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Review Article

Insights into E-waste as Global Concern: Sources, Composition and Impacts

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ABSTRACT

Since the 18th century, science and technology have driven industrial growth and improved human life. In the 21st century, rapid technological development has changed not only industries and lifestyles but has also brought new environmental challenges. One of the biggest issues today is the continuously increasing volume of electronic waste originating from discarded electrical and electronic equipment. Inaccurate and improper e-waste disposal and recycling lead to the release of toxic substances, posing a great threat to the environment and human health. This review discusses global e-waste sources, composition, and impacts.

1. Introduction

E-waste, also known as electronic waste, refers to discarded or surplus electronic devices, appliances, and components. Examples include computers, smartphones, televisions, refrigerators, and other household and industrial electronic equipment. E-waste is a rapidly growing global concern due to its potential negative impacts on the environment and human health. The rapid advancement of technology and the constant release of new electronic devices have led to a rapid increase in the amount of e-waste generated [1]. As these devices reach the end of their useful life, they are often discarded, leading to the buildup of e-waste in landfills and other disposal sites. E-waste contains a wide range of toxic materials, including lead, cadmium, mercury, and flame retardants, which can have harmful effects on the environment and human health if not properly managed. Improper disposal of e-waste can lead to the release of these toxins into the air, water, and soil, potentially contaminating food and drinking water. Current management practices for e-waste include recycling, incineration, and landfilling. However, many e-waste recycling operations in developing countries are informal, and lack proper safety and environmental protections, resulting in the release of toxic chemicals and pollutants into the environment [2]. To address the global concern of e-waste, modern perspectives include implementing extended producer responsibility programs, which place the responsibility for e-waste management on the manufacturers of electronic devices; promoting circular economy principles, which aim to reduce waste and resource consumption through product design, reuse, and recycling; and encouraging sustainable design, which aims to reduce the environmental impact of electronic products throughout their lifecycle.

The increased demand for electronics globally has resulted in a significant growth in the amount of e-waste created. This tendency is especially noticeable in emerging nations with a burgeoning middle class and increased access to technology. According to a World Economic Forum estimate, e-waste is expected to exceed 74 million metric tons by 2030 [3]. Lead, mercury, cadmium, and brominated flame retardants are among the harmful compounds found in e-waste [4]. When not adequately handled, these compounds can pose major environmental and health problems. Lead, for example, can harm the neurological system and create developmental issues in children. Mercury may harm the brain and kidneys, while cadmium can harm the kidneys and cause cancer. E-waste that is improperly disposed of can also contaminate soil and water, posing risks to human health and wildlife [5].

The lack of proper e-waste management is a significant challenge, particularly in developing countries where there may be limited resources and infrastructure for managing electronic waste. Many e-waste items end up in landfills or are illegally exported to other countries, where they may be handled in unsafe ways. This can lead to environmental contamination and health risks for people who live near the waste sites. There have been calls for increased regulation to address the e-waste problem. Many countries have enacted laws and regulations to promote proper e-waste management, including recycling and disposal standards [3, 6-7]. However, enforcement of these regulations can be a challenge, and there is a need for greater international cooperation to address the issue.

There has been growing awareness about the e-waste problem and its impact on the environment and human health. Many companies and organizations are taking steps to address the issue, such as implementing sustainable design practices, improving recycling programs, and reducing the use of hazardous materials in electronics by minimizing e-waste resulted in gaining positive applicability of green chemistry in circular economy [2,8]. Consumers are also becoming more aware of the issue and seeking out ways to responsibly dispose of their electronic devices.

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Moreover, the e-waste concern in 21st century has been driven by the increasing amount of electronic waste generated worldwide, as well as the environmental and health risks associated with improper e-waste management. There is a need for greater regulation and cooperation to address the issue, as well as a growing awareness of the problem among consumers, companies, and organizations [9]. The e-waste is a worldwide issue that affects both industrialized and poor countries. E-waste is shipped from developed countries to poor ones for recycling or disposal. This activity, known as "e-waste dumping," is prohibited by international law, yet it continues to occur owing to a lack of effective laws and enforcement. Developing nations sometimes have fewer environmental and labor laws, making them a more appealing destination for e-waste. Developed countries, such as the United States, Japan, and Germany, create the most e-waste per capita, while emerging countries are increasing their production [9-13]. The review demonstrates the current global e-waste scenarios and the health hazards, which could delay the achievement of sustainable development targets, in terms of their composition sources, composition, and associated impacts, to provide a comprehensive workflow for the requirements of e-waste awareness building and technological improvement to facilitate global long-term sustainable development.

2. Sources

Electronic garbage, or e-waste, is the term used to describe abandoned electronic devices such as computers, cellphones, televisions, and other electronic equipment [14]. Consumers, corporations, and institutions are all potential contributors of e-waste. Electronic gadgets are frequently discarded by consumers when they become obsolete or no longer perform correctly. Companies and organizations create e-waste when they upgrade their electronic equipment, and these things can soon become obsolete owing to technological advances [15]. Moreover, the production of electronic gadgets creates waste, such as scrap materials, damaged goods, and surplus inventories. Lastly, inappropriate electronic device disposal can add to e-waste since many individuals dispose of these goods in landfills rather than recycling them. The chief sources of e-wastes is schematically given in Fig. 1.

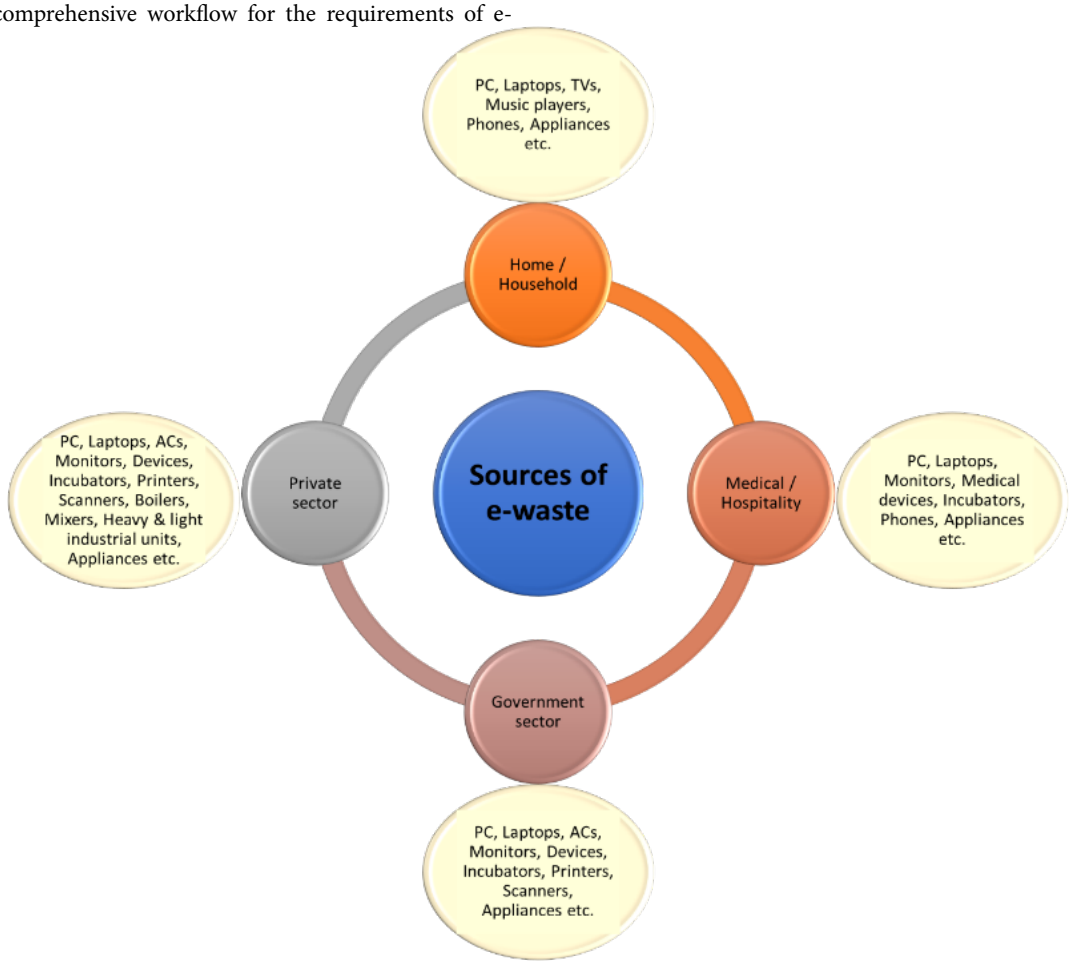

Fig. 1: Schematic representation of the Chief sources of e-waste

Al-Salem et al. in 2021 described a current summary of e-waste creation, recycling procedures, and growing management issues and defined in detail, the conditions of global e-waste management, the issues that different areas confront, and developing technology for e-waste recycling that is most desirous in the current era [16]. In a similar report, Singh and Sharma (2021) summarized further the worldwide e-waste construction and managing techniques [17]. It also goes into the environmental and health consequences of e-waste, as well as the legislation and regulations in place to handle it and it delves into innovative e-waste management methods, such as recycling and recovery techniques [14,17]. E-waste includes a wide range of sources, described herein:

2.1 Computers and laptops

Computers and laptops are considered e-waste when they are no longer functional or have been replaced with newer models. These devices typically contain a variety of materials such as plastics, metals, and electronic components, which can be recycled or safely disposed of to prevent harm to the environment and human health. When disposing of a computer or laptop, it is

important to remove any personal data or confidential information stored on the device to protect your privacy. This can be done by using secure data erasure software or physically destroying the hard drive. Many computers and laptops also have batteries, which should be removed and disposed of properly, since they can be hazardous if they are not handled correctly. Like other electronic devices, many computers and laptops can be recycled through in-store take-back programs or through specialized e-waste recycling facilities. These facilities will break them down into their component parts and recycle or safely dispose of the materials. This not only helps to prevent pollution but also conserve resources.

2.2 Televisions

Televisions are considered e-waste when they are no longer functional or have been replaced with newer models. Once televisions are no longer functioning or have been replaced by newer ones, they are classified as e-waste. Televisions include a range of elements, including plastics, metals, and electrical components, all of which may be recycled or disposed of securely to protect the environment and human health. To preserve your privacy, it is vital to erase any personal data or private information saved on a television before disposing of it, but this is not usually an issue with televisions. Many televisions also have batteries, which should be removed and disposed of appropriately because they can be dangerous if not handled properly. The situation worth noting that older televisions, such as cathode ray tube (CRT) televisions, contain a lot of lead. These facilities will break them down into their component parts and recycle or safely dispose of the materials. This not only helps to prevent pollution but also conserve resources.

2.3 Cell phones and smartphones

Cell phones and smartphones are considered e-waste when they are no longer functional or have been replaced with newer models. These devices typically contain a variety of materials such as plastics, metals, and electronic components, which can be recycled or safely disposed of to prevent harm to the environment and human health. It is important to remove any personal data or confidential information stored on the device to protect your privacy, when disposing of a cell phone or smartphone. This can be done by using secure data erasure software or restoring the device to factory settings. Many cell phones and smartphones also have batteries, which should be removed and disposed of properly, since they can be hazardous if they are not handled correctly. Similarly, to the other electronic devices, many cell phones and smartphones can be recycled through in-store take-back programs or through specialized e-waste recycling facilities. These facilities will break them down into their component parts and recycle or safely dispose of the materials. This not only helps to prevent pollution but also conserve resources. Additionally, many companies have trade-in programs that allow consumers to trade their old devices for discounts on new ones, or even donate them to be used in developing countries where access to technology is limited.

2.4 Tablets and e-readers

Also, tablets and e-readers are considered as e-waste because they are no longer functional or have been replaced with newer models. These devices typically contain a variety of materials such as plastics, metals, and electronic components, which can be recycled or safely disposed of to prevent harm to the environment and human health.

Many tablets and e-readers, like other electronic gadgets, may be recycled through in-store take-back programs or through specialist e-waste recycling facilities. These facilities will disassemble the items and recycle or dispose of them safely. This not only helps to reduce pollution but also to save resources. Furthermore, many firms have trade-in programs that allow customers to turn in their old gadgets for discounts on new ones, or even donate them to be used in underdeveloped nations where access to technology is limited [18]. After disposing of a tablet or e-reader, it is important to remove any personal data or confidential information stored on the device to protect your privacy. This can be done by using secure data erasure software or restoring the device to factory settings. Many tablets and e-readers also have batteries, which should be removed and disposed of properly, since they can be hazardous if they are not handled correctly.

2.5 DVD players and VCR (Video Cassettes Recorders)

DVD players and VCRs (Video cassette recorders) are considered e-waste when they are no longer functional or have been replaced with newer models. Like other electronic devices, many DVD players and VCRs can be recycled through in-store take-back programs or through specialized e-waste recycling facilities. These facilities will break them down into their component parts and recycle or safely dispose of the materials. This not only helps to prevent pollution but also conserve resources. The devices typically contain a variety of materials such as plastics, metals, and electronic components, which can be recycled or safely disposed of to prevent harm to the environment and human health. The disposing of a DVD player or VCR, it is important to remove any personal data or confidential information stored on the device to protect your privacy, but this is not typically an issue with these devices. Many DVD players and VCRs also have batteries, which should be removed and disposed of properly, since they can be hazardous if they are not handled correctly.

2.6 Gaming consoles

Gaming consoles, such as the Xbox, PlayStation, and Nintendo consoles, are also considered e-waste when they are no longer functional or have been replaced with newer models. These devices typically contain a variety of materials such as plastics, metals, and electronic components, which can be recycled or safely disposed of to prevent harm to the environment and human health.

When disposing of a gaming console, it is important to remove any personal data or confidential information stored on the device to protect your privacy. Many gaming consoles also have batteries, which should be removed and disposed of properly, since they can be hazardous if they are not handled correctly. Like other electronic devices, many gaming consoles can be recycled through in-store take-back programs or through specialized e-waste recycling facilities [16,19]. These facilities will break them down into their component parts and recycle or safely dispose of the materials. This not only helps to prevent pollution but also conserve resources.

2.7 Printers and scanners

Printers and scanners are also considered e-waste when they are no longer functional or have been replaced with newer models. Printers can contain a variety of materials such as plastics, metals, and electronic components. Scanners contain electronic components as well. Many of these materials can be recycled or safely disposed of to prevent harm to the environment and human health. Similar other electronic devices, many printers and scanners can be recycled through in-store take-back programs or through specialized e-waste recycling facilities. These facilities

will break them down into their component parts and recycle or safely dispose of the materials. This not only helps to prevent pollution but also conserve resources. To preserve your privacy, it is critical to erase any personal data or secret information contained on printers and scanners before disposing of them. Many printers and scanners have ink or toner cartridges, which may be recycled or disposed of securely separately.

2.8 Home appliances (microwaves and refrigerators)

Microwaves, refrigerators, washing machines, and dryers are examples of e-waste. These appliances can become e-waste when they are no longer working or have been replaced by newer versions. Because of their size and weight, they are sometimes more difficult to dispose of than smaller electronic goods. Some household appliances may also contain hazardous elements, such as refrigerants, which must be handled and disposed of correctly to avoid harm to the environment and human health. Numerous home appliances can also be recycled, either through in-store take-back programs or through specialized e-waste recycling facilities. The recycling process typically involves breaking down the appliances into their component parts, which can then be used to make new products or safely dispose of any hazardous materials. It also prevents them from ending up in landfills and polluting the environment.

2.9 Home theater systems

Home theater systems, also known as home entertainment systems, include a combination of electronic devices such as a TV, DVD player, speakers, amplifiers and other components like streaming devices, gaming consoles and others. They are considered e-waste when they are no longer functional or have been replaced with newer models. These devices typically contain a variety of materials such as plastics, metals, and electronic components, which can be recycled or safely disposed of to prevent harm to the environment and human health.

2.10 Small electronic devices (calculators and digital cameras)

E-waste includes calculators and digital cameras that are no longer working or have been replaced by newer ones. These devices often contain a range of materials, including plastics, metals, and electrical components, which may be recycled or disposed of securely to protect the environment and human health. These items may be discarded due to obsolescence, broken or malfunctioning parts, or simply because they have been replaced with newer models.

3. Chemical composition

The chemical composition of e-waste varies according to the kind of electronic equipment and its age [20-21], however the following are some of the most frequent compounds found in e-waste: *Metals:* E-waste contains a variety of metals, including copper, aluminum, iron, gold, silver, palladium, and platinum (Fig. 2). These metals are used in electronic products for their electrical conductivity, durability, and resistance to corrosion.E-waste contains a variety of metals that are used in electronic products for their electrical conductivity, durability, and other properties [22-23]. Some of the most common metals found in e-waste include [24]:

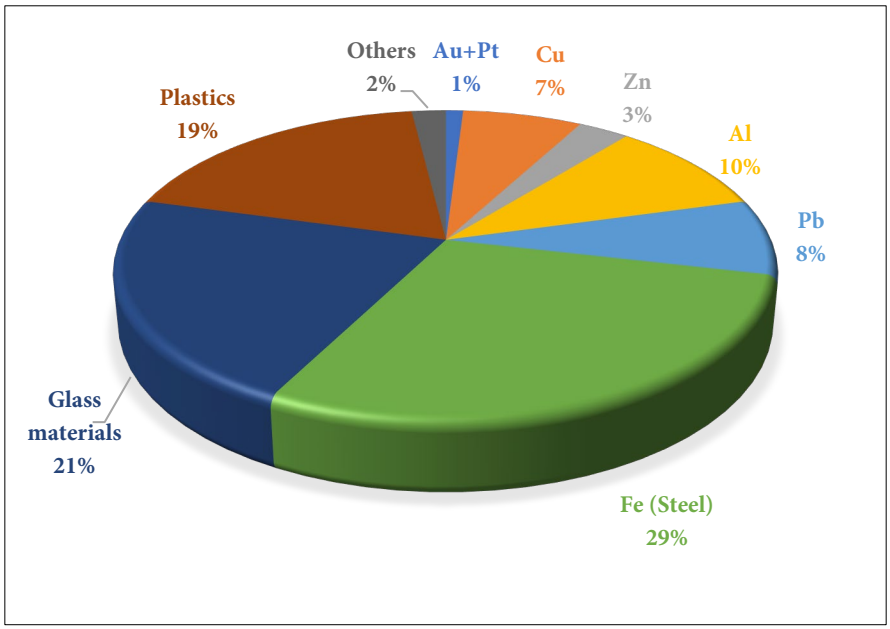

Fig. 2: Schematic illustration of e-waste composition.

- Cu: Copper is used in electronic products for its excellent electrical conductivity. It is commonly found in wiring, printed circuit boards (PCBs), and other components.
- Al: Aluminum is used in electronic products for its light weight and corrosion resistance. It is commonly found in components such as heat sinks and casings.
- Au: Gold is used in electronic products for its excellent electrical conductivity and resistance to corrosion. It is commonly found in connectors and other components.
- Ag: Silver is used in electronic products for its excellent electrical conductivity. It is commonly found in contacts, switches, and other components.
- Pd: Palladium is used in electronic products for its ability to absorb hydrogen. It is commonly found in components such as capacitors and resistors.
- Pt: Platinum is used in electronic products for its excellent electrical conductivity and resistance to corrosion. It is commonly found in contacts and other components.
- Pb: Lead is used in electronic products for its ability to absorb vibrations and to shield against radiation. However, due to its toxicity, lead has been phased out of many electronic products, and the use of lead in new products is restricted by various regulations.

Plastics: Electronic products contain a variety of plastic materials, including polycarbonate, polyethylene, polypropylene, and PVC. These plastics are used for their insulating properties and durability.

Glass materials: Electronic devices, such as CRT monitors and televisions, contain glass components. The glass used in electronic devices is typically a type of leaded glass, which can pose environmental and health risks if not properly disposed off. Cathode Ray Tube glass, for example, is composed of mainly SiO2, CaO, and Na.

Flame retardant components: Electronic devices often contain flame retardants, which are chemicals added to the materials used in electronic products to reduce their flammability. Common flame retardants used in electronic products include brominated flame retardants (BFRs) and phosphorus-based flame retardants (PBFRs).

Printed circuit boards (PCBs) and others: PCBs are used in electronic products to connect electronic components. They contain a variety of metals and other materials, including copper, gold, silver, tin, and lead.

Impacts: Environment and Human being's health

E-waste, or electronic waste, can have significant environmental impacts if not properly managed. E-waste, or electronic garbage, can have severe and far-reaching environmental consequences. Poor e-waste disposal can result in land and water degradation, air pollution, resource depletion, increased energy usage, and greenhouse gas emissions. Hazardous substances found in e-waste, such as lead, mercury, and cadmium, can be released into the environment and harm human health and the environment [24-26]. Furthermore, the production and disposal of electronic products consume a lot of energy and can contribute to climate change. Proper e-waste management measures, including proper electronic device disposal and recycling, are required to reduce negative environmental consequences and encourage sustainable resource usage. Some of the environmental impacts associated with e-waste are presented in Fig. 3.

The disposal of electronic gadgets and their components is referred to as electronic trash, or e-waste. Many of these products include hazardous compounds including lead, mercury, cadmium, and brominated flame retardants. These substances can seep into the land and water, posing a serious health danger to humans [27-29]. Lead is an extremely hazardous element that, especially in children, can cause major health problems such as developmental delays, learning challenges, and behavioral issues. Mercury is another hazardous element that may harm the nervous system, causing tremors, memory loss, and mood changes. Cadmium is a hazardous metal that has been associated to thyroid issues and developmental delays, whereas brominated flame retardants have been connected to thyroid problems and developmental delays. Toxic dust inhalation during e-waste deconstruction and disposal can cause respiratory difficulties and other health concerns, including lung cancer. Skin irritation, eye difficulties, and headaches can all result from exposure to electronic trash. Furthermore, poor e-waste disposal can lead to environmental contamination, harming local species and ecosystems. The components of e-waste, on the other hand, can have a substantial influence on human health, creating serious and possibly irreparable health issues. To reduce the health and environmental dangers connected with e-waste, electronic gadgets and their components must be properly disposed of and recycled. Electronic garbage, sometimes known as e-waste, refers to a wide spectrum of electronic gadgets and their components. Table 1 depicts some of the most frequent e-waste components [30-35]. Toxic components in electronic trash include mercury, lead, cadmium, polybrominated flame retardants, barium, and lithium, all of which are hazardous to human health. Toxins' harmful health impacts on humans include damage to the brain, heart, liver, kidneys, and skeletal system (Table 1) [36-43].

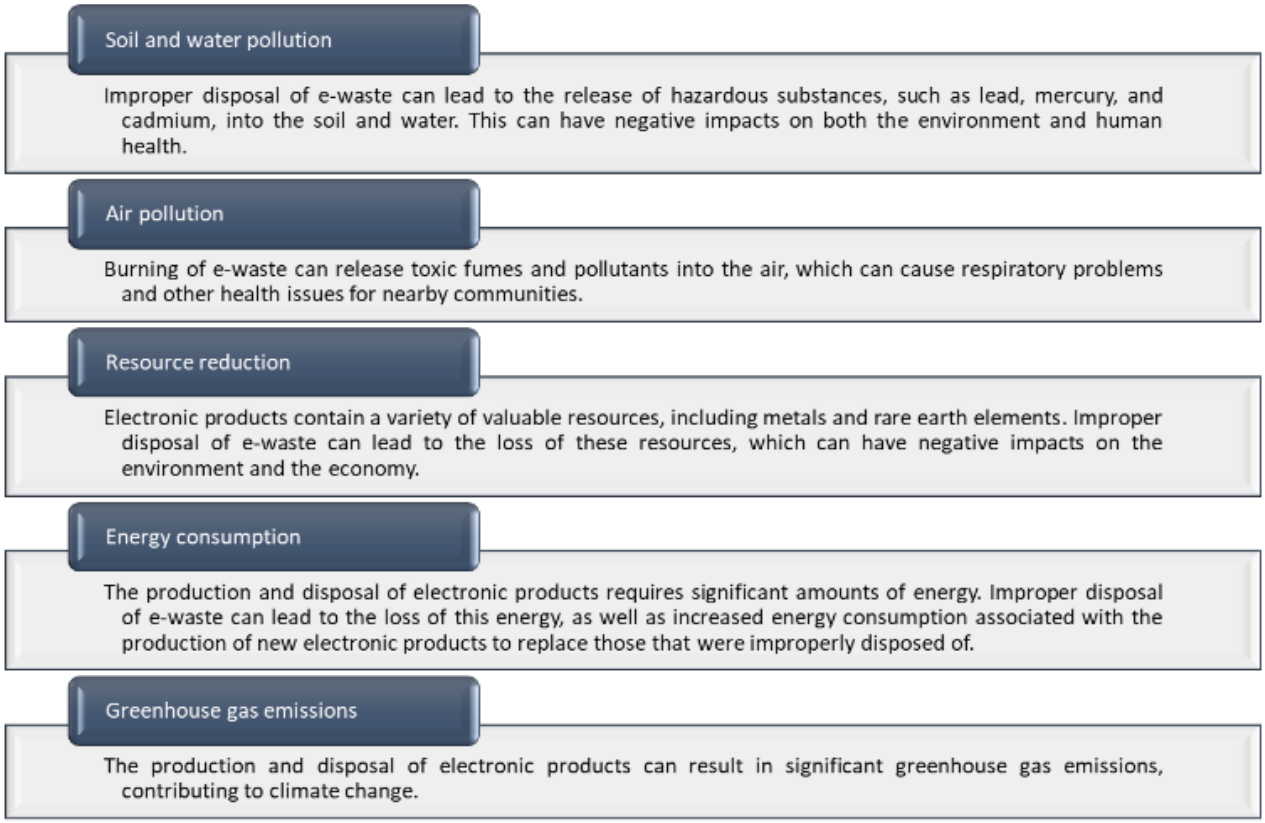

Fig. 3: Illustration of significant environmental impacts of e-waste.

Table 1: Human health impacts of e-waste components [1-4, 8-12, 20-24, 36-43].

Components of e-waste	Chief constituents	Associated health concerns
Cable insulation	PVC (Burning)	Immune system
Plastics housing	Br	Endocrine system
Motherboards	Be	Carcinogenic (Lungs) and Skin disorders (warts) and chronic disease (*Beryllicosis*)
Soldering	Pb Sn	Learning difficulties, Brain abnormality, Damage to central and peripheral nervous systems, blood systems and kidney damage Behavioral problems
Printed circuit boards (PCBs)	Pb Cd	Learning difficulties, Brain abnormality, Damage to central and peripheral nervous systems, blood systems and kidney damage Toxic irreversible effects- Teratogenic, neural damage, kidney and liver
Computer monitor/Screens/peripherals	Hg	Chronic damage to brain and skin and Respiratory and skin disorders
Cathode ray tubes	PbO Ba Cd	Kidney, Liver, Heart, Skin Muscle weakness, Damage to liver, heart and spleen Toxic irreversible effects- Teratogenic, neural damage, kidney and liver
Batteries (single-use and rechargeable)	Li	Loss of appetite, seizures, nausea, vomiting, diarrhea
Liquid crystal displays (LCDs)	Volatile organics (VOs) Pb	Learning difficulties, Brain abnormality, Damage to central and peripheral nervous systems, blood systems and kidney damage
Hard drives and other data storage devices	Al Pb	Mental disability Learning difficulties, Brain abnormality, Damage to central and peripheral nervous systems, blood systems and kidney damage
Conducting electronic plates (CEP), disposable and rechargeable batteries, luminous substances	Cr Pb Zn	Skin irritation and Lung cancer (*Bronchitis*) Learning difficulties, Brain abnormality, Damage to central and peripheral nervous systems, blood systems and kidney damage Damage to central and peripheral nervous systems and trauma

4. Conclusion and Future Outlook

With fast growth in all categories of electronic products and a relatively short life span, e-waste has become a serious global problem. It contains valuable materials such as gold and copper, as well as harmful substances like lead, mercury, and plastic additives. When e-waste is handled or recycled poorly, it contaminates the air, water, and soil, and creates health risks for humans and animals. To manage e-waste, safe recycling systems, proper legislation, and awareness among the public are greatly needed. All electronic products should be made more repairable, reusable, and recyclable by their very manufacturers. Support from governments toward formal recycling sectors is necessary, along with the encouragement of green technologies in material recovery. In the longer term, the adoption of circular economy concepts-where electronics materials is reused rather than discarded-will minimize pollution and preserve natural resources. With international cooperation, better technology, and responsible behavior from both producers and consumers in a market economy, e-waste can be transformed from a problem into a valuable resource for sustainable development.

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Author contribution

Mohd Yusuf: Concept, data collection, visual interpretation, editing manuscript and submission.
Shafat A. Khan: Data interpretation, revising writing, drafting manuscript.
Sandeep K. Chaurasiya: Data interpretation, visual editing, drafting manuscript.

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