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E-WASTE DISPOSAL AND MANAGEMENT

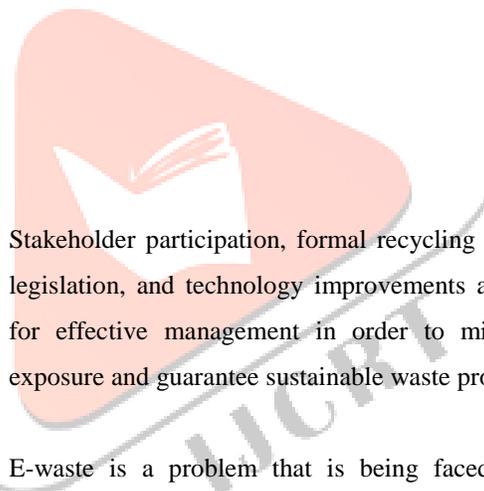
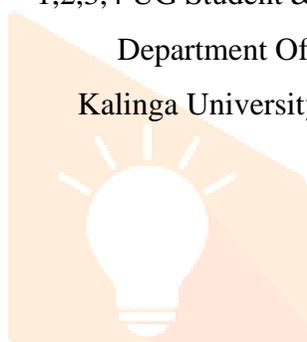
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Abstract

The rapid growth of electronic waste (e-waste) has emerged as a significant global environmental challenge due to its toxic components, which can harm both the environment and human health if not properly handled. This study examines the dangerous materials in e-waste, their potential environmental and health impacts, and current management approaches in various countries. Advanced nations have implemented strategies such as life cycle assessment (LCA), material flow analysis (MFA), multi-criteria analysis (MCA), and extended producer responsibility (EPR) to address e-waste issues more effectively.

Exposure to dangerous chemicals and e-waste can have major negative effects on the environment and human health. Research emphasizes the hazards of organophosphorus chemicals, incineration pollutants, and the existence of harmful materials in carpets. The disposal of e-waste in landfills, illicit imports, and lax laws are the main issues facing the United States and China. While large companies utilize better procedures than smaller ones, informal recycling practices in poor nations like India cause serious harm.

Stakeholder participation, formal recycling systems, stricter legislation, and technology improvements are all necessary for effective management in order to minimize harmful exposure and guarantee sustainable waste processing.

E-waste is a problem that is being faced by almost all countries globally but more so by developing countries as the e-waste is imported to these countries in bulk. Hence each of us must be committed to cutting down the waste and use, reuse and recycle all e-waste.

Keywords: recycling, waste management, e-waste, life cycle assessment , material flow analysis and sustainable waste.

Introduction

One of the biggest and fastest-growing sectors in the world is the electronics industry. Every year, millions of tons of electronic items are produced and transported around the world. But as these gadgets age, they decompose into complex trash made up of intoxicating chemicals, acids, heavy metals, and non-biodegradable polymers. This electronic garbage, or "e-waste," is imported for recycling, burned, or discarded in large quantities. About 75% of e-waste is unaccounted for

despite recycling efforts, and its disposal or reuse is unknown. Some electronic components end up as rubbish in homes, workplaces, and industrial facilities, while others are refurbished, remanufactured, or salvaged for repairs.

Leaded glass, circuit boards, and mercury-containing bulbs are among the hazardous products that many e-waste recycling companies ship, mostly to China, Africa, and India (Basel Action Network, 2013). Large amounts of e-waste are destroyed using labor-intensive procedures in nations like China and portions of India. This procedure involves more than just disassembly; it frequently includes burning, shredding, and chemical treatments. Carcinogens, among other dangerous compounds, are present in the ensuing smoke and dust and can lead to serious respiratory problems, skin conditions, and other health problems.

Burning circuit boards to extract valuable metals like gold, platinum, and cadmium is a widespread procedure in the processing of e-waste. However, polyvinyl chloride (PVC) and polychlorinated biphenyls (PCBs), which emit harmful vapors when burned, are frequently found in the plastic coatings on wires. Furthermore, toner cartridge carbon particles are recognized carcinogens that can cause skin and lung cancer (Kevin et al., 2008).

Some areas are still at risk of being exposed to e-waste hazards because of economic challenges. For example, despite health concerns, large amounts of abandoned computers and televisions are processed in Guangzhou, China. China received around 70% of the world's e-waste in 2007, with the rest traveling to India and Africa, according to data from that year. These areas have become international dumping sites for e-waste due to the availability of inexpensive labor. About 20% of Ghanaians work in e-waste-related fields, frequently repairing and reselling old gadgets (Basel Action Network, 2013). Because they import used electronics from the US and Europe for reuse or resale, poverty is the main factor contributing to the acceptance of e-waste in developing nations.

This expanding problem highlights the pressing need for better recycling practices, more stringent laws, and responsible e-waste management in order to reduce risks to the environment and public health.

Literature Review

Allsopp, M. (1999): This study examined hazardous chemicals in new UK carpets, finding high levels of organotins (TBT), BDE-209, and permethrin, with lower levels of formaldehyde. These chemicals pose potential health risks through indoor exposure, highlighting the need for urgent attention.

Allsopp, M. (2001): The National Research Council (2000) highlights the risks of pollutants from incineration facilities, which can be inhaled or ingested through contaminated food and water. Persistent pollutants, like metals, can travel long distances, undergo transformations, and cycle through the environment, posing widespread health risks.

Amini, N(2003): This review explores LC-MS techniques for detecting organophosphorus compounds (OPCs), which pose health and environmental risks. It discusses sample preparation, recent advances in extraction methods, and the growing role of electrospray ionization (ESI). LC-MS is emerging as a key tool for OPC analysis, including poisoning verification.

Kahhat (2008): examines e-waste growth and management in the U.S., highlighting landfill disposal and the need for better regulations. The study reviews global e-waste policies and emphasizes market-driven solutions for competitive recycling and reuse.

Wei (2012): highlights China's e-waste challenges, including illegal imports, informal recycling, environmental risks, and weak regulations. The study suggests strengthening regulations, promoting formal recycling, and enforcing Extended Producer Responsibility (EPR).

Sivaramanan (2013): highlights the global threat of e-waste, causing toxic environmental and health risks. The study reviews e-waste management efforts, including private firms' recycling roles, strict regulations, and public awareness initiatives.

Heeks (2015): explores e-waste management in developing countries, focusing on ICT firms in India. Large firms adopt proactive strategies, while smaller ones show indifference due

to varying influencing factors. The study highlights the need for better policies based on these determinants.

Awasthi, A. K.(2018):Environmental deterioration and health risk due to improper e-waste management has become a serious issue in India. The major portion of e-waste reaches an unorganized e-waste recycling sector and is then treated by using crude methods. This review article presents a brief highlight on e-waste management status, legislation, and technology uses in India. The present e-waste management needs to be more focused on environmentally sound management, by more active support from all the participants involved in the e-waste flow chain in India.

Methodology of Research

Information gathered from multiple sources, such as academic papers, video documentaries, and Greenpeace Technical Note 10 (2008), served as the foundation for this investigation. The collected data was examined to address important facets of e-waste, such as its origins, disassembly procedures, existing disposal techniques, the presence of hazardous chemicals and heavy metals, their effects on the environment and human health, potential remedies, and the function of organizations engaged in e-waste management. The goal of the project is to present a thorough analysis of the difficulties posed by e-waste and investigate methods for managing it sustainably.

E-Waste Sources

Electronic gadgets that are abandoned from both the consumer and industrial sectors are referred to as e-waste. Older or broken personal devices like cell phones, cameras, CD players, TVs, radios, and fax machines are common contributors of e-waste. Office supplies like printers, photocopiers, ink cartridges, and toners also play a big role in the buildup of e-waste.

Other significant contributors include digital gadgets like clocks and calculators, batteries (both rechargeable and disposable), and outdated computer parts like motherboards, keyboards, CRT monitors, and other peripherals. Ovens, refrigerators, sewing and washing machines, fans, air conditioners, grinders, irons, heaters, and other household and commercial electrical appliances contribute to the increasing amount of e-waste. Additionally, the worldwide e-waste problem is exacerbated by specialized electronic equipment utilized in military and scientific settings.

Background of Particles

Many dangerous particles and substances that come from various electronic parts and materials can be found in e-waste. These materials include heavy metals, plasticizers, flame retardants, and other hazardous chemicals that are harmful to the environment and human health. Polymerizers: Phthalates include di(2-ethylhexyl) phthalate (DEHP), diisononyl phthalate (DINP), butylbenzyl phthalate (BBP), diisodecyl phthalate (DIDP), and dibutyl phthalate (DBP) and are found in wire coatings and cables, such as polyvinyl chloride (PVC) (Otake et al., 2001; Butte & Heinzow, 2002; Fromme et al., 2004).

Chlorinated Compounds: Transformer oils, printing inks, plasticizers, capacitor dielectrics, and hydraulic fluids all emit polychlorinated biphenyls, or PCBs. The burning of PVC and other chlorinated materials also produces PCBs (Hedman et al., 2005; Wikstrom & Marklund, 2001). Furthermore, PVC burning releases chlorobenzenes, which are employed as solvents and intermediates in pigments and dyes (Grimes et al., 2006). Flame Retardants: Polybrominated diphenyl ethers (PBDEs), which are frequently added to foam materials and plastic electronic equipment casings as flame retardants, increase the toxicity of e-waste. Photocopy films, hydraulic fluids, lubricants, and plastic monitor casings all include triphenyl phosphate (TPP), another plasticizer and flame retardant (Carlsson et al., 1997).

Heavy Metals: According to Matthews (1996), lead is frequently alloyed with tin and used in electrical solder, batteries, cathode ray tube (CRT) glass, and PVC stabilizers. Rechargeable batteries, solder connections, electrical contacts, switches, and PVC stabilizers all contain cadmium (Matthews, 1996). The inside surface of CRT screens is illuminated by cadmium sulfide (Burstall, 1997). Lead-acid starter batteries, electrical solder, semiconductors, and flame-retardant plastic formulations all include antimony (Lau et al., 2001; Kentner et al., 1995). Antimony oxides are released into the atmosphere as e-waste burns. Switches, relays, and printed circuit boards all contain mercury. Chromium protects galvanized steel components against corrosion. CRT monitors frequently contain barium. Circuit motherboards include beryllium (Ramachandra & Saira Varghese, 2004).

E-waste's Effect on Human Health

There are serious risks associated with the disassembly, shredding, acid treatment, and burning of e-waste, including the possibility of cuts and burns. Additionally, there may be serious long-term health consequences from extended exposure to dangerous substances generated during these procedures.

While butylbenzyl phthalate (BBP) and dibutyl phthalate (DBP) are recognized reproductive poisons, phthalates, such di(2-ethylhexyl) phthalate (DEHP), interfere with testicular development. Reduced anogenital distance in male babies has been associated with phthalate exposure during pregnancy (Swan et al., 2005). Both diisodecyl phthalate (DIDP) and diisononyl phthalate (DINP) have the potential to harm the kidneys and liver.

By bioaccumulating in fish and other creatures, polychlorinated biphenyls (PCBs) raise concentrations in top predators, including humans. PCBs can cause neurotoxicity, liver damage, tumor development, immunological suppression, reproductive abnormalities, and aberrant sperm production if they are absorbed through the skin, breathed, or consumed (Allsopp et al., 1999, 2001a). As solvents and pigments, chlorobenzenes can be harmful both acutely and over time, impacting the thyroid, liver, and central nervous system (CNS). Tetrachlorobenzenes and other highly chlorinated substances also affect renal function. The immune system, liver, thyroid, central nervous system, kidneys, and nervous system are all harmed by hexachlorobenzene (HCB), a Group 2B carcinogen (van Birgelen, 1998). HCB poses long-term health hazards because it bioaccumulates in organisms.

Persistent environmental contaminants that are known to bioaccumulate are polybrominated diphenyl ethers (PBDEs). Learning, memory, behavior, thyroid function, estrogen levels, and immunological response are all impacted by exposure during fetal development, which also alters brain structure (Legler & Brouwer, 2003). The very hazardous compounds furans and brominated dioxins are released when PBDEs burn. Triphenyl phosphate (TPP), which is frequently present in human blood, affects immunological function by blocking important blood cell enzymes (Jonsson et al., 2001; Amini & Crescenzi, 2003). There are serious health dangers associated with heavy metals found in e-waste. Lead causes

blood abnormalities, renal damage, reproductive problems, and irreparable harm to the neurological system. It hinders the development of the child's brain (ATSDR, 2007; Canfield et al., 2003).

As cadmium builds up in tissues, it interferes with bone metabolism and renal function. It also has an impact on calcium control, which can result in heart disease and hypertension. Inhaling fumes of cadmium oxide raises the risk of lung cancer and causes respiratory disorders (Elinder & Jarup, 1996; WHO, 1992; ATSDR, 1999; DHSS, 2005). Immune system suppression, respiratory issues, and skin irritation are all brought on by antimony. The International Agency for Research on Cancer (IARC, 1989) has designated it as a potential carcinogen (Kim et al., 1999). Mercury causes serious neurological damage as well as long-term skin and respiratory disorders. Asthmatic bronchitis can be brought on by chromium, a recognized carcinogen that also destroys DNA.

Barium weakens muscles and damages the liver, spleen, and heart. According to Ramachandra and Saira Varghese (2004), beryllium is a carcinogen that has been connected to both lung cancer and chronic berylliosis, a lung condition that also causes skin warts. Further raising health dangers are the free carbon radicals from printer toners, which are categorized as carcinogens. Workers and surrounding communities are exposed to these dangerous compounds when e-waste is handled and disposed of improperly, underscoring the critical need for better recycling practices and more stringent laws.

E-waste in India's Raipur

Rapid urbanization, industrial expansion, and rising electronic product usage are making Raipur, the city of Chhattisgarh, a major hub for the production of e-waste. The amount of wasted electronic products in the city is increasing due to the increased usage of computers, mobile phones, home appliances, and industrial electronics. In Raipur, the informal sectors handle the majority of garbage, and the e-waste management system is still mainly disorganized.

Unsafe techniques like open burning and acid leaching are used by small-scale scrap dealers and workers, who frequently lack protective gear, to disassemble and extract valuable elements like copper, gold, and aluminum. These operations expose surrounding communities and employees to serious

health risks by releasing harmful materials into the air, soil, and water, such as lead, mercury, cadmium, and brominated flame retardants.



Combustion of E-Waste in Raipur, India (Dateline, 2011).

Regulations have been put in place by the Chhattisgarh State Pollution Control Board (CSPCB) to prevent the unlawful disposal of e-waste, and initiatives are underway to support approved recycling facilities. However, issues still exist because of low knowledge, insufficient collection methods, and lax enforcement of regulations pertaining to the disposal of e-waste. Better infrastructure, greater public knowledge, and more stringent oversight of Raipur's e-waste disposal procedures are all need to address the problem successfully.



A stream polluted by e- waste near Ram Ganga

E-waste's effects in India

About 80,000 individuals are employed in India's sizable informal e-waste recycling industry, many of whom operate in dangerous environments. There are sizable scrap markets in villages like Seelampur where mountains of abandoned electronics are disassembled by hand in order to be recycled. Workers burn valuable materials, like copper, to remove them

from wires, creating harmful fumes that irritate the eyes and create respiratory problems. Furthermore, metals are frequently isolated by acid treatment, which causes corrosive acids to leak from used computer and cell phone batteries.

Greenpeace experts claim that recycling a computer in India only costs \$2, but in the US it costs \$20 (Keekeesocean, 2012). The potential benefit from recovered metals and inexpensive labor are the main causes of the reduced cost. For about \$3 to \$5 a day, many laborers continue to disassemble e-waste, frequently at the price of their health. There are serious long-term health concerns associated with exposure to dangerous compounds such as lead, mercury, and brominated flame retardants.

Nonetheless, initiatives are underway to enhance the management of e-waste. An estimated 60,000 tons of e-waste can be handled annually by the massive e-waste recycling facility that is being built in Bangalore. Despite these advancements, managing e-waste remains a major concern for India. With about 24% of the nation's e-waste produced, Mumbai leads the pack, followed by Delhi (21.2%), Bangalore (10.1%), and Chennai (9.1%). To reduce the risks to the environment and human health posed by e-waste in India, appropriate laws, enforcement, and public education are crucial.

Current E-Waste Disposal Techniques

Incineration, acid baths, and landfilling are some of the techniques now employed to get rid of e-waste. Even though these procedures are good at getting rid of garbage, they frequently provide serious health and environmental hazards.

Landfills

The term "toxic time bomb" is frequently used to describe e-waste that is dumped in landfills because of the possibility that dangerous materials will eventually seep into the environment. Lead, zinc, nickel, copper, and other hazardous materials are found in electronic circuits, while batteries emit acids and heavy metals like cadmium, nickel, and mercury. These pollutants have the ability to permeate groundwater and soil, eventually making their way to people, animals, and freshwater sources like rivers and streams. Nearly half of e-waste is disposed of in landfills in nations like the US and Australia, with the remainder being transported to Asian and African nations for processing.

Acid Baths

One popular technique for removing valuable metals, especially copper, from e-waste is acid baths. This method dissolves the copper content of circuit boards by immersing them in sulfuric acid for around 12 hours. After boiling the solution, copper sulfate precipitates and is then collected. To extract more copper, more scrap materials are added to the residual solution. Additionally, lead is dissolved and valuable metals like gold and silver are extracted using acid baths. However, the trash produced by this process is extremely hazardous, endangering both the environment and the workers.



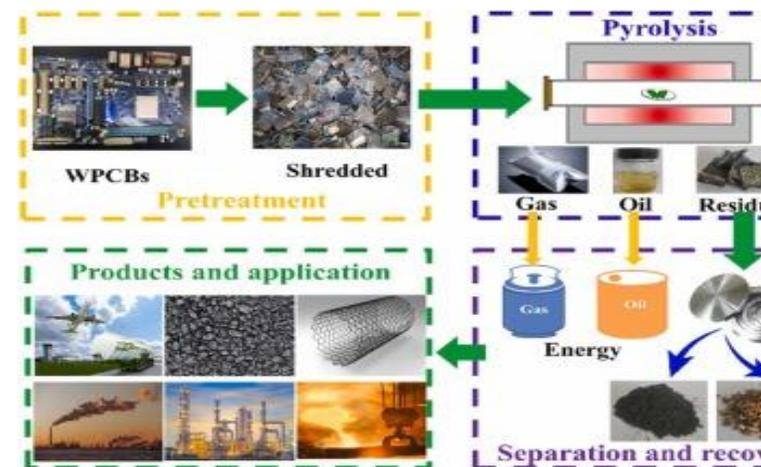
Current Disposal Methods of E-Waste

Combustion

Pyrolysis and other forms of incineration are common ways to dispose of e-waste in nations including China, India, Pakistan, and several regions of Africa. The procedure entails burning electronic garbage at high temperatures, which frequently releases extremely harmful compounds. Waste is converted into fumes, oils, and charcoal through pyrolysis, a type of incineration that involves heating materials without oxygen. Gasification produces fumes, ash, and tar by partially burning trash with a controlled amount of air injected.

The emission of dangerous compounds, many of which are more harmful than the original waste material, is one of the main issues with incineration. Heat causes plastics or PVC circuit boards to release toxic vapors that contain known carcinogens called polycyclic aromatics (PCA), polychlorinated dibenzo-para-dioxins (PCDDs), and polychlorinated dibenzofurans (PCDFs). Toxic chemicals like carbon monoxide, sulfur dioxide, and nitrogen oxides are also

produced during incineration and are linked to respiratory illnesses and air pollution. Traces of heavy metal oxides, such as antimony, lead, thallium, arsenic, copper, manganese, mercury, and nickel, are also present in the smoke produced by burning e-waste. There are long-term environmental risks because part of these harmful substances are discharged into the atmosphere, while the rest are left behind in the ash.



Pyrolysis of waste printed circuit boards: Parametric effects on product distribution, characterization and gas emissions

Safe Techniques for E-Waste Disposal and Authority Management

Recycling and reusing precious components, especially metals, through an industry-wide e-waste collecting system is the safest way to dispose of e-waste. In addition to preventing hazardous extraction techniques like cremation, acid baths, and landfill disposal, appropriate rules should be implemented to guarantee the required usage of protective equipment during disassembly, such as masks, gloves, and safety glasses. To stop e-waste from eventually leaking into groundwater or entering the environment, strict regulations should be put in place. In order to securely store gathered and extracted e-waste until it can be used again, a suitable storage system needs also be put in place.

In order to withstand corporate and political pressures that could jeopardize e-waste management initiatives, governments should enact robust laws and strengthen the enforcement of Basel Convention regulations. While research into better substitutes for dangerous chemicals and carcinogens should be promoted, unauthorized and unlawful e-waste collectors and dismantlers should be found and punished. Hazardous electronic devices should also be

prohibited, and the transfer of e-waste should be strictly regulated at the municipal, port, and harbor levels.

It is also essential to work together with manufacturers, e-waste processors, and environmental organizations. With the introduction of the e-Stewards certification system by the Basel Action Network (BAN), recyclers are guaranteed to follow morally and safely sound recycling procedures that safeguard the environment and workers. A list of approved e-waste recyclers is kept up to date by BAN, and the first certified standard for responsible recycling was created in 2010. The Natural Resources Defense Council (NRDC) and BAN are two groups that are still pushing for stricter enforcement of the laws prohibiting the export of illicit e-waste.

Several states in the US have put laws into place mandating that electronics manufacturers be responsible for the collection and recycling of their devices once they are used. Programs for raising public knowledge about the handling and disposal of e-waste should also be implemented.

Result

The study's conclusions show that e-waste contains dangerous substances that are extremely dangerous to human health and the environment, such as flame retardants, heavy metals, and organophosphorus compounds. In addition to long-term soil, water, and air contamination, exposure to these harmful compounds can cause immune system damage and respiratory issues. Particularly in underdeveloped nations, the unofficial recycling industry still handles e-waste in hazardous ways, increasing pollution and health hazards to people.

To lessen environmental harm, wealthy countries have adopted structured e-waste management techniques as Material Flow Analysis (MFA), Life Cycle Assessment (LCA), and Extended Producer Responsibility (EPR). There are still issues, though, such as the illicit trade in e-waste and the inappropriate landfilling of electronic debris. While smaller businesses and the unorganized sector frequently lack the resources and incentives for appropriate disposal, large corporations are more likely to embrace ethical recycling processes. To handle e-waste sustainably, it is imperative to invest in cutting-edge recycling technologies, strengthen legislation, and raise public awareness.

Conclusion

Improving e-waste management systems requires both active producer cooperation and public awareness. Governments must assume accountability by providing adequate financing and implementing globally accepted environmental laws within their borders. By putting certification programs like e-Stewardship into place, unlawful e-waste processing and smuggling may be avoided and compliance can be guaranteed.

Controlling the cross-border flow of e-waste, increasing awareness worldwide, and encouraging research into better disposal options are all important tasks that the Basel Action Network continues to perform. Because e-waste contains carcinogens, toxic compounds, and dangerous heavy metals, improper disposal can lead to major health hazards, such as cancer, immune system damage, skin disorders, and respiratory problems. To reduce these risks to human health and the environment, effective management and appropriate disposal techniques are crucial. Due to the massive importation of abandoned electronics, emerging nations bear the brunt of the expanding worldwide problem of e-waste. These countries frequently lack the legislative frameworks and infrastructure required for proper e-waste management, which poses serious health and environmental hazards. Long-term threats to ecosystems and human health arise from the contamination of soil, water, and air by hazardous compounds such as heavy metals, flame retardants, and toxic chemicals. The informal recycling industry, which is widespread in underdeveloped countries, uses risky practices that expose workers to dangerous chemicals, making health risks even worse.

All levels of society must work together to address this challenge. Reducing technological waste, reusing equipment, and correctly recycling are all ways that consumers may be more responsible. Governments ought to invest in official recycling infrastructure, encourage Extended Producer Responsibility (EPR), and impose stringent restrictions. Manufacturers must, however, give sustainable product design first priority, making sure that gadgets are robust, repairable, and recyclable. We can lessen the environmental impact of e-waste and progress toward a more sustainable future where technology developments do not come at the expense of the environment and public health by increasing

awareness and putting appropriate waste management systems into place.

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