Management of E-waste, an Emerging Contaminant in the Environment

Transforming the world from the industrial era to the technological era, the generation of electrical and electronic waste (e-waste) has become a major environmental concern in the world (Saldaña-Durán et al., 2020). e-waste includes all the assemblies, subassemblies, consumables of waste electronic and electrical equipment (WEEE) (Ranasinghe & Athapattu, 2020). The advancement of technology, introduction of "smart concepts and designs", marketing strategies, changing lifestyle, compatibility issues, and end-of-life have caused rapid obsolescence of many electrical and electronic devices (Forti et al., 2020; Kiddee et al., 2013). Thus, the annual generation of E-waste keeps growing, and according to the United Nations Global E-waste Monitor 2020, approximately 53.6 million metric tons of e-waste was generated worldwide by 2019 (Forti et al., 2020). Further, the report predicts that this annual generation will be doubled and will reach 74 million metric tons by 2030 (Forti et al., 2020). However, an extensive generation of e-waste in developing countries compared to developed countries is due to the importation of discarded electronic devices or used devices from the developed countries (Hicks et al., 2005). Statistics show that a massive quantity of e-waste is generated in Asian countries (China, India) followed by America and Europe (Abalansa et al., 2021).

Recycling, incineration, and landfill disposal are the widely practised treatment techniques in the world and improper disposal of waste can have adverse effects. Therefore, recycling and management policies and regulations are formulated at country, regional and global scale. However, due to the lack of awareness on the toxicity of e-waste and lack of e-waste collection infrastructure, improper handling and disposal of domestic and industrial WEEE are still practised globally (Saldaña-Durán et al., 2020). This accounts for the unregulated release of E-waste and its associated hazardous material, which can cause contamination of the environment (air, water, soil). Once released, they can be transported from the terrestrial environment to the aquatic environment and atmosphere. Since E-waste consists of both inorganic and organic hazardous pollutants, it will cause adverse effects on all the ecological receptors. Many research findings have highlighted the environmental and human health risks associated with the improper handling of E-waste.

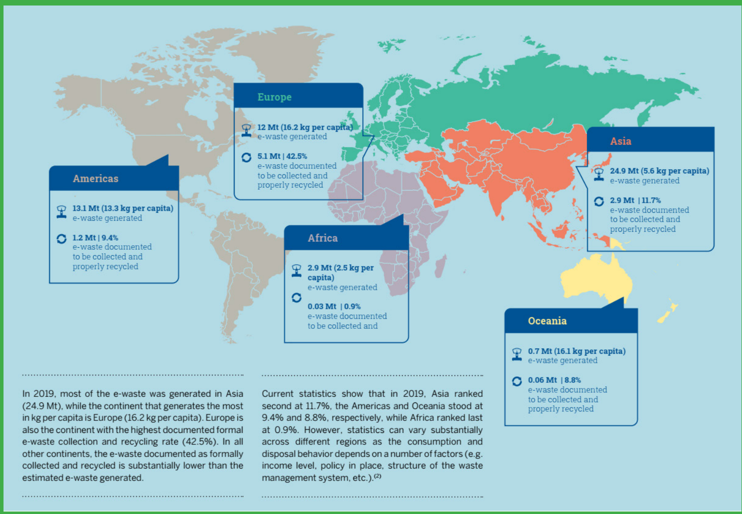

Figure 01: Global quantity of E-waste generated in the world
Source: Forti et al., 2020

What is E-waste and What Constituents it Includes?

Any electrical and electronic device that has completed its end-of-life and has been discarded or ready to be discarded is defined as e-waste. According to the Waste Electrical and Electronic Equipment Directive (WEEED), there are ten major categories of WEEE. Those are large household appliances; small household appliances; consumer equipment; lighting equipment; ICT and telecommunication equipment; electrical and electronic tools; medical devices; monitoring and control instruments; automatic dispensers; and toys, leisure and sports equipment (Ranasinghe & Athapattu, 2020). E-waste is a highly complex waste comprising heavy metals, polymers, plastics, ceramics, and other toxic and hazardous constituents (Kiddee et al., 2013; Saldaña-Durán et al., 2020). In addition, it includes economically valuable and rare metals (Saldaña-Durán et al., 2020). Depending on the nature of the pollutants, these contaminants are classified into three categories: primary, secondary, and tertiary contaminants (Figure 2). Primary contaminants are toxic substances that are used to manufacture electrical and electronic devices, and they are originally present in E-wastes. Secondary contaminants are byproducts or residues that originated during the E-waste recycling and recovery processes. The reagents used during the E-waste processing process are considered as tertiary contaminants (Cayumil et al., 2016).

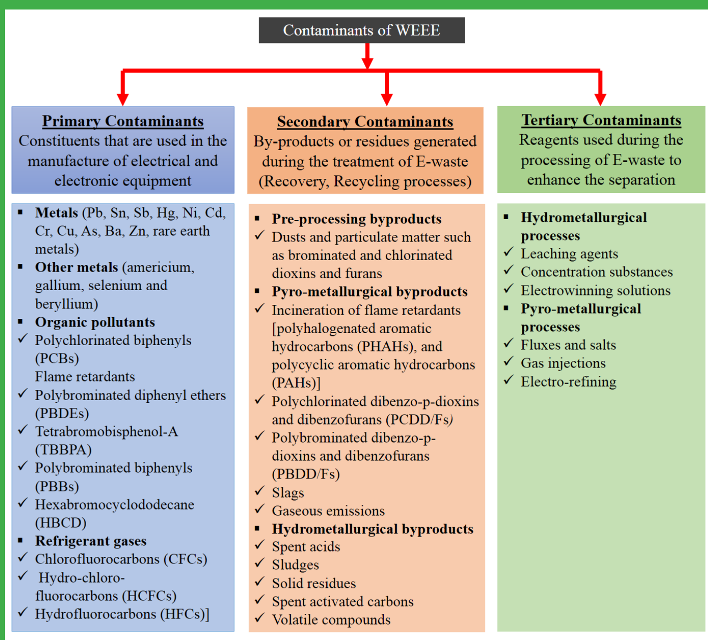

Figure 02; Hazardous and toxic contaminants present in E-waste
Source: Cayumil et al., 2016

Sources and Fate of E-waste in the Environment

Terrestrial environment, particularly soil ecosystems, is the major sink of e-waste from multiple sources such as landfills, open dumps, sludge from wastewater treatment plants, and micro and macroparticles released during the recycling processes (shredding, dismantling, and melting). Besides, discharging litter (batteries, cellular devices) from ships and boats adds e-waste into the oceans. When e-waste is disposed of in landfills, dumping sites or buried in soil, the chemical content leaches into soil and contaminates surface and groundwater sources. Further, untreated effluents released from recycling centers contain heavy metals, plastic, and ceramics particles, accumulating in the aquatic ecosystem. Incineration and open burning of E-waste emits dust, particulate matter, and toxic and hazardous gases.

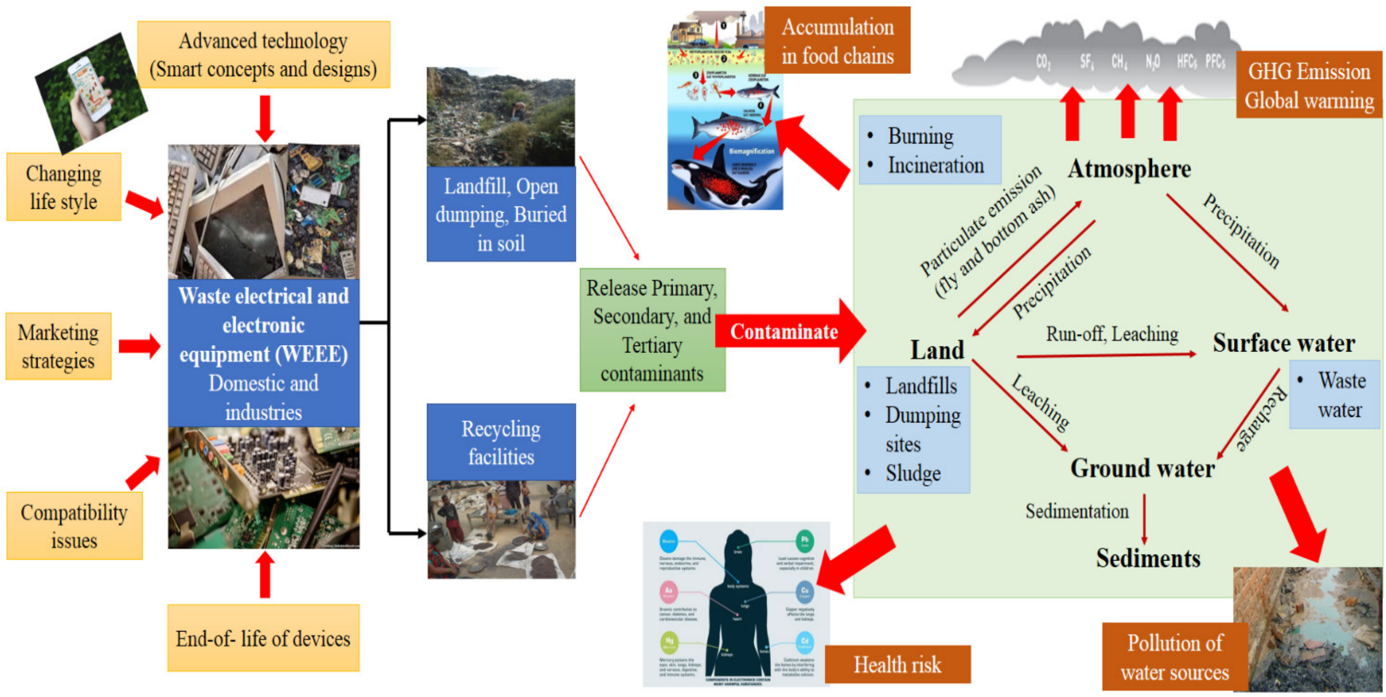

Figure 3: Sources and pathways of E-waste in the environment

The movement of e-waste in both terrestrial and aquatic environment are poorly investigated. However, the movement of individual compounds/ elements that exist or are associated with e-wastes have been studied intensely and will provide detailed insights on their fate and behaviour on terrestrial and aquatic ecosystems. Dust, particulate matter, persistent and volatile organic compounds, and gases circulate in the atmosphere through air currents. These pollutants move across a vast distance and distribute throughout the world. The atmospheric depositions and byproducts again reach into the terrestrial and aquatic environment in dissolved form through precipitation and fallout from the air. Most of the e-waste which cannot be recovered or recycled ends up in landfills. Although the modern landfills have been constructed safely, earlier e-wastes have been discarded in hazardous landfills. Still, in developing countries, e-waste is disposed of along with other

The landfill leachate contains decomposed organic and inorganic compounds, their by-products, and heavy metals of e-waste. Percolation of landfill leachate through the soil will cause contamination of land as well as groundwater. Application of sludge as soil fertiliser and irrigation of contaminated water may lead to absorption of contaminants into crops. Apart from landfills, industrially intense areas, especially areas, water streams in the vicinity of recycling centres are likely to be contaminated from toxic and hazardous compounds present in E-waste. Although the environmental factors (temperature, moisture, microorganisms, UV irradiations) might affect the weathering of e-waste particles in the environment, there is a lack of information.

Negative Impacts Associated with Unsafe Disposal of E-waste

Pollution and contamination of the environment with unsafe disposal of e-waste is now considered an emerging threat to the functioning of ecosystems, biodiversity, and environmental sustainability (Saldaña-Durán et al., 2020; Williams et al., 2008). Contamination of soil with hazardous substances negatively affects the physicochemical and biological properties of soil. Plants will easily absorb these toxic compounds. Thus, it will cause a threat to food security. Many studies have focused on the negative impacts of e-wastes in the environment and their toxicities. Humans exposed to the toxic and hazardous chemicals in E-waste have caused deleterious health effects (Zheng et al., 2008).

E-waste Management Strategies

Managing E-waste is one of the serious environmental problems faced by the world. The global demand for electrical and electronic equipment (EEE) has increased unprecedentedly due to the fast growth of technology and the economy. Further, EEE has become an essential part of our lives. These driving forces have led to generation and release of e-waste to the environment from different sources. This e-waste undergoes various changes and migration through different environmental compartments. In the terrestrial environment, soil acts as the major sink of E-waste. Besides, different constituents present in e-waste will enter into aquatic ecosystems and accumulate in sediments. These accumulated toxic and hazardous constituents pose risks to both terrestrial and aquatic flora and fauna.

Further, it may also cause a risk to human health through direct (inhalation, dermal exposure) and indirect (ingestion through food chains) pathways (Cesaro et al., 2018; Robinson, 2009). Although there is a vast volume of e-waste generation, the major challenge linked with the management of e-waste is the complexity of the toxic and hazardous chemicals present. However, e-waste can be considered a secondary metal resource to extract precious and rare metals such as gold, silver, platinum, and copper, which are economically beneficial. Lack of treatment facilities and proper disposal facilities with cheaper operating costs is the major barrier to recycling e-waste in developing countries. In 2019, only 17.4% of the e-waste has been collected and recycled in the world.

Further, a report published by the United Nations Environmental Program (UNEP) in 2015 has estimated that nearly 60-90% of e-waste is dumped or illegally traded every year (Rucevska et al., 2015). Moreover, China and India have the most extensive e-waste dumping grounds globally (Pathak & Srivastava, 2017; Zeng et al., 2017). Excluding China and India, many other developing countries, Cambodia, Pakistan, Indonesia, Thailand, and Nigeria, also receive vast amounts of e-waste for disposal and recycling purposes. Lack of awareness in people regarding the toxicity of e-waste and cheap labour availability are the major reasons for transporting e-waste to developing countries (Pathak & Srivastava, 2017). The problems associated with e-waste have affected the sustainability of the world. Therefore, managing the generation and generated E-waste is also identified as a key to achieve the United Nations sustainable development goals (SDGs), good health and well-being (Goal 3), clean water and sanitation (Goal 6), sustainable cities and communities (Goal 11), responsible production and consumption (Goal 12), and life below water (Goal 14), by 2030 (Forti et al., 2020). According to the waste management hierarchy, the most desirable option is the prevention of e-waste generation. Next, reduce, reuse, recycle, and recover (4-R concept) the generated e-waste to reduce the impact caused to the environment. The development of integrated recycling techniques and novel remediation strategies, making policies and regulations, and public awareness are the possible management strategies that can be adopted to mitigate e-waste pollution and to prevent the generation of e-waste. Further, it is necessary to find solutions to combat the improper informal market of recycling. Ineffective government policies and procedures, lack of commitment in organisations and governments, absence of specific guidelines/ specifications on product manufacturing, poor control in importation of new devices, and bad perception and lack of awareness of communities are the major barriers that affect the management of e-waste in most of the developing countries (Mallawarachchi & Karunasena, 2012).

The generation of e-waste can be minimised by importing high-quality, recyclable, eco-friendly products and materials. Further, the business partners and agencies dealing with importing EEE should pay attention to Green procurement policies. To address the existing e-waste within its geographic boundary, proper collection and storage centres should be established. Further, it is required to develop appropriate disposal and treatment facilities.

Several mechanisms which are practised in developed countries such as, Life Cycle Assessment (LCA), Material Flow Analysis (MFA), and Multi-Criteria Analysis (MCA) under the Extended Producer Responsibility (EPR) programme could be applied to reduce the e-waste problems in developing countries (Kiddee et al., 2013). LCA is a systematic tool that has been used to identify the potential environmental impacts (greenhouse gas emissions, depletion of ozone layer, acidification, etc.) of products and improve the environmental performance of products and develop eco-designed products (Kiddee et al., 2013; Park et al., 2006). MFA is usually applied to study e-waste movement, including the source of generation, their pathways, and destinations. MCA is a decision-making tool that can be applied to identify environmental and economic benefits of end-of-life (EOL) processing (Kiddee et al., 2013). Thus, these tools enable development of eco-designed devices; to collection, recovery, Policymaking is one of the reliable ways to control the illegal trade and dumping of e-waste from developed countries to developing countries. Several conventions and policies have been initiated to manage e-waste problems. Under the Basel convention, parties and stakeholders have been responsible for the transboundary movement of WEEE and their disposal. However, due to the limitations in the policies and laws, there are certain loopholes where illegal shipping of WEEE is happening in the world. Further, the USA, being the largest e-waste producing country, has not ratified the convention. The Rotterdam Convention in 2004 has been put forward to introduce the shared responsibility between e-waste exporting and importing countries. Restriction of Hazardous Substances (RoHS) Directive in 2011 has aimed to restrict the usage of hazardous substances (lead, mercury, cadmium, hexavalent chromium, poly-brominated biphenyl, and polybrominated diphenyl ethers) in the manufacturing of new electrical and electronic devices. WEED of the European Union in 2012 has aimed to promote reuse, recovery, and recycling to reduce or prevent adverse impacts of e-waste. Several other non-profit organizations in the world such as, International Telecommunication Union (ITU), International Electro-technical Commission (IEC), United Nations Environmental Program (UNEP), and World Health Organization (WHO) have been concerned about global actions to manage e-waste. At the same time, they are working to protect the health of laborers working in the informal processing of e-waste (Abalansa et al., 2021; Saldaña-Durán et al., 2020). Moreover, many organizations do not have the policy to mobilize organizational resources for e-waste management. Apart from that, when initiating new policies, laws, and rules and regulations, there should be an interaction between the policymakers and scientists and also should adopt the research findings. It will enable us to bring useful findings into practice. However, policies, laws, and regulations become ineffective without properly monitoring and evaluating e-waste management systems. Therefore, national and organisational systems should be established to monitor and evaluate the performance of e-waste management processes in the private and government sectors.

The most effective method to remove contaminants of e-waste from wastewater treatment facilities in recycling centers is to establish pre-treatment strategies. The addition of engineered biochar and clay minerals to soil as amendments would effectively immobilise and remove contaminants from the soil in the vicinity of recycling centers and dumping sites. Advances in biotechnology can be utilized to replace the conventional treatment strategies to extract metal resources from e-waste. Further, bioremediation and phytoremediation.

Approaches can be applied to the remediation of e-waste contaminated sites (Gunarathne et al., 2020). Bacteria, fungi, and their enzymes capable of degrading e-waste can be introduced to the polluted areas.

Raising public awareness on e-waste and its associated impacts could be another feasible option to reduce the potential risk and damages caused by e-waste exposure. Further, it is necessary to educate the public on purchasing durable products. Therefore, a proper mechanism should be established to create awareness among communities, employees on e-waste management at the national level. The government has a direct responsibility towards this as e national policymaker. Business parties, government, and media organisations can create awareness programmes through advertisements, product promotions, presentations, demonstrations at showrooms, etc

List of 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(9), 5302.

Cayumil, R., Khanna, R., Rajarao, R., Ikram-ul-Haq, M., Mukherjee, P., & Sahajwalla, V. (2016). Environmental impact of processing electronic waste–key issues and challenges. E-waste in transition—from pollution to resource. InTech, 9-35. doi: http://dx.doi.org/10.5772/64139

Cesaro, A., Belgiorno, V., Vaccari, M., Jandric, A., Chung, T. D., Dias, M. I., . . . Salhofer, S. (2018). A device-specific prioritization strategy based on the potential for harm to human health in informal WEEE recycling. Environmental Science and Pollution Research, 25(1), 683-692.

Forti, V., Baldé, C. P., Kuehr, R., & Bel, G. (2020). The Global E-waste Monitor 2020. United Nations University (UNU), International Telecommunication Union (ITU) & International Solid Waste Association (ISWA), Bonn/Geneva/Rotterdam.

Gunarathne, V., Gunatilake, S. R., Wanasinghe, S. T., Atugoda, T., Wijekoon, P., Biswas, J. K., & Vithanage, M. (2020). Phytoremediation for E-waste contaminated sites Handbook of Electronic Waste Management (pp. 141-170): Elsevier.

Hicks, C., Dietmar, R., & Eugster, M. (2005). The recycling and disposal of electrical and electronic waste in China—legislative and market responses. Environmental impact assessment review, 25(5), 459-471.

Kiddee, P., Naidu, R., & Wong, M. H. (2013). Electronic waste management approaches: An overview. Waste management, 33(5), 1237-1250.

Mallawarachchi, H., & Karunasena, G. (2012). Electronic and electrical waste management in Sri Lanka: Suggestions for national policy enhancements. Resources, conservation and recycling, 68, 44-53.

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. Resources, conservation and recycling, 48(1), 71-85.

Pathak, P., & Srivastava, R. R. (2017). Assessment of legislation and practices for the sustainable management of waste electrical and electronic equipment in India. Renewable and Sustainable Energy Reviews, 78, 220-232.

Ranasinghe, W. W., & Athapattu, B. C. (2020). Challenges in E-waste management in Sri Lanka Handbook of Electronic Waste Management (pp. 283-322): Elsevier.

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