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Review

Environmental Effects of Electrical and Electronic Waste on Water and Soil: A Review

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Abstract

Electrical and electronic waste (E-waste) production are not only increasing enormously every day but also continue to pollute water and soil which are very essential elements to assert life completely and crucial to sustainable development and prosperity. With the emergence of information and communication technology (ICT), people are excited to explore emerging innovations, contributing robust demand for and the use of today's electrical and electronic equipment (EEE). Due to the lack of a precise management and disposal approach, the expired EEE are rapidly discarded as E-waste in mass and dumped in an inapt landfill or stowed where large soil areas are available, such as near industries, institutions, etc. In addition, the majority of those areas are near to the water table and other watercourses. These induce soil and water to be unsuitable for different purposes due to harmful toxic metals. Consequently, they are leading harsh health and environmental problems in developing countries and to some extent in developed countries. This review paper compiles E-waste categories and their effects, as well as soil and water contamination processes, and also advocates viable remediation technology.

Keywords: soil and water contamination, electrical and electronic equipment, E-waste

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Introduction

Technology is currently highly integrated in several aspect of human life and it provides people with countless advantages. However, lifestyle, technological advances and the swift use of new electrical and electronic devices in our daily life have proved to be troublesome for the linear economy of E-waste handling [1]. In addition, the pursuit of innovative concepts and designs will reduce the scope of electronic devices, leading to the generation of E-waste schemes [2]. Generally, the term E-waste was differently mentioned by the idea of consumers based on their point of view [2]. Moreover, according to different authors, E-waste has different terminology as a global problem [3]. In this paper, the United Nations Environment Programme (UNEP) definition is used, describing E-waste as EEE that can no longer be used or reaches its end of life such as computers, phones, and others [4]. Otherwise, E-waste can be considered to be any secondary EEE like computers, refrigerators, computers, mobile phones, televisions, entertainment devices, etc.

EEE, in particular ICT equipment grows more and more worldwide. This refers to the global amount of waste produced over a long period of time when new technologies and usable electronics arise [5], [6]. Therefore, the rapidly growing technology and escalating purchasing power are leading the increasing amount of electronic products. Once they are expired, they could be considered as hazardous to the environment and public health [2, 7, 8]. Normally, increases in consumption of electrical and electronic devices have an adverse effect on the environment, whether during the extraction of raw materials or after the use of commodities [9]. Typically, groundwater quality is an important global environmental issue requiring a broad range of physicochemical parameters to be monitored, such as cations and anions. Numerous countries that rely on groundwater as a natural resource are threatened by water quality deterioration and diminution of water storage in the aquifer [10, 11], as well as soil pollution that makes it unsuitable for certain functions. However, they are being deteriorated and polluted due to E-waste. Perspicuously, E-waste covers a broad variety of EEE, including television, hard drives, batteries, tablets, printers, PCs and monitors, etc. which comprises dangerous heavy metals, such as Lead (Pb), Chromium (Cr), Zinc (Zn) and Copper (Cu), etc.).

An increase of E-waste disposal into landfills is a big concern because such wastes embody large concentrations of hazardous materials [12]. When EEE are exposed to an uncontrolled environment, their toxic elements may percolate through porous soil and eventually mix with groundwater, which causes water and soil pollution. In addition, inappropriate disposal of E-waste in landfills has a great possibility of contaminating groundwater and surrounded areas due to leachate production. Harmful substances in leachate from landfills are correlated with old or not E-waste receiver landfills. The potential of metal-contaminated soils can be expected by accurately determining the transport of metals and metalloids through the human food chain [13]. This is a worldwide concern in both developing and developed countries that consider several settlements built at the beginning of environmental legislation. When these leachates are not properly handled, they may create considerable pollution problems in soil, surface water, and groundwater, hence they can pose serious pollution unless preventative measures are implemented [14]. This is a global issue incorporated with the climatic regime, where precipitation is sluggish and permanent. Water percolation along the deposition profile might be significantly more effective with such precipitation patterns, resulting in leachates migrating rapidly into the subsurface ecosystem [15]. The leaching mechanism involves percolating the rainwater from topsoil and mixing with domestic waste contaminated with poisonous chemicals, like heavy metals and PBDEs. As several old waste disposal systems operate without an efficient collection and treatment scheme, the leachate problem is further exacerbated [16]. Several studies indicated that E-waste disposed of in landfills had a massive concentration of harmful substances than landfills with no E-waste [17, 18]. Some recent researchers evinced that leachate from E-wastes is the main cause of groundwater pollution in the Gazipur, Delhi site [19].

Numerous researchers have shown that the release of hazardous metals and polyhalogenated organic substances, including PBDEs, from E-waste presents a serious danger to the environment and public health when released into the environment [20, 21]. Therefore, the continuing dumping/disposal of wastes in an uncontrolled manner poses colossal health and environmental danger. This is still a difficult challenge in developing countries that lack policy guidelines and adequate financial support to build new recycling and dismantling plant. E-waste has been delineated to make about 70% of the heavy metals found in leachates [22]. Preciously, uncontrolled E-waste will have a detrimental effect on groundwater and soil fertility. Additionally, they can emit pollutants that may cause respiratory difficulties and also carcinogens that may cause cancer in humans and animals.

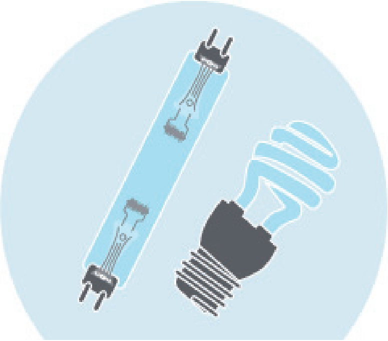
Knowing that EEE is an essential compartment for life that acts as a source of contamination for soil and watercourses, etc. This research was mainly aimed at describing the harmful e-waste compounds and their impacts on the environment, particularly on soil and water. It was also intended to address remediation options.

Categorization of E-waste and Its Pollutants

E-waste refers to all EEEs that their owners are unable to use or that have outlived their useful lives, such as mobile phones, Televisions, computers, etc. [4]. Rather, E-waste refers to electronic and electrical appliances that are discarded by their consumers and are no longer considered value unless they are recovered and recycled. Generally, E-waste covers six waste categories as shown in Fig. 1. [23]. Major categories of EEE contemplated in different shops in developing and developed countries are television and accessories (include television, receiver cables, decoder, DVD player, satellite dish); computer and accessories (such as laptops, computer speakers, computer, desktop computers, CD-R, CD-RW & DVD, notebooks, hard drives, USB sticks, CDMA sticks, printers, keyboards & mouse); Mobile devices and accessories (for instance mobile phone batteries, headsets, mobile chargers (separate), mobile phones) and other electronic objects

1. Temperature exchange equipment: Typical appliances includes cooling and freezing equipment like refrigerators, air conditioners, freezers, and heat pumps.

2. Screens, monitors: among them includes televisions, laptops, monitors, tablets and notebooks.



3. Lamps: Common equipment includes fluorescent lamps, LED lamps, and high-intensity discharge lamps.

4. Large equipment: Common appliances include washing machines, clothes dryers, electric stoves, dish-washing machines, large printing machines, photovoltaic panels and copying equipment.

5. Small equipment: Common examples are vacuum cleaners, toasters, microwaves, ventilation equipment, electric kettles, scales, electric shavers, calculators, video cameras, radio sets, electrical and electronic toys, small medical devices, small electrical and electronic tools, small monitoring and control instruments.

6. Small IT and telecommunication equipment: Typical appliances include mobile phones, pocket calculators, Global Positioning Systems (GPS), routers, printers, personal computers, printers, telephones.

Fig. 1. E-waste categories.

Table 1. Percentage of the materials contained in three main categories of e-waste.

Items	Large household gadgets	Small household gadgets	ICT and consumer electronics
Ferrous metal	43.0000000	29.0000000	36.0000000
Aluminum	14.0000000	9.30000000	5.00000000
Copper	12.0000000	17.0000000	4.00000000
Lead	1.60000000	0.57000000	0.29000000
Cadmium	0.00140000	0.00680000	0.01800000
Mercury	0.00003800	0.00001800	0.00007000
Gold	0.00000067	0.00000061	0.00024000
Silver	0.00000770	0.00000700	0.00120000
Palladium	0.00000030	0.00000024	0.00006000
Indium	0.00000000	0.00000000	0.00050000
Brominated plastics	0.29000000	0.75000000	18.0000000
Plastics	19.0000000	37.0000000	12.0000000
Lead glass	0.00000000	0.00000000	19.0000000
Glass	0.01700000	0.16000000	0.30000000
Glass	10.0000000	6.90000000	5.70000000
Total	100.000000	100.000000	100.000000

(like radios, power adaptor, tape recorders, power cables, stoves, washing machines, ironing machine, air conditioner, power dividers, men and women beauty appliances, varieties types of lamps, refrigerators, juice maker, dry cell batteries, coffee grinder, rechargeable batteries, kettles, and vacuum cleaners).

Generally, it is thought that many electrical and electronic device parts, such as hazardous and other metal parts, should also be dangerous when they are working or not working properly. However, when their reach on end of their useful life or become obsolete, they are regarded as E-waste which contains harmful compounds. As represented in Table 1, there are three main categories of E-waste [24]. Previously, in large household gadgets include freezers, refrigerators and washing machines. Small household gadgets represent materials such as vacuum cleaners, toasters, clocks, and fryers. Information and communication technologies stand materials like laptops, personal computers, and telephones, and consumer electronics include cameras, televisions, and audio amplifiers.

Contamination Processes and Effects of E-waste

Contamination Processes and Effects on the Soil

Soil has a huge influence on the whole globe and will continue to play a vital part in the well-being of future generations. Trivially, soil is a vital component that plays essential roles in food production, biological productivity, environmental quality, plant and animal health promotion, and environmental quality maintenance [25]. However, high amounts of heavy metals/metalloids in soil (such as lead, arsenic and cadmium) threaten the environment, food safety, the health of people and animals [25, 26] due to improper management. In addition, waste management procedures, especially in developing countries lead to harmful impacts on soil and human health [27-29]. It was shown that contaminants are often present in combination; hence, pollution conditions are difficult and varied from agricultural soils to hot spots at E-waste sites and open burning places [30]. Doing nothing, contamination can progress to an extent where our soil becomes the source of significant health problems. Naturally, soil contamination is the result of excessive dumping of E-waste in regular sites or improperly discarded. Heavy-metal such as cadmium, chrome, lead, and flammable residues may directly penetrate the soil from E-waste, allowing the soil to become polluted as represented in Fig. 2. E-wastes have different toxic content and harmful chemicals, which affect the strength of the soil layer when they have been accumulated in soil and decrease the fertility of the soil and its biological activities.

Furthermore, toxic heavy metals from E-waste contaminate the soil, crops become susceptible to the absorption of these contaminants and resulting in a certain situation that make farming impracticable.

These contaminants can stay in the soil for a long time due to pH level, temperature, soil type and composition. They can damage micro-organisms in soil and plants which also increases health and environmental hazards resulting from harmful activities [31], [32]. Furthermore, those who eat such plant products can be severely affected since soil and plants are tainted with harmful chemicals and dangerous materials. Ultimately, analysis of physiochemical characteristics of the sample collected near the place containing electrical and electronic equipment such as industries, institutions etc., should be a good option for choosing the areas of soil contaminated by E-waste among various regions.

Contamination Processes and Effects on Watercourses

Heavy metals from E-waste such as mercury, lead, lithium and barium seep into the soil, seep into different watercourses, mainly groundwater, after being released. When they meet the groundwater, these heavy metals enter pools, streams, waterways and lakes. These forms lead to acidification and toxification in the water, which can be dangerous for animals, plants, and populations, although a mile away from a recycling site. Acidification can destroy aquatic and freshwater ecosystems and damage biodiversity. If acidification is present in water sources, ecosystems can be harmed to the extent that recovery is doubtful, if not unlikely. The explanation behind this is that many experiments have already evaluated emissions from informal recovery practices.

Overview of the probity disposal practices, pollution types and general environmental mechanisms for E-waste was described in Fig. 3. [33]. In general, the disposal, decomposition and combustion of E-waste could pollute soil and water in various areas. Dismantling releases dust particles filled into the atmosphere with heavy metals and flammable retardants. These particles may either be recycled to the source or transported for a long time based on their size, depending on the volume of their stored particles. Dust integrates directly into wastewater may also go into the soil or water sources, leach into the groundwater, or react with the biota and the compounds present in wet and dry deposits [33]. The environment's

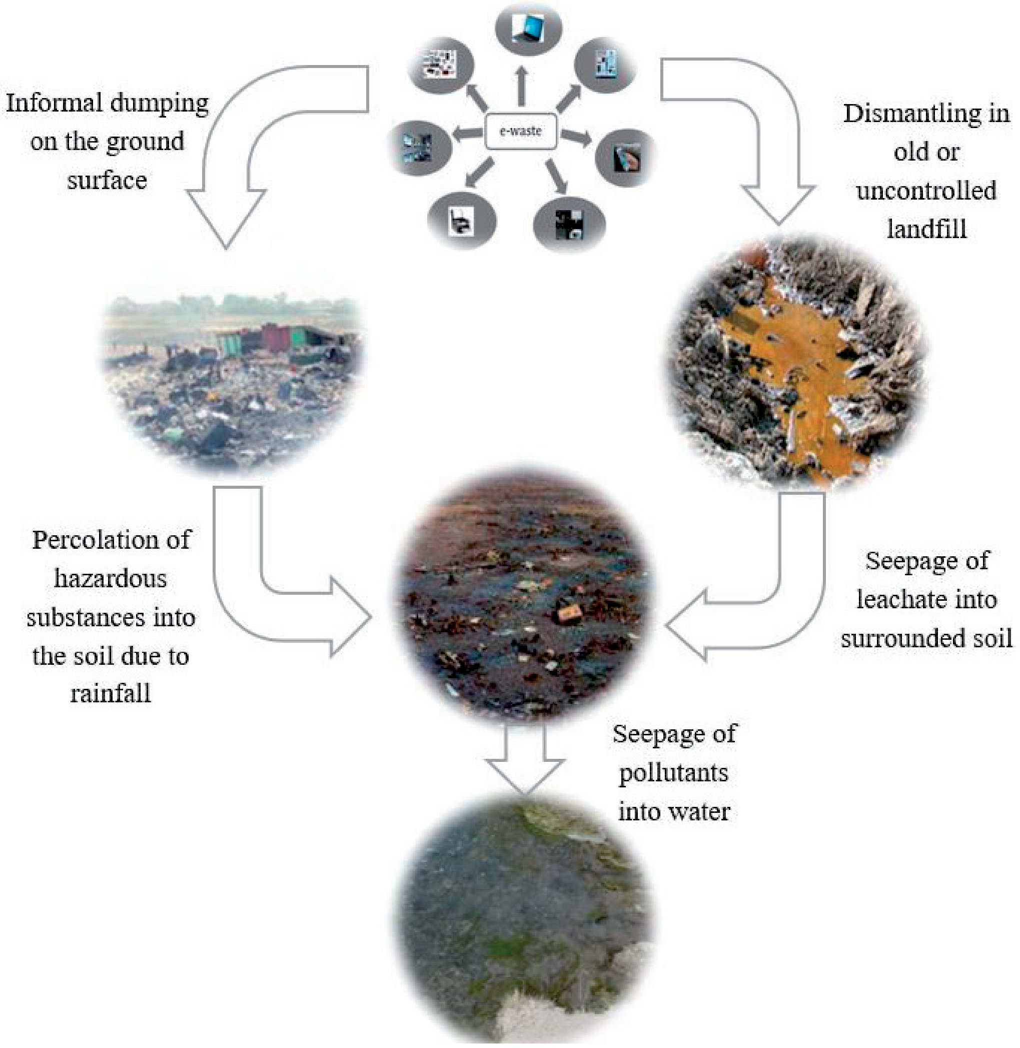


Fig. 2. Theoretical soil and water contamination processes.

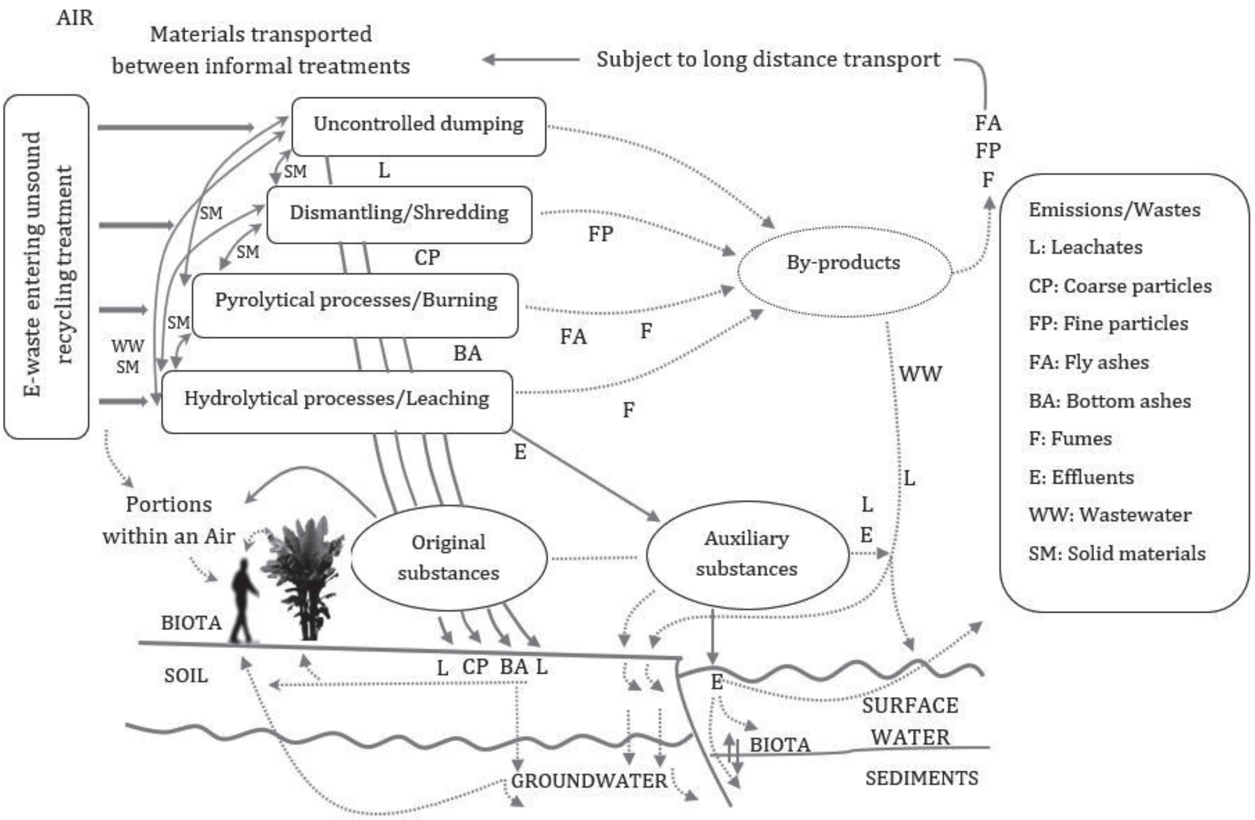


Fig. 3. Environmental pathways, emissions types, recycling activities of e-waste.

fate of toxic metals, ash and fumes, and PBDEs emitted from burning activities is close to pollution generated from waste disposal activities. However, thermal or metallurgical ineffective treatment of WEEE could generate extremely harmful by-products, including polyhalogenated dioxins and furans.

Main Contaminants and Effects of E-waste

Currently, the rate at which E-waste production is being increased is a significant concern. The informal disposal of this E-waste is becoming more problematic with grave environmental and human health consequences. Various studies have shown that elevated amounts of toxic metals such as lead (Pb), mercury (Hg), Barium (Ba), cooper (Cu), etc., and organic toxins such as polychlorinated biphenyls (PCBs), polybrominated dibenzo-p-dibenzofenyls/dibenzofurans (PCBB/Fs) and polycyclic aromatic hydrocarbons (PAHs) drip water, soil, air, and sediments which are connected to human activities [34], [35]. In addition, groundwater is adulterated by the open dumping of dangerous E-wastes in watercourses and landfills [36]. These chemical contaminants can cause an effect through dermal exposure, immediate inhalation and oral ingestion of water and food to laborers and local citizens.

Moreover, E-waste is linked to a broad range of chemicals, some containing toxic contaminants that could pollute the atmosphere and jeopardize human health without proper treatment. E-waste management procedures include incineration and waste disposal (landfills), can induce significant contamination risks[37]. These hazardous materials may also be delivered to groundwater through leachate, while toxic gasses are discharged by incineration into the atmosphere. The recycling of E-waste can dissipate dangerous materials into the air, mainly when the regeneration industry is at best moderately lucrative, sometimes cannot take the appropriate action to protect the environment and health of employees.

E-waste disposal provides a significant threat to both key components and ecological health and poses a problem to the environment in general [38]. Mostly, E-waste is not separate from other waste, especially in developing countries and are processed in improper containers such as flour, sugar and flavor pre-packaging. Unfortunately, these packages can suffer damage because they contain wet or liquefied substances. Often some households use rusty and old materials that can destroy them. During the day of the waste collection, bins are put on the street. However, unloaded waste are gathered and shipped back to its owners for reuse, which means that there are difficulties with waste collecting. Moreover, waste trucks are hand-packed or unpacked by workers without sufficient accountability for these unique jobs, and waste workers and even the environment are not safe and secure in such activities. Local authorities and waste collection companies should set up suitable health mechanisms for loading and unloading such waste trucks to ensure safety for employees. Additionally, the health effects of these heavy metals in these E-wastes should be considered in education programs [39].

Generally, over 1000 hazardous substances exist are associated to E-waste [37]. The substances most commonly listed are persistent organic pollutants (POPs), Polyvinyl chloride (PVC), toxic metals [40]. As represented in Table 2 [6, 17], E-waste contains both organic and hazardous substances. Governments should emphasize the proper separation of E-waste from its domestic resources to avoid any damage or danger to human health and the atmosphere. In addition, policies and regulations governing the carriage and E-waste disposal should be emphasized. Further, substances effects such as Antimony (Sb), Selenium (Se), Mercury (Hg), Arsenic (As), Barium (Ba), Cadmium (Cd), Beryllium (Be), Brominated flame retardants (BFRs), Chlorofluorocarbons (CFCs), Lead (Pb), Nickel (Ni), Polyvinyl chloride (PVC), Hexavalent chromium/chromium VI (Cr VI), Polychlorinated biphenyls (PCBs) etc., should be cautioned to combat with chronic diseases and disorders, including toxic environments and environmental changes.

Water Pollution and Soil Contamination Examples in Different Regions

More studies revealed the concentrations of different heavy metals and other physicochemical factors in soil and watercourses obtained from various regions and

Table 2. Popular toxic substances associated with e-waste and their impact on health

Nº	Substance	Location in e-waste	Health Impacts
1	Sb	Plastic computer housings, a solder alloy in cabling and a melting agent in CRT glass.	Sb has been classed as a carcinogen. The inhalation of high levels of antimony for a long period can foster stomach pain, diarrhea, vomiting, and stomach ulcers.
2	As	gallium arsenide has been utilized in light-emitting diodes.	It has some systemic effects, such as bestowing lung cancer, skin disease, and impaired nerve signaling.
3	Ba	Cathode-ray tube gutters in vacuum tubes, fluorescent lamps and sparkplugs	It is exposed to it within Short-term; it induces brain swelling, weakness of muscles, spleen damage, heart and liver.
4	Be	Finger clips, relays motherboards, Power supply boxes.	Be was categorized as a carcinogen, and it can induce skin disease, lung cancer and berylliosis.
5	BFRs	Cable insulation, plastic housings, printed circuit boards and keyboards. Some examples are tetrabromobisphenol (TBBPA), Polybrominated diphenyl ethers (PBDEs), and polybrominated biphenyls (PBBs).	Printed circuit boards and plastic casings spray toxic vapors deemed to induce hormonal disturbances under combustion.
6	Cd	Printer inks, infrared detectors, Rechargeable NiCd batteries, toners and semiconductor chips.	Compounds of Cadmium pose a risk of irreversible human health effects, especially kidneys disorders.
7	CFCs	Insulation foam and cooling items.	These pollutants abuse the ozone layer and could hasten skin cancer.
8	Cr VI	Plastic computer housing, Hard discs, cabling and colorant in pigments.	Cr VI is categorized among highly toxic elements to the environment. Obviously, it can induce damage to DNA and permanently impair the eyes.
9	Pb	Cabling, cathode-ray tubes, Solder, printed circuit boards, fluorescent tubes and lead-acid batteries.	It Can deface the brain, nervous system, reproductive system, kidney, and it cause Blood disorders. In addition, low levels of lead in fetuses and young children can impair the brain and nervous system. The trove of lead in the atmosphere has both chronic and acute health effects.
10	Hg	Thermostats, switches, Flat panel displays, backlight bulbs or lamps and batteries.	Kidneys, brains and fetuses may be battered by Mercury.
11	Ni	Printed circuit boards, Batteries, computer housing, and cathode ray tube.	Ni can induce bronchitis, allergic reactions, lung cancer and lower pulmonary function.
12	PCBs	Transformers, heat transfer fluids and condensers.	PCBs can induce animal cancer and damage the human liver.
13	PVC	Monitors, Keyboards, plastic computer housing and cabling.	Incomplete combustion of PVC generates great quantities of hydrogen chloride gas, combined with humidity forms hydrochloric acid, which can induce breathing difficulties.
14	Se	Older computers for photocopying	Higher levels of Se coadjutor to selenosis.

their adjacent areas, as represented in Table 3. A study of the impact of depth and distance from deposited sites suggested that watercourses from wells close to the deposit sites could be prevented. To use water, careful analyzes of the sample should be taken from deeper drilling in the water table or taking samples for other watercourses.

Table 3. Water and soil pollution in various areas.

Region	Water	Soil	Remarks	Sources
Longtang (Guangdong province, China)	√	√	The concentration of heavy metals reduced with depth in both the burning area and the paddy field, which was correlated to the higher pH and reduced TOM along the depth gradient. The pond water was severely acidified and loaded with heavy metals, but the well water was only marginally affected because heavy metals were largely kept in the top soil. The use of pond water for irrigation resulted in a significant amount of heavy metal pollution in the paddy soil.	[41]
Lagos (Niger a)	√	√	This study on groundwater and soil highlights the adverse consequences of electronic waste and why it must be handled adequately through proper landfill or recycling. It also shows the immediate need for measures to fix hazardous e-waste management and take cross-border restrictions for e-waste movement.	[42]
Delhi (India)	√	√	The results demonstrated that soil and groundwater and nearly sites have been polluted by chromium, lead, cadmium and copper to a greater extent.	[43]
Tamil Nadu (India)	√	χ	The concentrations of NH_4^+, NO_3^-, Cl^-, SO_4^{2-} have been reported at higher levels in groundwater, particularly areas close to the landfill, which showed that the quality of the groundwater is impaired considerably by the percolation of leachate.	[44]
South Australia (Australia)	√	χ	The leachates and groundwater gathered from the landfills had considerably higher Pb levels with the highest groundwater concentration, four times the rate of potable water in Australia. Both leachate and groundwater tests showed the existence of PBDE. In samples of leachate, the cumulative PBDEs are 10 times greater than in samples of groundwater.	[45]
Nduba (Rwanda)	√	√	The findings revealed that most of the surface water was polluted with amounts above permissible local and international potable conditions for the most physical and chemical parameters. The analytical findings of leachate samples have shown that heavy metals are emitted from municipal solid waste (MSW) (Cu: 38,5 mg/L, Zn:15 mg/l, Mn: 13,075 mg/l, TP:4525 mg/l, COD:7100mg/l, pH:8,52 mg/cm, BOD:182,1mg/L, Fe: 43,025 mg/L and TN:5 mg/l).	[46]
Taizhou city (China)	√	χ	The prevalent homologs for various groundwater samples are high-chlorinated PCBs (6-8 chlorinated biphenyls). It revealed certain variations in PCB trends in the shallow groundwater in the study site and that the cause had to be further researched.	[47]
Brazil and Mexico (USA)	√	√	As a result of mobility and solubility, metals such as chromium, cadmium, arsenic, lead, zinc, cadmium, mercury and copper can cause substantial environmental and human health harm due to groundwater and soil pollution.	[48]
Guangzhou (China)	χ	√	It was immediately apparent that the concentrations of some uncommon contaminants, such as Sb and Sn, were higher than the concentrations of principal contaminants, such as Ni, Cu, Zn, and Pb. Li and Be contamination in soils from the acid-leaching area and its surrounding environment could have resulted from other industrial activities or batteries, whereas Ni, Cu, Zn, Cd, Pb, Sn, and Sb contamination was most likely the result of uncontrolled electronic waste (e-waste) processing.	[49]
Shantou and puning pity (Guangdong Province, China)	χ	√	The concentrations and distributions of 21 mineral elements and 16 polycyclic aromatic hydrocarbons (PAHs) were determined. However, waste-related metals such as Hg, Sb, Au, Ag, Cd, Cu, Sn, and Ni were significantly more enriched than naturally occurring weathering elements.	[50]
Different region (China)	√	√	The findings show that groundwater contamination at MSW sites should be a problem and help remove groundwater contamination in the vicinity of municipal solid waste (MSW sites) and prevent secondary pollution from MSW sites, especially in developing countries considering similar conditions of MSW site disposal.	[51]

Table 3. Continued.

Wenling (Zhejiang Province, China)	χ	√	The results indicated that Cd levels in soils increased significantly in the southern and southeastern parts, C u levels in soils accumulated in the central and northwestern parts, and Ni levels in soils increased in the majority of the study region, while Pb and Zn levels accumulated in the northwestern part. These modifications were mostly impacted by the dismantling of E-waste.	[52]
Thohoyandou (South Africa)	√	χ	This study reveals the occurrence and concentrations of total mercury in landfill leachate, groundwater and sediment in winter and summer seasons at selected landfill sites. In winter, total mercury levels in all studied samples were slightly higher than in summer due to strong precipitation.	[53]
Kumasi (Ghana)	√	χ	Results show elevated levels of lead, iron, cadmium, and chromium (above the permissible limits of the World Health Organization) and the high levels of heavy metals detected in the Oti population indicated major contamination of groundwater by leachate percolation from the landfill site.	[54, 55]
Thailand (Buriram)	χ	√	Ecological risk assessments showed that the potential for e-waste separator housing for heavy metals on soils is greater than for non-repair sites, which was primarily attributed to Cu > As > Cd > PB for surface soils and Cd > Cu > As > Pb for surface soils. As > Pb for subsurface soils.	[56]
Karst (southwest China)	χ	√	Findings demonstrated that although the majority of heavy metal pollution in soil came from natural sources, the influence of human activities could not be disregarded.	[57]
China (South China)	χ	√	The findings showed that Cd, Cu, and Hg are the most abundant metals, Cd was more severe in agricultural land, and median concentration on farmland soil was beyond the soil level of environmental quality (China Grade II).	[58]
China (Hong Kong)	χ	√	Results indicated that E-waste practices lead to an uptick in hazardous chemical substances such as POPs that abandoned land and prevented soil rehabilitation.	[59]
Ghana (Accra)	√	χ	Sediments in local water sources showed massively heavy metals such as lead, cadmium, cotton, zinc and organic contaminants like PCDD/Fs and PBDEs.	[60]
Guiyu (Guangdong Province, China)	χ	√	It was shown that MSW open-burning sites likely held valuable e-waste, and abandoned sites earlier used for informal recycling are the new sources of soil-based environmental contamination in Guiyu.	[61]
Wenling (Zhejiang Province, China)	χ	√	According to the findings, agricultural soils were mostly polluted with Cd and Cu. In addition, the study's findings firmly suggested that industrial operations presented the greatest risk of total cancer; thus, further reducing industrial discharges via technological upgrades and improving emission controls is critical for preserving the health of local populations.	[62]

Potential Remediation Technologies

Soil Remediation Technologies

Due to heavy metal and organic compounds, soil pollution is a worldwide issue threatening human health and food safety. However, except for unusual geogenic sources, heavy metal pollutants are mainly brought into soils accidentally by anthropogenic activities such as electronic manufacturing, waste disposal, etc. Herein, soil pollution due to E-waste is an environmental concern. Consequently, to minimize the harmful impacts of polluted soil and reinstate ecosystem functioning, various remediation approaches have been developed. Commonly, there are various methods for addressing soil pollution by utilizing biological, chemical, physical, electrical and/or thermal processes (e.g., encapsulation, surface capping, and landfilling), immobilizing (e.g., stabilization, solidification, and vitrification), and extracting (e.g., electrokinetic, soil flushing, phytoextraction, and soil washing) as described in Table 4 [63]. The majority of the approaches are suitable *in-situ*, although landfilling and soil washing are *ex-situ*. However, solidification and vitrification could be used in both in-situ and *ex-situ.* Overall, remediation approaches have different mechanisms, demonstrations, benefits, and drawbacks in terms of cost competitiveness, applicability, implementation duration, and on-site/soil disturbance performance. However, soil remediation by removal/extraction processes is more attractive than containment/solidification because the cleaned soil can be put back to agricultural usage.

According to all remediation approaches, chemical stabilization is effective. Surface capping, encapsulation, and landfills are viable possibilities for small, high-contamination sites; solidification and vitrification are the ultimate options only when other cleanup procedures are not practical owing to time, economic, or geographic constraints. As a strategy for remediating large-scale sites having relatively low doses of pollutants at shallow depths, phytoremediation,

Table 4. Mechanisms, advantages, disadvantages, and application status of the available remediation techniques for heavy metal-contaminated soils.

Remediation technique & Applicability	Working mechanisms	Advantages	Disadvantages	Application status
1. Surface capping. *In-situ*, high contamination	Physical containment	Installable, Economical, tight security	Restricted to a small area and specific geographical locations, loss of land cropping function.	Broadly practiced
2. Encapsulation. *In-situ*, high contamination	Physical containment and isolation	Higher security, swift to install	High cost, restricted to small, shallow contamination areas, loss of land cropping function	Remediation of radionuclide and blended waste contamination
3. Electrokinetic. *In-situ*, fine soil, moderate to high contamination	Contaminant removal by electricity	Minimal soil disturbance, contaminant removal	Time intensive, quiet efficiency, foremost for fine-textured soils with low permeability	Under development with pilot application
4. Soil flushing. *In-situ*, coarse soil, moderate to high contamination	Contaminant removed by chemical solutions	Easy to install, minimal soil disturbance, Contaminant removal, affordable cost	Superior for coarse-textured soils with high permeability, plausible contamination of groundwater	Finite number of applications to blend waste remediation
5. Immobilization/ stabilization. *In-situ*, high contamination	Deactivation of contaminants via physiochemical transformation	Affordability, ease of implementation, and instant results	Metal-specific, transient efficacy, pollutants staying in the soil	Momentary remediation, not authorized
6. Phytoremediation. *In-situ*, low to moderate contamination	The removal and/ or stabilization of pollutants by plants	High public acceptability, relatively inexpensive, simplicity of application, and suitability for large areas with low contamination	Restricted to shallow contamination, metal-specific, time demanding, and inefficiency	Pilot demonstrations are now being conducted as part of the development process.
7. Bioremediation. *In-situ*, low to moderate contamination	Microorganisms convert contaminants	Inexpensive, easy to deploy, and minimal soil disruption	low yielding, merely supplementary to primary cleanup procedures	Heavy metal remediation is not routinely practiced.
8. Vitrification. *In-situ* and *ex-situ*, high contamination	Thermally vitrifying soil deactivates contaminants.	High effectiveness	Massive cost, restricted soil area/volume, and loss of environmental functions of soil and treated land.	Regularly practiced
9. Solidification. *In-situ* and *ex-situ*, high contamination	Contaminant deactivation through physical soil solidification	Implementation time is short, and efficiency is excellent.	Expensive, treated land and soil that loses environmental functions	Routinely practiced
10. Landfilling. *Ex-situ*, high contamination	Physical confinement and isolation	Physical confinement and isolation	High expense, requiring additional area for wastes storage	Widely practiced
11. Soil washing. *Ex-situ*, moderate to high contamination	Mechanical separation and chemical extraction are methods for removing contaminants.	High efficacy, quick effects	Soil disturbance to an extreme	Regularly practiced

Table 5. Biological and biochemical treatment technologies for water.

Remediation technique	Conditions and modalities of application	Mechanisms of operation	Advantages	Disadvantages
1. Biological activity in the sub-surface.	Aerobic bacteria cultivation in situ and tree planting Only in the sub surface's shallow layers	Precipitation, Bioaccumulation, oxidation	Meagre cost; applicable to huge tracts of land over a long time	Not suited for aquifer remediation; The procedure is relatively slow; There will be no modelling.
2. Enhanced biorestoration				
2.1 Immobilization of radionuclides by micro-organisms	Injecting carbon donor e.g., acetate to assist Geobactor species of bacteria in biobarrier	Agglomeration, absorption of U(IV) into sediments, Reduction	There are no hazardous byproducts created.	Acetate injection will be adjusted to inhibit sulphate, reducing bacteria growth.
2.2 *In-situ* bioprecipitation process	Carbon source injection (such as molasses) in the aquifer through deep wells	Fermentation of carbon sources within the aquifer and heavy metal entrapment in the inorganic matrix	There are low-cost carbon sources accessible.	Heavy metal ppts (such as Ni and Co) could remobilize as altering soil pH
2.3 Biological sulphate reduction	Electron injection donors and inoculation of bacterial cultures into the soil or aquifer.	SRB activity catalyzes the reduction of sulphate to metal sulphide ppts.	Acid mine drainage remediation on-site; off-site usage in bioreactors; can be utilized in PRBs	The reaction rate is restricted and requires enough dwell time.
2.4 In situ as elimination by ferrous oxides and microorganisms	Increasing aerobic oxidizing bacteria in an aquifer to oxidize iron (II) and As (II) in situ by introducing aerated water.	Oxidation of Fe (II) and As (III) by raising Eh and increasing microbial growth and then co-precipitating As, Fe and Mn	There are no chemicals utilized; no trash is created; and the running costs are low.	It is necessary to infuse aerated water regularly to keep the oxidation zone
3. Biosorption of heavy metals				
3.1 Biosurfactants	In the laboratory, rhamnolipids solution and foam were used to conduct experiments.	Bio-adsorption via metal complex formation with surfactants as a result of decreased interfacial tension	The high metal holding capacity	The product has not been field-tested. Although foam is thought to be more appropriate, transporting it to deep aquifers can be difficult.
3.2 Uptake by organisms	Laboratory experiments were conducted within pH 2-8 to eliminate Cd and Cr from the aqueous solution	Fungi, plants, bacteria, and DNA aptamers uptake or stabilize metals in the cell cytoplasm	Zn, As, Fe, Ni can also be adsorbed; anions don't really interfere.	Under the high acidic condition, there is Heavy metal desorption.
3.3 Cellulosic materials and agricultural wastes	A range of modified cellulose substances in the laboratory experiment.	Modified cellulose structure for Bio-adsorption of heavy metals with a pH range of 4-6	Affordable cellulose materials. A high range of heavy metals should be treated.	There is no significant field study conducted.

particularly phytoextraction, is a potential option. Generally, phytoremediation is more cost-effective than other remediation strategies. In spite of this, soil remediation by pollutant removal/extraction takes a lot more time than the soil containment approach and solidification vitrification approach.

Water Remediation Technologies

Water pollution with heavy metals is a major public health issue, whether from natural soil sources or artificial sources. However, contaminated groundwater treatment is of the utmost importance because it is used for drinking by billions of people worldwide. Heavy metal contamination of groundwater can occur from a variety of sources, including landfill leachate, deep well liquid waste disposal, sewage, seepage from industrial waste lagoon, or industrial spills and leaks [64, 65]. Some of the major metals treatment methods used in polluted water are biological/biochemical treatment technologies as displayed in Table 5 and Physico-chemical treatment technologies as represented in Table 6 [48, 65]. Due to the challenges in assessing the amount of pollution, the high costs of remediation, and the collateral effects of the approach on the ecosystem, selecting a site-specific soil remediation technique can be difficult [66].

Table 6. Physico-chemical treatment technologies for water.

Remediation technique& Applicability	Conditions and modes of application	Working mechanisms	Advantages	Disadvantages
1. Permeable reactive barriers				
1.1 Sorption process in PRBs				
1.1.1 Red mud	*In-situ* (acidified or unacidified) application of PRBs in aquifers	Metal cation absorption in the channel of a negative charge cancrinite structure	A low-cost byproduct of the aluminum industry; high sorption capacity; absorbed metals remain immobile	Sorbs cations with lower ionic radii; pH-dependent
1.1.2 Activated Carbon and peat	*In-situ* use in PRBs, primarily in granular form (GAC)	Adsorption caused by a large surface area (about 1000 m^2g^{-1}) and the presence of a surface group of Function	Adsorption capacity is high; regeneration is feasible; When combined with microorganisms, it performs better.	More field-scale research on inorganic and metal adsorption is required.
1.1.3 Zeolites, (chabazite-phillipsite, clinoptilolite, clinoptilolite, fly ash zeolites)	PRBs with *in-situ* application	Molecular sieving, catalysis, adsorption, and ion exchange can be sieved using a 3D aluminosilica framework.	Extremely high adsorption capacity; Zeolites of various natural origins are readily available.	Capacity for selective adsorption
1.1.4 Iron sorbents (ZVI and pyrite)	PRBs with *in-situ* application	As absorbed by ZVI rust and Hg absorbed by complexation at pyrite adsorption sites	ZVI and pyrite are inexpensive; handling is simple.	As released into an aquifer or soil due to the presence of silicate and phosphate
1.2 Chemical precipitation				
1.2.1 Reaction with ZVI	*In-situ* usage in PRBs synergistically with electrokinetic treatment	When ZVI was corroded, the pH increased, the redox potential dropped and the DO was consumed, and with reduction and precipitation of the metals, Fe (II) was produced.	Natural reactions can be replicated by using the electrokinetic technique.	Metal hydroxides and carbonates are clogging the barrier. ZVI is also rusted.
1.2.2 Alkaline Complexation agents (lime, $CaCO_3$, hydroxides)	*In-situ*, usage of Hydrated lime in PRBs	When the pH reaches 12, metal hydroxides form, and metal solubility lessens.	Inexpensive reagent; can make remediation for a no of anionic and cationic contaminants.	With the passage of time, the alkaline agent depletes.
1.2.3 Atomized Slag	*In-situ* Coupling of atomized slag and sand system in PRBs	Metal precipitation based on pH, followed by sorption in atomized slag.	Economical slag material from Fe and steel industry; Can recycle wastewater and leachate	Highly sensible to pH and the existence of organic materials
1.2.4 Caustic Magnesia	*In-situ* application in PRBs	Mg (OH)2 generated and pH reaches 8.5 when metals form hydroxides and precipitates	Traps several different metals; low-cost material	Cd, Co, and Ni may dissolute at a later stage.
1.3 Biological barriers in PRB				
1.3.1 Denitrification and BSR	1.3.1 Denitrification and BSR	Divalent metals are eliminated as sulphide, whereas trivalent metals are form hydroxide and oxyhydroxide.	Eliminates all divalent and trivalent heavy metal species; removes 95 percent of the metal in PRBs.	To maintain the microbial population thriving, a steady supply of nutrients must be delivered.
1.3.2 Coupling biotic components with ZVI	The use of in situ Fe^0, bacteria, and organic nutrients in PRBs	Metals are reduced by bacteria to sulphides and hydroxides, and Fe^0 retains the precipitates.	Ability to treat combinations of pollutants (organic, nitrate, and heavy metals)	PRB should give bacteria with C, N, and P for microbes growth and reproduction

Table 6. Continued.

2. Adsorption, filtration and absorption mechanisms				
2.1 Absorption by using inorganic surfactants	Application of anionic surfactants to soil or groundwater surfaces, particularly in an aquifer.	Sorption of metals based on surfactant charge	Surfactants come in a variety of forms, and they function well with complexing agents.	pH-dependent processes, high permeability aquifer required
2.2 Membrane and filtration technology	UF, EUF, nanofibre membrane, microfiltration, electrodialytic membrane, emulsion liquid membrane, polymer membrane, and so forth.	Separate mechanisms exist for each membrane and filter, such as electrostatic capture, micellar capture in 3-D structure, complexation, and dialysis.	There was a high removal efficiency detected.	Filter clogging; filter material recharge or regeneration
2.3 Adsorption by commercial and synthetic activated carbon	GAC, IMC, PHC, and tamarind wood carbon are employed and activated carbon with a greater ash concentration.	AC activated with Fe, ZnCl2, and other metals and a high BET surface area offer active sites for cation adsorption.	Adsorption sites for heavy metal cations are provided by high BET surface area and surface-active agents.	Regeneration of discarded materials may be required regularly.
2.4 Adsorption in industrial byproducts and wastes	In the laboratory, bone char, biochar, rice husk, and maple wood ash were tested.	Surface site adsorption	These are widely available from the industry; show impressive outcomes	Field application is required.
2.5 Use of ferrous materials as adsorbents	Fe (III) salts, Fe3O4 nanoparticles coated with FMBO, HA, blended magnetite and maghemite nanoparticles were injected.	Sorption by Fe oxides, oxyhydroxides, and sulfides, as well as microbe-mediated reactions including Fe as an e-acceptor.	Due to its highly geochemical interaction, As (V) and other metal cations from strong inner-sphere complexes with Fe (III).	As (III) oxidation is difficult to occur in anaerobic aquifers, ferrous elements deteriorate and must be replaced regularly.
2.6 Ferrous salts as *in-situ* soil amendments	*In-situ* application of goethite and Fe grit to soil and distribution over the contaminated land area to aid vegetation growth.	Adsorption on mineral surfaces, surface precipitation, production of stable complexes with organic ligands, and ion exchange.	Indicate results over an extended time (a few years); Suitable for use in highly contaminated locations.	Some supplements harm vegetation development; not all pollutants are effective.
2.7 Minerals and derived materials	Fuller's beads and hydrotalcite minerals were used in a lab experiment.	The precipitation in alkaline conditions (Fuller's bead) and adsorption via a wide surface area (hydrotalcite).	Heavy metals in aqueous solutions can be eliminated in a variety of ways.	The application in groundwater treatment is not carried out.
3. Electrokinetic remediation	DC current is provided through electrodes put in the soil, causing cations to migrate to the cathode and anions to flow to the anode, where they are retrieved.	Electro-osmosis, electromigration, and electrophoresis are all components of the process.	85-90 percent efficient at removing metals; applicable to a broad spectrum of metals.	In this method, the soil pore, the water current density, grain size, ionic mobility, contamination concentration, and the total ionic concentration are all considered.

It can be unequivocal and absolutel that decision-making in groundwater pollution is considerably more challenging owing to additional considerations such as soil permeability, groundwater flow pattern, and complicated chemical reactions occurring in the aquifer. Prior to adopting groundwater remediation techniques in polluted regions, compatibility analyses should be performed to look at interactions between remediation technologies and site factors, including the kinds and amounts of active pollutants, soil composition, and geological features [67]. They devised a decision support system to rank remediation approaches based on their projected compatibility index, which was obtained using a multiple-attribute decision-making framework [67]. Generally, *In-situ*, chemical injection in the aquifer is a really effective option. However, soil chemistry and the aquifer may be disturbed during cleaning.

In certain cases, chemicals do not degrade naturally and even when they do, they leave behind harmful byproducts. Therefore, caution should be exercised while introducing chemicals to aquifers. The permeable reactive barrier is a well-developed technique, and scientific research is still being conducted on the use of the site and contaminant-specific reactive cells, such as zeolites, strong chemicals, ion exchange resins, surfactants, iron, adsorptive substances, bio-active materials and organisms. Many adsorbents and separation methods used for heavy metal removal from aqueous solutions are discussed in this study. However, they can also be utilized in permeable reactive barriers to keep contaminants out of aquifers. Civil construction of barriers across large areas may be expensive, and reactive media should be eliminated once they've served their function.

Successful uses of permeable reactive barrier technology for arsenic remediation, comprehensive subsurface characterization data that encompasses geochemical and hydrogeologic variation, as well as flux-based analysis, is required. The electrokinetic separation field is also remarkable and it has demonstrated significantly better results when combined with iron-based technologies and biosorption. Nevertheless, biological or biochemical methods using microbes and nutrients for enzymatic oxidations, bioprecipitation, biosurfactants and sulphate reductions as heavy metal removal tools have emerged as the most promising technology field in the recent decade. The majority of the time, injecting nutrients and electron donors is a low-cost and non-toxic option. The success of the treatment procedure can be ensured by monitoring the microbial population and water quality on a regular basis.

Conclusion

Without attention, E-waste production and recycling processes can harm all environmental compartments and threaten the health of E-waste employees and places. Therefore, enough and appropriate E-waste recycling areas should be adopted by other countries, as done in China (Fig. S1, Table S1). The major gadgets for the production of E-waste are large household devices, small household devices, information and communication materials, all of which embody a large amount of hazardous chemicals. The high level of toxicity in soil and water makes them worse for drinking, agriculture, irrigation and other uses. As mentioned, soil and watercourses are contaminated by different substances, heavy metals and organic compounds, which are transferred into the food chain, mainly through rice cultivation in developed and developing countries. This study also reveals that specific sites are well documented in various countries as several experiments for a decade focused on pollution status and identification of toxic compounds in human tissues and blood. However, for the other countries that practice crude treatment, there is a drastic lack of evidence. We might speculate that vast regions have been impacted worldwide, and millions of people are endangered. There is also an extreme lack of understanding about the fate and toxicity of hazardous substances. As a result, data on pollution status in all the countries are urgently needed to enhance awareness of the effect of the toxic substance. Conclusively, water and soil should be protected by preventing improper disposal of waste, particularly E-waste. More importantly, efforts must be made to select appropriate remediation techniques for soil and watercourses to save the world.

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Conflict of Interest

The authors declare no conflict of interest.

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Supplementary Materials

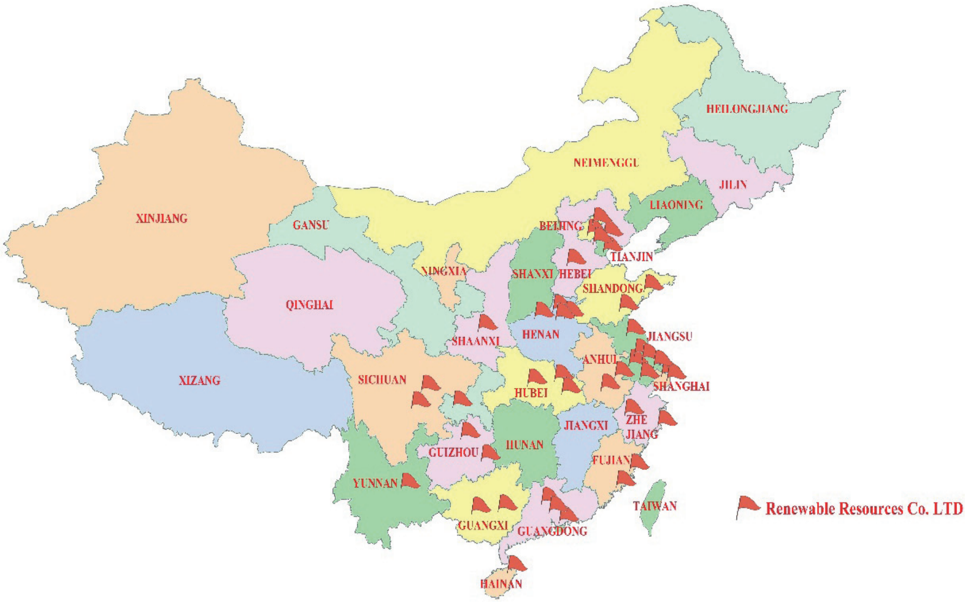

Fig. S1. Map of Renewable Resources Co.LTD in China.

Table S1. Electrical and electronic waste recycling areas in China.

Company Name	Address	Main types of e-waste treatment
Guangdong Bianbao Renewable Resources Co. LTD	Guangzhou, Guangdong Province	Waste electrical and electronic products, etc.
Qingyuan Dongjiang Environmental Protection Technology Co. LTD	Qingyuan, Guangdong Province	Printed circuit boards, used batteries, etc.
Qingyuan Huaqing Waste electric Appliance Disposal Co. LTD	Qingyuan, Guangdong Province	Waste electrical and electronic products, etc.
Shenzhen Yingchuang Crystal Core Electronics Co. LTD	Shenzhen, Guangdong Province	Battery, chip, graphics card, audion, etc.
Guangxi Waste battery Treatment Plant	Yulin, Guangxi Province	Waste zinc-manganese dry batteries, mobile phone batteries, etc.
Guangxi Hongfa Renewable Resources Recycling Co. LTD	Nanning, Guangxi Province	New energy vehicle waste battery, etc.
Xiamen Oasis Environmental Protection Industry Co. LTD	Xiamen, Fujian Province	Waste appliances (TV sets, washing machines, computers, etc.)
Hainan Hebao New Resource Recycling Industry Utilization Co. LTD	Haikou, Hainan Province	Waste batteries, waste circuit boards, etc.
Hainan Aolong Materials Recycling Co. LTD	Haikou, Hainan Province	Waste electronic components, etc.
Yunnan Shunyang Renewable Resources Recycling Co. LTD	Kunming, Yunnan Province	Electronic waste, used batteries, etc.
Yunnan Zhiheng Waste Materials Recycling Co. LTD	Kunming, Yunnan Province	Waste electronic products, refrigeration equipment, batteries, etc.
Yunnan Julu Environmental Protection Technology Co. LTD	Kunming, Yunnan Province	Waste appliances (TV sets, washing machines, computers, etc.)
Chengdu Renxin Technology Co. LTD	Chengdu, Sichuan Province	Waste printed circuit boards, etc.
Sichuan Zhongming Renewable Resources Comprehensive Utilization Co. LTD	Meishan, Sichuan Province	Waste electrical appliances, electronic products, etc.

Table S1. Continued.

Guizhou Honghu Environmental Protection Industry Co. LTD	Taijiang, Guizhou Province	Waste circuit boards, lead-containing batteries, etc.
Zunyi Lvhuan Waste electrical and electronic Products Recycling and Processing Co. LTD	Zunyi, Guizhou Province	Waste electronic products, waste electrical appliances, etc.
Zunyi Fuqiao Metal Recycling Co. LTD	Zunyi, Guizhou Province	Used circuit boards, batteries, communication equipment, etc.
Chongqing Zhongtian Electronic Waste Treatment Co. LTD	Dazu District, Chongqing	Waste electrical and electronic products, etc.
Jingmen Green Recycling Electronic Waste Disposal Co. LTD	Jingmen, Hubei Province	Waste electrical appliances, electronic products, etc.
Wuhan Bowang Xingyuanxing Environmental Protection Technology Co. LTD	Wuhan, Hubei Province	Waste electrical appliances, electronic products, etc.
Wuhan Green Recycling Electronic Waste Disposal Co. LTD	Wuhan, Hubei Province	Waste electrical appliances, electronic products, etc.
Hubei Dongjiang Environmental Protection Co. LTD	Xiaochang, Hubei Province	Waste appliances, etc.
Zhongzaisheng Luoyang Investment development Co. LTD	Luoyang, Henan province	Waste electrical appliances, electronic products, etc.
Henan Yuxiang Renewable Resources Utilization Co. LTD	Zhengzhou, Henan province	Waste appliances, etc.
Zhengzhou Gree Green Renewable Resources Co. LTD	Zhengzhou, Henan province	Waste electrical appliances, electronic products, etc.
Henan Mutong Environmental Protection Industry Co. LTD	Kaifeng, Henan Province	Waste electrical appliances, electronic products, etc.
Henan Hengchang Precious Metals Co. LTD	Jiaozuo, Henan Province	Waste appliances, etc.
Henan Erui Environmental Protection Technology Co. LTD	Kaifeng, Henan Province	Waste appliances, etc.
Shaanxi Beikong Renewable Resources Co. LTD	Xianyang, Shaanxi Province	Waste electrical appliances, electronic products, etc.
Shaanxi Jiuzhou Renewable Resources Co. LTD	Xianyang, Shaanxi Province	Waste electrical appliances, electronic products, etc.
Beijing Hazardous Waste Disposal Center	Fangshan District, Beijing	Used batteries, bulbs, lamps, etc.
Huaxin Luyuan Environmental Protection Industry Development Co. LTD	Zhongguancun, Beijing	Waste household appliances, electronic products, etc.
Wei Xiang United Environmental Protection Technology Development Co. LTD	Zhongguancun, Beijing	Waste household appliances, electronic products, etc.
Tianjin Hechang Environmental Protection Technology Co. LTD	Baodi District, Tianjin city	Waste household appliances, electronic products, etc.
Tianjin Tonghe Green Angel Peak Resources Regeneration Co. LTD	Jinghai District, Tianjin	Waste household appliances, electronic products, etc.
Shijiazhuang Green Renewable Resources Co. LTD	Shijiazhuang, Hebei Province	Electronic and electrical products, scrapped cars, etc.
Hebei Wanzhong Waste Material Recycling Co. LTD	Langfang, Hebei Province	Waste household appliances, waste office electronic equipment, etc.
Shanghai Xinjinqiao Environmental Protection Co. LTD	Pudong New Area, Shanghai	Waste electrical appliances, electronic products, etc.
Shanghai Electronic Waste Trading Center Co. LTD	Baoshan District, Shanghai	Household appliances, electronic communication equipment.
Shandong Zhonglu Resource Regeneration Co. LTD	Linyi City, Shandong Province	Waste electrical appliances, electronic products, etc.
Qingdao Xintiandi Ecological Cycle Technology Co. LTD	Qingdao, Shandong Province	Waste electrical appliances, electronic products, etc.

Table S1. Continued.

Suzhou Tonghe Resources Comprehensive Utilization Co. LTD	Suzhou, Jiangsu Province	Waste electrical appliances, electronic products, etc.
Jiangsu Subei Waste Car Appliance disassembly and Recycling Co. LTD	Huai ,an, Jiangsu Province	Waste cars, waste electrical appliances, etc.
Zhejiang Qingmao Environmental Protection Technology Co. LTD	Yuhuan, Zhejiang Province	Waste electrical appliances, electronic printing equipment, etc.
Zhejiang Blue sky Waste Household Appliances Recycling Co. LTD	Longyou, Zhejiang Province	Waste electrical appliances, electronic products, etc.
Fujian Hongyuan Environmental Resources Co. LTD	Fuqing, Fujian Province	Waste electrical appliances, electronic products, etc.
Nanjing Environmental Resources Regeneration Technology Co. LTD	Nanjing, Jiangsu Province	Waste appliances, etc.
Nanjing Kaiyan Electronics Co. LTD	Nanjing, Jiangsu Province	Waste appliances (washing machines, air conditioners, refrigerators)
Changzhou Xiangyu Resource Regeneration Technology Co. LTD	Changzhou, Jiangsu Province	Waste electrical appliances, electronic products, etc.
Suzhou Weixiang Electronic Waste Treatment Technology Co. LTD	Suzhou, Jiangsu Province	Waste appliances, etc.
Nantong Sanderson Blue Environmental Protection Technology Co. LTD	Nantong, Jiangsu Province	Waste electrical appliances, electronic products, refrigeration equipment, etc.
Yangzhou Ningda Precious Metals Co. LTD	Nantong, Jiangsu Province	Waste electrical appliances, electronic products, etc.
Wuhu Green Renewable Resources Co. LTD	Wuhu, Anhui Province	Waste household appliances, electronic products, etc.
Anhui Fumao Renewable Resources Recycling Technology Co. LTD	Tongling, Anhui Province	Waste electrical appliances, room air conditioners, computers, etc.