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Review on E-waste management and its impact on the environment and society

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ABSTRACT

Electronic trash, often known as E-waste, is a type of garbage generated by electronic in the industrial world, trash is one of the most difficult and rapidly expanding issues. E-waste is made up of old or end-of-life electronic appliances such as computers, laptops, televisions, generators, DVDs, mobile phones, freezers, and other items that are typically discarded by their original owners due to their short lifespan. It contains a number of hazardous constituents that have a negative impact on the environment and, more importantly, human health if not properly managed. Because it includes harmful chemical elements, E-waste proves to be a significant difficulty. Since it is believed that E-waste is a future of communications but due to the short life span of various appliances, they are being trashed and pollutes the environment. Many groups and governments from various nations have implemented a variety of ways to address the problem and threat to the environment and human health. Hence, this review presents a compendium of various sources of E-waste, environmental hazards, its composition and characterization, E-waste scenarios in India and global world. For the sake of the future, techniques of handling and processing, as well as E-waste recycling, should be used. This paper mainly outlines the issue of E-waste also covering the improvement and plan to tackle the issue.

Contents

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Introduction

The electronics industry is the world's largest and fastest-growing industrial sector. Humans have a significant reliance on modern technologies merely to live a luxury existence. As a result, the demand and the rate of consumption of these appliances has expanded globally (Arya and Kumar, 2020). People's use of electronic gadgets is quite high in today's situation, which aids the world's economy in the massive expansion of inventions and new technologies. Due to the widespread of new gadgets there is a huge segment of electrical waste on the planet. According to a survey, approximately seven billion people lives on this planet, out of which only 5 billion of them have access of their basic requirements and are capable of getting it. And more than 6 billion people uses mobile phones which becomes a basic need and necessity now (Krishnamoorthy et al., 2018; What a Waste Global Database, 2021; Programme, 2007). As a result of its harmful influence on human health, it poses a hazard to the ecosystem. The massive volume of E-waste produced by the electronics industry is starting to have serious effects. The phrase E-waste, or electronic trash, refers to obsolete and end-of-life electronics such as televisions, laptops, generators, freezers, computers, and other electronic gadgets that have been discarded by their owners. Thus, E-waste is produced which made up of things that are somewhat costly yet long lasting. Whenever there's a discussion about the term 'electronic trash' is mainly refers to anything that rely on electricity or power to function efficiently and effectively. Technically, E-waste is a division of electrical and electronic devices or equipment's. Since, E-waste composition is quite difficult and complex as it constitutes of around 1000 substances or more than that. Further these substances subdivided into the hazardous and non-hazardous categories (Wath et al., 2011). A wide range of source generates E-waste as discussed earlier, however, the bulk of E-waste elements led to the landfilling (EUR-Lex, 2022). There are three main reasons that why E-waste is becoming a huge health threat, firstly, a major lack of knowledge and understanding about the proper management and handling techniques of E-waste (http://www.basel.int/TheConvention/Overview/tabid/, 2022). Second, as the volume of electronic waste produced increases, it becomes a threat and a bigger risk to human health and the environment. Garbage and rubbish of all kinds have a significant influence on both physical and emotional health, whether direct or indirect (Rautela et al., 2021). Third, fast advancements in automation have resulted in a reduction in the number of legislations governing E-waste recycling. One main cause of E-waste collection is due to the people's habits which is shown in Fig. 1.

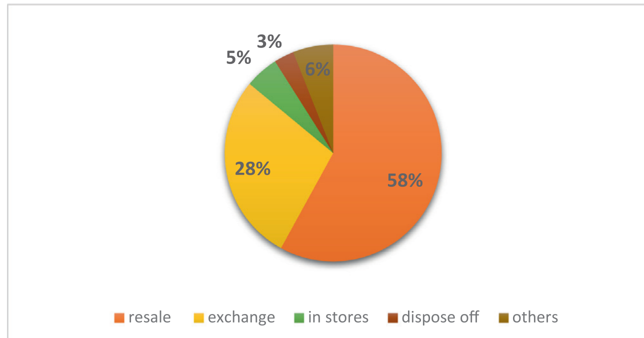

Fig. 1. Human habits for E-waste collection (Guerrero et al., 2013).

Globally, various rules and regulations are imposed related to the import and exports of waste generated and policies related to that. But no such serious action has been imposed on this serious issue. One reason of not taking action to such wastes which are increasing steeply worldwide, that since it is believed, electronic industry is the future of communications and due to this the economic growth is expanding day by day. The electronic devices are designed to be trashed so that they make future profits and upgraded the performance of products. These products are hardly new just for the time period of six months or one year and after that its monetary value gets reduced significantly, which resulted in the form of e- trash (LeBel, 2012). So, for all these things, there must be an organization which gives the regular suggestion on the improvement of these issues (Bhutta et al., 2011).

To that end, the present study examines electronic waste generation in India and throughout the world in order to better understand the waste management and, in particular, the effects on the environment and human health from such wastes.

E- waste sources

Due to the high demand of electronic waste especially mobile phones, computers, solar cells, electric vehicles and laptops, the economic growth of IT sectors is growing exponentially in high volumes which resulted in a good economic rate of the country. To introduce new technology to the market, the public and private sectors are replacing obsolete electronic products with new ones, resulting in an increase in E-waste garbage. Household appliances, small and big enterprises, PC manufacturers, institutions, and other industries create domestic E-waste. Since, as compared to the generation of mobile phones and computers, households contribute the least.

However, in many countries, disposing such items is forbidden, causing problems with E-waste disposal. Cheaper processing prices, lower labour costs, and a lack of environmental regulatory enforcement are all contributing factors to the surge in illegal E-waste imports. Although there is no accurate way to estimate the created E-waste since no one knows how much E-waste is produced or how much is imported and exported to other nations. On the other hand, getting accurate statistics on recycled E-waste by various sectors is problematic. (Mundada et al., 2004).

Households' E-waste

Since household contributes the less share in E-waste production. It's difficult to estimate the actual amount of E-waste produced. According to a survey, household appliances that includes personal computers, freezers, generators, etc. are not the major contributors for the production. It is around only 20–21% and other sectors are responsible for the E-waste production (LeBel, 2012; Mundada et al., 2004).

Business sector E-waste

This sector consists of government departments, public and private sectors, MNCs, etc. Since, this sector is the main benefactor for the E-waste production. As per the survey, they are subjected to around 79% of total installed PC's which is the highest in all the sectors. Around 1.38 million out of date PC's are being trashed from this sector as well as from the households too (LeBel, 2012; Mundada et al., 2004).

Manufacturers and Retailer's E-waste

PCs, IC chips, motherboards, cathode ray tubes (CRTs), and a variety of peripheral goods are all produced or manufactured in this industry. The waste generated from this sector is second major donor in this list. It has been observed that around 1050 million tonnes of these peripheral devices being trashed every year (Mundada et al., 2004).

Imports of E-waste

It is believed that importing garbage is undeniably the most profitable business. The primary goal of importing old electronics is to recover precious metals and elements that are mainly found in the electronic trash which includes steel, aluminium, gold, titanium, copper, tin, mercury, cadmium, etc. present in a bulk amount. These commodities provide useful raw material for the production of new products. Many markets extract kinds of plastics and other materials from the trash products. However, trade of export and import of electronic waste products has become an important ingredient for the E-waste recycling (Secretariat, 2011).

Global E-Waste production

Economic growth and widespread access to technology are predicted to expand global E-waste generation, as higher GDP leads to more purchases of electronic goods and, in turn, more E-waste production. The growth of electronic devices around the world is occurring in lockstep with the rapid shift in global information and technological advances (Rautela et al., 2021; Gaidajis et al., 2010). According to several predictions, garbage output in 2019 will set a new high of roughly 53.6 million metric tonnes. As in just five years, there is an increment of 21% of generated waste, which becomes a serious threat now. In the year 2015, United Nations University in the year 2015, released a report and claimed that global electronics waste has reached around 41.8 million metric tonnes. With rapidly changing of technologies and demand for the new advancements, results in the wastage of old products, which becomes the E-waste.

E-waste generation is expected to reach 20–50 Mt every year, accounting for 1–3 percent of worldwide rubbish production (Perkins et al., 2014; Widmer et al., 2005) as shown in Fig. 2 which describes the E-waste production produced in metric tonnes every year.

According to a survey, PC's, mobiles and televisions contributed 5.5 million metric tonnes in year 2010. In rich countries, E-waste accounted for 8% of total trash volume. The mass (in kg), quantity (in numbers) in the market, consumption (N), and average life cycle L (in year) of each electronic item indicate its contribution to yearly E-waste creation, or $MN/L = E$.

According to a current report, it has been claimed that around 4500 Eiffel Towers can be constructed from the amount of waste generated every year and by starting of the year 2022, the production rate has been started increasing (Baldé et al., 2017). China and other parts of the Asian countries are moreover responsible for generating around 40% of the total world's trash generated. There is a huge amount of such waste in the world, but only about 20% of it is collected and recycled; the remaining 80% of the unknown garbage is dumped, resulting in E-waste, which is exported to poor countries for dumping and primarily for the extraction of precious metals from the waste produced. Waste is imported and exported between nations under diverse conditions. (Sthiannopkao and Wong, 2013).

E-waste production in India

Since electronic garbage, often known as E-waste, is the world's fastest increasing waste source. The fast rise of the E-waste stream has been attributed to the expansion of the industrialisation process, technological advancements, and higher living standards. According to the global market, about 53.6 million metric tonnes of electronic garbage were created worldwide in 2020, with only 17–18% of the waste being recycled. However, when it comes to E-waste creation, India is the world's third largest contributor, with roughly 3.2 million metric tonnes of rubbish created every year, trailing only China and the United States.

Prime Minister Narendra Modi talked in December 2020 on the importance of maximising the use of electronic devices while properly eliminating the obsolete ones, as well as the need to effectively manage the E-waste. He announced an initiative dubbed 'Garbage to Wealth' in August 2021, which focuses on putting waste to better use. According to the Central Pollution Control Board of India's 2020 reports, about 1,014,961 tonnes of E-waste were created in the years 2019 and 2020 (https://science.thewire.in). As previously stated, most of the waste whether it is municipal or electronic, generated and exported from different countries particularly China and India show the pattern in the Fig. 3.

In Fig. 3, G shows the generating or origin country whereas, D shows the exporting or dumping country of E-waste (Baldé et al., 2017; 2015 | Latest Major Publications). Purple colour line i.e., G1, is North America, G2 is Western Europe and included some part of

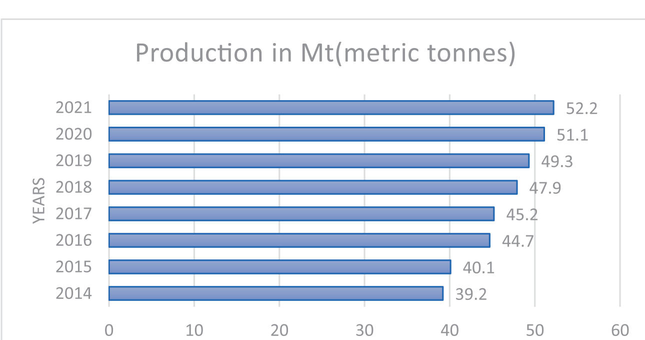

Fig. 2. E- waste production in different years (Widmer et al., 2005).

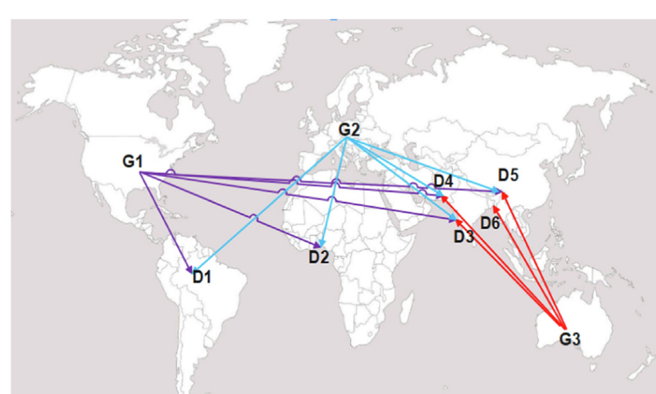

Fig. 3. Origin and Dumping country pattern of exporting E-Waste (", 2022).

Eastern Europe as well, G3 is Australia, D1 is Brazil, D2 shows some parts of Ghana, Nigeria, Ivory Coast, D3 is Thailand, D4 is India, D5 is China and D6 is Vietnam.

Despite the country's high rate of production and usage, official recycling and disposal procedures are only in use in some cities and towns. Most states have informed recycling techniques with about the presence of one million people in that place working in recycling processes which poses safety risks and environmental implications. But the problem arises with the informal sector as they are not aware and not having proper education about the hazardous health consequences (Awasthi and Li, 2017).

The many sources of E-waste created in India are depicted in Fig. 4. Household activities account for 15% of the source, the government, public, and commercial sectors for another 15%, and electrical and electronic trash accounts for the majority of the remaining 70%.

Impact of E-Waste

Various harmful impacts due to electronic waste are faced by the humans and as well as the environment. Due to improper management and advancements in the technologies, this situation has escalated into a major hazard to human life. The two main essentials that are badly

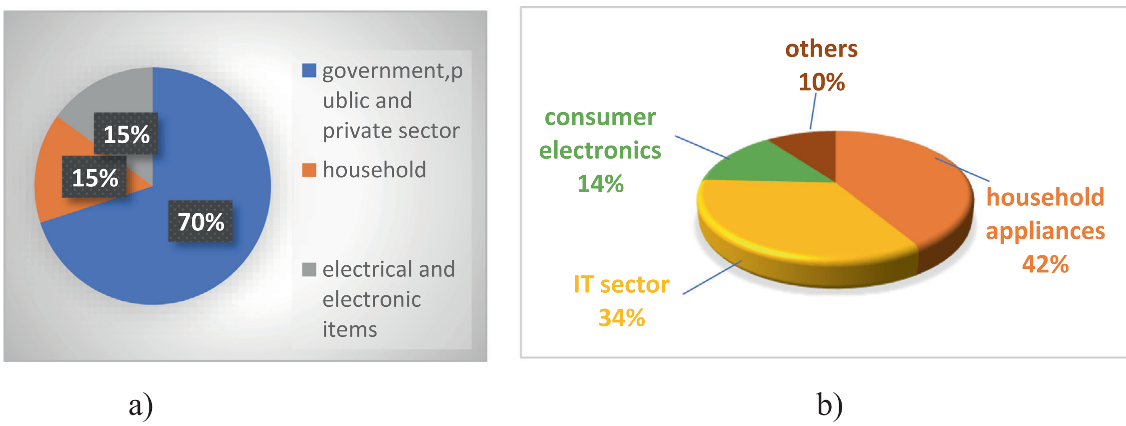

Fig. 4. A) e-waste sources in india and b) e-waste generation in different sectors (Arya and Kumar, 2020).

Table 1
Diseases caused by E-waste in human beings.

Hazardous Components	Present In	Consequences of hazardous components being present in E-waste	References
Arsenic	Semiconductors, diodes, microwaves, LEDs, solar cells	The nervous system and the skin may be impacted. Long-term asbestos exposure can cause lung cancer.	(Yang et al., 2020; Kumarathilaka et al., 2018; El-Ghiaty and El-Kadi, 2021)
Asbestos	Insulators in heating equipment's	Breathing problems, coughing, lung damage, and even cancer are all serious adverse effects.	(Debnath et al., 2021; Disposal of Asbestos, 2022)
Barium	Fillers for plastics and rubbers, as well as electron tubes.	Heart muscle can be affected by this	(Pinto, 2008; Ari, 2016)
BFR	Different Casing, circuit boards, chips	The reproductive and immune systems may be harmed. Hormone imbalances and endocrine system issues are possible side effects.	(Julander et al., 2014; Segev et al., 2009)
CD	PCB, batteries, some pigments, solders, and alloys	Joints and the spine are particularly vulnerable, resulting in terrible pain. It weakens the bones and damages the kidneys.	(Ari, 2016; Yang et al., 2013; Grant et al., 2013)
CFC	Cleaning solvents, refrigerants, and aerosol propellants.	There is a risk of skin cancer and perhaps genetic harm as a result.	(Salhofer, 2017)
CR	Dyes, pigments	Asthma, bronchitis, lung cancer, as well as damage to the liver and kidneys, are all possible side effects.	(97% of collected E-waste recycled for useful applications, 2022)
Dioxins	(PWB), different type of cables and from metal smelting	Increased cancer risk	(Tue et al., 2019)
Pb	Thermal elements that convert heat into electricity, such as thermoelectric elements, thermocouples, and thermistors	The kidneys, reproductive system, and nervous system may all be impacted. It's possible that this causes blood and brain illnesses.	(Yang and Zhang, 2018; Zeng et al., 2020)
Li	Batteries of mobiles, photographic equipment	Long-term exposure to lithium vapours can cause nausea, vomiting, disorientation, and muscular weakness, among other things.	(A Closer Look, 2022; Saha et al., 2021; Zhang et al., 2012)
Hg	Batteries, flat screen monitors, copper machines, switches,	It has a deleterious influence on the central nervous system, kidneys, and immunological system, as well as on foetal development. It has the potential to harm the brain or liver, as well as cause skin issues.	(Decharat, 2018)
PAH	Wiring, printed circuit boards	Eye discomfort, nausea, vomiting, diarrhoea, and disorientation are all possible side effects of this medication. Long-term exposure can result in cataracts, kidney and liver damage, as well as jaundice and other symptoms.	(Wang et al., 2012; Sánchez-Quiles and Tovar-Sánchez, 2015)
PVC	Cables, insulation coating	It can cause respiratory and immune system damage.	(E-Waste – Silicon Valley Toxics Coalition, 2022; Kurup and Senthil Kumar, 2017; Stapleton et al., 2008)
(PCB	Transformers, capacitors, softening agents	Damage can occur to the immunological system, reproductive system, neurological system, and endocrine system. PCBs are a concern to the environment as a result of their continual pollution.	(Stapleton et al., 2008; Tai et al., 2020; Managing And Reducing E-Waste From PCBs, 2022)

affected by the electronic wastes are environmental conditions and human health.

On human health

Since then, dioxin poisoning in the air has resulted in human exposure levels that range from 15 to 56 times the WHO's recommended maximum intake. Dioxin levels were found to be raised in human milk, placentas, and hair, indicating that dioxins are being ingested in significant quantities by humans through the air, water, or food to pose a serious health risk (Robinson, 2009). Health implications, on the other hand, are a direct reflection of the hazardous impact of E-waste, as illustrated in the Table 1. Since the previous decade, the volume of E-waste has been steadily growing, posing major health risks to humans. Many illnesses are affecting individuals as a result of electronic waste, including ingestion, inhalation, and most notably skin contact concerns (Köhler and Erdmann, 2004).

The diseases related to E-waste faced by humans which includes the hazardous components in which they are present in, along with the consequences of these components on humans which is described in given Table 1.

On the environment

E-waste affects human health, which can be considered in the category of environment. But the main aspects of environment like air, water and soil are badly affected by the improper management of electronic waste. The consequences of improper management leads to landfills, releasing of toxic chemicals, impacting earth's surface and most importantly human health (https://elytus.com).

Harmful effects on air

Dust particles and chemicals like as dioxins are discharged into the environment when E-waste is disposed of informally by dismantling, shredding, or melting the components, creating air pollution and hurting respiratory health (Mundada et al., 2004). Diseases like cancers and tumours especially chronic diseases are at high risks in human beings as the E-waste releases very fine particles which are hard to handle, creates numerous health issues to humans and animals. The high risks are especially for those humans who handles this type of waste. Due to this waste, the problem of air pollution kept on increasing day-by-day. Over the time, the quality of air, water and soil gets polluted and resulted in harmful damage to the ecosystem (Mundada et al., 2004; https://elytus.com).

Harmful effects on soil

When electronic trash is incorrectly disposed of in typical landfills or in areas where it is abandoned illegally, heavy metals and flame retardants can leach directly into soil, poisoning underlying groundwater or crops that may be cultivated locally or in the future. When heavy metals are present in the soil, crops are more vulnerable to absorbing these toxins, which can result in a range of illnesses and reduce agricultural productivity. Finally, the existence of plants and animals was jeopardised, resulting in internal troubles for those who rely on nature (https://elytus.com).

Table 2
Environmental impact of E-waste components (Mundada et al., 2004).

E-Waste Components	Environmental Impact
CRT (Cathode Ray Tube)	Heavy metals such as lead, barium, and other heavy metals, as well as harmful phosphorus, are leached into groundwater.
Circuit Boards	Air emission of substances
Chips and gold-plated components	Hydrocarbons, heavy metals, brominated compounds and some other chemicals dumped into the rivers and oceans that cause the problems of acidification and toxicity which badly harms the flora and fauna.
Computer Wires	Hydrocarbons discharged into the atmosphere, water and soil.
From metal smelting	Emission of dioxins causes cancer and tumour risks.

Harmful effects on water

Following soil contamination, heavy metals from E-waste, such as mercury, lithium, lead, and barium, seep further deeper into the earth, finally reaching groundwater. After reaching groundwater, these heavy metals eventually make their way into rivers, ponds, and lakes. These routes produce acidification and toxification in the water, which is detrimental to animals, plants, and communities even if they are kilometres away from a recycling facility. Even finding safe drinking water becomes tough (Mundada et al., 2004; https://elytus.com). Table 2 illustrates the various E-waste components which are in the surroundings and have a large environmental impact that affects and disturbs the whole ecosystem.

Global scenario of E-waste management

The worldwide E-waste monitor research found that just 20% of the total world's waste is properly handled. In an informal way, the great majority of the garbage was discarded or recycled. In comparison towards the profits that may be generated from recycled electronic components, efficient E-waste disposal and recycling is quite time consuming and expensive (Gregory, 2009). Stakeholders and legislators have made multiple attempts over the last decade to develop an effective E-waste collecting system. As part of a larger effort to combat E-waste, the take back system was devised as step initiative. In this process, garbage is collected, processed and controlled by the government, third parties via a particular drop off location and clearly marked pick up point in this system. A financial system that serves society, producers and consumers is required to support all three objectives (StEP solving the E-waste Problem, 2021). The illegal import of E-waste is the next obstacle to overcome. Orphan goods and free riders are two major difficulties with illicit imports having a detrimental impact on economic growth in nations where they are prominent. Only by implementing rules governing the movement of E-waste will this be managed. Another endeavour to control hazardous waste mobility is the Basel Convention on the limiting of transboundary movements and disposal of hazardous wastes. Since its inception in

Table 3
Worldwide Electronic waste generation from year 2010 to 2030 (Forti et al., 2020).

Year	Waste volume in million metric tonnes
2010	33.8
2011	35.8
2012	37.8
2013	39.8
2014	44.4
2015	46.4
2016	48.2
2017	50
2018	51.8
2019	53.6
2020	55.5
2021	57.4
2022	59.4
2023	61.3
2024	63.3
2025	65.3
2026	67.2
2027	69.2
2028	71.1
2029	72.9
2030	74.7

1992, the treaty has been ratified by a total of 179 nations (Aston et al., 2010). After following years of discussion, the European Union proposed a new global initiative in 2016 to regulate hazardous waste imports by putting them into three categories: prohibitive, notification controlled and green listed. All hazardous wastes were banned from entering African countries after being suggested in 1991 and becoming law in 1998 (Thakur et al., 2020).

In 2009, the World Health Organization (WHO) launched an E-waste and child health research to look at the impact on children's health. The purpose of this project was to bring together specialists from all around the world to look at long term effects of children being exposed to hazardous E-waste. Researchers from a variety of fields, including toxicology, industry, non-governmental organisations, economics, and demography, participated in a WHO evaluation on the effects of E-waste on children's health. (Atasu et al., 2013; Forti et al., 2020).

Internationally, to control E-waste management, several laws and legal frameworks have been enacted. Many nations have enacted their own legislation to limit and regulate the dangers of E-waste, such as:

- In China, the Administration of Control of Pollution Caused by Electronic Information Products, which was founded in February 2006, regulates total E-waste.
- In the United Kingdom, waste electrical and electronic equipment is governed by UK legislation, which was formed in 2007 after being enacted by parliament.
- The Ministry of Environment and Forests, India's national body, is in charge of waste management and environmental protection laws, which was adopted in March 2008. (Wath et al., 2011). Table 3 shows the data of electronic waste generation worldwide from year 2010 to 2030.

We have presented the data of electronic waste generation worldwide from year 2010 to 2030 in Table 3. E-waste production in 2019 was estimated at 53.6 million metric tonnes (Mt) (excluding PV panels), or 7.3 kg per person. In 2030, more than 74Mt of e-waste is anticipated to be produced. As a result, the amount of e-waste generated globally is rising at a startling pace of about 2 Mt year.

In comparison to the amount of e-waste created in 2019, the formal documented collection and recycling in 2019 totalled 9.3 Mt, or 17.4%. Since 2014, it has increased by 1.8 Mt, or approximately 0.4 Mt year. However, the output of electronic trash as a whole grew by 9.2 Mt, growing by over 2 Mt annually. This demonstrates how recycling efforts are not keeping up with the increase of e-waste on a worldwide scale. The vast majority of the e-waste produced in 2019 (82.6%) was probably not properly collected and not handled in an environmentally responsible way. Most of the time, the flows are not systematically or consistently documented. The absence of information on e-waste that is properly collected and recycled suggests that the majority of the 44.3 Mt of e-waste produced in 2019 is managed outside of the official collection system, and in some cases is exported to underdeveloped nations. Small-size gadgets can find their way into regular trash bins and be disposed of alongside municipal solid waste in residences in better income nations.

As a result, it is not properly recycled, which results in a loss of materials. According to estimates, 0.6 Mt of e-waste from EU nations ends up in trash cans (Forti et al., 2020).

Indian scenario of E-waste management

India has been the first country in South Asia to have a special E-waste law in place since 2011. The E-Waste Handling Rules created criteria for garbage transportation, storage, and recycling, as well as the concept of extended producer responsibility (EPR) (https://science.thewire.in). EPR is a well-known policy tool that requires electronic device producers to take financial and physical responsibility for handling their products' disposal once they have reached the end of their useful lives.

In 2016, the regulations were updated to establish a 'Producer Responsibility Organization' (PRO) to help with electronic trash collection and recycling. One option for addressing the E-waste problem is to improve regulation and implementation. In addition, the government should set realistic, evidence-based objectives. This would entail keeping track of how much E-waste is generated and how well recycling facilities can manage it. Second, a fundamental change in the policy framework is required. Most environmental rules in India are of the control and command variety, with manufacturers facing penalties if they fail to fulfil a specified objective. (https://science.thewire.in).

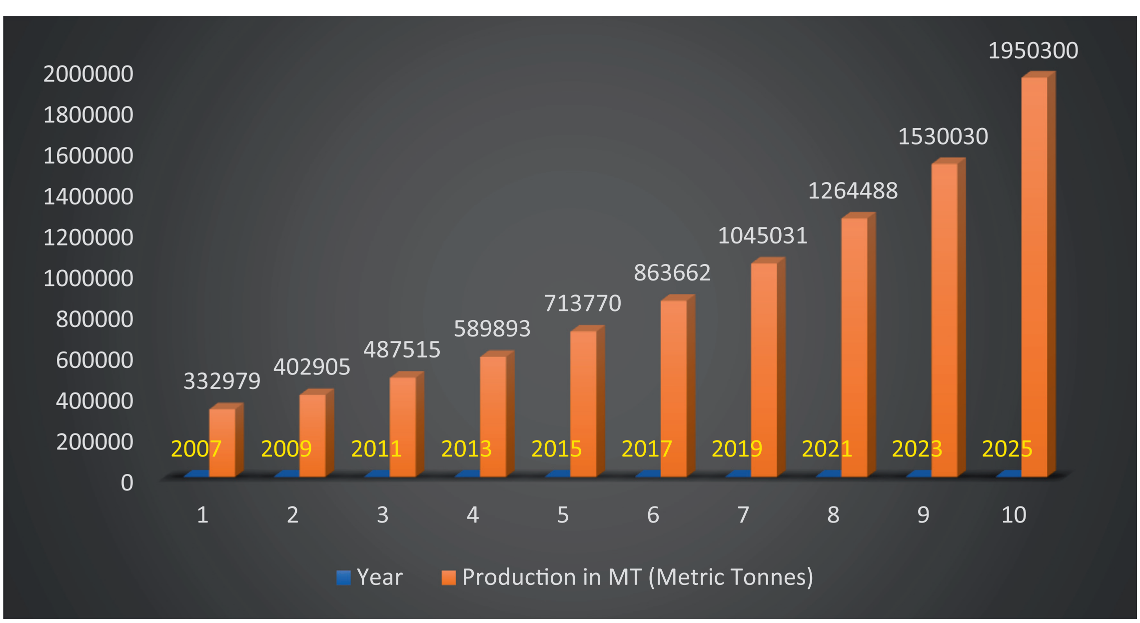

Fig. 5. India's electronic waste generation (Chatterjee, 2012).

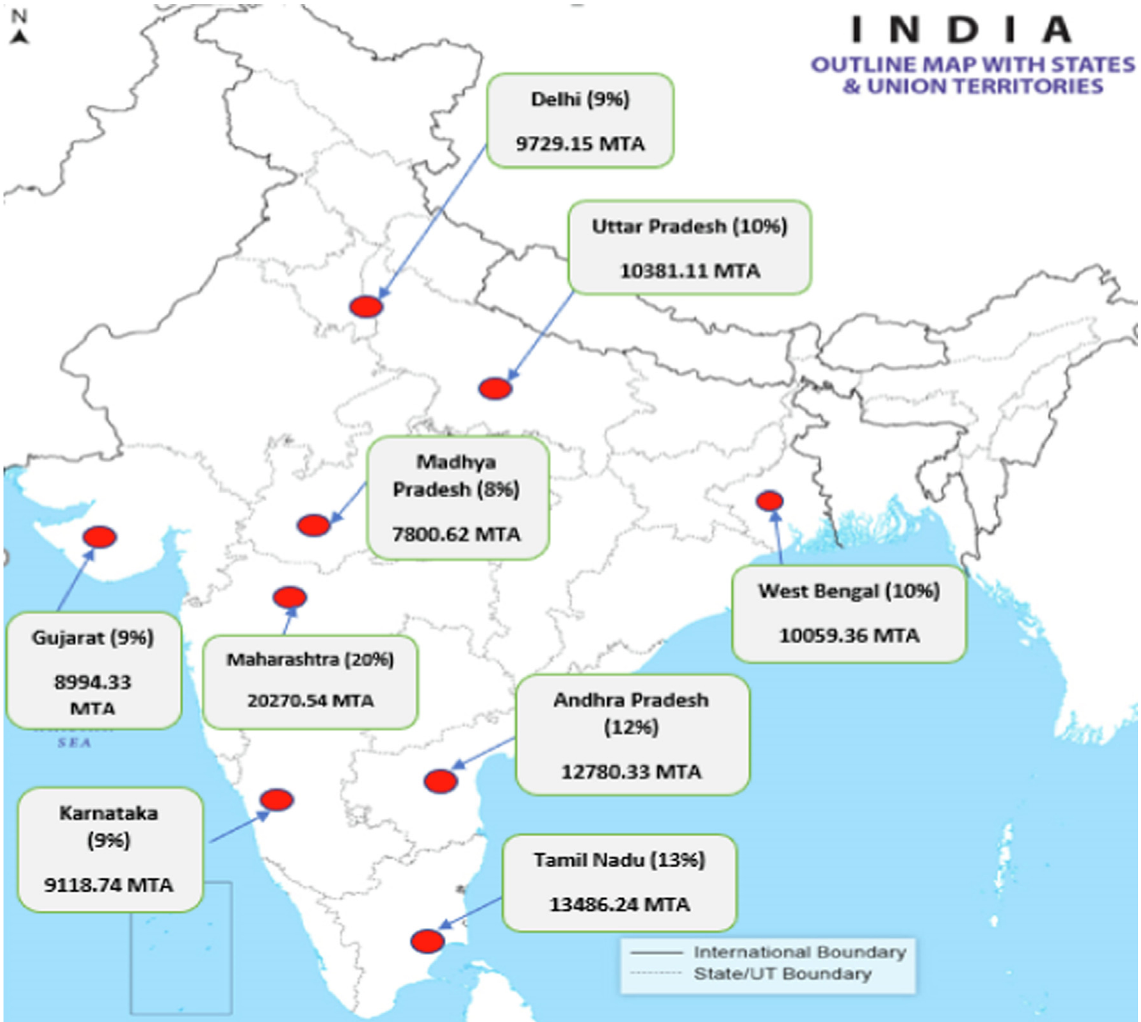

Fig. 6. E-Waste production (tonnes/year) in top states of India (Chatterjee, 2012).

The Hazardous Wastes Rules of 2008 and the Central Pollution Control Board were largely employed to monitor and advise on E-waste management. Manufacturers and recyclers were not required to collect and dispose of E-waste under these new guidelines. Furthermore, the sector lacked an appropriate licencing system. The informal sector that includes small businesses required to be licensed once the Indian government issued its E-waste collection and handling guidelines in May 2012 (UNU, 2022).

Consequently, it was changed and reformatted in some areas and towns and reintroduced in 2016 according to the E-Waste Management Rules. Producers now have more accountability as a result of this rule. Because to the passage of these laws, 128 new recycling facilities were registered up until September 2015 (Akenji et al., 2011). Fig. 5 shows the data of India's E-waste generation in metric tonnes in upcoming years as well as in past years that how much it has been actually generated in India.

Mumbai is the most E-waste-generating city in India, followed by Delhi, Bangalore, Chennai, Kolkata, Ahmadabad, Hyderabad, Pune, Surat, and Nagpur. 65 cities are responsible for more than 60% of total E-waste generation, whereas ten states are responsible for 70% of total E-waste production (Chatterjee, 2012). Fig. 6 shows the state wise production of E-waste across the popular cities of India.

The State Pollution Control Board (SPCB) was required, among other things to register all of the mentioned states in order to ensure adequate waste handling and disposal procedures as well as an expiry date for the storage and processing of E-waste at all levels of administration in order enable local government authorities to dispose of abandoned electronic trash in a safer and secure manner (Bandyopadhyay, 2008).

E-Waste administration in India

The large amounts of E-waste produced and are recycled which creates a major problem. As of 2012, India has just 20 officially registered recycling facilities in two large cities. The informal sector, for say, is totally engaged in removing E-waste, categorising it and reusing it. In India, dismantling of waste is done in a risky way for the recovering of precious metals (Turaga et al., 2019; Ministry of Housing and Urban Affairs, 2022).

In the organised industry, the use of technology in E-waste processing is safe and ecologically benign. Over 95% of E-waste is made up of recyclable elements including copper, plastic, iron, and aluminium. According to its statement, the Recycling Unit in the NCR region extracts more than a dozen components from garbage. The remaining 5% of hazardous E-waste is transferred for processing and recycling to government-approved treatment and disposal facilities. Only a few of the about 65 official sector recyclers have been licenced, according to CPCB statistics. Many of these companies have formed partnerships with other organisations to dispose of their electronic waste (Corwin, 2018).

The following are the phases of E-waste recycling in a formal setting: E-waste is separated into two stages: manual and mechanical processing. Metallurgical treatment facilities convert nonferrous materials into aluminium, copper, and other metals. As a result, efficiency outperforms rates of recycling and recovery. Even though there is a great deal of data on the bigger, legal, informal electronic garbage recyclers are not well documented and in India, there are both registered and unregistered facilities for the disposal of electronic trash. (Heacock et al., 2018). People in the unorganised sector, on the other hand, manage about 90% of India's E-waste. Informal units adopt riskier techniques to concentrate on profitable components like gold, iron, copper, and silver (Ohajinwa et al., 2017; Heeks et al., 2015; Pandey and Govind, 2014; Krishnamoorthy et al., 2018; Ceballos and Dong, 2016). Many people are now suffering from a range of health concerns as a direct result of these unhealthy practises. When unusable garbage is disposed of as a result of these activities, environmental damage ensues (Heacock et al., 2018).

The bulk of employees in the informal sector, on the other hand, are uneducated and unaware of the long-term dangers of releasing toxic chemicals into the water supply and the environment. Copper, metal, and glass must be manually removed from cathode ray tubes. Microchips, gold-plated brass pins, and condensers ornament circuit boards. Toxic vapours are created when these common components are heated. Gold and brass are separated from gold-plated brass pins using acid. Acid is used in large volumes to dissolve metallic components from condensers and microchips. (Singh et al., 2020).

E-Waste collection

Additional precautions, in addition to those already in place, are required to counteract the rising public health threat posed by E-waste. Other steps that must be taken include the collection and control of waste management procedures, the formulation of a business strategy, the creation of a monitoring mechanism, and worker protection.

E-waste management methods may be willingly improved by defining objectives, implementing fines, or providing incentives for towns to collect the debris. To improve the control and efficiency of E-waste management, all parties engaged in the collection and treatment of such trash should be forced to submit frequent reports to a central body. To maintain transparency and accountability, electronic waste management transactions must be done using traceable bank accounts or cards. A central register for data gathering and monitoring activities must be established and updated on a regular basis (Heacock et al., 2018; Ohajinwa et al., 2017; Heeks et al., 2015).

Various recycling methods for electronic waste

Various sectors implemented so many techniques/ methods for the recycling of electronic trash. The four main techniques which are considered in this review paper.

Landfilling

E-waste breakdown at landfills is particularly labour-intensive and takes a long time. It is no longer possible to look at the environmental effects of E-waste, but it still meets the compliance requirements.

- Landfills take a diverse range of waste kinds and mix them together.
- Landfills receive a wide range of waste kinds and combine them.

In garbage dump study, the environmental consequences of land dental filling of E-waste are well-documented (Awasthi et al., 2016; Uddin et al., 2021; Singh et al., 2020; "ASSOCHAM | Knowledge Architect of India." https://www.assocham.org/ (accessed Feb. 20, 2022).

Furthermore, cadmium and mercury are known to be produced in a number of ways, including by burning landfill gas. For compounds that are unstable and do not spontaneously degrade, an eco-audio treatment method based on land dental fillings does not appear to be a realistic alternative. The E-waste factory's product mix implies that environmental (long-term) dangers, such as dental fillings in safe land, cannot be overlooked. This is presented in Fig. 7.

Incineration process

Pyrolysis, which happens in the absence of oxygen and results in the transformation of materials into gases, oils, and charcoal, as well as the ashes that remain after the combustion process is complete, is also dangerous. In gasification, however, just a small quantity of air is necessary to transform the components into fume, ash, and tar.

On the African continent, as well as in India's neighbouring countries, incinerating electrical waste is a common practise. When a plastic or PVC motherboard is heated, PCAs, PCDDs, and PCDFs, as well as carbon monoxide gas, SO2, and NO2, are released into the air, releasing a poisonous gas that is harmful to human health and the environment Smoke can also include trace amounts of heavy metal oxides such as antimony, lead, thallium, arsenic, copper, manganese, mercury, and nickel as shown in Fig. 8 (Vehlow and Dalager, 2010; Hulgaard and Vehlow, 2010; Yang et al., 2012; Rotter, 2010).

Fig. 7. E-Waste landfilling.

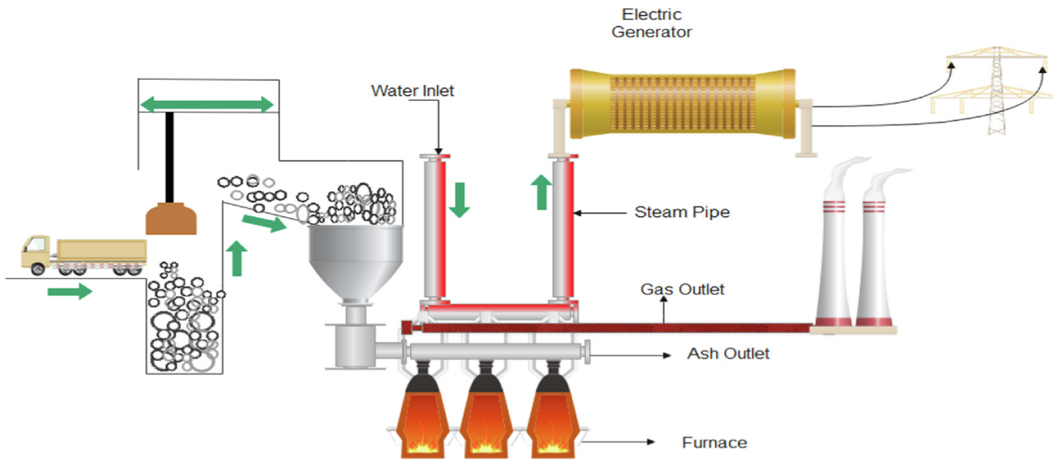

Fig. 8. Incineration procedure.

Fig. 9. Acid bath of E-waste (Sivaramanan, 2013).

Acid bath

To remove copper, an acid bath is employed, which entails soaking the circuit board in sulfuric acid for around 10–15 h to liquefy metals like copper. After that, using a steam bath, the leftover precipitated copper sulphate is mixed into the residual solution to eliminate any lingering copper spots. Lead was also dissolved and silver and gold were removed using acid treatments as shown in Fig. 9 (E-Waste Disposal Methods in US, 2022; Cleaning Up Electronic Waste, 2022).

Biological procedure for E-waste

The utilisation of biological techniques of metal extraction in steels like Au and Cu has emerged as a unique innovation. A promising new technique involves using microbes to break down metallic ores and electronic waste. Bio-metallurgical methods transform metal directly from ores, concentrates, and wastes into soluble salts in liquid media. Bio metallurgy is a single field that combines biotechnology and metallurgy (Goyal and Goyal, 2020; Awasthi et al., 2016; Uddin et al., 2021; Kwok, 2019).

Ore bioleaching is referred to as “direct” and “indirect” bio-oxidation in clinical terms. Most investigations have identified the indirect bio-oxidation route. As some researchers have demonstrated, we use bacteria to make chemical oxidants in order to carry out this hydrometallurgical physicochemical approach. (Awasthi et al., 2019) Bacteria such as Acid thiobacillus ferroxidase, Leptospiral ferroxidase, and Acidithiobacillus thiooxidans are examples of bacteria that extract metals from this sort of waste. (Researchers discover biological recycling process for E-waste, 2022) It is widely regarded as a well-known process for removing metals made up of diverse materials. (Damgaard and Christensen, 2011).

Computers, mobile phones, and other electronic equipment, among others, should all be built to be ecologically friendly. Computers, mobile phones, and other electronic equipment, among others, should all be built to be ecologically friendly.

Financial incentives can help to encourage the adoption of environmentally friendly and safe practises. Modern technology may enhance profitability by enhancing recovery and decreasing exposure, as illustrated by business case studies, in addition to examining the financial impacts of exposure and disease burden as shown in Fig. 10 (Awasthi et al., 2016; Awasthi et al., 2016).

Safety precautions and measures towards E-Waste

Newer, locally built solutions that combine technology and non-technological tactics, such as remedial tools, engineering controls, and educational programming, can help to reduce direct and indirect exposures. This policy might also be implemented with an emphasis on electronic waste reduction, community development, and universal health care coverage for workers in these unorganised industries

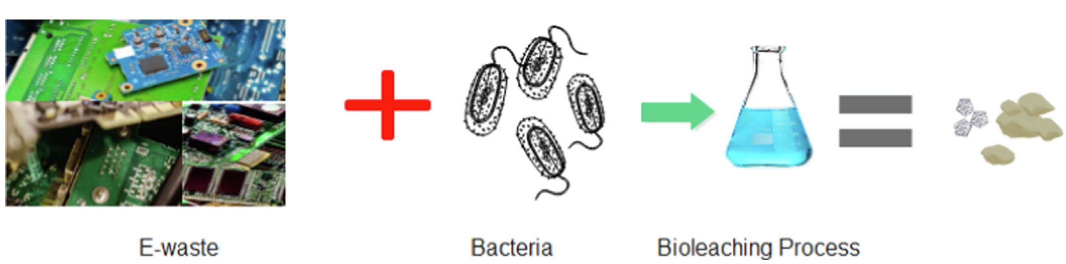

Fig. 10. Biological method for e-waste disposal.

(Abalansa et al., 2021; Masoom and Toufique, 2016; Heacock et al., 2018; Perkins et al., 2014).

All of the following should be included in increased efforts to raise public awareness and educate the public. Creating posters to remind workers of the importance of personal protection, distributing protective equipment such as gloves and masks, providing free tours of a formal recycling facility with all necessary safeguards in place and preventative measures observed, and finally educating local health care professionals about the potential health effects of these activities are all examples of information education and communication. The primary aim must be reduced risk, and health education materials must be understandable to employees (Berkun et al., 2011; Jaiswal et al., 2015).

Conclusions

According to the most recent studies, the informal sector handles the great majority of E-waste, endangering the environment and human health, especially in developing nations. Despite the passage of legislation governing E-waste management and disposal, several developing countries, such as India, have failed to implement effective formal recycling systems. More precise life cycle assessment models, such as those successfully used in developing nations, should thus be supported and adopted in their particular countries. Protecting society from the risks of E-waste in the environment must be a top priority. While the drawbacks of informal E-waste recycling have long been recognised, the health dangers to those who are exposed are just now becoming apparent. a deeper comprehension. Researchers should design a global study plan focused on children and other vulnerable groups to better understand the health effects of E-waste exposure. The international health community, researchers, and politicians, as well as non-governmental organisations and national governments, must work together to address E-waste exposure and its health consequences.

Declarations

Ethical Approval

Not applicable on this work.

Conflict of Interest

This manuscript does not include conflict of interest.

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Availability of data

Data and materials will be available on reasonable request.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

"2015 | Latest Major Publications - United Nations Department of Economic and Social Affairs."https://www.un.org/en/development/desa/publications/2015.html (accessed Feb. 12, 2022).

"97% of collected E-waste recycled for useful applications - PRé Sustainability." https://pre-sustainability.com/articles/almost-all-collected-E-waste-recycled/ (accessed Feb. 20, 2022).

"A Closer Look: Lithium-Ion Batteries in E-waste." https://www.simslifecycle.com/2019/05/21/a-closer-look-lithium-ion-batteries-in-E-waste/ (accessed Feb. 20, 2022).

Abalansa, S., El Mahrad, B., Icely, J., Newton, A., 2021. Electronic waste, an environmental problem exported to developing countries: the GOOD, the BAD and the UGLY. Sustainability 13 (9), 5302.

Akenji, L., Hotta, Y., Bengtsson, M., Hayashi, S., 2011. EPR policies for electronics in developing Asia: an adapted phase-in approach. Waste Manag. Res. 29 (9), 919–930.

Ari, V. 2016. A review of technology of metal recovery from electronic waste. E-Waste in transition—From pollution to resource.

Arya, S., Kumar, S., 2020. E-waste in India at a glance: Current trends, regulations, challenges and management strategies. J. Clean. Prod. 271, 122707.

"ASSOCHAM | Knowledge Architect of India." https://www.assocham.org/ (accessed Feb. 20, 2022).

Aston, J.E., Peyton, B.M., Lee, B.D., Apel, W.A., 2010. Effects of ferrous sulphate, inoculum history, and anionic form on lead, zinc, and copper toxicity to Acidithiobacillus caldus strain BC13. Environ. Toxicol. Chem. 29 (12), 2669–2675.

Atasu, A., Özdemir, Ö., Van Wassenhove, L.N., 2013. Stakeholder perspectives on e-waste take-back legislation. Prod. Oper. Manag. 22 (2), 382–396.

Awasthi, A.K., Li, J., 2017. Management of electrical and electronic waste: A comparative evaluation of China and India. Renew. Sustain. Energy Rev. 76, 434–447.

Awasthi, A.K., Zeng, X., Li, J., 2016. Comparative examining and analysis of E-waste recycling in typical developing and developed countries. Procedia Environ. Sci. 35, 676–680.

Awasthi, A.K., Zeng, X., Li, J., 2016. Relationship between E-waste recycling and human health risk in India: a critical review. Environ. Sci. Pollut. Res. 23 (12), 11509–11532.

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

Awasthi, A.K., Hasan, M., Mishra, Y.K., Pandey, A.K., Tiwary, B.N., Kuhad, R.C., Gupta, V.K., Thakur, V.K., 2019. Environmentally sound system for E-waste: Biotechnological perspectives. Current Research in Biotechnology 1, 58–64.

Baldé, C. P., Forti, V., Gray, V., Kuehr, R., & Stegmann, P. 2017. The global E-waste monitor 2017: Quantities, flows and resources. United Nations University, International Telecommunication Union, and International Solid Waste Association.

Bandyopadhyay, A., 2008. Indian initiatives on E-waste management—A critical review. Environ. Eng. Sci. 25 (10), 1507–1526.

Berkun, M., Aras, E., Anılan, T., 2011. Solid waste management practices in Turkey. J. Mater. Cycles Waste Manage. 13 (4), 305–313.

Bhutta, M.K.S., Omar, A., Yang, X., 2011. Electronic Waste: A Growing Concern in Today's Environment. Economics Research International 2011, 1–8.

Ceballos, D.M., Dong, Z., 2016. The formal electronic recycling industry: Challenges and opportunities in occupational and environmental health research. Environ. Int. 95, 157–166.

Chatterjee, S., 2012. India's readiness on ROHS directives: a strategic analysis. Global Journal of Science Frontier Research 10 (1), 14–26.

"Cleaning Up Electronic Waste (E-Waste) | US EPA." https://www.epa.gov/international-cooperation/cleaning-electronic-waste-E-waste (accessed Feb. 20, 2022).

Corwin, J.E., 2018. "Nothing is useless in nature": Delhi's repair economies and value-creation in an electronics "waste" sector. Environment and Planning A: Economy and Space 50 (1), 14–30.

Damgaard, A., & Christensen, T. H. 2011. Recycling of metals. In Solid waste technology and management (pp. 234-242). Wiley.

Debnath, B., Saha, I., Mukherjee, T., Mitra, S., Das, A., & Das, A. 2021. Sorbents from waste materials: a circular economic approach. In Sorbents Materials for Controlling Environmental Pollution (pp. 285-322). Elsevier.

Decharat, S., 2018. Urinary mercury levels among workers in E-waste shops in Nakhon Si Thammarat Province, Thailand. J. Prev. Med. Public Health 51 (4), 196–204.

"Disposal of Asbestos, Chemicals, Oil, Trade and e-Waste - Parkes Shire Council." https://www.parkes.nsw.gov.au/environment/waste-recycling/waste-facilities/disposal-of-chemicals-oil-trade-and-E-waste/ (accessed Feb. 14, 2022).

El-Ghiaty, M.A., El-Kadi, A.O., 2021. Arsenic: Various species with different effects on cytochrome P450 regulation in humans. EXCLI J. 20, 1184.

"EUR-Lex — Access to European Union law — choose your language." https://eur-lex.europa.eu/ (accessed Feb. 12, 2022).

"E-Waste – Silicon Valley Toxics Coalition." https://svtc.org/our-work/E-waste/ (accessed Feb. 20, 2022).

"E-Waste Disposal Methods in US - Pacebutler Recycling Blog." http://www.pacebutler.com/blog/E-waste-disposal-methods-in-us/ (accessed Feb. 20, 2022).

Forti, V., Baldé, C. P., Kuehr, R., & Bel, G. 2020. The Global E-waste Monitor 2020. United Nations University (UNU), International Telecommunication Union (ITU) & International Solid Waste Association (ISWA), Bonn/Geneva/Rotterdam, 120.

Gaidajis, G., Angelakoglou, K., Aktsoglou, D., 2010. E-waste: environmental problems and current management. Journal of Engineering Science and Technology Review 3 (1), 193–199.

Goyal, N., & Goyal, D. 2020. Exploring E-waste Management: Strategies and Implications. Handbook of Solid Waste Management: Sustainability through Circular Economy, 1-14.

Grant, K., Goldizen, F.C., Sly, P.D., Brune, M.N., Neira, M., Van den Berg, M., Norman, R. E., 2013. Health consequences of exposure to E-waste: a systematic review. Lancet Glob Health 1 (6), 350–361.

Gregory, J. 2009. E-waste take-back system design and policy approaches. Step Initiative, United Nations University.
Guerrero, L.A., Maas, G., Hogland, W., 2013. Solid waste management challenges for cities in developing countries. Waste Manag. 33 (1), 220–232.
Heacock, M., Trottier, B., Adhikary, S., Asante, K.A., Basu, N., Brune, M.-N., Caravanos, J., Carpenter, D., Cazabon, D., Chakraborty, P., Chen, A., Barriga, F.D., Ericson, B., Fobil, J., Haryanto, B., Huo, X., Joshi, T.K., Landrigan, P., Lopez, A., Magalini, F., Navasumrit, P., Pascale, A., Sambandam, S., Aslia Kamil, U.S., Sly, L., Sly, P., Suk, A., Suraweera, I., Tamin, R., Vicario, E., Suk, W., 2018. Prevention-intervention strategies to reduce exposure to E-waste. Rev. Environ. Health 33 (2), 219–228.
Heeks, R., Subramanian, L., Jones, C., 2015. Understanding E-waste management in developing countries: Strategies, determinants, and policy implications in the Indian ICT sector. Inf. Technol. Dev. 21 (4), 653–667.
http://www.basel.int/TheConvention/Overview/tabid/1271/Default.aspx (accessed Feb. 12, 2022).
https://elytus.com/blog/E-waste-and-its-negative-effects-on-the-environment.html.
https://science.thewire.in/environment/E-waste-india-must-take-a-closer-look-at-extended-producer-responsibility.
https://science.thewire.in/environment/E-waste-india-must-take-a-closer-look-at-extended-producer.
Hulgaard, T., Vehlow, J., 2010. Incineration: process and technology. Solid waste technology & management 1, 363–392.
Jaiswal, A., Samuel, C., Patel, B.S., Kumar, M., 2015. Go green with WEEE: Eco-friendly approach for handling E-waste. Procedia Comput. Sci. 46, 1317–1324.
Julander, A., Lundgren, L., Skare, L., Grandér, M., Palm, B., Vahter, M., Lidén, C., 2014. Formal recycling of E-waste leads to increased exposure to toxic metals: an occupational exposure study from Sweden. Environ. Int. 73, 243–251.
Köhler, A., Erdmann, L., 2004. Expected environmental impacts of pervasive computing. Hum. Ecol. Risk Assess. 10 (5), 831–852.
Krishnamoorthy, Y., Vijaya Geetha, M., Sakthivel, M., Sarveswaran, G., 2018. Emerging public health threat of E-waste management: global and Indian perspective. Rev. Environ. Health 33 (4), 321–329.
Krishnamoorthy, Y., Vijayageetha, M., Sakthivel, M., Sarveswaran, G., 2018. Emerging public health threat of E-waste management: global and Indian perspective. Rev. Environ. Health 33 (4), 321–329.
Kumarathilaka, P., Seneweera, S., Meharg, A., Bundschuh, J., 2018. Arsenic speciation dynamics in paddy rice soil-water environment: sources, physico-chemical, and biological factors-a review. Water Res. 140, 403–414.
Kurup, A.R., Senthil Kumar, K., 2017. Effect of recycled PVC fibres from electronic waste and silica powder on shear strength of concrete. Journal of Hazardous, Toxic, and Radioactive Waste 21 (3), 06017001.
Kwok, R., 2019. Inner Workings: How bacteria could help recycle electronic waste. Proc. Natl. Acad. Sci. 116 (3), 711–713.
LeBel, S., 2012. Wasting the future: The technological sublime, communications technologies, and E-waste. communication + 1 1 (1), 1–19.
“Managing And Reducing E-Waste From PCBs | EC Electronics.” https://ecelectronics.com/news/managing-and-reducing-E-waste-from-pcbs (accessed Feb. 20, 2022).
Masoom, M. R., & Toufique, M. M. K. (2016). Protecting environment, managing E-waste and ensuring development: perspective on ‘waste electrical and electronic equipment’situation in Guiyu, Agbogbloshie and Dhaka. International Letters of Natural Sciences, 52.
“Ministry of Housing and Urban Affairs, Goverment of India.” https://mohua.gov.in/ (accessed Feb. 20, 2022).
Mundada, M. N., Kumar, S., & Shekdar, A. V. (2004). E-waste: a new challenge for waste management in India. International Journal of Environmental Studies, 61(3), 265-279.
Ohajinwa, C.M., Van Bodegom, P.M., Vijver, M.G., Peijnenburg, W.J., 2017. Health risks awareness of electronic waste workers in the informal sector in Nigeria. Int. J. Environ. Res. Public Health 14 (8), 911.
Pandey, P., Govind, M., 2014. Social repercussions of E-waste management in India: a study of three informal recycling sites in Delhi. Int. J. Environ. Stud. 71 (3), 241–260.
Perkins, D.N., Drisse, M.N.B., Nxele, T., Sly, P.D., 2014. E-waste: a global hazard. Ann. Glob. Health 80 (4), 286–295.
Pinto, V.N., 2008. E-waste hazard: The impending challenge. Indian journal of occupational and environmental medicine 12 (2), 65.
U. N. E. Programme, “E-Waste Vol. 1: Inventory Assessment Manual,” 2007, Accessed: Feb. 12, 2022. [Online]. Available: https://wedocs.unep.org/xmlui/handle/20.500.11822/7857.
Rautela, R., Arya, S., Vishwakarma, S., Lee, J., Kim, K.-H., Kumar, S., 2021. E-waste management and its effects on the environment and human health. Sci. Total Environ. 773, 145623.
“Researchers discover biological recycling process for E-waste - Regional Policy - EuropeanCommission.” https://ec.europa.eu/regional_policy/en/newsroom/news/2020/04/04-10-2020-researchers-discover-biological-recycling-process-for-E-waste (accessed Feb. 20, 2022).
Robinson, B.H., 2009. E-waste: an assessment of global production and environmental impacts. Sci. Total Environ. 408 (2), 183–191.
Rotter, S., 2010. Incineration: RDF and SRF–solid fuels from waste. Solid waste technology & management 1, 486–501.
Saha, L., Kumar, V., Tiwari, J., Rawat, S., Singh, J., Bauddh, K., 2021. Electronic waste and their leachates impact on human health and environment: Global ecological threat and management. Environ. Technol. Innov. 24, 102049.
Salhofer, S. 2017. E-waste collection and treatment options: A comparison of approaches in Europe, China and Vietnam. Source Separation and Recycling, 227-227.
Sánchez-Quiles, D., Tovar-Sánchez, A., 2015. Are sunscreens a new environmental risk associated with coastal tourism? Environ. Int. 83, 158–170.
Secretariat, R. S. 2011. E-waste in India. India Research Unit (Larrdis), Rajya Sabha Secretariat, New Delhi.
Segev, O., Kushmaro, A., Brenner, A., 2009. Environmental impact of flame retardants (persistence and biodegradability). Int. J. Environ. Res. Public Health 6 (2), 478–491.
Singh, N., Duan, H., Tang, Y., 2020. Toxicity evaluation of E-waste plastics and potential repercussions for human health. Environ. Int. 137, 105559.
Sivaramanan, S., 2013. E-Waste Management, Disposal and Its Impacts on the Environment. Univers J Environ Res Technol 3 (5).
Stapleton, H.M., Allen, J.G., Kelly, S.M., Konstantinov, A., Klosterhaus, S., Watkins, D., McClean, M.D., Webster, T.F., 2008. Alternate and new brominated flame retardants detected in US house dust. Environ. Sci. Tech. 42 (18), 6910–6916.
“StEP solving the E-waste Problem - StEP Initiative.” https://www.step-initiative.org/ (accessed Aug. 20, 2021).
Sthiannopkao, S., Wong, M.H., 2013. Handling E-waste in developed and developing countries: Initiatives, practices, and consequences. Sci. Total Environ. 463, 1147–1153.
Tai, W., He, L., Zhang, X., Pu, J., Voronin, D., Jiang, S., Zhou, Y., Du, L., 2020. Characterization of the receptor-binding domain (RBD) of 2019 novel coronavirus: implication for development of RBD protein as a viral attachment inhibitor and vaccine. Cell. Mol. Immunol. 17 (6), 613–620.
Thakur, D., Ganguly, R., Gupta, A. K., & Ghali, V. 2020. Evaluation of existing solid waste management system in Una Town, India. In Sustainable Waste Management: Policies and Case Studies (pp. 367-381). Springer, Singapore.
Tue, N.M., Matsushita, T., Goto, A., Itai, T., Asante, K.A., Obiri, S., Mohammed, S., Tanabe, S., Kunisue, T., 2019. Complex mixtures of brominated/chlorinated diphenyl ethers and dibenzofurans in soils from the Agbogbloshie E-waste site (Ghana): Occurrence, formation, and exposure implications. Environ. Sci. Tech. 53 (6), 3010–3017.
Turaga, R.M.R., Bhaskar, K., Sinha, S., Hinchliffe, D., Hemkhaus, M., Arora, R., Chatterjee, S., Khetriwal, D.S., Radulovic, V., Singhal, P., Sharma, H., 2019. E-waste management in India: Issues and strategies. Vikalpa 44 (3), 127–162.
Uddin, M.N., Arifa, K., Asmatulu, E., 2021. Methodologies of E-waste recycling and its major impacts on human health and the environment. Int. J. Environ. Waste Manag. 27 (2), 159–182.
“UNU, UNIDO Implementing Ethiopian E-Waste Management Project | News | SDG Knowledge Hub | IISD.” http://sdg.iisd.org/news/unu-unido-implementing-ethiopian-E-waste-management-project/ (accessed Feb. 20, 2022).
Vehlow, J., Dalager, S., 2010. Incineration: flue gas cleaning and emissions. Solid waste technology & management 1, 393–420.
Wang, Y., Tian, Z., Zhu, H., Cheng, Z., Kang, M., Luo, C., Li, J., Zhang, G., 2012. Polycyclic aromatic hydrocarbons (PAHs) in soils and vegetation near an E-waste recycling site in South China: concentration, distribution, source, and risk assessment. Sci. Total Environ. 439, 187–193.
Wath, S.B., Dutt, P.S., Chakrabarti, T., 2011. E-waste scenario in India, its management and implications. Environ. Monit. Assess. 172 (1), 249–262.
“What a Waste Global Database | Data Catalog.” https://datacatalog.worldbank.org/dataset/what-waste-global-database (accessed Aug. 20, 2021).
Widmer, R., Oswald-Krapf, H., Sinha-Khetriwal, D., Schnellmann, M., Böni, H., 2005. Global perspectives on E-waste. Environ. Impact Assess. Rev. 25 (5), 436–458.
Yang, J., Zhang, B., 2018. Air pollution and healthcare expenditure: Implication for the benefit of air pollution control in China. Environ. Int. 120, 443–455.
Yang, J., Bertram, J., Schettgen, T., Heitland, P., Fischer, D., Seidu, F., Felten, M., Kraus, T., Fobil, J.N., Kaifie, A., 2020. Arsenic burden in E-waste recycling workers–A cross-sectional study at the Agbogbloshie E-waste recycling site. Ghana. Chemosphere 261, 127712.
Yang, H., Huo, X., Yekeen, T.A., Zheng, Q., Zheng, M., Xu, X., 2013. Effects of lead and cadmium exposure from electronic waste on child physical growth. Environ. Sci. Pollut. Res. 20 (7), 4441–4447.
Yang, N., Zhang, H., Chen, M., Shao, L.M., He, P.J., 2012. Greenhouse gas emissions from MSW incineration in China: Impacts of waste characteristics and energy recovery. Waste Manag. 32 (12), 2552–2560.
Zeng, X., Huo, X., Xu, X., Liu, D., Wu, W., 2020. E-waste lead exposure and children's health in China. Sci. Total Environ. 734, 139286.
Zhang, K., Schnoor, J.L., Zeng, E.Y., 2012. E-waste recycling: where does it go from here? Environ. Sci. Tech. 46 (20), 10861–10867.