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E-Waste: Current Scenario, Risks And Management Approaches

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ABSTRACT
The accelerated gro th of information and communication technologies, together with increasingly shorter life spans of electronic products, has resulted in a sharp rise in electronic waste (e-waste) across the lobe. Although e-waste is a rich source of recoverable materials, including valuable precious metals, it also contains toxic ubstances such as lead, mercury, and cadmium. When these materials are not properly handled or disposed of, they present serious threats to environmental quality and human health. This review analyzes the global and regional status of e-waste generation, its environmental and health consequences, and the prevailing methods used for its management. It discusses sustainable approaches, policy initiatives, and emerging technological solutions designed to enhance e-waste processing a d resource recovery. The volume of e-waste is expanding rapidly, driven by growing consumer demand for electronic devices and rapid technological obsolescence. Items such as mobile phones and batteries constitute a significant proportion of this waste stream, particularly in developing nations. In India, the fast-growing information technology and electronics industries have substantially increased the generation of e-waste, turning its management into a critical environmental and public health concern. Inadequate disposal methods and the dominance of informal recycling practices intensify environmental contamination and pose severe occupational health risks. Additionally, many developing countries encounter further challenges due to the illegal transboundary movement of e-waste, often misrepresented as second-hand electronic equipment. This review evaluates existing e-waste management systems and identifies gaps that need to be addressed. It outlines future pathways for sustainable e-waste management, emphasizing the importance of robust policy enforcement, technological advancements, and increased public awareness. The review covers sources and composition of e-waste, key facts, harmf l impacts, recycling and recovery strategies, Indian and global scenarios, associated risks, management practices, ongoing challenges, and future prospects.

INTRODUCTION

Electronic waste, commonly known as e-waste, refers to electrical and electronic devices that have been discarded because they are obsolete, nonfunctional, or no longer fit for their intended use. This category spans a broad range of products, including computers, smartphones, household appliances, and their components. While specific definitions differ across regions and regulatory systems, e-waste generally encompasses electrical and electronic equipment (EEE) and parts that are disposed of without plans for reuse or refurbishment and are instead directed toward recycling, recovery, or final disposal (Trinh and Sakurai 2025). Driven by rapid technological innovation, shorter product lifespans, and growing consumer demand, e-waste has emerged as one of the fastest-expanding waste streams worldwide. In 2022 alone, global e-waste generation reached approximately 62 million tonnes; however, only about 22.3% was formally collected and recycled, with the majority being improperly handled or untracked (Balde 2024).

E-waste is composed of a diverse mix of materials, containing both economically valuable resources—such as copper, aluminum, silver, and gold—and hazardous substances, including heavy metals like lead, mercury, and cadmium, as well as brominated flame retardants and other toxic chemicals. When e-waste is poorly managed through practices such as open dumping, burning, or informal recycling, these substances can contaminate soil, water, and air, posing serious risks to ecosystems and human health (Trinh and Sakurai 2025). Given its rapid growth and low recovery rates, e-waste presents a dual challenge: mitigating environmental and health impacts while harnessing its potential for resource recovery. Addressing this issue requires stronger policies, expanded formal collection and recycling systems, and safer, more sustainable management practices on a global scale (Trinh and Sakurai 2025).

Sources of e-waste
Electronic waste (e-waste) encompasses a diverse range of obsolete or discarded electrical and electronic equipment, which can be grouped into several major categories. These include sm ll household devices such as vacuum cleaners, watches, and food grinders, along with large domestic appliances—such as refrigerators, washing machines, and cooking units—which constitute nearly 20% of the total e-waste stream. Information and communication technology (ICT) equipment, including desktop computers and mobile phones, contributes approximately 15% of global e-waste. Consumer electronic products—such as televisions, radios, camcorders, and sound systems—represent about 10% of the total volume (Ismail Mohamed et al., 2025).

Lighting devices, including compact fluorescent lamps (CFLs) and high-pressure sodium lamps, account for nearly 15% of e-waste generation. Similarly, toys, recreational, and sports-related electronic products, such as video game consoles and electric train sets, contribute roughly 10%. Other classifications comprise electrical and electronic tools, medical equipment, vending machines for hot and cold beverages, and monitoring and control instruments. In addition, nearly 30% of e-waste consists of various other household electrical items composed of complex mixtures of plastics, metals, and composite materials, which present significant challenges for recycling and resource recovery (Ismail Mohamed et al., 2025). The types of e-waste are shown in Figure-1.

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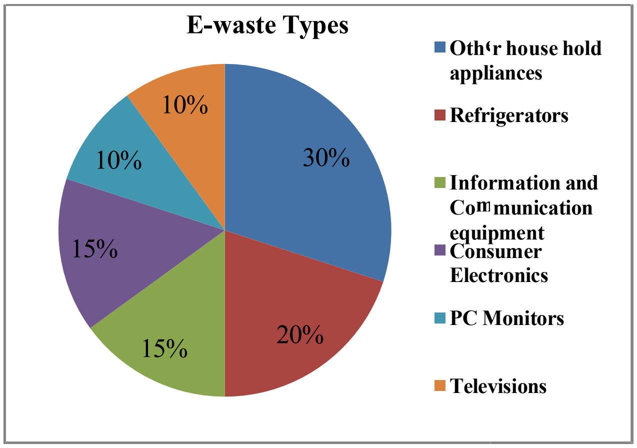

Figure-1: Types of e-waste

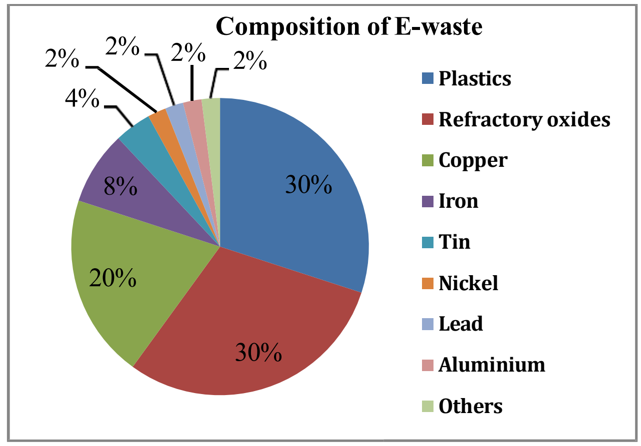

Figure-2: Composition of e-waste

Composition of e-waste

Electronic waste is characterized by its highly heterogeneous and intricate composition, containing more than one thousand distinct substances that can generally be categorized as either hazardous or non-hazardous. Its principal material constituents include ferrous and non-ferrous metals, various types of plastics, glass, printed circuit boards (PCBs), and numerous other electronic components. In contrast to ordinary municipal solid waste, e-waste is distinctive because it simultaneously contains high-value recoverable materials and potentially toxic substances, making its treatment both economically beneficial and environmentally challenging. Among its valuable constituents are economically significant metals such as copper, gold, silver, platinum, and other scarce, non-renewable resources including tin, nickel, zinc, and aluminium. Copper typically represents the dominant recoverable fraction due to its relatively high concentration in electronic equipment. Estimates suggest that of the roughly 20 million metric tonnes of e-waste generated worldwide each year, approximately 820,000 tonnes are composed of copper. Despite this resource potential, e-waste also incorporates dangerous elements such as lead, mercury, arsenic, cadmium, beryllium, and brominated flame retardants. If improperly managed or processed, these toxic substances can pose severe threats to both human health and ecological systems (Desye et al., 2023).

On average, the material distribution of e-waste consists of about 43–44% metals, 23% plastics, 15% glass, and roughly 17% electronic assemblies and components. Mobile phones, for instance, contain nearly 28% metallic content, including approximately 10–20% copper, 1–5% lead, and 1–3% nickel, while precious metals make up around 0.3–0.4% of their total mass (Figure-2). The remainder is composed of plastics, glass, ceramics, and other composite materials. Unsound disposal methods, such as open dumping, landfilling, or uncontrolled incineration, may result in the release of hazardous pollutants into soil, air, and water, thereby underscoring the importance of implementing environmentally sound recycling and management strategies for e-waste (Kumar et al., 2024; Tabassum et al., 2024).

Key Facts about E-waste

In India, electronic waste is generated predominantly by government bodies, public sector organizations, and private enterprises, which together contribute nearly 70% of the total volume, while households account for a comparatively smaller share. The rapid expansion in the use of mobile phones, computers, tablets, and other digital technologies has significantly increased the quantity of discarded electronic equipment each year. According to estimates by the Manufacturers' Association of Information Technology (MAIT), India generates approximately 400,000 tonnes of e-waste annually. Despite this substantial volume, only a small fraction—around 5%—is processed through formal recycling systems. Additionally, a considerable proportion of obsolete devices, estimated at nearly 40%, remains unused and stored in residences and storage facilities rather than being properly discarded or recycled (Parishwad, 2011).

At the global level, annual e-waste generation is estimated to range between 20 and 50 million tonnes, creating serious environmental and public health concerns (Sohaili et al., 2012). Hazardous constituents such as lead, when released from improperly managed landfills, can contaminate soil and water systems, disrupt ecosystems, reduce biodiversity, and negatively affect the growth, reproduction, and neurological health of various organisms, including invertebrates. Although electronic waste contains substantial quantities of recoverable materials, only about 12.5% is recycled worldwide. Data from the United States Environmental Protection Agency (EPA) highlight the significant recovery potential of discarded electronics: recycling one million mobile phones can yield approximately 75 pounds of gold, 772 pounds of silver, 35,274 pounds of copper, and 33 pounds of palladium. Furthermore, one tonne of obsolete personal computers contains a greater concentration of gold than 17 tonnes of extracted gold ore. Globally, manufacturing activities for mobile phones, computers, tablets, and related electronic devices consume roughly 320 tonnes of gold and more than 7,500 tonnes of silver each year. The concentration of precious metals in e-waste is estimated to be 40–50 times higher than that found in natural mineral ores; however, only about 10–15% of this gold is currently recovered, leaving the majority unexploited. In the United States alone, discarded mobile phones are estimated to contain more than $60 million worth of gold and silver annually, and electronic waste continues to represent the most rapidly growing segment of municipal solid waste streams (Palav Torres 2024).

Adverse effects of e-waste

The disposal of electronic waste in landfill sites not only leads to the depletion of valuable non-renewable materials but also creates significant environmental concerns. Hazardous constituents within discarded electronic products can seep into surrounding soil and infiltrate groundwater systems. Additionally, by-products such as acidic residues and sludge generated during informal recycling activities—particularly from processes like battery dismantling and circuit melting—can alter soil chemistry and contribute to acidification when not properly managed. The burning or incineration of e-waste further compounds the problem by emitting toxic gases and particulate matter into the atmosphere, thereby increasing air pollution and human exposure to harmful substances. Inadequately regulated or poorly engineered landfill facilities intensify these risks, accelerating ecological damage and increasing the likelihood of contamination pathways that affect nearby communities (Abogunrin-Olafisoye 2025).

Contact with pollutants originating from e-waste has been linked to numerous negative health outcomes. Studies have associated such exposure with reproductive complications including miscarriage, preterm delivery, and reduced birth weight. Additional concerns involve disruptions to thyroid function, impaired developmental processes, neurobehavioral abnormalities, and genotoxic effects. Children and fetuses are especially at risk because their physiological systems are still developing and are more susceptible to toxic insults. Emerging research suggests that exposure during early stages of life may produce persistent and long-term health consequences. These findings highlight the urgent necessity for environmentally responsible e-waste handling practices and strengthened public health interventions to minimize exposure risks (Abogunrin-Olafisoye 2025).

Necessity of E-waste recycling strategies

Electronic devices are composed of a complex mixture of materials, many of which are hazardous and can cause severe environmental and health problems if not properly managed. During the handling and processing of e-waste, toxic heavy metals and harmful organic compounds may be released into the environment, posing risks to both ecosystems and human health. In many informal recycling practices, these hazardous substances are managed with minimal consideration for worker safety or environmental protection. Therefore, the development and implementation of efficient and safe Waste Electrical and Electronic Equipment (WEEE) recycling strategies are essential. Effective recycling strategies are crucial for minimizing environmental contamination and reducing occupational health risks. Environmentally sound recycling not only prevents the release of toxic substances such as lead, mercury, and brominated flame retardants but also enables the recovery of valuable secondary raw materials, reducing dependence on virgin resources. According to recent studies, formal recycling systems supported by advanced technologies and strict regulatory oversight significantly lower emissions and health impacts compared to informal recycling practices (Forti et al., 2020). Strengthening policy enforcement, improving recycling infrastructure, and promoting worker safety standards are key components of sustainable e-waste management frameworks (Balde et al., 2022).

Benefits of e-waste recycling

A large proportion of materials present in electronic waste can be recovered and reused effectively. Metals can be extracted and refined through smelting processes, while plastics can be separated and recycled for use in new products. Recovering valuable materials from e-waste helps conserve natural resources, reduces energy consumption, and lowers greenhouse gas emissions. Recycling also minimizes environmental pollution, as fewer raw materials need to be mined and processed to manufacture new electronic products. Beyond material recovery, e-waste recycling offers significant environmental and economic benefits. Recycling metals such as copper, aluminum, and precious metals requires considerably less energy than primary extraction from ores, resulting in reduced carbon emissions (Balde et al., 2022). Proper recycling also prevents hazardous substances from entering landfills and incinerators, thereby protecting soil, water, and air quality (Forti et al., 2020). Additionally, the development of formal recycling systems can create employment opportunities and support a circular economy by reintegrating recovered materials into production cycles. These benefits highlight the importance of strengthening e-waste recycling infrastructure worldwide.

Reason for the low rates of e-waste recycling

One of the primary factors contributing to low e-waste recycling rates is the high cost associated with collection, transportation, and environmentally safe processing. The extraction of valuable materials such as gold and copper requires advanced technologies and strict environmental controls, which often make recycling economically unviable. In many cases, the financial return from recovered materials is lower than the overall cost of collection and processing. Another significant barrier is the lack of public awareness regarding existing e-waste recycling programs and proper disposal methods. Additionally, consumers often retain old electronic devices, particularly mobile phones, as backups or for perceived future use, further reducing recycling participation. Beyond these factors, inadequate recycling infrastructure and weak enforcement of e-waste regulations also limit recycling rates, especially in developing countries. Informal recycling sectors dominate e-waste handling in many regions, prioritizing short-term economic gains over environmental safety (Forti et al., 2020). Concerns about data security and privacy further discourage consumers from handing over used electronic devices for recycling (Balde et al., 2022). Strengthening public awareness campaigns, improving collection systems, ensuring data protection, and providing financial incentives can significantly enhance participation in formal e-waste recycling programs.

Impacts of e-waste

Electronic waste has a range of environmental, economic, and social implications. Both the positive and negative aspects associated with e-waste management are outlined below (Eze 2024; Charan, 2011; Kurian, 2007).

Benefits

- Conservation of natural resources through the recovery and reuse of valuable materials.
- Improved energy efficiency by recycling metals and components instead of extracting virgin raw materials.
- Reduction in health and environmental risks when hazardous substances are properly treated and removed.
- Contribution to economic development by creating employment opportunities in collection, recycling, and resource recovery sectors.

Drawbacks

- Improper handling and disposal of e-waste can result in significant environmental degradation due to the presence of toxic substances used in electronic manufacturing, posing serious risks to human health.
- Burning electronic waste can release highly toxic compounds such as dioxins and furans into the atmosphere.
- Disposal of e-waste in landfills may cause harmful elements, particularly lead, to seep into soil and groundwater systems.
- A single mobile phone battery containing cadmium has the potential to contaminate up to 600 cubic meters of water if not properly managed.

Indian scenario of e-waste generation

In India, e-waste generation is concentrated in specific regions, with 65 cities contributing over 60% of the total waste and ten states accounting for approximately 70% of national e-waste production (Agnihotri 2011). The top ten cities producing the highest amounts of e-waste are Mumbai, Delhi, Bangalore, Kolkata, Chennai, Ahmedabad, Hyderabad, Pune, Surat, and Nagpur. Similarly, the leading states include Maharashtra, Andhra Pradesh, Tamil Nadu, Uttar Pradesh, West Bengal, Delhi, Karnataka, Gujarat, Madhya Pradesh, and Punjab (Figure-3). A significant portion of e-waste processed in India originates from developed countries, with reports indicating that around 70% of the collected e-waste is imported or dumped from abroad (Jeyaraj 2021).

India generated roughly 0.47 million tonnes of e-waste in 2011, alongside an additional 50,000 tonnes of illegally imported electronic waste. By 2020, projections suggested a sharp increase, with e-waste from mobile phones expected to grow eighteen fold and from computers by 500%. In 2023–24, India produced approximately 1.751 million tonnes of e-waste, with an extra 50,000 tonnes illegally imported. Despite efforts to improve recycling, only 43% of this waste was formally processed, leaving 57% unprocessed, while around 40% of e-waste remains stored in warehouses. The rapid adoption of mobile phones has significantly contributed to this growth, expanding from the first users in the 1970s to over three billion users globally by 2008, with sales reaching 294.3 million units in the first quarter alone. Industrial hazardous waste further adds to the challenge: India generates 6.2 million tonnes annually, including 2.7 million tonnes of landfillable waste, 0.41 million tonnes suitable for incineration, and 3.08 million tonnes of recyclable hazardous waste. To address these challenges, India has set an e-waste recycling target of 60% for 2024, aiming to increase it by 10% every two years to reach 80% by 2029 (Jeyaraj 2021).

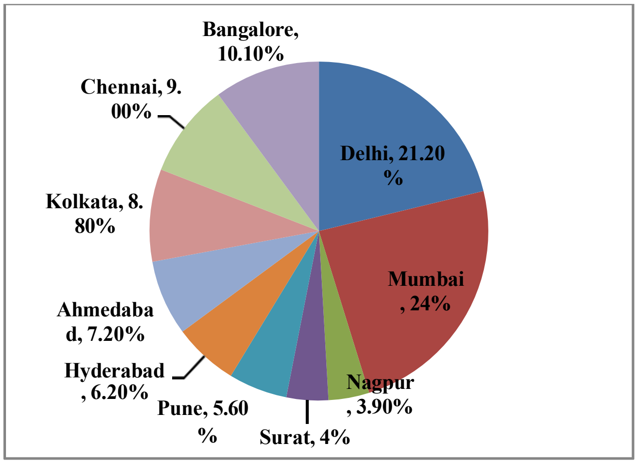

Figure 3: E-waste generation from different cities of India

Global scenario of e-waste

E-waste generation worldwide is escalating rapidly, with an estimated 40 to 50 million tonnes produced annually. Major contributors include China (2.5 million tonnes/year), the European Union (7 million tonnes/year), and India (0.8 million tonnes/year), while Asia as a whole discards approximately 12 million tonnes of e-waste each year. Developed nations, particularly the United States and Europe, remain the largest producers, with the US generating around 3 million tonnes annually and Europe experiencing a 3–5% annual increase—almost three times faster than the overall municipal waste growth rate. The Basel Action Network reports that up to 80% of e-waste from developed countries is exported to developing nations such as China, India, Pakistan, and Ghana, causing severe environmental and health challenges (Balde 2017).

Rapid technological turnover and the frequent replacement of devices such as mobile phones, computers, televisions, and printers have made e-waste the fastest-growing component of the municipal solid waste stream, now accounting for roughly 5% of all municipal waste globally. In India, e-waste is growing at approximately 10% per year due to insufficient infrastructure, with projections indicating that by 2020 mobile phone waste would increase 18-fold and computer waste by 500% (Agnihotri 2011). Cities like Ahmedabad generate between 1,000–2,200 tonnes of e-waste annually from domestic and commercial sources (Balde 2017). Despite the enormous volume, recycling rates remain low. Globally, only 10–20% of e-waste is formally recycled, while the remainder is landfilled or incinerated, releasing hazardous substances into the environment. E-waste contains valuable materials at concentrations far exceeding natural ores for example, gold levels are 40–50 times higher than in mined ore. Recycling metals from e-waste can substantially reduce environmental impacts; one tonne of recycled electronic scrap requires only 0.037 tonnes of ore to recover the same amount of gold, compared to 10 tonnes of mined ore. The growing volume of e-waste, coupled with low recycling and inadequate infrastructure, underscores the urgent need for effective management strategies to mitigate environmental and public health risks while recovering valuable resources (Balde 2017).

Risks Associated with E-Waste

Improper handling and disposal of electronic waste pose substantial environmental risks. When e-waste is dumped in landfills or left in unmanaged sites, heavy metals such as lead, mercury, cadmium, and other hazardous substances can leach into soil and groundwater, degrading water quality and harming plant and animal life. These toxicants may persist in the environment for long periods, entering food chains and reducing biodiversity in affected ecosystems. Open burning and informal processing release toxic gases and fine particulates into the atmosphere, contributing to air pollution, respiratory disorders, and broader ecosystem disruption. These pollutants can also exacerbate climate change through the release of greenhouse gases and persistent organic pollutants that affect global atmospheric chemistry (Sandwal 2025).

Human health risks from e-waste exposure are equally serious. People living or working near informal recycling sites often lack protective equipment and are directly exposed to hazardous substances through inhalation, ingestion of contaminated food or water, and dermal contact. Chronic exposure to heavy metals and toxic compounds has been linked to neurological impairments, respiratory diseases, kidney and liver damage, reproductive and developmental problems, and increased cancer risk. Vulnerable populations especially children, pregnant women, and informal sector workers are particularly at isk, as early-life exposure to toxicants like lead and mercury can result in lifelong cognitive and developmental deficits. Systematic studies have documented adverse health outcomes, including impaired growth in children, hormonal disruption, and organ function disturbances, highlighting significant gaps in protection for at-risk communities (Andeobu et al., 2023). Effective policy interventions, formal recycling infrastructure, and enhanced public awareness are essential to reducing these environmental and health hazards and promoting safer e-waste man gement practices worldwide (Eze, 2024).

E-waste Management Practices in India

In India, the majority of e-waste handling including collection, segregation, dismantling, recycling, and disposal is performed manually due to limited access to advanced technologies and equipment. This reliance on informal techniques often makes recycling operations hazardous. Workers typically dismantle e-waste using basic tools such as hammers, hand drills, cutters, or, occasionally, electric drills, often without adequate personal protective equipment. Recycling and dismantling areas frequently lack proper lighting and ventilation, further increasing occupational risks. Improper practices, such as open burning of plastics, dumping of acids, and exposure to toxic solders, release pollutants into soil, air, and water, causing severe environmental and public health issues (Biswas and Singh 2020). Despite these challenges, e-waste represents a valuable source of reusable and precious materials, providing livelihoods for a significant portion of the Indian population, who collect and sell metals, plastics, glass, and other recoverable items (Sandwal 2025).

E-waste generation in India has grown sharply over the past decade, driven by economic growth, digital adoption, and rapid technological turnover. Current research indicates that the rate of e-waste accumulation is far outpacing documented recycling efforts, with projections suggesting continued increases by 2030. While developed countries have established structured e-waste management systems, many low- and middle-income countries—including India—rely heavily on informal recycling, leading to widespread environmental contamination and health hazards (Sandwal 2025).

E-waste management strategies for the industries and society

A range of e-waste management strategies has been proposed for industries and the society, each playing a distinct but interconnected role in addressing the growing e-waste challenge.

Role of Industry

The electrical and electronic equipment (EEE) sector is among the fastest-growing segments of global manufacturing and is a major contributor to e-waste generation. Industries are expected to adopt waste minimization and cleaner production strategies to significantly reduce the volume of waste and its environmental impact. This includes implementing reverse logistics systems that enable the recovery, reuse, and recycling of valuable materials such as copper, aluminum, lead, precious metals, plastics, and glass. Manufacturers, distributors, and retailers should also assume extended responsibility for the end-of-life management of their products, including collection, recycling, or safe disposal, in line with extended producer responsibility (EPR) principles (Balde 2017).

Responsibilities of Citizens and Civil Society

Consumers play a critical role in ensuring effective e-waste management. Electronic waste should never be discarded with general household garbage due to the presence of hazardous substances. Instead, consumers should choose environmentally responsible products that are energy-efficient, designed for easy repair, upgrading, or disassembly, and manufactured with minimal packaging and recycled content. Preference should be given to products that offer take-back schemes and are certified by recognized regulatory or environmental authorities. Non-governmental organizations can further strengthen e-waste management by adopting participatory approaches, facilitating public awareness, supporting collection drives, and acting as intermediaries between communities, recyclers, and policy makers (Widmer 2005).

Challenges and Future Directions

Persistent challenges in e-waste management include inadequate infrastructure, low public awareness, weak enforcement of existing regulations, and financial barriers associated with investment in recycling facilities. Furthermore, the international movement of electronic waste exacerbates these issues, often transferring environmental and health risks to countries with less stringent regulatory frameworks. Addressing these obstacles requires a multi-pronged approach, including strengthening education and outreach programs to increase consumer and industry awareness, expanding the capacity and efficiency of formal recycling systems, and promoting the development and adoption of scalable, cost-effective recycling technologies. International collaboration is also crucial to ensure responsible transboundary e-waste management and prevent illegal dumping. Policy and research initiatives must continue to emphasize circular economy strategies and lifecycle thinking, encouraging the design of electronics that are repairable, reusable, and recyclable. By integrating these approaches, stakeholders can mitigate environmental hazards, foster sustainable economic opportunities, and create a more resilient global e-waste management system (Ghulam and Abushammala 2023).

Electronic waste management presents key opportunities through reduction, reuse, and repurposing, contributing to environmental sustainability, social inclusion, and economic development. Reduction minimizes hazardous impacts by strengthening access to formal and efficient recycling systems. Reuse extends the lifespan of electronic products through repair, refurbishment, and resale, improving affordability for underserved communities. When devices reach end-of-life, repurposing allows recovery of valuable materials via dismantling and transfer to authorized recyclers. The sector also creates green jobs in collection, repair, recycling, and awareness initiatives. In India, despite EPR-based regulations, e-waste generation continues to grow, highlighting the need for sustainable product design and circular economy practices.

Suggested changes regarding the problem of e-waste

- Ensure systematic and efficient collection of electronic waste.
- Enhance the durability and quality of electrical and electronic products, while promoting affordable technologies.
- Conduct educational and awareness campaigns about e-waste management for school students and the general public.
- Establish comprehensive e-waste policies and legal frameworks to regulate handling and disposal.
- Prohibit the import of e-waste and implement fees for manufacturers and consumers to cover safe disposal of hazardous materials.
- Support and incentivize formal, organized recycling systems to increase recovery of valuable materials.
- Enforce strict health and safety standards in workplaces to protect workers from exposure to toxic substances during e-waste handling.

CONCLUSION

Electronic waste, particularly from mobile phones, poses significant environmental, health, and social challenges on a global scale. Improper disposal of mobile phone batteries releases toxic chemicals and heavy metals, contaminating soil, water, and air, and creating long-term risks for ecosystems and human well-being. This growing issue highlights the urgent need for robust and effective management strategies. Tackling e-waste requires a comprehensive approach that combines strict regulations, sustainable technological solutions, and advanced recycling techniques, while engaging all stakeholders, including manufacturers, consumers, and regulatory bodies. Raising public awareness, promoting responsible disposal habits, and applying circular economy principles are essential for reducing waste and conserving resources. Additionally, international collaboration, continuous research, and sound policy development are vital to establishing frameworks that support safer, environmentally sustainable, and resource-efficient use of mobile technology, minimizing the negative impacts of e-waste on both communities and ecosystems worldwide.

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