Section: Community Medicine

Systematic Review

E-WASTE MANAGEMENT AND ITS CHALLENGES IN INDIA: A SYSTEMATIC REVIEW

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ABSTRACT

Background: The economic worth of global production of e-waste is 62.5 billion dollars with India being the 2nd largest producer of electronic waste in Asia. **Aim:** Present systematic review was conducted with the objective to review and document the practices of E- waste management in foreign countries and India and to explore the various challenges associated with the different E-waste management techniques used globally and recommend best practices for India.

Methods and Materials: Search strategy adopted consisted of PubMed, Google scholar, Embase, Cochrane library, all relevant major journals, National guideline clearing house, Google Search, National Medical Library, Government guidelines and orders, cross –referral and Standard Public health textbooks. Key words for search were E-waste disposal, E-waste management, E- waste guidelines, Legislations on E-waste, E-waste impact on health.

Results: A total of 191 studies were selected for assessment. substantial issues include rapidly rising volumes of e-waste, both domestically produced and imported, low awareness, and inaccurate knowledge about how to dispose of e-waste while being exposed to substantial health risks. Material value is significantly lost as a result of ineffective recycling procedures. The main obstacles in India are a lack of awareness, nascent technology, and ambiguous laws and regulations on the disposal of e-waste.

Conclusion: Developing eco-design devices, collecting e-waste with caution, recovering and recycling materials, disposing e-waste using proper techniques, forbidding the shipping of second-hand electronic devices to the developing countries, and raising awareness of the impact of e-waste are the major emerging ideas in developing countries.

Keywords: E-waste, Reuse, Management, Recycle, Legislations, Life Cycle Assessment.

INTRODUCTION

Electronic waste is the term used to describe electrical and electronic products that are no longer useful.[1] According to United Nations studies, less than 20% of e-waste is recycled, posing a risk to the environment and depleting vital natural resources. Additionally, it emphasises that 50 million tonnes of electronic trash are produced worldwide, and that number is expected to rise to 120 million tonnes by 2050.[2] The economic worth of global production of e-waste is 62.5 billion dollar.[1] And India is the second largest producer of electronic waste in Asia.[3]

Electronic waste is categorised as toxic (e.g. Arsenic, Cadmium, Chromium, Lead, Selenium etc.) and non-toxic products (e.g. iron, non-ferrous metals (Copper, Aluminium, Gold, Silver, Platinum).[2] Depending on the manufacturing material, the components of e-waste can cause poisoning (arsenic poisoning) and harm the heart (barium), skin (cobalt), kidney (cadmium), liver (cadmium), eyes (copper), lungs (chromium), and neurological system (lead).[2] Electronic waste pollutes the atmosphere through informal e-waste dismantling and recycling (it has been reported that Bi, Co, Cr, Cu, Mn, and Pb were detected in the atmosphere near reprocessing territories in India), groundwater, soil, and aquatic systems through leaching of constituents from dumpsites where unprocessed or processed e-waste has been dumped, as well as through various electronic activities such as production, sales, repair, disposal, and recycling (near old e-waste landfill sites).[2,4,5] WHO emphasises that improper disposal of electronic waste puts the health of children, adolescents, and expectant mothers at risk.[6]

Metals can be recovered from electronic waste via pyrometallurgical, hydrometallurgical, or bio-hydrometallurgical processes, as well as unofficial recycling techniques.[5,7] Waste electrical and electronic equipment (WEEE) must be processed in order to minimise negative impacts on the environment and human health, extract resources, and provide renewable energy.[5] As a result, this review outlines the diverse management strategies employed in various nations for the disposal and processing of electronic trash, along with its benefits and drawbacks.

E-waste is likely to become a big public health problem and not enough is being done about it in India. Guidelines, legislations are less known to the common man and public health professionals.

There are gaps in knowledge regarding what is being done with e waste and what are the good practices in its management in India and the good practices of similar demographic and gadget use profile countries have not been reviewed yet. India specific reviews have not been done yet.

Therefore, the present systematic review was conducted with the following objectives:

a. To review and document the good practices of E- waste management in foreign countries and India
b. To explore the various challenges associated with the different E-waste management techniques used globally and recommend best practices for India.

MATERIALS AND METHODS

Search Strategy: The present study aims to build novel research framework for enablers of e-Waste Management through a thorough systematic literature review. Search strategy adopted consisted of electronic search using Major search engines namely: PubMed, Google scholar, Embase, Scopus, and Cochrane library; all relevant major journals; National guideline clearing house; web-search using Google Search; search on relevant thesis using Shodh-Ganga, Offline search in National Medical Library, Government guidelines and orders, cross – referral and Standard Public health text Books. Key words used for search were E-waste disposal, E-waste management, E- waste guidelines, Legislations on E-waste, E-waste impact on health. The search was limited to Indian sub-continent population. The literature search included those articles which were on E-waste Management and not merely on its harmful effects. All study designs were included. And literature published in English only were included. This systematic review also included all articles on review of methods of E-waste disposal in India, review of methods of e-waste disposal in foreign countries with similar demographic and electronic use profile (mostly other Asian countries), review of good practices in such countries regarding their e-waste management and attitudes towards recycling and management of the waste that cannot be recycled.

Inclusion Criteria: Articles should be on management (All study designs) of e-waste (not merely on its harmful effects). Exclusion criteria: Articles covering only effects of e-waste. This review was justified as there are many harmful effects of e-waste accumulation in the environment on human health and is now an important public health problem.

Quality Assessment: The Quality assessment was done by expert and peer reviews as well as through Delphi method.

Data Extraction: Data extracted from selected articles was on the subtopics of: Types of waste, Method of e-waste management and outcomes of e-waste management. Removal of duplicates and initial exclusion of articles through title and abstract was done using Rayyan software. The bibliographic software used was Zotero and the data extraction was done through Microsoft Excel.

Ethics: The Institutional Ethics Committee of Government Medical College, Pali, Rajasthan was duly informed about the review, and permission was taken vide letter no. GMC/IEC/2021/135 dated 29/12/2021. The study was also registered on Prospero (CRD42021287163).

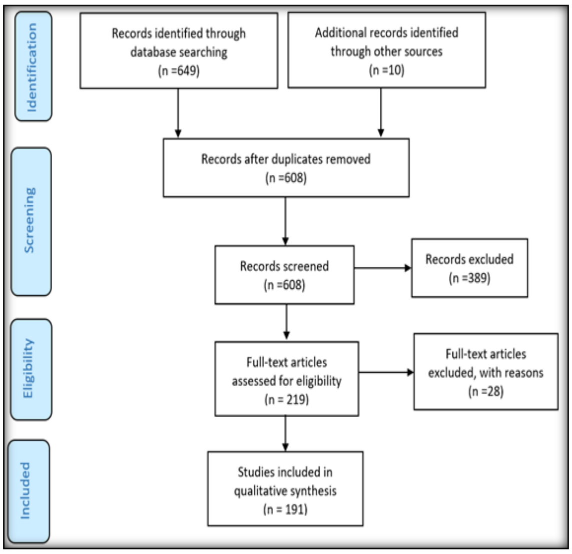

Figure 1: List of researched shortlisted for review as per PRISMA Flow Diagram

RESULTS

A total of 649 articles were found through initial search and 10 other relevant documents were identified through other sources. Of these, 191 studies were shortlisted for review.

Figure 1 shows the PRISMA Flow Diagram for the current study. Table 1 shows the various sites for e-waste generation. Table 2 is mentioning the various e-waste management approaches that are being practiced and their advantages and disadvantages.

Table 3 shows the various pollutants that are generated through e-waste management by various methods, and also their common sources. The main issues facing India are the rapidly rising volumes of e-waste produced both domestically and through imports (such as donated used computers to close the digital divide or just as metal scrap); the lack of precise estimates of the amount of e-waste produced; and the lack of knowledge about the health risks associated with managing e-waste as well as the environmentally friendly options available to both manufacturers and consumers. When someone handles e-waste, a lack of understanding and information about it might have major consequences. Material value is significantly lost as a result of ineffective recycling procedures. The main obstacles in India are a lack of awareness, nascent technology, and ambiguous laws and regulations on the disposal of e-waste.

Table 1: Types of E-waste generation

Household appliances	Microwaves, induction cooktops, fridges, Deep freezers, air conditioners, heaters, washing machines and dryers, electric kettle, vacuum cleaners, electric knives
Consumer equipment	Fluorescent lamps, Stereos, television sets, Radios, DVD players, video recorders, photocopiers, printers, fax machines, smoke detectors, leisure and sports equipment, electric shavers
Information and communication technology (ICT) and telecom equipment	Desktops, laptops, i-pads, calculators, mobiles, cordless phones monitors, routers
Equipment components/accessories	Battery cells, switch boards, button cells, activated glass, capacitors

Source: Miner et al. Survey on Household Awareness and Willingness to Participate in E-Waste Management in Jos, Plateau State, Nigeria

Table 2: Advantages and Disadvantages of common methods of E-waste management worldwide

S. No.	Method described	Countries using it	Special Characteristics / Advantages	Disadvantages
1	Hydrometallurgy	All Asian and African	Both Pyrometallurgy and Hydrometallurgy help in recovery of precious metals like platinum, gold, silver and cobalt	Long time consumption Expensive
2.	Pyrometallurgy	All Asian and African	Helps to reclaim valuable compounds from the components Recovery of energy resource material, Environmental friendly, can operate at lower temperatures, technologically simpler and does not produce gaseous emissions. Used to recover valuable metals like gold, silver, copper, and palladium which can be further utilized Economically Cost Efficient; Eco-efficient	High time consumption; Expensive, Chemicals like Cyanide used is dangerous.
3.	Bio-metallurgy	European & USA	Uses natural microorganisms like bacteria and fungi, making it a green alternative to conventional methods. Can extract specific metals such as gold, copper, and palladium with high precision. Cost effective. Can be adapted to small-scale and large-scale applications. Operates at ambient temperatures.	Expensive as high capital investment. Lack of knowledge about the efficiency and maintenance of large-scale processes High risk of toxicity from biological elements
4.	Super-critical Energy Extraction	European & USA	Economically efficient, and environmental friendly, Recovery rate of more than 90%. Usage of green solvents.	Corrosion, Salt precipitation.
5.	Electrochemical Separation	European & USA	Utilizes far less solvent (minimum reagent), Environment friendly. Has convenient and precise control, reduced energy usage.	Use of harmful chemicals
6.	Bioleaching	European & USA	Based on a microorganism's long-term and environmentally beneficial ability to convert waste into a valuable resource, bioleaching is regarded as one of the best processes. *Acidithiobacillus ferroxidans* (mesophilic-chemolithoautotrophic bacterium) is one of the few microbes extensively cited for PCB resource recovery. *Sulphobacillus thermosulfidooxidans*, *Thermoplasma acidophilum* (acidophilic moderately thermophilic bacteria), and *Chromobacterium violaceum* (acidophilic moderately thermophilic bacteria)	Lower yield
7.	Crude technologies like stone, hammer	Asian and African	Manual procedures Direct exposure to harmful chemicals & toxic heavy metals	Soil pollution, water pollution, air pollution. Toxic fumes generation

	for recovering valuable parts Burning, hitting on ground to crush			
8.	Burning	Asian and African	Manual procedures Direct exposure to harmful chemicals & toxic heavy metals	Burning E-waste contaminates environment by releasing lead, mercury, and cadmium Causes multiple irreversible damage to nervous system, respiratory diseases and birth defects.
9.	Shredding /Crushing	European & USA	Manual procedures Direct exposure to harmful chemicals & toxic heavy metals	40% of metals may be lost and dust particles containing BFRs and dioxins
10.	Acid bathing	Asian and African	Manual procedures Direct exposure to harmful chemicals & toxic heavy metals	Toxic effluents
12.	Landfilling	Asian and African	Uses up land space rendering it useless for other activities including agriculture	Soil pollution Exposure harmful to human and animal health
13.	Incineration	Asian and African	Recover Energy or Heat from e-waste	Low economic value
14.	Pyrolosis	Asian and African	Recover synthetic fuel	Environment pollution Toxic fumes
15.	2-stage pyrolysis-gasification and Liquid Crystal coated Polaroid Glass Electrode		Microbial cell-based electricity production	
16.	Manual dismantling	African (Nigeria, South Africa, Ghana, Egypt)	Conventional, Easy and cheap procedure involving manual labour	Crude process, economically not viable. Human health risks - involves heating, manual dismantling and open burning. Heavy metal toxicity among the handlers of the e-waste.
17.	Recycling	China, India, Pakistan, Philippines, Sri Lanka, Thailand and Vietnam, in Africa (Ghana, Nigeria and South Africa), South America (Brazil, Chile and Uruguay)	Conventional, Easy and cheap procedure involving manual labour	The majority of e-waste is processed and recycled by informal businesses in Asia; Low environmental impact; Medium Economic value.
18.	WEEE	China	A hybrid WEEE collecting plan with delivery terminals at stores, metro stations, and community centres, a pre-treatment phase involving private corporations, cooperatives, and social enterprises, and complete nationwide recycling of all components make up the suggested system.	Requires co-ordination
19.	Material Substitution	European & USA	Less hazardous to environment; Less/no leaching of heavy metals; Corrosion resistance	High cost
20.	Interventions to reduce exposure to e-waste	European & USA	Health education, community engagement, Mechanized wire strippers, culturally appropriate communication, better exposure measurement, reduction in exposure through usage of PPE.	High cost. Involves trained workers
21.	Material flow analysis (MFA)	Asian (Japan, China, Hong Kong)	Another technique that describes the flow of e-waste into locations for disposal or reuse is Material Flow Analysis (MFA). MFA functions as an interface between the materials' origins, pathways, or intermediate and final destinations. It is seen as a useful criterion in management and decision-making if environmental harm can be minimised.	High cost. Specialized procedures
22.	Informal E waste recycling	China, India, Pakistan, Philippines, Sri Lanka, Thailand and Vietnam, Africa (Ghana, Nigeria and South Africa) South America (Brazil, Chile and Uruguay)	The majority of e-waste is processed and recycled by informal businesses in Asia: Dumping sites (huge), or live in recycle shops, family living nearby, processes carried out by children and adolescents.	High levels of exposure to harmful compounds (PAH, metals, plasticisers, etc.). extensive air, soil, and water pollution as well as health issues. Genetic abnormalities are caused in foetuses as a result of exposure to e-waste toxins.

23	Disassembly (upgrading and refining)	Asian and African	Manual procedures Direct exposure to harmful chemicals & toxic heavy metals	Physical Injury to the workers
24	Backyard Recycling process	Asian and African	It avoids air and water pollution, as well as greenhouse gas emissions associated with material production and manufacturing.	Open burning of plastics and Copper wires cause air pollution. Limited personal protection equipment. Contamination of food, soil and surface water after deposition.

Table 3. Pollutants and their occurrence in waste electrical and electronic equipment Source: Alexander and Bilitewski, (2008),[8]

Pollutant	Occurrence
Arsenic	Solar cells, diodes, LEDs, semiconductors, microwave ovens
Barium	Electron tubes, filler for plastic and rubber, lubricant additive
Brominated flame proofing agent	Circuit boards, Cables, PVC cables, casings
Cadmium	Monitors, Batteries, Computer batteries, pigments, solder, alloys, circuit boards, cathode ray tubes (CRTs)
Chrome	Switch boards, Dyes/pigments
Cobalt	Insulators
Copper	Cable wires, coils, ribbons, wire circuits, pigments
Lead	LEDs, Thermoelectric elements, circuit Boards, Lithium batteries, Lasers, Lead rechargeable batteries, solar transistors, stabilizers
Liquid crystal Displays	Digital watches, Smart watches, Display devices, Mobile telephones, Laptops, Calculators
Lithium	Mobiles, photography and video equipment (batteries)
Mercury	Clock batteries, pocket calculators, switches, LCDs, components in copper machines and steam irons
Nickel	Pigments, semiconductors, relays, Alloys, batteries
PCBs (Polychlorinated biphenyls)	Transformers, capacitors, softening agents for paint, glue, plastic
Selenium	Fax machines, Pigments, Photoelectric cells, photocopiers
Silver	Batteries, Switches, Resistors, Capacitors, switches
Zinc	Luminous substances, Steel, brass, alloys, disposable, rechargeable batteries,

Table 4: Summary of Best practices of E-waste management

Policy/Practice	Benefits	Countries already following it
Life cycle assessment	Evaluates economic and environmental aspects related to 'end-of-life' disposal of e-waste	Japan, Korea, Thailand, Taiwan
Extended producer responsibility	Enforces producers based on 'polluter pays' principle.	Japan, Malaysia, Thailand
Multi criteria analysis	Multiple policies are analysed to resolve e-waste problems at policy level	Philippines, Singapore, Cambodia
Material flow analysis	Estimates e-waste generation, flow of e-waste and is used for decision making in environmental conservation and safety	Japan, China, Hong Kong

Source: Management of E waste in Malaysia,[9]

DISCUSSION

The challenges of managing E-waste in India are very different from those in other countries, both the developed and developing. Rapidly increasing E-waste volumes, both domestically generated as well as through imports.[10,11] Imports include things like used computers that are donated to help close the digital divide or just metal trash. There are no precise estimates of how much e-waste is produced and recycled, such as used computers that are donated to close the digital divide. Manufacturers, customers, and e-waste workers/handlers are not well-informed on the dangers of improper e-waste disposal, which exposes them to major health risks. Material value is significantly lost as a result of ineffective recycling procedures. The main issue in India is the lack of such technology and explicit laws or regulations to regulate the disposal of e-waste. The production of dangerous metals in electrical and electronic devices is having a negative impact on both human health and the environment.[12,13] All academic researchers, practitioners, and policy makers are concerned about the management of e-waste since it has highlighted issues with its recycling and disposal on a global scale.[14] E waste has crossed 48.5 Million Tonnes (MT) mark in 2018 which is projected to get double in 5 years but only 20% out of it is recyclable.

Recycling WEEE is important for the recovery of valuable waste materials and mechanical/physical processing provides an alternative means of recovering valuable materials, but several difficulties exist. The main difficulty industries have to afford is the separation of the different material in WEEE. The definition of separation systems based on the physical and chemical characteristics of materials is one of the most effective ways to facilitate material recycling. Plastics from bodies and computer monitors make up a sizable portion of WEEE. About 2,872,000 t of polymers, 718,000 t of lead, 1363 t of cadmium, and 287 t of mercury are found in 500 million PCs. Additionally, 861 t of hexavalent chromium may be present. About 15–22% of WEEE is made up of e-plastics, of which one-third can be recycled mechanically and the other two-thirds must be disposed of in another way.[16]

Low-level processing techniques like granulation or pelletisation, followed by melt or partial melt and extrusion to create the final product, are typically used in the recycling of this plastic waste. Because of the variety of polymeric materials utilised, recycling e-plastic waste can be challenging. For instance, comparatively high amounts of flame retardants (compounds containing halogen) were added during production, as well as thermoplastics and thermosets.[17] The typical high halogen levels brought on by the addition of flame retardants must be considered while attempting to recover the plastic material from discarded electronic gadgets. Remelting the thermoset polymer will not allow it to be remoulded or processed. Because electronic equipment is getting smaller, less garbage is produced, which makes recycling, repair, and collecting more challenging. There is a need to develop an effective and efficient system e-WM, which may be considered as the only possible solution to overcome this problem faced by the developing nations.[18]

Currently management of E waste is being done by unskilled and untrained people under unorganised sector leading to mishandling and malpractices like open dumping and open burning.[19] Many issues plague E trash management, including a shortage of recycling factories and institutions. According to a report, 5 lakh children work in this field. This review has helped us better grasp the difficulties and causes of E trash mismanagement in third-world nations.

Toxic compounds discharged into the air, water, and soil from e-waste products, such as arsenic, cadmium, chromium, mercury, and lead, cause soil degradation and environmental damage. Although their activities in biological systems are poorly understood, they have tremendous hazardous and carcinogenic potential.[10,21] It is therefore critical to monitor footprint and device strategies to address e-waste-linked issues from manufacturing, exportation, to ultimate dumping, including technology transmissions for recycling e-waste processing areas.

Best practices adopted in other similar demographic profile countries:

Some popular ideas in developing countries which have emerged are developing eco-design devices, collecting e-waste with caution, recovering and recycling materials, disposing e-waste using proper techniques, forbidding the shipping of second hand electronic devices to the developing countries, and raising awareness of the impact of e-waste.[9] For that, it utilized different tools such as LCA, MFA, MCA and EPR. Over and above all of this, no matter how well the policies are developed and implemented, gains will only be realised if end users are willing to accept and follow them. Life cycle assessment analysis is a well-known approach for designing environmentally friendly electronic equipment and reducing the complexity of e-waste management. While there are other tools available for managing e-waste challenges, most Asian countries have prioritised LCA, MFA, MCA, and EPR due to their popularity.[21] LCA tools emphasize the necessity of developing electronic equipment accounting for both environmental and economic factors. In essence, LCA is a contemporary, systematic, and practical approach to identify and evaluate ecological inventory, impacts, essential elements, disposal decisions, optimization of e-waste, and refined opportunities at stages of the system boundary.[22] The disposal of this waste into the landfills or recycling them is dangerous to the environment.[22,23] Each tool has distinctive features when applied to e-waste management and these are summarized in Table 4. A combination of life cycle assessment and environmental system management is the need of the hour.

The use of Plasma Waste Treatment technology for example, offers a very promising technology to treat hazardous waste in the near future.[24] The use of thermal plasma technology has made it possible to reduce the volume and weight of e-waste by converting it into combustible gas with solid leftovers that may be utilised in other industrial operations. This kind of technological advancement in recycling has the potential to generate electricity from e-waste and greatly increase the amount of valuable and recyclable materials that may be obtained in the future.

E-waste in India today necessitates a shift in people's behaviour to view garbage as a product and help create a sustainable circular economy. To alter the way that e-waste is managed in India, policymakers and stakeholders—including producers, recyclers, government representatives, and users of e-products—must work together.[25] For an efficient e-WM system in India, there is need of robust legislation framework to smoothly conduct the e-WM practices from manufacturing to recycling with more scientific and environmental friendly manner.[26]

Reducing the production of hazardous waste, encouraging sustainable handling practices, limiting the transportation of e-waste across borders, and establishing stringent legal frameworks for when such movements are permitted are the goals of the Basel Convention and the European Union WEEE directives.[27] The G8 3Rs initiative promotes to Reduce, reuse and recycle while the StEP (Solving the E-waste problem) aims at continuous research on e-waste treatment, strategical assessment to eliminate the e-waste issues and training and awareness on e-waste issues.[28] The Basel Ban

Amendment in accordance with local needs, monitor e-waste trading and processing activities, and launch initiatives to facilitate the shift to small-scale, unofficial, and socioeconomically sustainable e-waste processing.[29] There is massive data generation during the production, consumption and disposal of E-waste. Reuse and recovery of electronics reduced the environmental impact of these products, and effects the primary production of metals and fractions found in electronics. The USA came up with the National Strategy Electronics Stewardship 2011[30] to come up with policies to follow for better E-waste management.

Eco-friendly technology (ESTS) implementation in developing nations, such as the National Solid Waste Policy (PNRS), which mandates that customers (both individuals and organisations) dispose of their e-waste separately at suitable delivery locations specified in Municipal Solid Waste Plans[31] The National Solid Waste Policy (2010) enforces the implementation of reverse logistics systems under the shared responsibility of consumers, companies and governments.[32]

E Waste rules ignore the unorganized and small and medium sectors where substantial quantity of the ‘E-waste’ is processed.[33] There is currently no mechanism in place under the law to rehabilitate individuals engaged in informal recycling. Second, the business plan for collecting "e-waste" from customers is not described in the E Waste Rules. The government's laws address the production, handling, transportation, and disposal of hazardous waste, but they don't provide a more efficient way to gather it.

Additionally, the E garbage Rules are totally unaware of the electronic garbage that is brought into the nation. According to a study conducted by the Centre for Science and Environment, the nation imports about 50,000 MT of electronic trash annually. However, there are no import control measures under the E Waste Rules. Despite the Basel Convention's ban on the transboundary transport of hazardous waste[34], dealers sneak in consignments of electronic scrap as they are not properly classified. According to environmental activists, most electronic scrap that comes into the country is classified as plastic scrap or mixed waste.

In order to ensure that the created e-waste is disposed of appropriately, the E Waste Rules provide a very broad role for manufacturer coordination and investment.[35] Despite acknowledging the value of the coordination process and the fact that a suitable disposal mechanism can only be accomplished with the manufacturer's help, the government has not passed legislation pertaining to the system.[36] The need for the change is further increased by the fact that a significant amount of e-waste is brought into India unregulated and that the current laws do not address this problem.[37-39]

E-waste management is a great challenge for governments of many developing countries. It is becoming a huge public health issue and is exponentially increasing by the day. It has to be collected separately, treated effectively, and disposed of e-waste.[40] It also serves as an alternative to open burning and traditional landfills. Integrating the informal sector with the formal sector is crucial. Children are our future, thus we must instill in them a dedication to recycling e-waste at a young age.[41] The competent authorities in developing countries like India need to establish mechanisms for handling and treating e-waste safely and sustainable manner.

CONCLUSION

Drawing from the systematic review, India faces significant hurdles in managing its substantial e-waste generation, despite the considerable global economic value associated with it. While international practices offer valuable insights, India's current techniques likely grapple with inadequate infrastructure, a dominant informal sector employing unsafe methods, limited public awareness, and inconsistent regulatory enforcement.

To adopt best practices, India should prioritize investments in formal, technologically advanced recycling facilities. Simultaneously, public education campaigns are crucial to encourage responsible disposal. Strengthening and consistently enforcing regulations, alongside integrating the informal sector through training and safer technologies, is essential. This includes developing eco-design devices, ensuring cautious e-waste collection, promoting material recovery and recycling, and employing proper disposal techniques. Furthermore, forbidding the shipment of second-hand electronics to developing nations and raising public awareness about e-waste impacts are vital.

Future research should focus on quantifying the impacts of current practices, evaluating policy effectiveness, and exploring suitable sustainable recycling solutions for India. Collaborative action across government, industry, research, and the public are vital for establishing an effective and sustainable e-waste management system, safeguarding health and the environment.

REFERENCES

1. Hub ISK. UN Report Highlights Environmental, Health Risks from E-Waste, Urges Circular Economy Shift | News | SDG Knowledge Hub | IISD [Internet]. [cited 2022 Feb 13]. Available from: https://sdg.iisd.org:443/news/un-report-highlights-environmental-health-risks-from-e-waste-urges-circular-economy-shift/
2. Akram R, Natasha, Fahad S, Hashmi MZ, Wahid A, Adnan M, et al. Trends of electronic waste pollution and its impact on the global environment and ecosystem. Environ Sci Pollut Res. 2019 Jun;26(17):16923–38.
3. Purushothaman M, Inamdar MohdG, Muthunarayanan V. Socio-economic impact of the e-waste pollution in India. Mater Today Proc. 2021 Jan 1;37:280–3.
4. Alabi OA, Adeoluwa YM, Huo X, Xu X, Bakare AA. Environmental contamination and public health effects of

electronic waste: an overview. J Environ Health Sci Eng. 2021 Jun;19(1):1209–27.
5. Awasthi AK, Li J. Management of electrical and electronic waste: A comparative evaluation of China and India. Renew Sustain Energy Rev. 2017 Sep;76:434–47.
6. Hub ISK. Growing Threat of E-waste Affecting Millions of Children Worldwide, WHO Warns | News | SDG Knowledge Hub | IISD [Internet]. [cited 2022 Feb 13]. Available from: https://sdg.iisd.org:443/news/growing-threat-of-e-waste-affecting-millions-of-children-worldwide-who-warns/
7. Abdelbasir SM, Hassan SSM, Kamel AH, El-Nasr RS. Status of electronic waste recycling techniques: a review. Environ Sci Pollut Res. 2018 Jun;25(17):16533–47.
8. Alexander Janz and Bernd Bilitewski, 'Hazardous substances in waste electrical and electronic equipment' in Rakesh Johri, E-waste: Implications, regulations and management in India and current global best practices, TERI, New Delhi, 2008, p.93.
9. Zainu ZA, Ali WMSWM, Songip AR. Challenges and Innovations in Household E-waste Management in Malaysia -A Comparative Review. [cited 2023 Dec 29]; Available from: https://www.academia.edu/36424764/Challenges_and_Innovations_in_Household_E_waste_Management_in_Malaysia_A_Comparative_Review
10. Lakshmi, Sai & Raj, Aiswarya & T., Jarin. A Review Study of E-Waste Management in India. Asian J Appl Sci Technol AJAST. 2017;33–6.
11. Johri R, Institute E and R, editors. E-waste: implications, regulations, and management in India and current global best practices. New Delhi: Energy and Resources Institute; 2008.
12. Heeks R, Subramanian L, Jones C. Understanding e-Waste Management in Developing Countries: Strategies, Determinants, and Policy Implications in the Indian ICT Sector. Inf Technol Dev. 2015 Oct 2;21(4):653–67.
13. Pandve H. E-waste management in India: An emerging environmental and health issue. Indian J Occup Env Med [Internet]. 2007 [cited 2023 Jan 20];11(3):116. Available from: http://www.ijoem.com/text.asp?2007/11/3/116/38461
14. Mihai FC, Gnoni MG, Meidiana C, Ezeah C, Elia V. Waste Electrical and Electronic Equipment (WEEE): Flows, Quantities, and Management—A Global Scenario. In: Electronic Waste Management and Treatment Technology [Internet]. Elsevier; 2019 [cited 2023 Jan 20]. p. 1–34. Available from: https://linkinghub.elsevier.com/retrieve/pii/B9780128161906000017
15. Electronic Waste: A Case Study. Res J Chem Sci [Internet]. 2011 [cited 2023 Dec 29];1(9):49–56. Available from: https://www.isca.me/rjcs/Archives/v1/i9/09.ISCA-RJCS-2011-198.php
16. Al-Rahmi, Waleed & Alias, A.P Dr Norma & Dahawi, Abdullah & Yahaya, Noraffandy & Saleh, Muneer & Al-Maatouk, Qusay. Strategies to manage electronic waste approaches: An overview in Malaysia. Nternational J Eng Technol. 7:3276–9.
17. Pandve H. E-waste management in India: An emerging environmental and health issue. Indian J Occup Environ Med. 2007;11(3):116.
18. Shen H, Forssberg E, Pugh RJ. Selective flotation separation of plastics by particle control. Resour Conserv Recycl. 2001 Aug;33(1):37–50.
19. Pérez-Martínez MM, Carrillo C, Rodeiro-Iglesias J, Soto B. Life cycle assessment of repurposed waste electric and electronic equipment in comparison with original equipment. Sustain Prod Consum. 2021 Jul 1;27:1637–49.
20. Bajpai S. E-Waste Management in India - Challenges and Strategies [Internet]. Hindrise. 2021 [cited 2023 Dec 29]. Available from: https://hindrise.org/resources/e-waste-management-in-india/
21. Chibunna JB, Siwar C, Begum RA, Mohamed AF. The Challenges of E-waste Management Among Institutions: A Case Study of UKM. Procedia - Soc Behav Sci. 2012 Oct;59:644–9.
22. Robinson BH. E-waste: an assessment of global production and environmental impacts. Sci Total Environ. 2009 Dec 20;408(2):183–91.
23. Wong MH, Wu SC, Deng WJ, Yu XZ, Luo Q, Leung AOW, et al. Export of toxic chemicals - a review of the case of uncontrolled electronic-waste recycling. Environ Pollut Barking Essex 1987. 2007 Sep;149(2):131–40.
24. Tippayawong, N., & Khongkrapan, P. Development of a laboratory scale air plasma torch and its application to electronic waste treatment. Int J Env Sci Tech 6 3 407-414 Summer 2009 ISSN 1735-1472. 2009 Summer;6(3):407–14.
25. Pradhan, Jatindra & Sudhir, K.. (2009). E-Waste Management: A Case Study of Bangalore, India. Res J Environ Earth Sci. :111–5.
26. Sivasubramanian LDr. Jeyakumaran. MANAGEMENT STRATEGIES FOR VARIOUS EWASTE GENERATORS IN MYSORE - A CASE STUDY. Singaporean J Sci Res. 2015;7(1):327–35.
27. UNEP1992. Basel convention protocol on liability and compensation for damage resulting from transboundary movements of hazardous wastes and their disposal. 1992.
28. Turaga RMR, Bhaskar K, Sinha S, Hinchliffe D, Hemkhaus M, Arora R, et al. E-Waste Management in India: Issues and Strategies. Vikalpa J Decis Mak. 2019 Sep;44(3):127–62.
29. Ádám B, Göen T, Scheepers PTJ, Adliene D, Batinic B, Budnik LT, et al. From inequitable to sustainable e-waste processing for reduction of impact on human health and the environment. Environ Res. 2021 Mar;194:110728.
30. US EPA O. National Strategy for Electronics Stewardship (NSES) [Internet]. 2015 [cited 2023 Dec 29]. Available from: https://www.epa.gov/smm-electronics/national-strategy-electronics-stewardship-nses
31. Implementation of E-Waste Rules2011: Guidelines. Ministry Of Environment, Forest And Climate Change. Available from: https://cpcb.nic.in/displaypdf.php?id=aHdtZC9JbXBsaW1lbnRhdGlvbkUtV2FzdGUucGRm.
32. The Solid Waste Management Rules, 2016. Ministry Of Environment, Forest And Climate Change. Available from: https://hspcb.gov.in/content/laws/msw/MSW_Rules.pdf.
33. Tsydenova O, Bengtsson M. Chemical hazards associated with treatment of waste electrical and electronic equipment. Waste Manag. 2011 Jan;31(1):45–58.
34. The basel ban amendment and implications for India August 2020 https://ipen.org/sites/default/files/documents/ban-basel-fact-sheet-v2_3-india-en.pdf.
35. WEEE assessment study by the International Resource Group Systems South Asia Pvt. Ltd (IRGSSA) (2005) m/s IRG Systems South Asia Pvt. Ltd. 2005.
36. Tiwari D, Dhawan NG. E-waste Management: An Emerging Challenge to Manage and Recover Valuable Resources. Int J Environ Res Dev. 2014;4(3):253–60.
37. Kaur H, Goel S. E-waste Legislations in India— A Critical Review. Manag Labour Stud. 2016 Feb;41(1):63–9.
38. https://www.downtoearth.org.in/blog/waste/recycling-of-e-waste-in-india-and-its-potential-64034.
39. Miner KJ, Rampedi IT, Ifegbesan AP, Machete F. Survey on Household Awareness and Willingness to Participate in E-Waste Management in Jos, Plateau State, Nigeria. Sustainability. 2020 Feb 2;12(3):1047.
40. Ibrahim Mohammed S. E-Waste Management in Different Countries: Strategies, Impacts, and Determinants. In: Advances in Green Electronics Technologies [Working Title] [Internet]. IntechOpen; 2022 [cited 2023 Jan 21]. Available from: https://www.intechopen.com/online-first/83011
41. Miner KJ, Rampedi IT, Ifegbesan AP, Machete F. Survey on Household Awareness and Willingness to Participate in E-Waste Management in Jos, Plateau State, Nigeria. Sustainability. 2020 Feb 2;12(3):1047.