidneys and cause bronchial maladies, including asthmatic bronchitis and lung cancer.
7	Cobalt	Insulators	Accumulate to toxic levels in the liver, kidney, pancreas, heart, and skeleton and skeletal muscle. Cobalt has been found to be human carcinogen.
8	Copper	Conducted in cables, copper ribbons, coils.	Nausea, Vomiting, Diarrhoea, Liver Damage, Kidney Damage, Death.
9	Lead	Lead rechargeable batteries, transistors, lithium batteries, PVC (polyvinyl chloride), stabilizers, lasers, thermoelectric elements, circuit boards.	A neurotoxin that affects the kidneys and the reproductive system. High quantities can be fatal. It affects mental development in children.
10	Lithium	Mobile telephones, photographic equipment, video equipment (batteries).	Corrosive to the eyes, the skin and the respiratory tract. Corrosive on ingestion. Inhalation of the substance may cause lung oedema.
11	Mercury	Components in copper machines and steam irons; batteries in clocks and pocket calculators, switches, LCDs.	Affects the cardiovascular system, central nervous system, kidneys and immune system.
12	Nickel	Alloys, batteries, relays, semiconductors, pigments.	Carcinogenic; Lung cancer, nose cancer, larynx cancer and prostate cancer, Asthma and chronic bronchitis.
13	PCBs (polychlorinated biphenyls)	Transformers, capacitors, softening agents for paint, glue, plastic.	PCBs have been shown to cause a number of serious non-cancer health effects, including effects on the immune system, reproductive system, nervous system, endocrine system and other health effects.
14	Selenium	Photoelectric cells, pigments, photocopiers, fax machines.	Cause selenosis. The major symptoms are hair loss, nail brittleness, and neurological abnormalities.
15	Silver	Capacitors, switches (contacts), batteries, resistors.	Cardiac abnormalities, permanent brain and nervous system damage.
16	Zinc	Steel, brass, alloys, disposable and rechargeable batteries, luminous substances.	Cause health problems like stomach cramps, skin irritations, vomiting, nausea and anaemia.
17	Toner Dust	Toner cartridges for laser printers/ copiers.	An irritant to people with respiratory conditions such as asthma or bronchitis.
18	Americium	Medical equipment, fire detectors, active sensing element in smoke detectors.	Radioactivity.

lected. Rag pickers accumulate all categories of waste such as paper, books, newspapers, plastic, cardboard, polythene, metals, etc. including E-waste, and earn their livelihood by selling it to mediators or scrap dealers. This is a significant income source not only for rag pickers but also for mediators and scrap dealers. E-waste is typically handled by unskilled staff and they do not take sufficient safety precautions to reduce the cost (Purushothaman *et al*., 2020). Recycling and disposal techniques are not used properly due to lack of adequate technology. Very few companies have voluntarily adopted the 'take-back' system. There is no clear data on the quantity generated (Arya *et al*., 2020) and disposed-off per annum and the resulting extent of environmental risk. According to the literature analysis, only 50% of the public are aware of the electronic goods' environmental and health impacts, so there is an immediate need to introduce a proper E-waste management system in India (Khurrum *et al.,* 2011). Shirodkar and Terkar (2017) highlight the condition and consequences of E-waste management in India and propose a new, specific management model as the best approach for E -waste management in India.

E-waste regulation in India

There are various laws that directly or indirectly affect hazardous wastes and toxic substances. Environmental (Protection) Act, 1986 deals comprehensively with environmental issues. Section 6 explicitly authorized the Central Government to lay down rules on different matters including -

1) Protocols and precautions for the processing of hazardous substances.

2) Prohibition and limitation on the handling of hazardous substances.

In view of E-waste's growing problems, the Central Government has notified these rules in the exercise of the powers provided under Sections 6, 8 and 25 of the Environmental (Protection) Act, 1986. E-waste (Management) Rules, 2016 supersedes the E-waste (Management and Handling) Rules, 2011. It consists of 24 rules split into 6 Chapters and 4 Schedules. This regulation aims to encourage recycling of usable E-waste products, thus minimizing hazardous wastes destined for landfill and ensuring that all forms of E-waste are handled in an environmentally sound manner. These rules shall come into force from October 1 2016.

E-waste (Management) Rules 2016 recognizes and defines each of the stakeholders (producer, manufacturer, consumer, bulk consumer, collection centers, dealers, e-retailers, refurbishers, dismantlers, and recyclers), who are involved with the production of electric equipment and management of the waste generated at the end of its useful life. The responsibilities of each stakeholder are also explicit in the rule. E-waste management is based on the concept of Extended Producer responsibility (EPR). It is considered an environmental protection policy that makes the producer of the product responsible for the entire life cycle of the product and particularly for the take-back, recycling, and final disposal of the product. One of E-waste management's important aspects is the designation and application of EPR (Corsini *et al*., 2015). Many researchers have investigated various aspects of E-waste management based on EPR. The EPR is considered internationally as one of the most successful ways to resolve the problem of E-waste. However, unlike in the developed world, the introduction of EPR in developing countries is a significant concern for policymakers due to the informal sector's active participation (Pariatamby and Victor, 2013). EPR is a regulatory strategy that allows manufacturers to finance the costs of collecting, recycling, and/or safely disposing of products consumers no longer want (Nash and Bosso, 2013). Favot *et al*., (2016) analyze the Italian collective system for the management of household Waste Electrical and Electronic Equipment (WEEE), and its evolution over time, following the European Directives on WEEE, which include the EPR. The EPR and Producer Responsibility Organization (PRO) programs have been presented in an articulated manner in European countries and in India, we are yet to explore its full potential (Garlapati, 2016).

Specific targets have been set up for the producers to manage 30% of the waste generated during the first two years of implementation of the rule. This target has been gradually increased so that by the seventh year of implementation of this rule, nearly 70% of the E-waste generated is properly managed. The penalty of non-compliance of meeting the target includes cancellation of EPR authorization which would result in the producer not being able to put products in the market until EPR authorization is re-granted. Apart from having a planned system for managing E-waste, the producers are required to reduce the number of hazardous substances in their equipment. The equipment should not contain lead, mercury, hexavalent chromium, polybrominated biphenyls and polybrominated diphenyl ethers beyond a maximum concentration value of 0.1% cadmium of 0.01% by weight in homogenous materials.

Amendments in E-waste Management Rules 2018

The E-waste Management Rules 2016 is amended vide notification G.S.R. 261(E), dated March 22, 2018. The amendment in rules was carried out to channel the E-waste produced within the country to authorized dismantlers and recyclers to formalize the E-waste recycling market. The collection targets under the supply of Extended Producer Responsibility (EPR) within the Rules are updated and targets are set for new producers who have recently begun their sales operations.

Key facets of the E-waste (Management) Amendment Rules, 2018 are as follows:

1. The E-waste collection targets under EPR are revised and can be applicable from October 1 2017. The phase-wise collection targets for E-waste in weight shall be 10 % of the waste generation quantity as set out in the EPR Plan during 2017-18, with a yearly increase of 10 % by 2023. After 2023 onwards, the target will be set at 70 % of the volume of waste generation as stated in the EPR Plan.
2. The quantity of E-waste collected by producers from the October 1 2016 to September 30 2017 shall be taken into account for the updated EPR targets until March 2018.
3. Separate E-waste collection targets are set for the new producers, i.e., those producers whose number of years of sales operation is smaller than their products' average lives. Standard lives of the things must be in accordance with the guidelines provided by CPCB, 2016 (Central Pollution Control Board, India) from time to time.
4. Producer Responsibility Organizations (PROs) shall apply to the CPCB for registration to carry out the activities stated in the regulations.
5. According to the Reduction of Hazardous Substances (RoHS) provisions, the cost for sampling and testing shall be borne by the Government to execute the RoHS test. If the test results do not validate the specification of RoHS, the manufacturer shall bear the cost of the test.

Conclusion

E-waste not only contains hazardous material but also at the same time has precious material. There is a lot of concern about E-waste from the government side, but people should also be concerned because it has a variety of hazardous materials. In India reuse, remanufacturing and recycling of E-waste are done by mostly informal recycling, i.e., not authorized by the Government. Some of the E-waste amount is recycled in the informal sector, but most of the E-waste is being dumped in a landfill after recovery of the valuable material. It triggers different forms of health and environmental hazards. Therefore, it is important to overcome the gap between the formal and informal E-waste sectors to fully exploit E-waste's resource value and develop a sustainable management pattern. Formalizing the informal sector through a consistent recycling scheme is critical and strongly advised. Proper E-waste management will enable effective procurement and collection right up to extraction and disposal of material, ensuring that this large E-waste volume will turn into lucrative goods. Efficient recycling, E-waste disposal, and stringent enforcement of E-waste Management regulations are required to mitigate the adverse effects of E-waste on the environment and human health that will ensure India's waste management viability system.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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