PRINT ISSN 1119-8362
Electronic ISSN 2659-1499

Full-text Available Online at
https://www.ajol.info/index.php/jasem
https://www.bioline.org.br/ja

J. Appl. Sci. Environ. Manage.
Vol. 29 (4) 1075-1085 April 2025

Impact of Informal Electronic Waste Recycling and Dumping Activities on Soil Ecosystems: A review from 2000 to 2024

[1,2]LY, NHT; [1]*HONG, TTK; [1]*GIAO, NT

[1]*College of Environment and Natural Resources, Can Tho University, 3-2 Street, Xuan Khanh Ward, Ninh Kieu District, Can Tho City, 900000, Vietnam*
[2]*Doctoral Student in Soil and Water Environment, College of Environment and Natural Resources, Can Tho University, 3-2 Street, Xuan Khanh Ward, Ninh Kieu District, Can Tho City, 900000, Vietnam*

**Corresponding Author Email: ttkhong@ctu.edu.vn; ntgiao@ctu.edu.vn*
**OCRID: https://orcid.org/0000-0001-5916-4710; https://orcid.org/0009-0000-7891-8653*
**Tel: +84907739582*

Co-Authors Email: ttkhong@ctu.edu.vn; nhtly@ctu.edu.vn; ntgiao@ctu.edu.vn

ABSTRACT: The objective of this paper was to examine the impact of informal electronic waste recycling and dumping activities on soil ecosystems: a review from 2000 to 2024 using domestic and foreign studies related to electronic waste issues on soil ecosystems from various scientific databases. The results showed that toxic metals and other pollutants in e-waste are released into the environment from improper disposal and informal e-waste recycling and treatment. These toxic substances eventually penetrate into soil, water, air and sediments leading to adverse effects on organisms in soil and water, causing toxicity to plants, and accumulating in the tissues of organisms and gradually amplifying along the food chain. It also seriously affects human health through exposure routes such as eating, breathing and absorbing through the skin. The findings of this review provided an overview of the toxic substances in e-waste affecting different components in the soil, water and air environment.

DOI: https://dx.doi.org/10.4314/jasem.v29i4.8

Cite this Article as: : LY, NHT; HONG, TTK; GIAO, NT (2025) Impact of Informal Electronic Waste Recycling and Dumping Activities on Soil Ecosystems: A review from 2000 to 2024. *J. Appl. Sci. Environ. Manage.* 29 (4) 1075-1085

Dates: Received: 27 February 2025; Revised: 26 March 2025; Accepted: 09 April 2025; Published: 30 April 2025

Keywords: e-waste, environment, hazardous, pollution, impact

E-waste is the fastest growing waste stream due to the increasing demand for the latest electrical and electronic devices by consumers (Sankhla *et al*., 2016; Zeng *et al*., 2017). Electrical and electronic products are discarded before the end of their life cycle, and very little e-waste is sent to formal recycling units (Ankit *et al*., 2021). Most e-waste is sent to landfills, incinerated, or dumped in developing countries, where it is recycled using rudimentary dismantling techniques without regard to worker safety and environmental protection (Niinimaki and Karell, 2020). The composition of e-waste is quite complex as it consists of about 1000 different substances, including not only recyclable precious metals but also toxic components (Jain *et al*., 2023). Toxic components found during the treatment and recycling of e-waste are dangerous such as lead (Pb), nickel (Ni), cadmium (Cd), mercury (Hg) and halogenated organic substances such as PCB, PBB found in e-waste are very toxic to plants, humans and organisms (Jiang *et al*., 2019; Ali and Mahrukh, 2020; Nuruddin, 2022). Therefore, although e-waste accounts for only 2-5% of the total solid waste volume, it contributes more than 70% in

**Corresponding Author Email: ttkhong@ctu.edu.vn; ntgiao@ctu.edu.vn*
**OCRID: https://orcid.org/0000-0001-5916-4710; https://orcid.org/0009-0000-7891-8653*
**Tel: +84907739582*

terms of toxicity (Ankit *et al*., 2021). The presence of toxic components from e-waste into the environment has been documented in many domestic and international studies. Studies by Ohajinwa *et al*. (2018), Han *et al*. (2019) and Kuntawee *et al*. (2020) found very high concentrations of heavy metals in soil, water, sediment and dust at e-waste processing and recycling sites in Nigeria, China and Thailand. At the same time, PCBs and PBDEs were also found in dust from informal e-waste recycling areas in India and China at very high concentrations (Prithiviraj and Chakraborty, 2020; Lin *et al*., 2022). In Vietnam, high concentrations of heavy metals have been recorded in soil, dust and groundwater at e-waste processing facilities (Oguri *et al*., 2018; Ngo *et al*., 2021). Former study by Thao *et al*. (2015) also showed that direct contact with e-waste during collection, sorting and recycling has accumulated the levels of metals As, Zn, Cu, Cr, Co in the hair and nails of the elderly in the recycling area. This shows that heavy metals have the ability to diffuse directly into soil and groundwater, leading to pollution of soil, crops, groundwater sources in neighboring areas and posing risks to human health (Ali and Mahrukh, 2020). In addition, leachate from e-waste also significantly affects microorganisms, organisms living in soil and water and even humans (Ankit *et al*., 2021). Therefore, the objective of this paper was to examine the impact of informal electronic waste recycling and dumping activities on soil ecosystems: a review from 2000 to 2024.

MATERIALS AND METHODS

Data collection: The study used secondary data obtained through a literature review of articles related to the impacts of e-waste on soil, water and air environments published in domestic and foreign journals. In this study, documents were collected from the databases included ScienceDirect, Springer Nature, Google Scholar. These databases were selected due to their representativeness and coverage in publishing and searching for research articles on e-waste. Many studies around the world have also used these database to systematically review and evaluate documents on e-waste (Maphosa and Maphosa, 2020; Andeobu *et al*., 2021; Madkhali *et al*., 2023). In addition, journals such as Science of the Total Environment, Journal of Hazardous Materials, Sustainability, Polish Journal of Environmental Studies, Renewable and Sustainable Energy Reviews, Environmental Pollution, International Journal of Environmental Research and Public Health, Environmental Technology and Innovation, Environment International, Process Safety and Environmental Protection, Resources, Conservation and Recycling were selected for further review to focus on finding relevant documents on e-waste. The selected documents must be academic articles, book chapters, conference papers or reports of organizations and be full-text articles. The publication dates of the documents range from 2000 to 2024. To ensure wide coverage of the documents in search engines, avoid biased research and find relevant research documents, some keywords in both Vietnamese and English languages were used including electronic waste (electronic waste or e-waste), e-waste recycling, e-waste and environmental pollution, adverse impacts of e-waste, environmental impact of e-waste dumpsite, environmental effects of heavy metals from the e-waste, heavy metals contamination of water and soil, etc. The titles and abstracts of all documents were screened to check their relevance to e-waste. After reviewing the titles and abstracts of the documents, documents with irrelevant content and duplicate documents were eliminated. A total of about 63 domestic and foreign research documents are selected for further evaluation and in-depth research.

Data analysis: These documents are entered into Microsoft Excel software for synthesis and classification. Then, the results related to the impacts of electronic waste on the soil, water and air environment are evaluated and commented on.

RESULTS AND DISCUSSION

Composition of electronic waste: E-waste contains valuable components as well as hazardous and highly toxic metals and chemicals. Therefore, if not prevented through recycling and scientifically sustainable disposal, it can become a threat to the environment and public health. Table 1 shows the hazardous components and chemicals found in e-waste. Therefore, the recycling and treatment of e-waste in informal areas and inappropriate technology can cause significant impacts on people and the surrounding environment, especially releasing highly toxic substances into the soil, air and groundwater (Ari, 2015). Substances released from e-waste are divided into three types of pollutants. Primary pollutants are the most dangerous components of e-waste such as heavy metals, halogenated compounds. Secondary pollutants are by-products or residues created by improper recycling, including dioxins, polyaromatic hydrocarbons, etc. Finally, emissions or tertiary pollutants are compounds used to recycle e-waste. These substances must be properly handled to avoid environmental and health problems including aqua regia, hydrochloric acid, and cyanide during the leaching process of metal recycling (Khanna *et al*., 2014).

Table 1:. Hazardous components in electronic waste

Hazardous substances	**Existing in electronic waste**
Halogenated compounds	
PCB	Capacitors, transformers, adhesives in plastics, old fluorescent lighting fixtures
TBBA, PBB, PBDE	Flame retardant for plastics, insulation in cables
Chlorofluorocacbon	Cooling unit, insulating foam
PVC	Insulation in cables
Heavy metals	
As	Semiconductor, LED, IC, solar cell
Ba	Getters in spark plugs, CRT monitors, fluorescent lamps
Be	Circuit board, motherboard, connector
Cr	Anti-corrosion coatings, tapes, floppy disks, dyes, pigments
Cd	Batteries, soldering irons, CRT monitors, infrared detectors, chips, ink, photocopiers, mobile phones
Cu	TV, DVD, cable and cord
Pb	Batteries, CRT monitors, cables and wires
Li	Mobile phones, photographic equipment, video equipment, batteries
Hg	Sensors, displays, electrodes, PCBs, fluorescent lamps, LCD screens, batteries in watches and calculators
Ni	Rechargeable Ni-Cd battery, electron in CRT
Zn	Inside the CRT monitor, a mixture of rare earth metals.
Sn	Solder for electrical circuits, battery electrodes
Se	Sensors in lamps, photocopiers
Ag	Capacitors, switches, batteries

(Sources: Garlapati, 2016; Nahar *et al*., 2017; Ankit *et al*., 2021; Dockrell *et al*., 2023*)*

Impact of e-waste on soil environment: Soil pollution is one of the major environmental impacts of unsustainable e-waste management (Adanu *et al*., 2020). Unsafe e-waste recycling releases toxic substances in e-waste into the soil environment and causes serious pollution, significantly affecting the soil ecosystem as well as indirectly affecting human health. In addition, burning e-waste is also one of the causes of increased heavy metal content in soil and causing soil pollution (Ghulam and Abushammala, 2023). Heavy metals and other pollutants can enter the soil directly by partly leaching from leachate containing heavy metals and pollutants into the surrounding soil, partly by rain leaching toxic substances into the soil. This contaminates the soil, and then these heavy metals and pollutants leak and enter the surrounding water sources. Soil is the main sink for toxic substances released into the environment from the processes of dismantling, recovering valuable materials, and unsafe incineration of e-waste (Chakraborty *et al*., 2022). Most of the toxic substances in e-waste are non-biodegradable and persist in the environment for a long time. Therefore, the excess of various toxic components accumulates in the soil and affects the soil strength, reduces soil fertility and biological activities, which can lead to soil degradation (Twagirayezu *et al*., 2022). The negative effects of metals also depend on soil properties, organic matter, clay content, and pH (Chakraborty *et al*., 2022). Similarly, the study by Twagirayezu *et al*. (2022) also showed that contaminants from e-waste can persist in the soil for a long time due to pH, temperature, soil type, and soil composition. Among them, pH significantly affects the solubility, mobility and bioavailability of metals in soil, affecting the formation of ion pairs and complexes, surface charge and solubility of organic matter (Appel and Ma, 2002; Muhlbachova *et al*., 2005). Soil organic matter affects the adsorption of heavy metals into soil, while the clay content in soil plays an important role in the mobility of heavy metals (Carrillo-Gonzalez *et al*., 2006; McCauley *et al*., 2009). This means that clay-rich soils often have a higher ability to retain heavy metals in soil (Elnajdi *et al*., 2023).

In addition, toxic components accumulated in soil also increase the risk of exposure to the environment around e-waste recycling and treatment sites. Study by Kyere *et al*. (2016) found very high concentrations of heavy metals in the main working areas of e-waste incineration and dismantling sites, and heavy metal contamination has spread to residential, recreational, agricultural, and commercial areas. Studies by Peng *et al*. (2019) and Wu *et al*. (2019) have also shown that PCBs and some heavy metals are still present at relatively high concentrations in e-waste recycling sites three decades after the ban on recycling activities. In addition, abandoned e-waste recycling sites are still considered a source of contamination including trace metals, plastics, halogenated compounds that pose a risk to the surrounding environment and human health (Li and Achal, 2020). In addition, contaminants in e-waste also affect soil-dwelling bacteria, invertebrates such as earthworms, insects, and other animals such as birds. High concentrations of metals and toxic compounds accumulated in the soil reduce the amount of soil microbial biomass and the activities of various enzymes are also hindered (Quadros *et al*., 2016; Zou *et al*., 2021). This leads to a reduction in the functional diversity of bacteria in the soil ecosystem and changes in the bacterial community structure (Abdu *et al*., 2017; Beattie *et al*., 2018). In addition, exposure to heavy metals can cause metal tolerance in microbial populations (Ankit *et al*., 2021). However, some cases showed that although heavy metal and organic pollutant contamination reduced the normal soil microbiota, it increased the emergence of microbial populations with disease resistance and biodegradation properties (Xie *et al*., 2016; Jiang *et al*., 2017). For earthworms, the study of Nfor *et al*. (2021) also showed that heavy metal contamination arising from unsafe electronic waste recycling and disposal activities inhibited the growth and reproduction of earthworms.

Plants are susceptible to absorbing these contaminants through their roots, which then transport the metals to the shoots and accumulate within their tissues. This significantly affects plant growth. This makes cultivation unfeasible (Li and Achal, 2020; Twagirayezu *et al*., 2022). Former study by Chakraborty *et al*. (2022) revealed that metals are potentially toxic and toxic to plants leading to yellowing of leaves, poor plant growth, reduced yield and may even be accompanied by reduced nutrient uptake, plant metabolic disorders and reduced molecular nitrogen fixation in legumes. This is also consistent with research by Lenart-Boron and Boron (2014), heavy metal contaminated soils have reduced nitrogen-fixing bacterial biomass, leading to a significant reduction in nitrogen fixation. In addition, the absorption of metals by plants and subsequent accumulation along the food chain is a potential threat to animal and human health (Sprynskyy *et al*., 2007). Because although vegetables can be cooked before consumption, heavy metals cannot be decomposed. Therefore, the accumulation of heavy metals in plants leads to the gradual accumulation of heavy metals in the human body and can lead to adverse health effects. A study by Olafisoye *et al*. (2013) analyzed heavy metals in plants grown on soil near the Alaba e-waste recycling and treatment area, showing that all vegetable samples had high concentrations of heavy metals. Therefore, if consumers consume them regularly, they may be poisoned by heavy metals due to bioaccumulation.

Impact of e-waste on water environment: After the soil is polluted, heavy metals from e-waste such as mercury, lead, etc. seep deeper into the soil and groundwater. After reaching groundwater, these heavy metals will eventually enter rivers, streams, ponds, lakes and settle in sediments. For surface water environments, during the migration process, it would create acidification and toxicity in the water, harming animals and plants even when they are kilometers away from the e-waste treatment and recycling site (Jain *et al*., 2023). Acidification can destroy aquatic and freshwater ecosystems and reduce biodiversity. If acidification occurs in water sources, ecosystems can be damaged beyond repair (Twagirayezu *et al*., 2022). Among the types of e-waste, mobile phones and batteries are e-waste that contains many hazardous metals. A mobile phone battery can pollute 600 m^3 of water. In addition, about 12.5% of the e-waste is recycled through leaching and hydrometallurgy which leads to the entry of toxic substances into the aquatic ecosystem and affects human health (Rajesh *et al*., 2022). Different e-waste has a major impact on the environment, affecting and disturbing the entire ecosystem as shown in Table 2.

Table 2.Impact of some types of electronic waste on the environment

Electronic waste	Possible impact
CRT	Heavy metals such as lead, barium and other heavy metals, as well as harmful phosphorus, would leach into groundwater.
Circuit board	Emissions of substances into the air
Gold plated chips and components	Hydrocarbons, heavy metals, bromine compounds and some other chemicals discharged into rivers and oceans cause acidification and toxicity problems, seriously harming flora and fauna.
Computer cables	Hydrocarbons released into the atmosphere, water and soil.
From burning and smelting metals in electronic waste	Dioxin emissions cause cancer and tumor risk

Source: Mundada et al. (2004)

For groundwater, toxic components in e-waste enter the groundwater, leading to changes in pH, total dissolved solids, turbidity, chloride concentration, and conductivity (Dharini *et al*., 2017). This poses a health hazard to children and adults who use groundwater near e-waste recycling and processing areas as the water becomes unsafe for consumption. A study by Gupta and Nath (2020) has shown that the amount of pollutants found is significant near e-waste landfills and tends to decrease as the distance between the landfill and the aquifer increases. A study by Babbar *et al*. (2017) also showed that leachate generated from e-waste is the main cause of groundwater pollution. In addition, toxic substances from e-waste can accumulate in the tissues of aquatic organisms because they can absorb these toxic substances directly or indirectly and amplify them along the food chain. Among them, fish play an important role in biomagnification and are one of the species most affected by pollutants due to their relatively high trophic position in aquatic ecosystems (Martins *et al*., 2020). The transport of metals in aquatic organisms, especially fish, takes place through the blood and the ions are often bound to proteins. The metals come into contact with organs such as the liver, bile, kidney as well as the tissues of the fish and accumulate there at different levels. Potential pathways for pollutants to enter fish include food, non-food particles, water, gills and skin (Ayandiran *et al*., 2009). Many heavy metals in e-waste can affect the development of fish during the embryonic stage, leading to a reduction in the number and quality of offspring. In addition, when fish are exposed to PCBs at different stages of development, it is likely to cause population decline or extinction (Igbo *et al*., 2022). Study by Huang *et al*. (2014) also showed that water bodies near areas where recycling and uncontrolled storage of e-waste activities have been heavily polluted and have reduced the diversity of aquatic species in the water body. When a river has an increasing concentration of heavy metals in its water, it can cause ecological imbalance and reduce the diversity of aquatic organisms (Ayandiran *et al*., 2009).

Impact of e-waste on air environment: Air pollution is another environmental consequence of e-waste. When the informal sector recovers valuable materials by methods such as burning unsoldered circuit boards in the open, melting plastics, burning cables to recover copper, soaking in acid baths, etc., pollutants are released into the air (Rajesh *et al*., 2022). When e-waste is burned, it creates smoke containing large amounts of toxic gases and heavy metals such as lead, cadmium, mercury, etc. into the air (Meem *et al*., 2021) and also increases the concentration of air pollutants, especially particulate matter (PM10) (Jayaraman *et al*., 2019). Specifically, fly ash from burning PCBs can emit metals such as tin, copper, lead, bromine, zinc, etc. (Rajesh *et al*., 2022). In addition, unsafe disposal of e-waste also releases particulate matter into the atmosphere along with heavy metals and flame retardants (Twagirayezu *et al*., 2022). These particles can travel further through the air depending on their size or volume. In addition, particulate matter can be incorporated directly into wastewater or can also enter soil or water sources, leach into groundwater sources, or react with organisms and compounds present in wet and dry sediments (Rajesh *et al*., 2022; Twagirayezu *et al*., 2022; Bhardwaj *et al*., 2023). The impacts of e-waste on the air are the most severe and can extend thousands of miles from landfills (Bhardwaj *et al*., 2023). This in turn pollutes the air around animals and humans as it remains the main route of exposure for humans through ingestion, inhalation, and dermal absorption (Li and Achal, 2020). Dust particles combined with pollutants can increase the risk of lung cancer and other chronic diseases (Bhardwaj *et al*., 2023). Inefficient thermal treatment of e-waste can produce extremely harmful by-products, including dioxins and furans (Twagirayezu *et al*., 2022). A study by Leung *et al*. (2008) found increased levels of suspended particles and particulate matter in the environment surrounding an e-waste dump in Guiyu, China. In addition, dust from an e-waste recycling site also had concentrations of lead, copper, and zinc five times higher than those found in road dust in other areas. Zhang *et al*. (2017) and Qin *et al*. (2019) showed that informally treated e-waste dumps had significantly higher concentrations of particulate matter and heavy metals in the atmosphere, posing a threat to the environment and the health of people living near these dumps. A study by Kuntawee *et al*. (2020) found toxic particles in dust and air from open burning of e-waste in Thailand. Therefore, it can be seen that burning of e-waste in informal areas has contributed significantly to high levels of air pollution. This has resulted in the highest levels of heavy metal exposure for residents in these areas and even neighboring areas (Gangwar *et al*., 2019). Overall, pollutants from improper recycling and disposal activities have posed high risks and serious impacts on human health as well as the soil, water and air environments. The hazardous effects of these pollutants have been presented in Table 3. It can be seen that many people have not been properly aware of the release of electrical and electronic equipment, causing increased risk of water and soil pollution, leading to decline in biodiversity and socio -economic development. Currently, almost all countries depend on the source of groundwater partly or completely in order to use for living purposes, agriculture and industry .

Table 3 Hazardous impacts of contaminants from e-waste on human health and the environment

Hazardous substances	Source of exposure	Impact on human health	Environmental Impact
PAH	Ingestion, inhalation and skin contact	Exposure causes cancer. Mutagenicity and teratogenicity may also occur.	Often released as a by-product of combustion into air, dust, soil and vegetation.
BRF	Ingestion, inhalation and skin contact	Affecting thyroid function and causes cancer in humans. Also affects the reproductive and immune systems and disrupts the function of the endocrine system.	BFRs can leach into landfills. They are organic airborne contaminants and sources of dioxins.
PCDD PCDF	Ingestion, inhalation and skin contact.	Effects on reproductive system, nervous system.	Air pollution
PCB	Ingestion, inhalation, dermal and placental exposure.	Causing liver, kidney and thyroid cancer. Affects the immune system and reproductive and neurological development.	Contaminating soil and affects vegetation and aquatic life. Accumulates in plants and causes harm.
PBDE PBB	Ingestion, inhalation, and placental exposure.	Causing thyroid problems and impaired function of the nervous system, reproductive system and hormonal imbalances.	Polluting air, dust, water, plants and soil.
As	Ingestion, inhalation and skin contact.	Long-term exposure to arsenic causes skin diseases, lung cancer and damage to the nervous system. It also causes skin changes and leads to an increased risk of diabetes.	Polluting air, soil, water and plants.
Ba	Ingestion, inhalation and skin contact.	Causing high blood pressure, stomach irritation, changes in heart rate, muscle weakness, changes in nerve reflexes, and swelling of the brain, liver, and kidneys.	Polluting air, dust and water.
Be	Digestion and inhalation.	Causing lung cancer, can damage other organs, including the heart. Also causes pneumonia.	Polluting air, soil, water and plants.
Cd	Inhalation and ingestion	Causing irreversible toxic effects on human health; can accumulate in the kidneys and liver and lead to nerve damage; causes cancer, softens bones and severe pain in the spine and joints.	Polluting air, dust, water, soil and plants (especially rice and vegetables).
Cr	Digestion and inhalation.	Leading to asthma bronchitis, liver, kidney disease and can cause lung cancer.	Polluting air, soil, water and plants.
Pb	Ingestion, inhalation and skin contact.	Harming for reproductive organs, central nervous systems, respiratory systems and lung damage. May adversely affect children's brain development; causing damage to the circulatory system; and hinder the activity of enzymes in the human body.	Polluting the air and dust; causing soil acidification; and absorbed into the groundwater and surface water.
Li	Ingestion, inhalation and skin contact.	Causing kidney disease, cough and burning sensation; Difficulty breathing, shortness of breath, sore throat, skin redness, skin burns, pain, blistering and red eyes.	Polluting the air, dust, water, soil and plants.
Hg	Ingestion, inhalation and skin contact	This leads to behavioral and neurological disorders such as headache, insomnia, dementia and emotional instability. Fetus underdeveloped; pollutants are absorbed into breast milk. Disrupt kidney, immune system and central nervous system. Mercury can pollute human food chains through soil, groundwater and surface water.	Polluting the air, dust, soil, plants, surface water and groundwater.
Ni	Ingestion, inhalation and skin contact	Causing pulmonary embolism causes cancer, respiratory failure, birth defects, asthma and chronic bronchitis. In addition, it also leads to skin allergies.	Polluting air, soil, water and plants.
Se	ngestion, inhalation and skin contact	Causing hair loss and crunchy nails. It also causes cardiovascular, kidney and nerve abnormalities.	Polluting the air, dust, water and soil.
Zn	Consumption and inhalation	This leads to abdominal pain, skin irritation, nausea, anemia and can cause serious damage to the pancreas.	Polluting the air, dust, soil, surface water and groundwater.
Cu	Ingestion, inhalation and skin contact,	Causing eye, nose, mouth and throat irritation. It also leads to severe dizziness, headache, migraine, stomach pain, vomiting and diarrhea.	Polluting the air, dust, water and soil

Source: Andeobu *et al*. (2023)

Besides, the dismantlement and treatment of electronic waste improperly have emitted significant pollutants into soil, water and air environments, thereby harming the environment and health of people working in the field of electronic waste. Therefore, if electronic waste is controlled, treated by effective, proper methods and recovering materials of safe, environmentally friendly values, electronic waste would bring great value and prospects in the economy without causing risks to public health and environment (MMEREKI *et al*., 2016; Kumar *et al*., 2017).

Conclusion: The analysis of domestic and foreign articles showed that unofficial recycling and waste treatment activities have led to direct and indirect exposure through the soil, water, air and negative impacts on human health. Electronic waste contains both valuable components and contains toxic ingredients. The toxic substances in electronic waste have affected the soil environment as well as can cause soil degeneration destroying freshwater ecosystems and pollute groundwater. It also accumulated in the tissues of aquatic organisms and amplify them along the food chain. In addition, dust particles and pollutants generated from the dismantling and burning of e-waste cause air pollution of toxic gases and heavy metals. This exposes workers in the e-waste recycling area to health risks. There is a need for preventing the indiscriminate disposal of e-waste and improper e-waste recycling and treatment activities to minimize the impact on the environment and human health.

Acknowledgements: The authors extend their appreciation to the Master, PhD Scholarship Programmes of Vingroup Innovation Foundation (VINIF) for funding this research with a Grant Number VINIF.2023.TS.064. This study is partly funded by the Can Tho University with a research grant Code: T2024-29.

Declaration of Conflict of Interest: The authors declare no conflict of interest.

Data availability: Data are available upon request from the first author or corresponding author or any of the other authors.

REFERENCES

Abdu, N; Abdullahi, AA; Abdulkadir, A (2017). Heavy metals and soil microbes. *Environ. Chem. Lett.*, *15*(1), 65-84. DOI: https://doi.org/10.1016/j.soilbio.2009.04.026

Adanu, SK; Gbedemah, SF; Attah, MK (2020). Challenges of adopting sustainable technologies in e-waste management at Agbogbloshie, Ghana. *Heliyon*, *6*(8), e04548 DOI: https://doi.org/10.1016/j.heliyon.2020.e04548

Adesokan, MD; Adie, GU; Osibanjo, O (2016). Soil pollution by toxic metals near e-waste recycling operations in Ibadan, Nigeria. *J. Health Pollut.*, *6*(11), 26-33. DOI: 10.5696/2156-9614-6-11.26

Ali, SR; Mahrukh (2020). Chapter 19: Impacts of e-wastes on water resources and their management. *Adv. Pollut. Environ. Manag*., 129-144. DOI: https://doi.org/10.26832/aesa-2020-aepm-09

Andeobu, L; Wibowo, S; Grandhi, S (2021). A systematic review of E-waste generation and environmental management of Asia Pacific countries. *Int. J. Environ. Res. Public Health.*, *18*(17): 9051. DOI: https://doi.org/10.3390/ijerph18179051

Andeobu, L; Wibowo, S; Grandhi, S (2023). Environmental and health consequences of e-waste dumping and recycling carried out by selected countries in Asia and Latin America. *Sustainability*, *15*(13), 10405. DOI: https://doi.org/10.3390/su151310405

Ankit, SL; Kumar, V; Tiwari, J; Sweta, RS; Singh, J; Bauddh, K (2021). Electronic waste and their leachates impact on human health and environment: Global ecological threat and management. *Environ. Technol. Innov*., *24*, 102049. DOI: https://doi.org/10.1016/j.eti.2021.102049

Appel, C; Ma, L (2002). Concentration, pH, and surface charge effects on cadmium and lead sorption in three tropical soils. *J. Environ. Qual*., *31*, 581-589. DOI: https://doi.org/10.2134/jeq2002.5810

Ari, V (2015). A review of technology of metal recovery from electronic waste. *IntechOpen*, 61569. https://www.intechopen.com/chapters/49287

Ayandiran, T; Fawole, O; Adewoye, S; Ogundiran, MJJC (2009). Bioconcentration of metals in the body muscle and gut of Clarias gariepinus exposed to sublethal concentrations of soap and detergent effluent. *J. Cell Anim. Biol.*, *3*(8), 113-118. DOI: https://doi.org/10.5897/JCAB.9000026

Babbar, P; Verma, S; Mehmood, G (2017). Groundwater contamination from non-sanitary landfll sites – a case study on the ghazipur landfll site, Delhi (India). *Int. J. Appl. Environ. Sci.*, *12*(11), 1969-1991. DOI: 10.37622/IJAES/12.11.2017.1969-1991

Beattie, RE; Henke, W; Campa, MF; Hazen, TC; McAliley, LR; Campbell, JH (2018). Variation in microbial community structure correlates with heavy-metal contamination in soils decades after mining ceased. *Soil Biol. Biochem.*, *126*, 57-63. DOI: https://doi.org/10.1016/j.soilbio.2018.08.011

Bhardwaj, LK; Rath, P; Choudhury, M (2023). Assessment of e□waste pollution level in soil and water and its impact on human health: A review. *Preprints*, 1-15. DOI: 10.20944/preprints202311.1714.v1

Carrillo-González, R; Simunek, J; Sauve, S; Adriano, D (2006). Mechanisms and pathways of trace element mobility in soils. *Adv. Agron.*, *91*, 111-178. DOI: https://doi.org/10.1016/S0065-2113(06)91003-7

Chakraborty, SC; Qamruzzaman, M; Zaman, MWU; Alam, MM; Hossain, MD; Pramanik, BK; Nguyen, LN; Nghiem, LD; Ahmed, MF; Zhou, JL; Mondal, MIH; Hossain, MA; Johir, MAH; Ahmed, MB; Sithi, JA; Zargar, M; Moni, MA (2022). Metals in e-waste: Occurrence, fate, impacts and remediation technologies. *Process Saf. Environ. Prot.*, *162*, 230-252. DOI: https://doi.org/10.1016/j.psep.2022.04.011

Dharini, K; Cynthia, JB; Kamalambikai, B; Celestina, JAS; Muthu, D (2017). Hazardous E-waste and its impact on soil structure. *IOP Conf. Ser.: Earth Environ. Sci.*, *80*, 012057. DOI: https://iopscience.iop.org/article/10.1088/1755-1315/80/1/012057

Dockrell, MEC; Purchase, D; Price, RG (2023). E-waste and metal contamination in the environment: Health effects. *IntechOpen*, 1001826. DOI: https://www.intechopen.com/chapters/1132524

Elnajdi, A; Berland, A; Haeft, J; Dowling, C (2023). Influence of soil pH, organic matter, and clay content on environmentally available lead in soils: A case study in Muncie, Indiana, USA. *J. Soil Sci.*, *13*(10), 414-430. DOI: https://doi.org/10.4236/ojss.2023.1310019

Gangwar, C; Choudhari, R; Chauhan, A; Kumar, A; Singh, A; Tripathi, A (2019). Assessment of air pollution caused by illegal e-waste burning to evaluate the human health risk. *Environ. Int.*, *125*, 191-199. DOI: https://doi.org/10.1016/j.envint.2018.11.051

Garlapati, VK (2016). E-waste in India and developed countries: management, recycling, business and biotechnological initiatives. *Renew. Sust. Energ. Rev.*, *54*, 874-881. DOI: https://doi.org/10.1016/j.rser.2015.10.106

Ghulam, ST; Abushammala, H (2023). Challenges and Opportunities in the management of electronic waste and its impact on human health and environment. *Sustainability*, *15*(3), 1837. DOI: https://doi.org/10.3390/su15031837

Gupta, N; Nath, M (2020). Groundwater contamination by E-waste and its remedial measure-a literature review. *J. Phys.: Conf. Ser.*, *1531*, 012023. DOI: https://iopscience.iop.org/article/10.1088/1742-6596/1531/1/012023

Han, Y; Tang, Z; Sun, J; Xing, X; Zhang, M; Cheng, J (2019). Heavy metals in soil contaminated through e-waste processing activities in a recycling area: Implications for risk management. *Process Saf. Environ. Prot.*, *125*, 189-196. DOI: https://doi.org/10.1016/j.psep.2019.03.020

Huang, J; Nkrumah, PN; Anim, DO; Mensah, E (2014). E-waste disposal effects on the aquatic environment: Accra, Ghana. *Rev. Environ. Contam. Toxicol.*, *229*, 19-34. DOI: https://doi.org/10.1007/978-3-319-03777-6_2

Igbo, JK; Chukwu, LO; Oyewo, EO; Blum, JL; Schanzer, A; Wirgin, I; Meltzer, GY; Roy, NK; Zelikoff, JT (2022). The chemistry and health outcomes of electronic waste (e-waste) leachate: Exposure to e-waste is toxic to Atlantic Killifish (Fundulus heteroclitus) Embryos. *Sustainability*, *14*(18), 11304. DOI: https://doi.org/10.3390/su141811304

Jain, M; Kumar, D; Chaudhary, J; Kumar, S; Sharma, S; Verma, AS (2023). Review on e-waste management and its impact on the environment and society. *Waste Manag. Bull.*, *1*(3), 34-44. DOI: https://doi.org/10.1016/j.wmb.2023.06.004

Jayaraman, K; Vejayon, S; Raman, S; Mostafiz, I (2019). The proposed e-waste management model from the conviction of individual laptop disposal practices-An empirical study in Malaysia. *J. Clean. Prod.*, *208*, 688-696. DOI: https://doi.org/10.1016/j.jclepro.2018.10.125

Jiang, B; Adebayo, A; Jia, J; Xing, Y; Deng, S; Guo, L; Liang, Y; Zhang, D (2019). Impacts of heavy metals and soil properties at a Nigerian e-waste site on soil microbial community. *J. Hazard. Mater.*, *362*, 187-195. DOI: https://doi.org/10.1016/j.jhazmat.2018.08.060

Jiang, L; Cheng, Z; Zhang, D; Song, M; Wang, Y; Luo, C; Yin, H; Li, J; Zhang, G (2017). The influence of e-waste recycling on the molecular ecological network of soil microbial communities in Pakistan and China. *Environ. Pollut.*, *231*, 173-181. DOI: https://doi.org/10.1016/j.envpol.2017.08.003

Khanna, R; Cayumil, R; Mukherjee, PS; Sahajwalla, V (2014). A novel recycling approach for transforming waste printed circuit boards into a material resource. *Procedia Environ. Sci.*, *21*, 42-54. DOI: https://doi.org/10.1016/j.proenv.2014.09.006

Kumar, A; Holuszko, M; Espinosa, DCR (2017). E-waste: an overview on generation, collection, legislation and recycling practices. *Resour. Conserv. Recycl.*, *122*, 32-42. DOI: https://doi.org/10.1016/j.resconrec.2017.01.018

Kumar, P; Fulekar, MH (2019). Multivariate and statistical approaches for the evaluation of heavy metals pollution at e-waste dumping sites. *SN Appl. Sci.*, *1*, 1506. DOI: https://link.springer.com/article/10.1007/s42452-019-1559-0

Kuntawee, C; Tantrakarnapa, K; Limpanont, Y; Lawpoolsri, S; Phetrak, A; Mingkhwan, R; Worakhunpiset, S (2020). Exposure to heavy metals in electronic waste recycling in Thailand. *Int. J. Environ. Res. Public Health*, *17*(9), 2996. DOI: https://doi.org/10.3390/ijerph17092996

Kyere, VN; Greve, K; Atiemo, SM (2016). Spatial assessment of soil contamination by heavy metals from informal electronic waste recycling in Agbogbloshie, Ghana. *Environ Health Toxicol.*, *31*, 2016006. DOI: https://pmc.ncbi.nlm.nih.gov/articles/PMC5080776/

Lenart-Boron, A; Boron, P (2014). The effect of industrial heavy metal pollution on microbial abundance and diversity in soils – A review. *IntechOpen*, 57406. DOI: https://www.intechopen.com/chapters/46266

Leung, AO; Duzgoren-Aydin, NS; Cheung, KC; Wong, MH (2008). Heavy metals concentrations of surface dust from e-waste recycling and its human health implications in southeast China. *Environ. Sci. Technol.*, *42*, 2674-2680. DOI: https://pubs.acs.org/doi/10.1021/es071873x

Li, W; Achal, V (2020). Environmental and health impacts due to e-waste disposal in China – A review. *Sci. Total Environ.*, *737*, 139745. DOI: https://doi.org/10.1016/j.scitotenv.2020.139745

Lin, C; Zeng, Z; Xu, R; Liang, W; Guo, Y; Huo, X (2022). Risk assessment of PBDEs and PCBs in dust from an e-waste recycling area of China. *Sci. Total Environ.*, *803*, 150016. DOI: https://doi.org/10.1016/j.scitotenv.2021.150016

Madkhali, H; Duraib, S; Nguyen, L; Prasad, M; Sharma, M; Joshi, S (2023). A comprehensive review on e-waste management strategies and prediction methods: A Saudi Arabia perspective. *Knowledge*, *3*(2), 163-179. DOI: https://doi.org/10.3390/knowledge3020012

Maphosa, V; Maphosa, M (2020). E-waste management in Sub-Saharan Africa: A systematic literature review. *Cogent Bus. Manag.*, *7*(1), 1814503. DOI: https://doi.org/10.1080/23311975.2020.1814503

Martins, MF; Costa, PG; Bianchini, A (2020). Contaminant screening and tissue distribution in the critically endangered Brazilian guitarfish Pseudobatos horkelii. *Environ. Pollut.*, *265*, 114923. DOI: https://doi.org/10.1016/j.envpol.2020.114923

McCauley, A; Jones, C; Jacobsen, J (2009). Soil pH and Organic Matter. *Nutrient Management Module*, *8*, 1-12. DOI: https://www.scirp.org/reference/referencespapers?referenceid=2593413

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*(2), 116-125. DOI: https://doi.org/10.30574/gscarr.2021.8.2.0174

Mmereki, D; Li, B; Baldwin, A; Hong, L (2016). The generation, composition, collection, treatment and disposal system, and impact of e-waste. *IntechOpen*, 61332. DOI: https://www.intechopen.com/chapters/49247

Muhlbachova, G; Simon, T; Pechova, M (2005). The availability of Cd, Pb and Zn and their relationships with soil pH and microbial biomass in soils amended by natural clinoptilolite. *Plant, Soil. Environ. 51*, 26-33. DOI: 10.17221/3552-PSE

Mundada, MN; Kumar, S; Shekdar, AV (2004). E□ waste: a new challenge for waste management in India. *Int. J. Environ. Sci*., *61*(3), 265-279. DOI: :10.46647/ijetms.2022.v06i06.021

Nahar, N; Anwar, MA; Tanni, SA (2017). Electronic waste: A review. *Proceedings of the International Conference on Engineering Research, Innovation and Education*, *146*, 186-191. DOI: https://jnanoworld.com/articles/v9s1/nwj-s1-kumar-vaibhav.pdf

Nfor, B; Fai, PBA; Fobil, JN; Basu, N (2021). Effects of electronic and electrical waste–contaminated soils on growth and reproduction of earthworm (Alma nilotica). *Environ. Toxicol.*, *41*(2), 287-297. DOI: https://doi.org/10.1002/etc.5198

Ngo, HTT; Liang, L; Nguyen, DB; Doan, HN; Watchalayann, P (2020). Environmental pollution of heavy metals in a Vietnamese informal e-waste processing village. *App. Envi. Res.*, *42*(1), 71-84. DOI: https://doi.org/10.35762/AER.2020.42.1.6

Ngo, HTT; Watchalayann, P; Nguyen, DB; Doan, HN; Liang, L (2021). Environmental health risk assessment of heavy metal exposure among children living in an informal e-waste processing village in Viet Nam. *Sci. Total Environ.*, *763*, 142982. DOI: https://doi.org/10.1016/j.scitotenv.2020.142982

Niinimaki, K; Karell, E (2020). Closing the loop: Intentional fashion design defined by recycling technologies. *Technology-driven sustainability*, 7-25. DOI: https://link.springer.com/chapter/10.1007/978-3-030-15483-7_2

Nuruddin, NAH (2022). E-waste: Environmental impact and current challenges review. *Int. J. Soc. Sci. Res.*, *4*(3), 325-331. DOI: https://myjms.mohe.gov.my/index.php/ijssr/article/view/20153

Oguri, T; Suzuki, G; Matsukami, H; Uchida, N; Tue, NM; Tuyen, LH; Viet, PH; Takahashi, S; Tanabe, S; Takigami, H (2018). Exposure assessment of heavy metals in an e-waste processing area in northern Vietnam. *Sci. Total Environ.*, *621*, 1115-1123. DOI: https://doi.org/10.1016/j.scitotenv.2017.10.115

Ohajinwa, CM; Bodegom, PM; Vijver, MG; Olumide, AO; Osibanjo, O; Pejinenburg, WJGM (2018). Prevalence and injury patterns among electronic waste workers in the informal sector in Nigeria. *Injury Prevention*, *24*, 185-192. DOI: https://doi.org/10.1136/injuryprev-2016-042265

Olafisoye, OB; Adefioye, T; Osibote, OA (2013). Heavy metals contamination of water, soil, and plants around an electronic waste dumpsite. *Pol. J. Environ. Stud.*, *22*(5), 1431-1439. DOI: https://www.pjoes.com/pdf-89108-22967?filename=22967.pdf

Peng, Y; Wu, J; Luo, X; Zhang, X; Giesy, JP; Mai, B (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. DOI: https://doi.org/10.1016/j.envint.2019.104952

Prithiviraj, B; Chakraborty, P (2020). Atmospheric polychlorinated biphenyls from an urban site near informal electronic waste recycling area and a suburban site of Chennai city, India. *Sci. Total Environ.*, *710*, 135526. DOI: https://doi.org/10.1016/j.scitotenv.2019.135526

Qin, Q; Xu, X; Dai, Q; Ye, K; Wang, C; Huo, X (2019). Air pollution and body burden of persistent organic pollutants at an electronic waste recycling area of China. *Environ. Geochem. Health*, 41, 93-123. DOI: https://doi.org/10.1007/s10653-018-0176-y

Quadros, PD; Zhalnina, K; Davis-Richardson, AG; Drew, JC; Menezes, FB; Flavio, ADO; Triplett, EW (2016). Coal mining practices reduce the microbial biomass, richness and diversity of soil. *Appl. Soil Ecol.*, *98*, 195-203. DOI: https://doi.org/10.1016/j.apsoil.2015.10.016

Rajesh, R; Kanakadhurga, D; Prabaharan, N (2022). Electronic waste: A critical assessment on the unimaginable growing pollutant, legislations and environmental impacts. *Environ. Chall.*, *7*, 100507. DOI: https://doi.org/10.1016/j.envc.2022.100507

Sankhla, MS; Kumari, M; Nandan, M; Mohril, S; Singh, GP; Chturvedi, B; Kumar, DR (2016). Effect of electronic waste on environmental & human health – a review. *J Environ Sci Toxicol Food Technol.*, *10*(9), 98-104. DOI: https://www.iosrjournals.org/iosr-jestft/papers/vol10-issue9/Version-1/P10090198104.pdf

Sprynskyy, M; Kosobucki, P; Kowalkowski, T; Buszewski, B (2007). Influence of clinoptilolite rock on chemical speciation of selected heavy metals in sewage sludge. *J. Hazard. Mater.*, *149*, 310-316. DOI: https://doi.org/10.1016/j.jhazmat.2007.04.001

Srivastav, AL; Markandeya, PN; Pandey, M; Pandey, AK; Dubey, AK; Kumar, A; Bhardwaj, AK; Chaudhary, VK (2023). Concepts of circular economy for sustainable management of electronic wastes: challenges and management options. *Environ. Sci. Pollut. Res.*, *30*, 48654-48675. DOI: https://link.springer.com/article/10.1007/s11356-023-26052-y

Thao, TT; Ha, NM; Cam, BD; Trung, DQ (2015). Assessment of heavy metal pollution levels in groundwater and heavy metal accumulation in hair and nails of residents in the electronic waste collection and recycling area. *J. Anal. Chem. Phys. Biol.*, 20(1), 111-119. DOI: https://vjol.info.vn/index.php/TCPTHLS/article/view/19297

Twagirayezu, G; Irumva, O; Huang, K; Xia, H; Uwimana, A; Nizeyimana, JC; Manzi, HP; Nambajemariya, F; Itangishaka, AC (2022). Environmental effects of electrical and electronic waste on water and soil: A review. *Pol. J. Environ. Stud.*, *31*(3), 2507-2525

Uchida, N; Matsukami, H; Someya, M; Tue, NM; Tuyen, LH; Viet, PH; Takahashi, S; Tanabe, S; Suzuki, G (2018). Hazardous metals emissions from e-waste-processing sites in a village in northern Vietnam. *Emerg. Contam.*, *4*(1), 11-21. DOI: https://doi.org/10.1016/j.emcon.2018.10.001

Wu, Q; Leung, JYS; Du, Y; Kong, D; Shi, Y; Wang, Y; Xiao, T (2019). Trace metals in e-waste lead to serious health risk through consumption of rice growing near an abandoned e-waste recycling site: comparisons with PBDEs and AHFRs. *Environ. Pollut.*, *247*, 46-54. DOI: https://doi.org/10.1016/j.envpol.2018.12.051

Xie, Y; Fan, J; Zhu, W; Amombo, E; Lou, Y; Chen, L; Fu, J (2016). Effect of heavy metals pollution on soil microbial diversity and bermudagrass genetic variation. *Front. Plant Sci.*, *7* (755). DOI: https://doi.org/10.3389/fpls.2016.00755

Zeng, X; Duan, H; Wang, F; Li, J (2017). Examining environmental management of e-waste: China's experience and lessons. *Renew. Sust. Energ. Rev.*, *72*, 1076-1082. DOI: https://doi.org/10.1016/j.rser.2016.10.015

Zhang, B; Huo, X; Xu, L; Cheng, Z; Cong, X; Lu, X; Xu, X (2017). Elevated lead levels from e-waste exposure are linked to decreased olfactory memory in children. *Environ. Pollut.*, *231*, 1112–1121. DOI: https://doi.org/10.1016/j.envpol.2017.07.015

Zhang, WH; Wu, YX; Simonnot, MO (2012). Soil contamination due to e-waste disposal and recycling activities: A review with special focus on China. *Pedosphere*, *22*(4), 434-455. DOI: https://doi.org/10.1016/S1002-0160(12)60030-7

Zou, L; Lu, Y; Dai, Y; Khan, MI; Gustave, W; Nie, J; Liao, Y; Tang, X; Shi, J; Xu, J (2021). Spatial variation in microbial community in response to As and Pb contamination in Paddy Soils Near a Pb-Zn mining site. *Front. Environ. Sci., 9*: 138. DOI: https://doi.org/10.3389/fenvs.2021.630668