Chapter 1
Current Scenario on Conventional and Modern Approaches Towards Eco-friendly Electronic Waste Management

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Abstract In the leap of electronic vehicle era, an enormous amount of electronic trash is produced due to the growing usage of electrical and electronic devices (e-waste), which is one of the ever-increasing urgent issues, especially in developing nations. Many e-wastes are buried, burned outdoors, or discharged into surface water bodies in these nations since there is no infrastructure to handle them properly. Many

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developing countries currently use inefficient and highly polluting recycling techniques. Several harmful compounds of e-wastes are detrimental to the environment and endanger human health if disposal processes are not carefully handled. Design for environment cleaner production, extended producer responsibility, standards and labelling, product stewardship, recycling, and remanufacturing are some strategies many nations take to cope with the e-waste stream. This chapter discusses an overview of traditional (landfills and dumps, recycling, thermo-chemical treatment, pyrometallurgical treatment, bio-sorption, bioleaching, bioremediation methods, phytoremediation) and modern techniques (life cycle assessment (LCA), material flow analysis (MFA), and multi-criteria analysis (MCA)) in e-waste management that contribute to the eco-friendly, sustainable management of e-waste.

Keywords E-wastes · Heavy metals · Remediation · E-wastes management · E-wastes recycling

1.1 Introduction

Electronic wastes (e-wastes) are the remnants of electrical or electronic equipment such as computers, mobile phones, TVs, fans, washers, and dryers that have been abandoned (Rautela et al. 2021). Approximately, 17.4% of the e-waste generated globally in 2019 was properly disposed or recycled. However, the fate of the remaining 82.6% may be disposed without sufficient treatment or recycling since it was not recorded. The development of e-waste worldwide is vital due to the enormous demand for electronic goods in contemporary society. Managing e-waste requires efficient techniques and management means because e-wastes possess of several hazardous components in the form of halogenated compounds like polychlorinated biphenyls (PCBs), tetrabromobisphenol A (TBBPA), polybrominated biphenyls (PBB), etc., and these toxic materials that are harmful to plants, microbes, and humans (Kaifie et al. 2020). The issue is made worse because the informal sector in developing nations manages heavy metals (HMs), such as As, Cr, Cd, Cu, and Hg, which must be treated carefully when deconstructing electronic garbage. Additionally, the e-waste management and treatment methods are inadequate and negatively affect human health directly and indirectly (Ganguly 2016; Garg and Adhana 2019).

Among the hazardous substances found in e-waste include lead, mercury, and brominated flame retardants, to name a few. After extended exposure during risky e-waste recycling methods, these substances cause harm to practically all significant biological systems, including the nerve and circulatory systems, brain development, skin issues, lung cancer, and heart, liver, and spleen damage. This is crucial in the unorganized sector since many unorganized e-waste workers do not adhere to preventative health and safety procedures (Garg and Adhana 2019).

Conventional methods for extracting metals from e-waste can either cause secondary contamination that requires additional treatment or be extremely expensive, whereas the biological technique is more environmentally benign

References

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

Adanu SK, Gbedemah SF, Attah MK (2020) Challenges of adopting sustainable technologies in e-waste management at Agbogbloshie, Ghana. Heliyon 6:e04548

Ahmed S, Panwar RM, Sharma A (2014) Forecasting e-waste amounts in India. Int J Eng Res Gen Sci 2:2091–2730

Ajibo KI (2016) Transboundary hazardous wastes and environmental justice: implications for economically developing countries. Environ Law Rev 18:267–283

Alabi OA, Bakare AA, Xu X et al (2012) Comparative evaluation of environmental contamination and DNA damage induced by electronic-waste in Nigeria and China. Sci Total Environ 423:62–72. https://doi.org/10.1016/j.scitotenv.2012.01.056

Alam M, Bahauddin K (2015) Electronic waste in Bangladesh: evaluating the situation, legislation and policy and way forward with strategy and approach. Present Environ Sustain Dev 81–102

Alkorta I, Garbisu C (2001) Phytoremediation of organic contaminants in soils. Bioresour Technol 79:273–276. https://doi.org/10.1016/S0960-8524(01)00016-5

Ananno AA, Masud MH, Dabnichki P et al (2021) Survey and analysis of consumers' behaviour for electronic waste management in Bangladesh. J Environ Manage 282:111943

Andrade DF, Romanelli JP, Pereira-Filho ER (2019) Past and emerging topics related to electronic waste management: top countries, trends, and perspectives. Environ Sci Pollut Res 26:17135–17151

Anju A, Ravi SP, Bechan S (2010) Water pollution with special reference to pesticide contamination in India. J Water Resour Prot 2010

Arain AL, Pummill R, Adu-Brimpong J et al (2020) Analysis of e-waste recycling behavior based on survey at a Midwestern US University. Waste Manag 105:119–127

Arain AL, Neitzel RL, Nambunmee K et al (2022) Material flow, economic and environmental life cycle performances of informal electronic waste recycling in a Thai community. Resour Conserv Recycl 180:106129

Arvaniti OS, Kalantzi O-I (2021) Determinants of flame retardants in non-occupationally exposed individuals—a review. Chemosphere 263:127923

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

Aslam S, Ali F, Naseer A, Sheikh Z (2022) Application of material flow analysis for the assessment of current municipal solid waste management in Karachi, Pakistan. Waste Manag Res 40:185–194

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

Awasthi AK, Cucchiella F, D'Adamo I et al (2018a) Modelling the correlations of e-waste quantity with economic increase. Sci Total Environ 613:46–53

Awasthi AK, Wang M, Wang Z et al (2018b) E-waste management in India: a mini-review. Waste Manag Res 36:408–414

Awasthi AK, Hasan M, Mishra YK et al (2019) Environmentally sound system for E-waste: biotechnological perspectives. Curr Res Biotechnol 1:58–64. https://doi.org/10.1016/j.crbiot.2019.10.002

Babu BR, Parande AK, Basha CA (2007) Electrical and electronic waste: a global environmental problem. Waste Manag Res 25:307–318

Baldé CP, Forti V, Gray V et al (2017) The global e-waste monitor 2017: quantities, flows and resources. United Nations University (UNU), International Telecommunication Union (ITU) & International Solid Waste Association (ISWA), Bonn/Geneva/Vienna

Barbieri L, Giovanardi R, Lancellotti I, Michelazzi M (2010) A new environmentally friendly process for the recovery of gold from electronic waste. Environ Chem Lett 8:171–178

Beula D, Sureshkumar M (2021) A review on the toxic E-waste killing health and environment—today's global scenario. Mater Today Proc 47:2168–2174

Bhadra U, Mishra PP (2021) Extended producer responsibility in India: evidence from Recykal, Hyderabad. J Urban Manag 10:430–439
Bhaskar K, Turaga RMR (2018) India's E-waste rules and their impact on E-waste management practices: a case study. J Ind Ecol 22:930–942
Birloaga I, Coman V, Kopacek B, Vegliò F (2014) An advanced study on the hydrometallurgical processing of waste computer printed circuit boards to extract their valuable content of metals. Waste Manag 34:2581–2586
Borthakur A (2020) Policy approaches on E-waste in the emerging economies: a review of the existing governance with special reference to India and South Africa. J Clean Prod 252:119885
Boyle D, Catarino AI, Clark NJ, Henry TB (2020) Polyvinyl chloride (PVC) plastic fragments release Pb additives that are bioavailable in zebrafish. Environ Pollut 263:114422
Brandl H, Lehmann S, Faramarzi MA, Martinelli D (2008) Biomobilization of silver, gold, and platinum from solid waste materials by HCN-forming microorganisms. Hydrometallurgy 94:14–17
Brusseau ML, Anderson RH, Guo B (2020) PFAS concentrations in soils: background levels versus contaminated sites. Sci Total Environ 740. https://doi.org/10.1016/j.scitotenv.2020.140017
Budnik LT, Casteleyn L (2019) Mercury pollution in modern times and its socio-medical consequences. Sci Total Environ 654:720–734
Cai H, Xu X, Zhang Y et al (2019) Elevated lead levels from e-waste exposure are linked to sensory integration difficulties in preschool children. Neurotoxicology 71:150–158
Campos VM, Merino I, Casado R, Gómez L (2008) Phytoremediation of organic pollutants: a review. Span J Agric Res 6:38–47. https://doi.org/10.5424/sjar/200806S1-372
Cao Y, Chen A, Radcliffe J et al (2009) Postnatal cadmium exposure, neurodevelopment, and blood pressure in children at 2, 5, and 7 years of age. Environ Health Perspect 117:1580–1586
Chakraborty P, Selvaraj S, Nakamura M et al (2018) PCBs and PCDD/Fs in soil from informal e-waste recycling sites and open dumpsites in India: levels, congener profiles and health risk assessment. Sci Total Environ 621:930–938
Chatterjee S (2012) Sustainable electronic waste management and recycling process. Am J Environ Eng 2:23–33
Chatterjee R (2017) Bioremediation: a tribute to green chemistry. CONSCIENTIA 35
Chaurasia PK (2014) E-waste management approaches in India. Int J Eng Trends Technol 15:21–24
Chen Y, Tang X, Cheema SA et al (2010) β-cyclodextrin enhanced phytoremediation of aged PCBs-contaminated soil from e-waste recycling area. J Environ Monit 12:1482–1489
Chen A, Dietrich KN, Huo X, Ho S (2011) Developmental neurotoxicants in e-waste: an emerging health concern. Environ Health Perspect 119:431–438
Cheng W-H (2021) Revisiting selenium toxicity. J Nutr 151:747–748
Choi B-C, Shin H-S, Lee S-Y, Hur T (2006) Life cycle assessment of a personal computer and its effective recycling rate (7 pp). Int J Life Cycle Assess 11:122–128
Cong X, Xu X, Xu L et al (2018) Elevated biomarkers of sympatho-adrenomedullary activity linked to e-waste air pollutant exposure in preschool children. Environ Int 115:117–126. https://doi.org/10.1016/j.envint.2018.03.011
Copani G, Picone N, Colledani M et al (2019) Highly evolvable E-waste recycling technologies and systems. In: Factories of the future. Springer, Cham, pp 109–128
Cui J, Zhang L (2008) Metallurgical recovery of metals from electronic waste: a review. J Hazard Mater 158:228–256
Dai Q, Xu X, Eskenazi B et al (2020) Severe dioxin-like compound (DLC) contamination in e-waste recycling areas: an under-recognized threat to local health. Environ Int 139:105731
Danzeisen R, Araya M, Harrison B et al (2007) How reliable and robust are current biomarkers for copper status? Br J Nutr 98:676–683
Darnerud PO, Eriksen GS, Jóhannesson T et al (2001) Polybrominated diphenyl ethers: occurrence, dietary exposure, and toxicology. Environ Health Perspect 109:49–68

Davis JM, Garb Y (2019) A strong spatial association between e-waste burn sites and childhood lymphoma in the West Bank, Palestine. Int J Cancer 144:470–475. https://doi.org/10.1002/ijc.31902

Decharat S, Kiddee P (2020) Health problems among workers who recycle electronic waste in southern Thailand. Osong Public Health Res Perspect 11(1):34–43

De Meester S, Nachtergaele P, Debaveye S et al (2019) Using material flow analysis and life cycle assessment in decision support: a case study on WEEE valorization in Belgium. Resour Conserv Recycl 142:1–9

de Oliveira Neto JF, Monteiro M, Silva MM et al (2022) Household practices regarding e-waste management: a case study from Brazil. Environ Technol Innov 102723

Devika S (2010) Environmental impact of improper disposal of electronic waste. In: Recent advances in space technology services and climate change 2010 (RSTS & CC-2010). IEEE, pp 29–31

De Vries A, Stoll C (2021) Bitcoin's growing e-waste problem. Resour Conserv Recycl 175:105901

Diep P, Mahadevan R, Yakunin AF (2018) Heavy metal removal by bioaccumulation using genetically engineered microorganisms. Front Bioeng Biotechnol 6:157

Directive EU (2002) 96/EC of the European Parliament and of the Council of 27 January 2003 on waste electrical and electronic equipment (WEEE). Off J Eur Union L 37:24–38

Directive EU (2003) Directive 2003/108/EC of the European Parliament and of the Council of 8 December 2003 amending Directive 2002/96/EC on waste electrical and electronic equipment (WEEE). Off J Eur Communities L 345:12

Doan LT, Amer Y, Lee S-H et al (2019) E-waste reverse supply chain: a review and future perspectives. Appl Sci 9

Ebrahimi M, Khalili N, Razi S et al (2020) Effects of lead and cadmium on the immune system and cancer progression. J Environ Health Sci Eng 18:335–343

Edmunds WM (2011) Beryllium: environmental geochemistry and health effects

Forti V, Balde CP, Kuehr R, Bel G (2020) The global e-waste monitor 2020: quantities, flows and the circular economy potential

Fowler B (2017) Current e-waste data gaps and future research directions, pp 77–81

Ganguly R (2016) E-waste management in India—an overview. Int J Earth Sci Eng 9:574–588

Gangwar C, Choudhari R, Chauhan A et al (2019) Assessment of air pollution caused by illegal e-waste burning to evaluate the human health risk. Environ Int 125:191–199

Gao Y, Ge L, Shi S et al (2019) Global trends and future prospects of e-waste research: a bibliometric analysis. Environ Sci Pollut Res 26:17809–17820. https://doi.org/10.1007/s11356-019-05071-8

Garfi M, Tondelli S, Bonoli A (2009) Multi-criteria decision analysis for waste management in Saharawi refugee camps. Waste Manag 29:2729–2739

Garg N, Adhana D (2019) E-waste management in India: a study of current scenario. Int J Manag Technol Eng 9

Gaur A, Gurjar SK, Chaudhary S (2022) Circular system of resource recovery and reverse logistics approach: key to zero waste and zero landfill. In: Advanced organic waste management. Elsevier, pp 365–381

Gautam A, Shankar R, Vrat P (2022) Managing end-of-life solar photovoltaic e-waste in India: a circular economy approach. J Bus Res 142:287–300

Ghimire H, Ariya P (2020) E-wastes: bridging the knowledge gaps in global production budgets, composition, recycling and sustainability implications. Sustain Chem 1:154–182. https://doi.org/10.3390/suschem1020012

Gollakota ARK, Gautam S, Shu C-M (2020) Inconsistencies of e-waste management in developing nations—facts and plausible solutions. J Environ Manage 261:110234. https://doi.org/10.1016/j.jenvman.2020.110234

Gopikrishnan V, Vignesh A, Radhakrishnan M et al (2020) Microbial leaching of heavy metals from e-waste: opportunities and challenges. In: Biovalorisation of wastes to renewable chemicals and biofuels, pp 189–216

Gunarathne V, Gunatilake SR, Wanasinghe ST et al (2020) 7—Phytoremediation for E-waste contaminated sites. In: Prasad MNV, Vithanage M, Borthakur A (eds) Handbook of electronic waste management. Butterworth-Heinemann, pp 141–170

Gundaboina L, Badotra S, Bhatia TK et al (2022) Mining cryptocurrency-based security using renewable energy as source. Secur Commun Netw 2022

Gupt Y, Sahay S (2019) Waste management and extended producer responsibility. Econ Polit Wkly 54:35

Gupta A, Joia J, Sood A et al (2016) Microbes as potential tool for remediation of heavy metals: a review. J Microb Biochem Technol 8:364–372

Habib H, Wagner M, Baldé CP et al (2022) What gets measured gets managed—does it? Uncovering the waste electrical and electronic equipment flows in the European Union. Resour Conserv Recycl 181:106222

Hasan Razi C (2011) Serum heavy metal and antioxidant element levels of children with recurrent wheezing. Allergol Immunopathol (Madr) 39:248. https://doi.org/10.1016/j.aller.2011.04.004

Hatami-Marbini A, Tavana M, Moradi M, Kangi F (2013) A fuzzy group Electre method for safety and health assessment in hazardous waste recycling facilities. Saf Sci 51:414–426

Hazra A, Das S, Ganguly A et al (2019) Plasma arc technology: a potential solution toward waste to energy conversion and of GHGs mitigation. In: Waste valorisation and recycling. Springer Singapore, pp 203–217

Herat S (2008) Contamination of solid waste from toxic materials in electronic waste (E-waste). J Solid Waste Technol Manag 34:1–18

Herat S (2021) E-waste management in Asia Pacific region: review of issues, challenges and solutions. Nat Environ Pollut Technol 20:45–53

Hibbing ME, Fuqua C, Parsek MR, Peterson SB (2010) Bacterial competition: surviving and thriving in the microbial jungle. Nat Rev Microbiol 8:15–25

Hossain MS, Al-Hamadani SMZF, Rahman MT (2015) E-waste: a challenge for sustainable development. J Health Pollut 5:3–11

Huang C-L, Bao L-J, Luo P et al (2016) Potential health risk for residents around a typical e-waste recycling zone via inhalation of size-fractionated particle-bound heavy metals. J Hazard Mater 317:449–456

Hula A, Jalali K, Hamza K et al (2003) Multi-criteria decision-making for optimization of product disassembly under multiple situations. Environ Sci Technol 37:5303–5313

Huo X, Wu Y, Xu L et al (2019) Maternal urinary metabolites of PAHs and its association with adverse birth outcomes in an intensive e-waste recycling area. Environ Pollut 245:453–461

Ibanescu D, Cailean D, Teodosiu C, Fiore S (2018) Assessment of the waste electrical and electronic equipment management systems profile and sustainability in developed and developing European Union countries. Waste Manag 73:39–53

Ilankoon I, Ghorbani Y, Chong MN et al (2018) E-waste in the international context—a review of trade flows, regulations, hazards, waste management strategies and technologies for value recovery. Waste Manag 82:258–275

Ilyas S, Lee J, Kim B (2014) Bioremoval of heavy metals from recycling industry electronic waste by a consortium of moderate thermophiles: process development and optimization. J Clean Prod 70:194–202

Islam MT, Huda N (2019) Material flow analysis (MFA) as a strategic tool in E-waste management: applications, trends and future directions. J Environ Manage 244:344–361. https://doi.org/10.1016/j.jenvman.2019.05.062

Islam MT, Dias P, Huda N (2021a) Young consumers' e-waste awareness, consumption, disposal, and recycling behavior: a case study of university students in Sydney, Australia. J Clean Prod 282:124490

Islam MT, Huda N, Baumber A et al (2021b) A global review of consumer behavior towards e-waste and implications for the circular economy. J Clean Prod 316:128297. https://doi.org/10.1016/j.jclepro.2021.128297

Ismail H, Hanafiah MM (2020) A review of sustainable e-waste generation and management: present and future perspectives. J Environ Manage 264:110495
Jadhav U, Hocheng H (2015) Hydrometallurgical recovery of metals from large printed circuit board pieces. Sci Rep 5:1–10
Jarema KA, Hunter DL, Shaffer RM et al (2015) Acute and developmental behavioral effects of flame retardants and related chemicals in zebrafish. Neurotoxicol Teratol 52:194–209
Jeyaraj P (2021) Management of E-waste in India—challenges and recommendations. World J Adv Res Rev 11:193–218
Jha MK, Lee J, Kumari A et al (2011) Pressure leaching of metals from waste printed circuit boards using sulfuric acid. JOM 63:29–32
Jiang C, Bo J, Xiao X et al (2020) Converting waste lignin into nano-biochar as a renewable substitute of carbon black for reinforcing styrene-butadiene rubber. Waste Manag 102:732–742
Joo J, Kwon EE, Lee J (2021) Achievements in pyrolysis process in E-waste management sector. Environ Pollut 287:117621
Juwarkar AA, Singh SK, Mudhoo A (2010) A comprehensive overview of elements in bioremediation. Rev Environ Sci Biotechnol 9:215–288
Kahhat R, Kim J, Xu M et al (2008) Exploring e-waste management systems in the United States. Resour Conserv Recycl 52:955–964
Kaifie A, Schettgen T, Bertram J et al (2020) Informal e-waste recycling and plasma levels of non-dioxin-like polychlorinated biphenyls (NDL-PCBs)—a cross-sectional study at Agbogbloshie, Ghana. Sci Total Environ 723:138073
Kapp Jr RW (2016) Arsenic: toxicology and health effects
Karim SM, Sharif SI, Anik M, Rahman A (2018) Negative impact and probable management policy of E-waste in Bangladesh. arXiv Preprint arXiv:1809.10021
Karn B, Kuiken T, Otto M (2009) Nanotechnology and in situ remediation: a review of the benefits and potential risks. Environ Health Perspect 117:1813–1831
Karthika S, Lakshmanan A, Rajkishore SK et al (2019) The green synthesis and characterisation of zero valent iron nanoparticles using azolla and blue green algal systems. Int J Agric Sci Res 9:13–20
Kaya M (2016) Recovery of metals and nonmetals from electronic waste by physical and chemical recycling processes. Waste Manag 57:64–90
Khanpour-Alikelayeh E, Partovinia A (2021) Synergistic and antagonistic effects of microbial co-culture on bioremediation of polluted environments. In: Microbial rejuvenation of polluted environment. Springer, pp 229–265
Khaobang C, Sarabhorn P, Siripaiboon C et al (2022) Pilot-scale combined pyrolysis and decoupling biomass gasification for energy and metal recovery from discarded printed circuit board and waste cable. Energy 245:123268
Khuda K-E (2021) Electronic waste in Bangladesh: its present statutes, and negative impacts on environment and human health. Pollution 7:633–642
Kiddee P, Naidu R, Wong MH (2013) Electronic waste management approaches: an overview. Waste Manag 33:1237–1250
Kim S, Hwang T, Overcash M (2001) Life cycle assessment study of color computer monitor. Int J Life Cycle Assess 6:35–43
Kumar U, Singh DN (2013) E-waste management through regulations. Int J Eng Invent 3:6–14
Kumar A, Holuszko M, Espinosa DCR (2017) E-waste: an overview on generation, collection, legislation and recycling practices. Resour Conserv Recycl 122:32–42
Kuntawee C, Tantrakarnapa K, Limpanont Y et al (2020) Exposure to heavy metals in electronic waste recycling in Thailand. Int J Environ Res Public Health 17:2996
Lanzerstorfer C (2015) Air classification: potential treatment method for optimized recycling or utilization of fine-grained air pollution control residues obtained from dry off-gas cleaning high-temperature processing systems. Waste Manag Res 33:1041–1044
Laur N, Kinscherf R, Pomytkin K et al (2020) ICP-MS trace element analysis in serum and whole blood. PLoS ONE 15:e0233357

Laurmaa V, Kers J, Tall K et al (2011) Mechanical recycling of electronic wastes for materials recovery. In: Recycling of electronic waste II, proceedings of the second symposium. TMS (The Minerals, Metals & Materials Society), Pittsburgh, PA
Leclerc SH, Badami MG (2020) Extended producer responsibility for E-waste management: policy drivers and challenges. J Clean Prod 251:119657
Leung AOW (2019) Environmental contamination and health effects due to E-waste recycling. In: Electronic waste management and treatment technology, pp 335–362
Li J, Tian B, Liu T et al (2006) Status quo of e-waste management in mainland China. J Mater Cycles Waste Manag 8:13–20
Li Y, Richardson JB, Mark Bricka R et al (2009) Leaching of heavy metals from E-waste in simulated landfill columns. Waste Manag 29:2147–2150. https://doi.org/10.1016/j.wasman.2009.02.005
Li C, Zhou K, Qin W et al (2019a) A review on heavy metals contamination in soil: effects, sources, and remediation techniques. Soil Sediment Contam Int J 28:380–394
Li T-Y, Ge J-L, Pei J et al (2019b) Emissions and occupational exposure risk of halogenated flame retardants from primitive recycling of e-waste. Environ Sci Technol 53:12495–12505
Li X, Wu Y, Tan Z (2022) An overview on bioremediation technologies for soil pollution in E-waste dismantling areas. J Environ Chem Eng 107839
Liu S (2020) Interactions between industrial development and environmental protection dimensions of sustainable development goals (SDGs): evidence from 40 countries with different income levels. Environ Socio-Econ Stud 8:60–67
Liu Y, Huo X, Xu L et al (2018) Hearing loss in children with e-waste lead and cadmium exposure. Sci Total Environ 624:621–627
Liu J, Xu H, Zhang L, Liu CT (2020) Economic and environmental feasibility of hydrometallurgical process for recycling waste mobile phones. Waste Manag 111:41–50
Luo J, Cai L, Qi S et al (2017a) Improvement effects of cytokinin on EDTA assisted phytoremediation and the associated environmental risks. Chemosphere 185:386–393
Luo J, Cai L, Qi S et al (2017b) A multi-technique phytoremediation approach to purify metals contaminated soil from e-waste recycling site. J Environ Manage 204:17–22
Ma H, Liao X, Liu X, Shi B (2006) Recovery of platinum (IV) and palladium (II) by bayberry tannin immobilized collagen fiber membrane from water solution. J Memb Sci 278:373–380
Maheswari H, Yudoko G, Adhiutama A, Agustina H (2020) Sustainable reverse logistics scorecards for the performance measurement of informal e-waste businesses. Heliyon 6:e04834
Manhart A, Osibanjo O, Aderinto A, Prakash S (2011) Informal e-waste management in Lagos, Nigeria—socio-economic impacts and feasibility of international recycling co-operations. Final Rep Compon 3:1–129
Marappa N, Dharumadurai D, Thajuddin N (2017) Biological recovery of metals from electronic waste polluted environment using microorganisms, pp 149–172
Mazhandu ZS, Muzenda E, Mamvura TA et al (2020) Integrated and consolidated review of plastic waste management and bio-based biodegradable plastics: challenges and opportunities. Sustainability 12:8360
Meem RA, Ahmed A, Hossain MS, Khan RA (2021) A review on the environmental and health impacts due to electronic waste disposal in Bangladesh. GSC Adv Res Rev 8:116–125
Mishra S (2020) Electronic waste: management, material flows, present and future scenario
Mmereki D, Li B, Baldwin A, Hong L (2016) The generation, composition, collection, treatment and disposal system, and impact of E-waste. In: E-waste in transition—from pollution to resource, pp 65–93
MoEF (Ministry of Environment and Forests) (2010) Draft for E-waste (management and handling) rules, 2010
Mohod CV, Dhote J (2013) Review of heavy metals in drinking water and their effect on human health. Int J Innov Res Sci Eng Technol 2:2992–2996
Montano L, Pironti C, Pinto G et al (2022) Polychlorinated biphenyls (PCBs) in the environment: occupational and exposure events, effects on human health and fertility. Toxics 10:365

Mudila H, Prasher P, Kumar M et al (2019) An insight into cadmium poisoning and its removal from aqueous sources by graphene adsorbents. Int J Environ Health Res 29:1–21
Mudila H, Prasher P, Kumar A et al (2021) E-waste and its hazard management by specific microbial bioremediation processes. In: Panpatte DG, Jhala YK (eds) Microbial rejuvenation of polluted environment: volume 2. Springer Singapore, Singapore, pp 139–166
Muñoz I, Gazulla C, Bala A et al (2009) LCA and ecodesign in the toy industry: case study of a teddy bear incorporating electric and electronic components. Int J Life Cycle Assess 14:64–72
Needhidasan S, Samuel M, Chidambaram R (2014) Electronic waste—an emerging threat to the environment of urban India. J Environ Health Sci Eng 12:36. https://doi.org/10.1186/2052-336X-12-36
Nowakowski P (2020) Reconfigurable recycling systems of E-waste. In: E-waste recycling and management. Springer, pp 19–38
Nti AAA, Arko-Mensah J, Botwe PK et al (2020) Effect of particulate matter exposure on respiratory health of e-waste workers at Agbogbloshie, Accra, Ghana. Int J Environ Res Public Health 17. https://doi.org/10.3390/ijerph17093042
OECD (2001) Extended producer responsibility: a guidance manual for governments. OECD, Paris
Osibanjo O, Nnorom IC (2007) The challenge of electronic waste (e-waste) management in developing countries. Waste Manag Res 25:489–501
Oskarsson A, Reeves AL (2015) Handbook on the toxicology of metals
Owusu-Sekyere SO (2018) Cardio-respiratory function among formal sector workers at Agbogbloshie E-waste recycling site in Accra, Ghana
Pahari AK, Dubey BK (2018) Waste from electrical and electronics equipment. In: Plastics to energy: fuel, chemicals, and sustainability implications. Elsevier, pp 443–468
Panchal R, Singh A, Diwan H (2021) Economic potential of recycling e-waste in India and its impact on import of materials. Resour Policy 74:102264
Panda S, Biswal A, Mishra S et al (2015) Reductive dissolution by waste newspaper for enhanced meso-acidophilic bioleaching of copper from low grade chalcopyrite: a new concept of biohydrometallurgy. Hydrometallurgy 153:98–105
Pant VK, Kumar S (2018) Global and Indian perspective of E-waste and its environmental impact. In: 2018 international conference on system modeling & advancement in research trends (SMART). IEEE, pp 132–137
Pant D, Joshi D, Upreti MK, Kotnala RK (2012) Chemical and biological extraction of metals present in E waste: a hybrid technology. Waste Manag 32:979–990. https://doi.org/10.1016/j.wasman.2011.12.002
Pant D, Giri A, Dhiman V (2018) Bioremediation techniques for E-waste management. In: Waste bioremediation. Springer, pp 105–125
Parajuly K, Kuehr R, Awasthi AK et al (2019) Future E-waste scenarios. StEP Initiative, UNU ViE-SCYCLE, UNEP IETC
Park P-J, Tahara K, Jeong I-T, Lee K-M (2006) Comparison of four methods for integrating environmental and economic aspects in the end-of-life stage of a washing machine. Resour Conserv Recycl 48:71–85
Patel S, Kasture A (2014) E (electronic) waste management using biological systems—overview. Int J Curr Microbiol Appl Sci 3:495–504
Pathak P, Srivastava RR (2017) Assessment of legislation and practices for the sustainable management of waste electrical and electronic equipment in India. Renew Sustain Energy Rev 78:220–232
Patil RA, Ramakrishna S (2020) A comprehensive analysis of e-waste legislation worldwide. Environ Sci Pollut Res 27:14412–14431
Paul H, Helmut R (2004) Practical handbook of material flow analysis. Lewis Publishers, Washington, DC
Peana M, Medici S, Dadar M et al (2021) Environmental barium: potential exposure and health-hazards. Arch Toxicol 95:2605–2612

Peng Y, Wu J, Luo X et al (2019) Spatial distribution and hazard of halogenated flame retardants and polychlorinated biphenyls to common kingfisher (*Alcedo atthis*) from a region of South China affected by electronic waste recycling. Environ Int 130:104952
Philp JC, Atlas RM (2005) Bioremediation of contaminated soils and aquifers. In: Bioremediation: applied microbial solutions for real-world environmental cleanup, pp 139–236
Pokhrel P, Lin S-L, Tsai C-T (2020) Environmental and economic performance analysis of recycling waste printed circuit boards using life cycle assessment. J Environ Manage 276:111276
Pollock D, Coulon R (1996) Life cycle assessment: of an inkjet print cartridge. In: Proceedings of the 1996 IEEE international symposium on electronics and the environment. ISEE-1996. IEEE, pp 154–160
Ponder SM, Darab JG, Mallouk TE (2000) Remediation of Cr (VI) and Pb (II) aqueous solutions using supported, nanoscale zero-valent iron. Environ Sci Technol 34:2564–2569
Prek M (2004) Environmental impact and life cycle assessment of heating and air conditioning systems, a simplified case study. Energy Build 36:1021–1027
Queiruga D, Walther G, Gonzalez-Benito J, Spengler T (2008) Evaluation of sites for the location of WEEE recycling plants in Spain. Waste Manag 28:181–190
Ramachandra TV, Saira-Varghese K (2004) Environmentally sound options for e-wastes management. Envies J Hum Settl
Ranasinghe WW, Athapattu BCL (2020) 13—Challenges in E-waste management in Sri Lanka. In: Prasad MNV, Vithanage M, Borthakur A (eds) Handbook of electronic waste management. Butterworth-Heinemann, pp 283–322
Rautela R, Arya S, Vishwakarma S et al (2021) E-waste management and its effects on the environment and human health. Sci Total Environ 773:145623
Rode S (2012) E-waste management in Mumbai metropolitan region: constraints and opportunities. Theor Empir Res Urban Manag 7:89–103
Rohwerder T, Gehrke T, Kinzler K, Sand W (2003) Bioleaching review. Part A: progress in bioleaching: fundamentals and mechanisms of bacterial metal sulfide oxidation. Appl Microbiol Biotechnol 248
Rotter VS, Maehlitz P, Korf N et al (2016) ProSUM deliverable 4.1—waste flow studies, pp 1–100
Rousis K, Moustakas K, Malamis S et al (2008) Multi-criteria analysis for the determination of the best WEEE management scenario in Cyprus. Waste Manag 28:1941–1954
Roychowdhury P, Alghazo JM, Debnath B et al (2019) Security threat analysis and prevention techniques in electronic waste. In: Waste management and resource efficiency. Springer, pp 853–866
Sahajwalla V, Hossain R (2020) The science of microrecycling: a review of selective synthesis of materials from electronic waste. Mater Today Sustain 9:100040
Sahle-Demessie E, Glaser J, Richardson T (2018) Electronics waste management challenges and opportunities. In: American chemical society 2018 national meeting
Sakhuja D, Ghai H, Bhatia RK, Bhatt AK (2022) Management of e-Waste: technological challenges and opportunities. In: Handbook of solid waste management, pp 1523–1557
Salhofer S (2017) E-waste collection and treatment options: a comparison of approaches in Europe, China and Vietnam. In: Source separation and recycling, p 227
Scharnhorst W, Althaus H-J, Classen M et al (2005) The end of life treatment of second generation mobile phone networks: strategies to reduce the environmental impact. Environ Impact Assess Rev 25:540–566
Schumacher KA (2016) Electronic waste management in the US practice and policy. University of Delaware
Secretariat RS (2011) E-waste in India. India research unit (Larrdis). Rajya Sabha Secretariat, New Delhi
Seith R, Arain AL, Nambunmee K et al (2019) Self-reported health and metal body burden in an electronic waste recycling community in northeastern Thailand. J Occup Environ Med 61:905–909. https://doi.org/10.1097/JOM.0000000000001697

Sepúlveda A, Schluep M, Renaud FG et al (2010) A review of the environmental fate and effects of hazardous substances released from electrical and electronic equipments during recycling: examples from China and India. Environ Impact Assess Rev 30:28–41
Shahabuddin M, Uddin MN, Chowdhury JI et al (2022) A review of the recent development, challenges, and opportunities of electronic waste (e-waste). Int J Environ Sci Technol 1–8
Shaikh S, Thomas K, Zuhair S, Magalini F (2020) A cost-benefit analysis of the downstream impacts of e-waste recycling in Pakistan. Waste Manag 118:302–312
Sharma M, Joshi S, Kumar A (2020a) Assessing enablers of e-waste management in circular economy using DEMATEL method: an Indian perspective. Environ Sci Pollut Res 27:13325–13338
Sharma S, Wakode S, Sharma A et al (2020b) Effect of environmental toxicants on neuronal functions. Environ Sci Pollut Res 27:44906–44921
Sharma J, Goutam J, Dhuriya YK, Sharma D (2021) Bioremediation of industrial pollutants. In: Microbial rejuvenation of polluted environment. Springer, pp 1–31
Sharma P, Bano A, Singh SP et al (2022) Engineered microbes as effective tools for the remediation of polyaromatic aromatic hydrocarbons and heavy metals. Chemosphere 135538
Sheel A, Pant D (2018) Recovery of gold from electronic waste using chemical assisted microbial biosorption (hybrid) technique. Bioresour Technol 247:1189–1192
Shen Y, Yuan R, Chen X et al (2018) Co-pyrolysis of E-waste nonmetallic residues with biowastes. ACS Sustain Chem Eng 6:9086–9093
Shi J, Xiang L, Luan H et al (2019) The health concern of polychlorinated biphenyls (PCBs) in a notorious e-waste recycling site. Ecotoxicol Environ Saf 186:109817
Shittu OS, Williams ID, Shaw PJ (2021) Global E-waste management: can WEEE make a difference? A review of e-waste trends, legislation, contemporary issues and future challenges. Waste Manag 120:549–563. https://doi.org/10.1016/j.wasman.2020.10.016
Shuey SA, Taylor P (2005) Review of pyrometallurgical treatment of electronic scrap. Min Eng 57:67–70
Sinduja M, Sathya V, Maheswari M et al (2022a) Chemical transformation and bioavailability of chromium in the contaminated soil amended with bioamendments. Bioremediat J 1–22. https://doi.org/10.1080/10889868.2022.2049677
Sinduja M, Sathya V, Maheswari M et al (2022b) Evaluation and speciation of heavy metals in the soil of the Sub Urban Region of Southern India. Soil Sediment Contam Int J 1–20. https://doi.org/10.1080/15320383.2022.2030298
Singh C, Lin J (2010) Bioaugmentation efficiency of diesel degradation by *Bacillus pumilus* JLB and *Acinetobacter calcoaceticus* LT1 in contaminated soils. Afr J Biotechnol 9:6881–6888
Singh M, Thind PS, John S (2018) Health risk assessment of the workers exposed to the heavy metals in e-waste recycling sites of Chandigarh and Ludhiana, Punjab, India. Chemosphere 203:426–433
Sivaramanan S (2013) E-waste management, disposal and its impacts on the environment. Univers J Environ Res Technol 3
Skinner A, Dinter Y, Lloyd A, Strothmann P (2010) The challenges of E-waste management in India: can India draw lessons from the EU and the USA. Asien 117:26
Srivastava RR, Pathak P (2020) Policy issues for efficient management of E-waste in developing countries. In: Handbook of electronic waste management. Elsevier, pp 81–99
Streicher-Porte M, Bader H-P, Scheidegger R, Kytzia S (2007) Material flow and economic analysis as a suitable tool for system analysis under the constraints of poor data availability and quality in emerging economies. Clean Technol Environ Policy 9:325–345
Sundar S, Chakravarty J (2010) Antimony toxicity. Int J Environ Res Public Health 7:4267–4277
Tiller KG (1989) Heavy metals in soils and their environmental significance. In: Advances in soil science. Springer, pp 113–142
Tratnyek PG, Johnson RL (2006) Nanotechnologies for environmental cleanup. Nano Today 1:44–48
Tutton CG, Young SB, Habib K (2022) Pre-processing of e-waste in Canada: case of a facility responding to changing material composition. Resour Environ Sustain 9:100069

Vats MC, Singh SK (2014) E-waste characteristic and its disposal. Int J Ecol Sci Environ Eng 1:49–61
Verma AK (2020) E-wastes and their impact on environment and public health. Int J Appl Res
Vymazal J (2007) Removal of nutrients in various types of constructed wetlands. Sci Total Environ 380:48–65. https://doi.org/10.1016/j.scitotenv.2006.09.014
Wang D, Cai Z, Jiang G et al (2005) Determination of polybrominated diphenyl ethers in soil and sediment from an electronic waste recycling facility. Chemosphere 60:810–816
Wang F, Huisman J, Meskers CEM et al (2012) The best-of-2-worlds philosophy: developing local dismantling and global infrastructure network for sustainable e-waste treatment in emerging economies. Waste Manag 32:2134–2146
Wang F, Kuehr R, Ahlquist D, Li J (2013) E-waste in China: a country report
Wang C, Chen H, Li H et al (2020) Review of emerging contaminant tris (1, 3-dichloro-2-propyl) phosphate: environmental occurrence, exposure, and risks to organisms and human health. Environ Int 143:105946
Wath SB, Vaidya AN, Dutt PS, Chakrabarti T (2010) A roadmap for development of sustainable E-waste management system in India. Sci Total Environ 409:19–32
Widmer R, Oswald-Krapf H, Sinha-Khetriwal D et al (2005) Global perspectives on e-waste. Environ Impact Assess Rev 25:436–458
Williams E (2005) International activities on E-waste and guidelines for future work. In: Proceedings of the third workshop on material cycles and waste management in Asia. National Institute of Environmental Sciences, Tsukuba, Japan
Xavier LH, Ottoni M, Lepawsky J (2021) Circular economy and e-waste management in the Americas: Brazilian and Canadian frameworks. J Clean Prod 297:126570
Xia M-C, Wang Y-P, Peng T-J et al (2017) Recycling of metals from pretreated waste printed circuit boards effectively in stirred tank reactor by a moderately thermophilic culture. J Biosci Bioeng 123:714–721
Xu X, Chen X, Zhang J et al (2015a) Decreased blood hepatitis B surface antibody levels linked to e-waste lead exposure in preschool children. J Hazard Mater 298:122–128. https://doi.org/10.1016/j.jhazmat.2015.05.020
Xu X, Yekeen TA, Liu J et al (2015b) Chromium exposure among children from an electronic waste recycling town of China. Environ Sci Pollut Res 22:1778–1785
Xu L, Huo X, Liu Y et al (2020) Hearing loss risk and DNA methylation signatures in preschool children following lead and cadmium exposure from an electronic waste recycling area. Chemosphere 246:125829
Yong YS, Lim YA, Ilankoon IMSK (2019) An analysis of electronic waste management strategies and recycling operations in Malaysia: challenges and future prospects. J Clean Prod 224:151–166. https://doi.org/10.1016/j.jclepro.2019.03.205
Youcai Z (2018) Leachate generation and characteristics. In: Pollution control technology for leachate from municipal solid waste, pp 1–30
Zanghelini GM, Cherubini E, Soares SR (2018) How multi-criteria decision analysis (MCDA) is aiding life cycle assessment (LCA) in results interpretation. J Clean Prod 172:609–622
Zeng G, Luo S, Deng X et al (2013) Influence of silver ions on bioleaching of cobalt from spent lithium batteries. Miner Eng 49:40–44
Zeng J, Gou M, Tang YQ et al (2016a) Effective bioleaching of chromium in tannery sludge with an enriched sulfur-oxidizing bacterial community. Bioresour Technol 218:859–866. https://doi.org/10.1016/j.biortech.2016.07.051
Zeng X, Xu X, Boezen HM, Huo X (2016b) Children with health impairments by heavy metals in an e-waste recycling area. Chemosphere 148:408–415
Zeng X, Xu X, Zheng X et al (2016c) Heavy metals in PM2.5 and in blood, and children's respiratory symptoms and asthma from an e-waste recycling area. Environ Pollut 210:346–353
Zeng X, Duan H, Wang F, Li J (2017) Examining environmental management of e-waste: China's experience and lessons. Renew Sustain Energy Rev 72:1076–1082

Zeng Z, Huo X, Zhang Y et al (2019) Differential DNA methylation in newborns with maternal exposure to heavy metals from an e-waste recycling area. Environ Res 171:536–545
Zhang W (2003) Nanoscale iron particles for environmental remediation: an overview. J Nanopart Res 5:323–332
Zhang M (2017) Air pollution and human health risk assessment in e-waste recycling sites and urban indoor environment in South China
Zhang S, Forssberg E (1997) Mechanical separation-oriented characterization of electronic scrap. Resour Conserv Recycl 21:247–269
Zhang S, Forssberg E (1999) Intelligent liberation and classification of electronic scrap. Powder Technol 105:295–301
Zhang Y, Xu X, Chen A et al (2018) Maternal urinary cadmium levels during pregnancy associated with risk of sex-dependent birth outcomes from an e-waste pollution site in China. Reprod Toxicol 75:49–55. https://doi.org/10.1016/j.reprotox.2017.11.003