A Mini Project report on

Theoretical Approach on E-waste Contaminated Soil and its Management

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Submitted by:

RAJDEEP PAUL

M.TECH 3RD Semester

Roll No: PG-CE-23/14

ASTU Registration No: 406707119 of 2023-2024

Under the guidance of:

DR.SASANKA BORAH

Assistant Professor, Assam Engineering College Department of Civil Engineering

ASSAM ENGINEERING COLLEGE

JALUKBARI, GUWAHATI-13, ASSAM

CERTIFICATE OF SUPERVISION

This is to certify that the work presented in this report entitled - "Theoretical approach on E-waste contaminated soil and its Management" is carried out by Rajdeep Paul, Roll No:PG-CE-23/14, a student of M.Tech 3rd semester, Department of Civil Engineering, Assam Engineering College, under my guidance and supervision and submitted in the partial fulfilment of the requirement for the award of the Degree of Master of Technology in Civil Engineering with specialization in Geotechnical Engineering under Assam Science and Technology University.

DR.SASANKA BORAH
Professor, Department of
Civil Engineering,
Assam Engineering College,
Jalukbari, Guwahati-781013

CERTIFICATE FROM THE HEAD OF THE DEPARTMENT

This is to certify that the following student of M.Tech 3rd semester of Civil Engineering Department (Geotechnical Engineering), Assam Engineering College, has submitted her project on — “Theoretical approach on E-waste contamination in soil” in partial fulfilment of the requirement for the award of the Degree of Master of Technology in Civil Engineering with specialization in Geotechnical Engineering under Assam Science and Technology University.

Name: RAJDEEP PAUL

College Roll No: PG-C-23/14

ASTU: 230620062011

ASTU Registration No: 406707119

Date:

Place:

DR.JAYANTA PATHAK

Professor & Head of Department

Department of Civil Engineering

Assam Engineering College,

Jalukbari, Guwahati-781013

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ABSTRACT

The rapid generation of electronic waste (e-waste) due to technological advancements poses a significant environmental challenge, particularly with regard to soil contamination. This study investigates the impact of e-waste on soil quality and its geotechnical and environmental implications. A series of field and laboratory experiments were conducted to assess the extent of heavy metal leaching, changes in soil properties, and potential risks to groundwater systems. Key heavy metals such as lead (Pb), cadmium (Cd), and chromium (Cr) were found to exceed permissible limits in soils exposed to e-waste, indicating a significant threat to soil health and agricultural productivity. Additionally, geotechnical properties such as Atterberg limits, permeability, and compaction characteristics were analysed to evaluate the influence of contaminants on soil behaviour. The findings highlight the urgent need for sustainable e-waste management practices, remediation strategies, and policy interventions to mitigate soil contamination. This research contributes to a better understanding of the interplay between e-waste pollution and soil systems, offering insights into improving environmental and geotechnical practices in urban and industrial regions.

Keywords: E-waste contamination, soil pollution, heavy metals, geotechnical properties, soil health, sustainable waste management, environmental remediation, soil behaviour, urban pollution, heavy metal leaching

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CHAPTER 1

INTRODUCTION

1.1 Background

The rapid proliferation of electronic devices has led to an exponential increase in electronic waste (e-waste) generation globally. E-waste consists of discarded electronic appliances, including computers, mobile phones, and household devices, which often contain hazardous substances like heavy metals, flame retardants, and toxic chemicals. When improperly disposed of or processed, e-waste can release these substances into the environment, causing significant contamination of soil and groundwater. This contamination poses risks to agricultural productivity, human health, and ecosystems. In developing countries, the informal processing and unregulated dumping of e-waste exacerbate these challenges, making it imperative to understand its geotechnical and environmental impact comprehensively.

1.2 Objectives of the Study

The primary objectives of this study are:

1. To evaluate the extent of soil contamination caused by e-waste, focusing on heavy metal leaching and accumulation.
2. To analyze the effect of e-waste contamination on the geotechnical properties of soil, including permeability, compaction, and Atterberg limits.
3. To identify the potential environmental and geotechnical risks associated with e-waste-affected soils.
4. To propose sustainable waste management practices and remediation strategies for mitigating soil contamination.

1.3 Significance of the Study

1. **Assessment of Environmental Impact**
    - The study sheds light on how improper disposal of e-waste contributes to soil and groundwater contamination.
    - It highlights the leaching of toxic heavy metals such as lead (Pb), cadmium (Cd), and mercury (Hg) into the soil, which can cause long-term environmental degradation.
2. **Understanding Changes in Soil Properties**
    - Contaminants from e-waste can alter the geotechnical properties of soil, such as permeability, shear strength, and compaction characteristics.
    - This study examines these changes, which are critical for civil engineering applications like foundation design and land development.
3. **Human Health and Agricultural Implications**
    - Contaminated soil can adversely affect crop quality, reducing agricultural productivity and potentially leading to the bioaccumulation of toxins in the food chain.
    - The research provides data on the risks posed to human health, particularly in areas where e-waste is improperly managed.
4. **Guidance for Policy and Regulation**
    - Findings can inform policymakers about the severity of soil contamination due to e-waste.
    - The study can support the creation of stricter regulations for e-waste recycling and disposal, especially in developing countries where informal processing is prevalent.
5. **Contribution to Sustainable Waste Management**
    - By identifying the effects of e-waste on soil, the study encourages the adoption of sustainable waste management

practices, such as eco-friendly recycling methods and proper disposal systems.

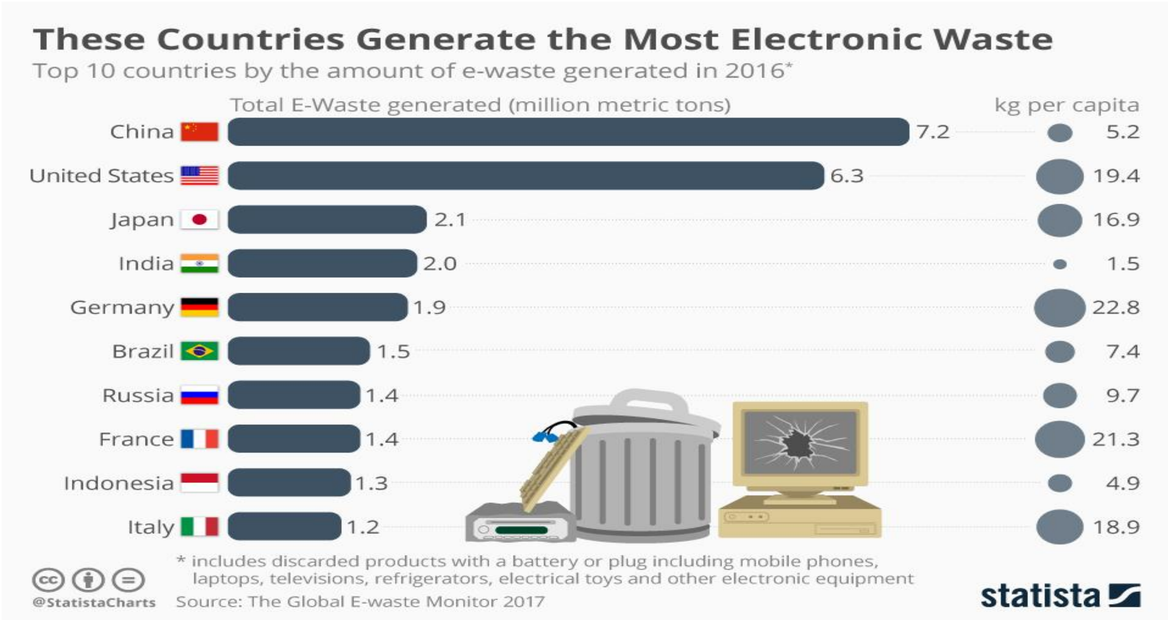
6. **Enhancement of Geotechnical Practices**
    - The research bridges a gap in understanding the interplay between environmental contamination and geotechnical engineering.
    - It provides engineers with knowledge to assess and remediate contaminated soils in construction projects.
7. **Foundation for Remediation Strategies**
    - The findings can be used to develop cost-effective and sustainable remediation techniques to restore contaminated soils.
    - It helps in identifying soil stabilization methods that can mitigate the adverse effects of e-waste contaminants.
8. **Global Relevance and Local Impact**
    - While the issue is of global concern, the study focuses on local contexts, providing region-specific insights into e-waste contamination in areas with poor waste management infrastructure.
9. **Awareness and Education**
    - The research raises awareness among stakeholders, including government bodies, engineers, and the public, about the importance of addressing e-waste contamination.
    - It also serves as an educational resource for future studies in geotechnical and environmental engineering.
10. **Support for Circular Economy Initiatives**
    - By emphasizing the need to reduce e-waste contamination, the study supports global efforts toward a circular economy, promoting recycling and reuse of electronic materials.

CHAPTER 2

E-WASTE GENERATION OF IN DIFFERENT COUNTRIES

2.1 E-waste Global scenario:

As far as global e-waste management is concerned, Switzerland is the first country to implement the organized e-waste management system in the world. Extended Producer Responsibility(EPR) and Advance Recycling Fee (ARF) are the backbone of e-waste management system in Switzerland and other developed countries Advanced countries like USA, UK, France &Germany generate 1.5 to 3 million tons of eWaste annually and are among the largest generators of eWaste. But these countries also have standardized e-waste management processes in place. Proper eWaste management (Awasthi* et al., 2015.), from efficient sourcing and collection right up to extraction and disposal of material, has ensured that this huge pile of junk turns into a lucrative business opportunity. Due to very stringent environmental standards, the cost of collection, pre-processing, recycling and disposal are pretty high. So for every organized recycler in the first world countries, there are quite a few who pose as recyclers and are mere brokers who ship these obsolete items to developing countries like India and China in the pretext of donation or second-hand goods. With very ambiguous laws related to environmental protection, India , China and a few African countries have become dumping sites to the first world countries. There are many countries that have already started the take back system for electronic products and they also have dedicated laws on e-waste management. In USA, National Electronics Action Plan has been initiated by US Environment Protection Agency to address the various issue related to electronic waste. Two very important frameworks for protecting environment from e-waste have been put forward by European Union i.e., WEEE Directives and Restriction of use of Certain Hazardous Substances (RoHS), which are also implemented by other countries. According to E directives (2003), it is mandatory for all 27 countries of European Union to recycle their e-waste. Basel Convention is also nice step taken by UNEP to control the international trading of hazardous waste and India is also signatory to this.

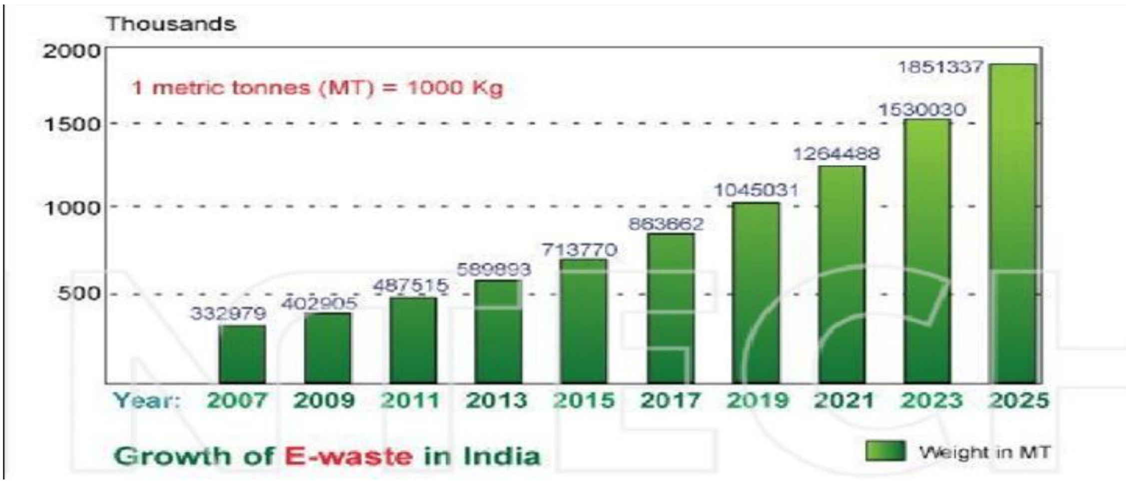


Source- https://www.statista.com/chart/2283/electronic-waste/

2.2 E-waste Indian Scenario

The story of current Indian e-waste management is different from the worldwide. Practices waste is a serious Issue because of the Informal recycling activities. Therefore, quantification of e-waste in India is very difficult and, there is no mechanism and policy to check the flow of e-waste I the system. In case of PCs, 22% of the e-waste is generated by households and it is the business sector which accounts for the 78% the e-waste, because 83% of household customers are first time buyers. So business sector is mainly responsible for the waste generation. In addition to this, about 1050 tonnes per year of computer waste comes from retailers' and manufacturers. This is important to note that in spite of global agreements, e-waste from developed nations is imported to developing nations like India. Sixty-five cities in India generate more than 60% of the total e-waste generated in India. Ten states generate 70% of the total e-waste generated in India. Among top ten cities generating ewaste, Mumbai ranks first followed by Delhi, Bangalore, Chennai, Kolkata, Ahmadabad, Hyderabad, Pune, Surat and Nagpur. There are two small e-waste dismantling facilities are functioning in Chennai and Bangalore. There is no large scale organized e waste recycling facility in India and the entire recycling exists in unorganized sector. In India, probably the e waste is given to the rag pickers who pay some amount to the customer from whom they are collecting the waste. Most of the activities, like collection, transportation, segregation, dismantling, recycling, disposal, etc., are carried out by informal sector. The rag pickers (also known as kabadiwala) collect all kind of waste like papers, books, newspapers, plastic, cardboard, polythene, metals, etc. including e-waste, and earn their livelihood by selling it to middlemen or scrap dealers. This is a very good source of income not only for rag pickers but also for middlemen and scrap dealers. E-waste is mostly handled by unskilled workers and they do not take proper safety measures. Recycling and disposal is not properly done due to lack of appropriate technology. Also, very few companies are there which have implemented take back" system voluntarily. There is no clear data on the quantity generated and disposed of each year and the resulting extent of environmental risk. According to the literature review it's revealed that about 50% of the public are aware of environmental and health impacts of the electronic items. Hence, there is an urgent need of implementation of proper e-waste management system in India. It is an emerging problem because of the volumes of e-waste being generated and the content of both toxic and valuable materials in them. The fraction including iron, copper, aluminium, gold and other metals in e-waste is over 60%, while plastics account for about 30% and the hazardous pollutants comprise only about 2.70%. Electronic devices form a complex mixture of materials and components, often containing several hundreds of different substances, many of which are toxic and create serious pollution upon disposal. These include heavy metals such as mercury, lead, cadmium, chromium and flame retardants such as polybrominated biphenyls (PBB) and polybrominateddiphenylethers (PBDEs). Disposal of the e-wastes is an emerging global environmental issue, as these wastes have become one of the fastest growing waste types in the world. The recent investigations of workers involved in manufacturing the chips, he drives and circuit boards are reporting health problems. Even the workers who handle even e-waste as a scrap has health problems. The cycling and disposal of computer waste in these countries becomes a serious problem since their treatment methods remain rudimentary. Such activities pose grave environmental and health hazards; for example, the deterioration of local drinking water which can result in serious illnesses.

Most of the e-waste was generated in Asia: 16 Mt in 2014. This was 3.7 kg for each inhabitant (Balde et al., 2015). According to National WEEE task force, reported that total E-waste or WEEE generation was about 146,000 tonnes/year in India in 2005 (Wath et al., 2010). Another hand, Central Pollution Control Board (CPCB) estimated that 1.347 lakh MT of E-waste was generated in the country in the year 2005, which can be expected to reach 8.0lakh MT by 2012. In addition, GTZ (Deutsche Gesellschaft für Technische Zusammenarbeit)-MAIT (2007)1 had estimated and suggested that huge amount (3,30,0000 tonnes) of WEEE generated in 2007 in India. However, other researcher also estimated as 420,000 tonnes/year (Wath 2010), and 382,979 tonnes/year generated in India (Skinner 2010). Although, E-waste flows complexity in India along with inadequate record-keeping pushing its estimation more difficult (Streiche-Porte et al., 2007.



Source-https://www.researchgate.net/publication/304771310_E-Waste_in_Transition_-_From_Pollution_to_Resource/figures?lo=1

2.3 E-waste China Scenario

The total amount of e-waste was estimated as 3.6 million tonnes in 2010 and nests to 5.5 million tonnes in 2013, and is expected to reach 11.7 million tonnes by 2020 and 20 million tonnes by 2040. This e-waste, mainly includes air conditioners (26%), televisions (24%), computers (14%), refrigerators (12%), washing machines (7%), printers (9%) and fluorescent lamps (7%) are produces respectively (Li et al., 2015). On January 1, 2015, a new Catalogue of WEEE Recycling (Batch 2) was issued, extended by covering of more nine type of categories of WEEE. This ‘new’ WEEE categories will increase the amount of governmental oversight of the recycling industry (Zeng et al., 2015 (Under review paper).2 although, formal as well as informal activities involved in the collection system. In the meantime, the informal collection is reported from urban areas due to its most chances in highly populated places as well as availability of discarded or obsolete EEE. Another hand its availability is very low because slow penetration rate of home appliances with introduction/replacement of new technologies (Wang et al., 2013).

Fig1- Chinese port city of Taizhou

2.4 E-waste USA Scenario

According to UNEP (2007) e-waste is rapid growing component of municipal waste, including e-waste accounted about 70% of the heavy metals, by covering 40% of the lead, found in landfills with total 40 million metric tons annually at global. However, citizens have no idea what to do with their old computers and 75% of which are still sitting in closets of homes. The fate of most of the e-waste produced in the US remains a mystery, with experts assuming the majority is placed into landfill, incinerated, exported, or just abandoned in storage. In this regard, presently, USA generated 11.7 Mt of e-waste (7.9 Mt for North America, 1.1 Mt for Central America, and 2.7 Mt for South America), which represented 12.2 kg/inh. According to Balde et al. (2015) report the United States (7.1 Mt) is at top position in e-waste generation as absolute quantities followed by Brazil (1.4 Mt) and Mexico (1.0 Mt). In another hand, America generated highest e-waste quantity United States (22.1 kg/inh.), Canada (20.4 kg/inh.) and the Bahamas (19.1 kg/inh.).

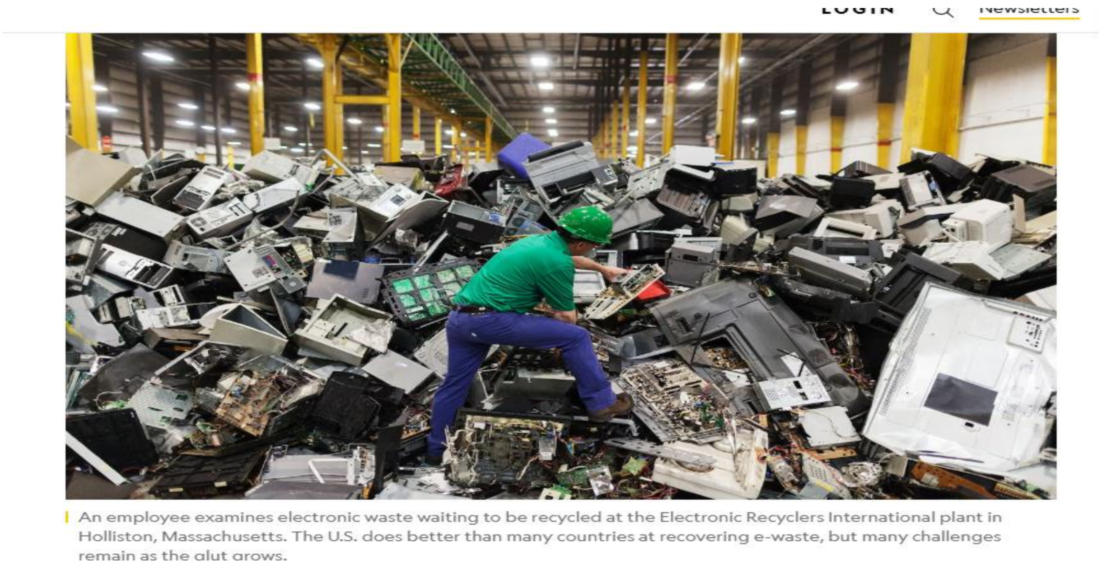


Fig 2 Electronic Waste at Massachusetts,US

2.5 E-waste European Union Scenario

European waste policy does not mainly aim to treat waste streams but rather place in the foreground of interest the complete supply chain of a product. Recycling only takes the third place whereas recovery and disposal represent the least favourable options (Bartl, 2014). The highest per inhabitant e-waste quantity (15.6 kg/inh.) was generated in Europe. However, the per inhabitant amount was nearly as high as Europe's (15.2 kg/inh.). Basically, waste generation is a huge business and numerous stakeholders are not interested to reduce waste. More sophisticated incentives are required to decouple economic growth from waste generation (Cucchiella et al., 2015).

Fig 3. E waste at Europe

CHAPTER 3

LITERATURE REVIEW AND BACKGROUND

3.1 Literature Review

The increasing proliferation of electronic waste (e-waste) poses significant environmental and health challenges. Various studies have explored the impacts, management strategies, and policy frameworks surrounding e-waste, providing a foundation for addressing its consequences, particularly in soil contamination. This section reviews the key findings from selected research works. Some of the famous research works are "E-Waste: Challenges and Its Management" (2015)by N. Tyagi, S.K. Baberwal, and N. Passi, "Comparative Examining and Analysis of E-Waste Recycling in Typical Developing and Developed Countries" (2016)by Abhishek Kumar Awasthi, Xianlai Zeng, and Jinhui Li, "Perils of Electronic Waste: Issues and Management Strategies" (2012) by Bina Rani, Upma Singh, Raaz Maheshwari, and A.K. Chauhan, "E-Waste Management and Its Consequences: A Literature Review" (2017) by Jitendra Patel and ArnavChowdhury, "E-Waste and Its Future Challenges in India" (2018) by Lamma O.A. and A.V.V.S. Swamy, "Electronic Waste in India: Problems and Policies" (2017) by Anwesha Borthakur and Pardeep Singh.

Impacts of Contaminants from Different Sources on Geotechnical Properties of Soils by Shan Zhao , Baoju Zhang , Wenbing Zhang , Xinjia Su and Botao Sun (2023)

Within sites affected by industrial, domestic, and agricultural contaminants, the geotechnical characteristics of soils are susceptible to a certain degree of deterioration. The resultant corrosion of concrete exacerbates the vulnerability of underground structures, posing a potential hazard to the stability of superstructures. It aims to elucidate the underlying mechanisms of various impacts, revealing that the permeability, shear strength, and compressibility of soils can either increase or decrease depending on the specific contaminants present.

E-Waste: Challenges and Its Management (2015) by N. Tyagi, S.K. Baberwal, and N. Passi

This 2015 study provides an overview of the challenges posed by e-waste and its management strategies. It emphasizes that improper e-waste disposal is a significant contributor to soil and water contamination, with heavy metals such as lead, cadmium, and mercury being the primary pollutants. The authors advocate for sustainable management practices, including recycling and recovery of valuable materials from e-waste. The paper highlights the lack of awareness and infrastructure in developing countries, which exacerbates the environmental impact. This work serves as a call to improve e-waste policies and recycling technologies to mitigate contamination risks.

Comparative Examining and Analysis of E-Waste Recycling in Typical Developing and Developed Countries (2016) by Abhishek Kumar Awasthi, Xianlai Zeng, and Jinhui Li

This comparative analysis, published in 2016, investigates e-waste recycling systems in developing and developed countries, emphasizing the disparities in infrastructure and regulations. The authors reveal that developing countries rely heavily on informal recycling methods, which lead to significant environmental degradation, including soil contamination. Developed nations, on the other hand, employ advanced technologies that minimize environmental harm. The study highlights the importance of adopting best practices from developed countries, such as formalized recycling systems and stringent regulations, to improve e-waste management in developing regions.

Perils of Electronic Waste: Issues and Management Strategies (2012) by Bina Rani, Upma Singh, Raaz Maheshwari, and A.K. Chauhan

This 2012 paper examines the hazards of e-waste, focusing on its environmental and health impacts. The authors identify heavy metals, flame retardants, and persistent organic pollutants as the primary contaminants in e-waste. Their leaching into soil and groundwater creates long-term risks to ecosystems and human health. The study discusses the potential for phytoremediation and other innovative techniques to remediate contaminated soils. Additionally, it underscores the need for public awareness campaigns and stricter enforcement of e-waste management regulations to prevent contamination at the source.

E-Waste Management and Its Consequences: A Literature Review (2017) by Jitendra Patel and Arnav Chowdhury

This comprehensive review, published in 2017, synthesizes existing research on e-waste management, focusing on its environmental consequences. The authors highlight the role of poorly managed e-waste in contaminating soils, particularly in regions where informal recycling practices are prevalent. They discuss various management strategies, including extended producer responsibility (EPR) and the development of circular economies, which could help reduce e-waste's environmental footprint. The paper also emphasizes the need for technological advancements in recycling processes and the importance of global collaboration to tackle the growing e-waste crisis.

E-Waste and Its Future Challenges in India (2018) by Lamma O.A. and A.V.V.S. Swamy

Published in 2018, this paper addresses the specific challenges posed by e-waste in India, where the informal sector dominates recycling practices. The authors emphasize that inadequate infrastructure, lack of enforcement of existing laws, and limited public awareness have led to widespread soil and water contamination. The study calls for strengthening India's regulatory frameworks, increasing investments in formal recycling facilities, and fostering public-private partnerships to address the growing e-waste crisis effectively.

Electronic Waste in India: Problems and Policies (2017) by Anwesha Borthakur and Pardeep Singh

This 2017 study provides a detailed analysis of the issues associated with e-waste in India and evaluates the effectiveness of existing policies. The authors identify gaps in India's e-waste management system, particularly concerning soil contamination from informal recycling. They argue that while regulations such as the E-Waste Management Rules (2016) are steps in the right direction, their implementation remains weak. The study advocates for increased public awareness, stricter enforcement of regulations, and incentives for businesses to adopt environmentally friendly practices.

Key Takeaways from the Literature

1. **Environmental Impact**: All reviewed studies emphasize that e-waste is a significant source of soil contamination, with heavy metals and persistent organic pollutants being the primary contributors.
2. **Regional Challenges**: Studies specific to India highlight the dominance of informal recycling practices and their impact on soil and water quality.
3. **Policy and Infrastructure Gaps**: Several studies identify a lack of infrastructure, weak implementation of policies, and limited awareness as major barriers to effective e-waste management.
4. **Sustainable Practices**: There is a consensus on the need for formalized recycling systems, public awareness campaigns, and advanced remediation techniques to tackle e-waste contamination.
5. **Global Perspectives**: Comparing developed and developing countries underscores the need for international collaboration and knowledge-sharing to address the global e-waste crisis.

This literature review highlights the critical gaps in e-waste management and the urgent need for sustainable practices to prevent soil contamination, aligning with the objectives of the present study.

3.2 Definition and Composition

E-waste means electrical waste and electronic equipment, whole or in part included in, but not confined to equipment, scraps or rejects from their manufacturing process. E-waste is divided into different categories according to Environment Protection Act, 1986.

E-Waste: Types and Composition

Electrical and electronic equipment can contain a large number of hazardous substances, including heavy metals (e.g., mercury, cadmium, lead, etc.), flame retardants (e.g., pentabromophenol, polybrominateddiphenyl ethers

(PBDEs), tetrabromobisphenol A (TBBPA), etc.) and other substances (figure presence of these substances, e-waste is generally considered as hazardous waste, which, if improperly managed, may pose significant human and environmental health risks. components' of ewaste can be divided on the basis of their quantity; large, small and trace amounts. large quantities include epoxy resins (polyvinyl chlorides), thermosetting plastics silicon, beryllium, carbon, iron certain common components/parts of electrical and electronic appliances that contain the majority of the hazardous substance.

Americium: one of the radioactive sources, known to be carcinogenic.

Mercury: Mainly found in fluorescent tubes applications), tilt switches (mechanical doorbells, and flat screen monitors. It causes health effects such as; sensory impairment, dermatitis, memory loss, and muscle weakness. Environmental effects in animals include death, reduced fertility, slower growth and development.

Sulphur: Found in lead-acid batteries. Health effects include liver damage, kidney damage, heart damage, and eye and throat irritation. When released in to the environment, it can create sulphuric acid.

BFRs (Brominated flame retardants): Used as flame retardants in plastics in most electronics includes PBBs, OctaBDE, PentaBDE. Health effects include impaired development of the nervous system, thyroid p problems. Environmental effects: similar effects as in animals as humans. PBBs were banned from 1973-1977 on. PCBs were banned during the 1980's.

Cadmium: Found in light-sensitive resistors, corrosion alloys for marine and aviation environments and cadmium batteries. When not properly recycled it can leach into the soil, harming microorganisms and disrupting the soil ecosystem. Exposure is caused by proximity to hazardous waste sites factories and workers in the metal refining industry. The inhalation of cadmium can cause severe damage to the lungs and is also known to cause kidney damage.

Lead: Found in CRT monitor glass, lead-acid batteries formulations of PVC. A typical 15-inch cathode ray tube may contain 1.5 pounds of lead but other CRTs have been estimated as having up to 8 pounds of lead.

Beryllium oxide: Commonly used as filler in some thermal interface materials such as thermal grease used on CPUs and power transistors, magnetrons, X-ray transparent ceramic windows, heat transfer fins in vacuum tubes and gas lasers.

CHAPTER 4

Assessment of E-Waste Contaminants and Their Interaction with Soil Components

4.1 Introduction

The improper disposal and recycling of e-waste pose significant environmental threats, primarily through the release of toxic contaminants into the soil. These contaminants, including heavy metals, plastics, and organic chemicals, interact with soil components in complex ways that can disrupt soil structure, chemistry, and biological activity. This chapter explores how these contaminants interact with soil components and analyses the potential effects on microbial ecology and plant health.

4.2 E-Waste Contaminants and Their Properties

E-waste contains a variety of hazardous substances, which can be broadly classified into two categories: **inorganic contaminants** (such as heavy metals) and **organic contaminants** (such as flame retardants and persistent organic pollutants). Each of these contaminants has distinct interactions with soil components, influencing soil chemistry, structure, and biology.

1. **Heavy Metals**

    - **Lead (Pb):** Common in solders, lead is highly toxic to soil organisms and plants. It can bind with soil particles, particularly clay, and affect the mobility of other nutrients. Lead accumulation in soil often leads to nutrient imbalances, reducing soil fertility.

    - **Cadmium (Cd):** Found in batteries, cadmium is another toxic metal that binds strongly with soil organic matter and clay. Its toxicity disrupts plant growth and microbial activity by interfering with enzymes involved in nutrient uptake.

    - **Mercury (Hg):** Often released through the breakdown of fluorescent lights, mercury can accumulate in soil in both organic and inorganic forms, affecting microbial diversity and disrupting the biogeochemical cycles in soil.

2. **Plastics and Other Non-Biodegradable Components** Plastics, commonly found in e-waste, are non-biodegradable and can persist in soil for hundreds of years. The presence of microplastics can lead to physical changes in soil texture, affecting water retention and root penetration. Plastics may also leach harmful additives like phthalates and bisphenol A (BPA), which can further disrupt soil quality.

3. **Flame Retardants and Persistent Organic Pollutants (POPs)**

   - **Polybrominateddiphenyl ethers (PBDEs):** These flame retardants can accumulate in soil and enter the food chain, affecting both plant and animal health. PBDEs are highly persistent in the environment and disrupt endocrine function, which can have long-term consequences on soil fertility.

   - **Polychlorinated biphenyls (PCBs):** Present in older electronic equipment, PCBs are toxic to microorganisms and can accumulate in soil over time, reducing microbial biodiversity and soil health.

4.3 Interaction of E-Waste Contaminants with Soil Components

The contaminants released from e-waste interact with the soil in various ways, primarily affecting soil pH, fertility, texture, and biological activity. These interactions can be categorized as chemical, physical, and biological.

1. **Chemical Interactions**

   - **Soil pH and Metal Bioavailability:** Heavy metals like cadmium, lead, and mercury can alter soil pH. For example, acidic conditions enhance the solubility of these metals, increasing their bioavailability and toxicity to plants and soil organisms. In contrast, alkaline soils may reduce metal solubility but can lead to the precipitation of harmful compounds, which could still impact plant growth.

   - **Complexation with Soil Organic Matter (SOM):** Many heavy metals, such as lead and cadmium, can bind with organic matter in the soil, forming complexes that reduce their mobility. However, this also means that these metals are often retained in the soil for long periods, posing a risk to long-term soil health.

2. **Physical Interactions**

   - **Soil Structure and Compaction:** The introduction of non-biodegradable materials like plastics can disrupt the physical structure of soil, reducing porosity and affecting water retention. Micro plastics, in particular, can reduce the soil's ability to absorb water and nutrients, which in turn affects root growth and soil aeration.

   - **Changes in Soil Texture:** Some e-waste contaminants may alter the texture of the soil. For example, plastic particles can reduce soil permeability, leading to increased surface runoff, water logging, and reduced root penetration.

3. **Biological Interactions**

   - **Impact on Soil Microbial Ecology:** Heavy metals and other toxic substances from e-waste can significantly affect soil microbial communities. These contaminants can reduce microbial diversity by inhibiting the growth of beneficial microorganisms, such as nitrogen-fixing bacteria and decomposers. The loss of these organisms can impair nutrient cycling and decrease soil fertility.

   - **Disruption of Soil Enzyme Activity:** Soil enzymes, which play a critical role in nutrient cycling and organic matter decomposition, are highly sensitive to contaminants. For example, heavy metals such as mercury and cadmium can inhibit the activity of enzymes like phosphatases and dehydrogenases, leading to reduced nutrient availability in the soil.

   - **Altered Microbial Communities:** E-waste contamination can lead to a shift in microbial community composition, with a decline in the populations of beneficial microbes and an increase in those capable of tolerating toxic environments. This shift can disrupt soil health and the ability of the soil to support plant growth.

CHAPTER 5

Impacts of Contaminants on Geotechnical Properties of Soil

The foundation soil consists of both coarse and fine particles. Coarse-grained soil typically exhibits a single-grained structure, with varying void ratios and dry densities Sustainability **2023**, 15, 12586 5 of 19 across different gradations. In the case of fine-grained soils, the interactions between clay particles result in either net attraction or net repulsion forces, leading to the formation of a flocculent structure with larger pores or a dispersed structure with smaller pores, respectively. The thickness of the double layer formed by clay particles is microscopically influenced by the permeating fluid, while changes in the clay structure impact the permeability, shear strength, and compressibility of the clay. Consequently, the proportion of fine-grained and coarse-grained components plays a crucial role in determining the magnitude of the physical and mechanical properties of the soil.

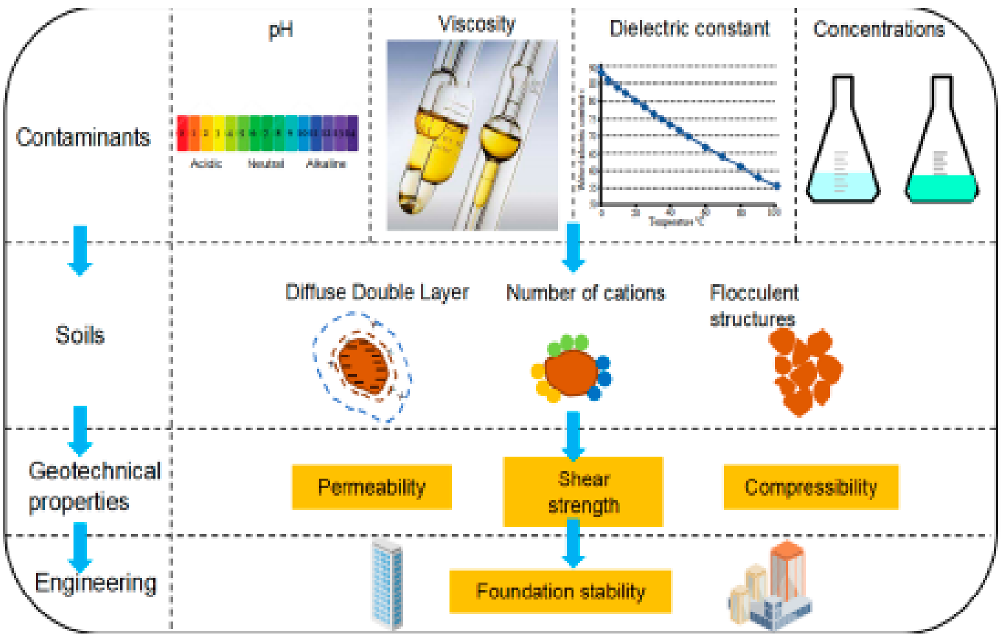


Figure 1. Mechanisms of the impacts of contaminants on the geotechnical properties of soils.

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Permeability which refers to the capacity of a soil to transmit specific fluids, is a significant indicator of soil settlement. Various factors influence permeability, including soil types, soil structure, and the characteristics of permeating fluids. In terms of the soil itself, gradation plays a crucial role in determining the magnitude of the permeability coefficient. In the context of contaminated soil and groundwater environments, the variability in permeability primarily stems from changes in the permeating fluids, which can consist of one or more combinations of acidic, alkaline, neutral, polar, and nonpolar fluids. The density, viscosity, and dielectric constant of the permeating fluid are vital factors that influence soil permeability. The impacts of different contaminants on soil permeability are summarized in **Table1-**

SOIL TYPE	CONTAMINANT	PERMEABILITY COEFFICIENT (m/s)		MECHANISMS
		NATURAL SOIL	CONTAMINATED SOIL	
HIGH PLASTIC CLAY	LEAD NITRATE	3.22*10^-10	1.86*10^-10	The deposition of salt in the pores of the soil
COMPACTED BENTONITE	COPPER SULFHATE	1.0*10^-13	2.0*10^-13	The shrinkage of the double layer of clay particles and increase of effective pore.

Shear Strength

The shear strength of soil refers to its maximum resistance against shearing stress at the failure plane. According to the Mohr–Coulomb strength theory, soil shear strength comprises cohesion strength and friction strength, as shown in **Equation (1):** $\tau = c + \sigma \tan \varphi$

Cohesion is the combined result of attractive and repulsive forces between soil particles, while internal friction is the resistance between individual soil particles at their contact points due to friction. It is worth noting that the internal friction angle is typically greater in coarse-grained soil compared to fine-grained soil. Numerous studies have investigated the factors influencing soil shear strength, including soil bulk density, water content, organic carbon content, and permeable fluids. Both cohesion and the internal friction angle are crucial parameters that affect soil shear strength. Therefore, it is essential to explore the variations in soil cohesion and the internal friction angle resulting from contamination.

Table2 provides a summary of the changes in soil cohesion and the internal friction angle before and after soil contamination.

Impacts of different contaminants on **Cohesion c(MPa)** and the **Internal friction angle (*φ*)** of soil.

Soil Type	Test Method	Contaminant	Cohesion		Internal Friction		Mechanisms
			Natural Soil	Contaminated Soil	Natural Soil	Contaminated Soil	
90% Kaolinite and 10% sand	Direct Shear Test	Lead Nitrate	36	21	32.48	32.93	The invasion of heavy metal cations leads to the double layer contraction, which leads to the flocculent structure of the clay and the decrease of the shear strength.
90% Kaolinite and 10% sand	Direct Shear Test	Zinc Nitrate	36	28.67	32.48	33.45	
60% Kaolinite and 40% sand	Direct Shear Test	Lead Nitrate	31	15	36.17	37.47	
60% Kaolinite and 40% sand	Direct Shear Test	Zinc Nitrate	31	23.74	36.17	37.88	

CHAPTER 6

Impact on Human Health and Environment

Electronic waste can come in many forms including computers, photocopiers, printers, faxes, monitors, batteries and mobile phones. E-waste contains significant quantities of toxic metals and chemicals. Electronic wastes can cause widespread environmental damage due to the use of toxic materials in the manufacture of electronic goods Hazardous materials such as lead, mercury and hexavalent chromium in one form or the other are present in such wastes primarily consisting of Cathode ray tubes (CRTs), Printed board assemblies, Capacitors, Mercury switches and relays, Batteries, Liquid crystal displays (LCDs), Cartridges from photocopying machines, Selenium drums (photocopier) and Electrolytes. Although it is hardly known, e-waste contains toxic substances such as Lead and Cadmium in circuit boards; lead oxide and Cadmium in monitor Cathode Ray Tubes (CRTs); Mercury in switches and flat screen monitors; Cadmium in computer batteries; polychlorinated biphenyls (PCBs) in older capacitors and transformers; and brominated flame retardants on printed circuit boards, plastic casings, cables and polyvinyl chloride (PVC) cable insulation that releases highly toxic dioxins and furans when burned to retrieve Copper from the wires. All electronic equipments contain printed circuit boards which are hazardous because of their content of lead (in solder), brominated flame retardants (typically 5-10 % by weight) and antimony oxide, which is also present as a flame retardant (typically 1- 2% by weight). Nickel (Ni) which is present in E-waste causes skin damage, asthma, lung damage and carcinogen. It enters in environment through air. Antimony (Sb) causes skin irritation, hair loss, lung and heart damages and fertility problems. This element is better absorbed in soil containing steel, magnesium or aluminium. Poly brominated diphenylethers(PBDE) causesanaemia damages skin,liver,stomach and thyroid, contamianted water and contaminate chain of production of some food. Tetra bromobisA(TBBPA) has some mutations and carcinogen effects. It causes damages to endocrine system. Poly brominatedbiphenyls (PBB) passes along with food chain damages kidneys liver and thyroid. Chlorofluorocarbon (CFC) destroys ozone layer. Polyvinyl chloride (PVC) damages animal kidney and soluble in water and Arsenic is carcinogenic causes skin and lung cancer. Barium causes gastrointestinal disorder and muscle weakness, changes heart beat rate, paralysis and accumulate in aquatic system. Beryllium inhalation causes pneumonia, respiratory inflammation and lung cancer. Cadmium and Mercury are carcinogenic and causes lung damage. Therefore, a treatment technology needs to be developed for clean-up of ewaste from the environment.

CHAPTER 7

Management of E-Waste

Because of uncertainty of the ways to manage, electronic junks lie unattended in homes, offices, warehouses etc. and its commonly mixed with family wastes, that are finally disposed off at landfills. This necessitates implementable management measures. In industries management of e-waste ought to begin at the purpose of generation. This will be done by waste step-down techniques and by property product style (Ramachandra T.V. &Saira Varghese K., 2004). Waste step-down in industries involves adopting:

- Inventory Management,
- Production-Process Modification,
- Volume Reduction,
- Recovery and Utilise

Inventory management

Proper management over the materials employed in producing method is a crucial thanks to cut back waste generation (Freeman, 1989). By reducing each, the number of venturous materials employed in the method and also the amount of excess raw materials available, the amount of waste generated will be reduced. This could be tired 2 ways i.e. establishing material-purchase review and management procedures and inventory pursuit system. Developing review procedures for all material purchased is the initiative in establishing a listing management program. Procedures ought to need that each material should be approved before purchase. Within the approval method, all production materials area unit evaluated to look at, whether they contain venturous constituents or various hazardous materials area unit obtainable.

Another inventory management procedure for waste reduction is to confirm that only required amount of a fabric is ordered. This can need the institution of a strict inventory pursuit system. Purchase procedures should be enforced to make sure that materials area unit ordered solely associate with need basis.

Production-process modification

Changes should be created within the production method, which can scale back waste generation. This reduction is accomplished by a lot of economical use of input materials within the production method. Potential waste reduction techniques are weakened into 3 categories:

• Improved operational and maintenance procedures,

• Material amendment and

• Process-equipment modification.

Improvements within the operation and maintenance of method instrumentality may result in vital waste reduction. This will be accomplished by reviewing current operational procedures and examination of the assembly method for methods to boost its potency. Instituting normal operation procedures will optimise the employment of raw materials within the production method and scale back the potential for materials to be lost through leaks and spills. A strict maintenance program, that stresses corrective maintenance, will scale back waste generation caused by failure. Nursing employee-training program may be a key component of any waste reduction program. Training ought to embrace correct operational and handling procedures, correct instrumentality use, counselled maintenance and examination schedules, correct method management specifications and correct management of waste materials. Hazardous materials utilized in either a product formulation or a production method should be replaced with a less dangerous or non-hazardous material. Implementation of this waste - reduction technique might require just some minor changes or it should need intensive new method instrumentality. As an example, a printed circuit manufacturer will replace solvent based product with water-based flux and at the same time replace solvent vapour degreaser with detergent elements washer.

Volume Reduction

Volume reduction includes those techniques that take away the venturesome portion of a waste from a non-hazardous portion. These techniques area unit typically to scale back the quantity, and therefore the value of eliminating a waste product. The techniques that may be wont to cut back waste-stream volume may be divided into two general categories: supply segregation and waste concentration. Segregation of wastes is in several cases an easy and economical technique for waste reduction. Wastes containing differing types of metals may be treated one by one so the metal worth within the sludge may be recovered. Concentration of a waste stream might increase the probability that the fabric may be recycled or reused.

Recovery and use

This technique might eliminate waste disposal prices, scale back staple prices and supply financial gain from a in demand waste. Waste is recovered on-the-scene, or at an off-site recovery facility, or through put down trade exchange. Variety of physical and chemical techniques like reverse diffusion, electrolysis, condensation, electrolytic recovery, filtration, activity etc are accessible to reclaim stuff. As an example, a printed-circuit board manufacturer will use electrolytic recovery to reclaim metals from copper and tin-lead plating bathtub. However, usage of risky merchandise has very little environmental profit if it merely moves the hazards into secondary merchandise that eventually ought to be disposed of. Unless the goal is to revamp the merchandise to use non-hazardous materials, such usage may be a false resolution.

CHAPTER 8

Need For E-Waste Policy And Regulation

The policy should address all issues ranging from production and trade to final disposal, including technology transfers for the recycling of electronic waste. Clear regulatory instruments, adequate to control both legal and illegal exports and imports of e-waste and ensuring their environmentally sound management should be in place. There is also a need to address the loop holes in the prevailing legal framework to disposal of e wastes in municipal landfills and encourage owners and generators of e-waste to properly recycle the wastes. Conductivity refers to the ability of a material to transmit water. In the context of Geosynthetic Clay Liners (GCLs), understanding hydraulic conductivity is crucial for evaluating their effectiveness as barriers against fluid migration. A complete national level inventory, covering all the cities and all the sectors must be initiated. A public-private participatory forum (E-Waste Agency) of decision making and problem resolution in e-waste management must be developed. This could be working group comprising Regulatory Agencies, NGOs, Industry Associations, experts, etc. to keep pace with the temporal and spatial changes in structure and content of e-waste. This working group can be the feedback providing mechanism to the government that will periodically review the existing rules, plans and strategies for e-waste management. Mandatory labelling of all computer monitors, television sets and other household/industrial electronic devices may be implemented for declaration of hazardous material contents with a view to identifying environmental situation through regulations. Though an important step; are usually only modestly effective because of the lack of enforcement. While there has been some progress made in this direction with the support of various agencies, enforcement of regulations is often weak due to lack of resources and underdeveloped legal systems. Penalties for noncompliance and target for collection or recycling are often used to ensure compliance.

Policy level initiatives in India

In view of the ill-effects of hazardous wastes to both environment and health, several countries exhorted the need for a global agreement to address the problems and challenges posed by hazardous waste. However, the policy level initiatives regarding E-waste in India is quite rudimentary and needs immediate attention. Following are some of the policy level initiatives in India regarding E-waste.

1. The Hazardous Wastes (Management and Handling) Amendment Rules, 2003 Under Schedule 3, E-waste is be defined as “Waste Electrical and Electronic Equipment including all components, sub-assemblies and their fractions except batteries falling under these rules”. The definition provided here is similar to that of Basal Convention. E-waste is only briefly included in the rules with no detail description.
2. Guidelines for Environmentally Sound Management of E-waste, 2008 This guideline was a Government of India initiative and was approved by Ministry of Environment and Forest and Central Pollution Control Board. It classified the E-waste according to its various components and compositions and mainly emphasises on the management and treatment practices of E-waste. The guideline incorporated concepts such as “Extended Producer Responsibility”.
3. The e-waste (Management and Handling) Rules, 2011 this is the very recent initiative and the only attempt in India meant solely for addressing the issues related to E-waste. These rules are not implemented in India as yet and will only come into practice from 1st May, 2012. According to this regulation, ‘electrical and electronic equipment’ means equipment which is dependent on electric currents or electro-magnetic fields to be fully functional and ‘e-waste’ means waste electrical and electronic equipment, whole or in part or rejects from their manufacturing and repair process, which are intended to be discarded. These rules are meant to be applied to every producer, consumer or bulk consumer involved in manufacturing, sale purchase and processing of electrical and electronic equipment, collection centres, dismantlers and recyclers of e-waste. Responsibilities of producers, collection centres, consumers, dismantlers, recyclers etc. are defined and incorporated in these rules.

CHAPTER 9

Challenges and Future Development

9.1 Concerns & Challenges

The management of e-waste faces several significant challenges, including a lack of awareness among both consumers and manufacturers regarding proper disposal methods. There is inadequate regulation of e-waste generation and recycling, with much of the processing being carried out by the informal sector using out dated and polluting techniques. Workers in these sectors remain unaware of the toxic hazards they face, and the absence of modern technologies results in incomplete resource extraction. Additionally, there are no strict regulations to handle e-waste, leading to improper disposal, such as landfilling of partially dismantled products. Moreover, e-waste sites often rely on women and child labour, exacerbating the issue.

9.2 Future Scope

The issue of e-waste contamination and its impact on soil ecosystems is a growing concern, especially as technological advancements continue to accelerate the generation of electronic waste. While significant progress has been made in understanding the nature of e-waste contaminants and their effects on soil components, much remains to be explored. The following outlines the future scope for research and development in addressing e-waste contamination in soils:

9.2.1 Development of Sustainable E-Waste Management Technologies

As e-waste volumes increase globally, developing more efficient, sustainable, and environmentally friendly recycling technologies will be critical. Future research should focus on creating closed-loop recycling systems that minimize the release of hazardous substances into the environment. Advancements in green chemistry and bio-recycling processes could offer innovative solutions for reducing soil contamination.

Additionally, technologies that can recover and reuse valuable materials from e-waste without releasing toxic chemicals will contribute to reducing the long-term environmental footprint of electronic waste.

9.2.2 Improved Soil Remediation Techniques

Current soil remediation methods, such as phytoremediation and bioremediation, show promise for mitigating the effects of e-waste contaminants. However, these techniques need further refinement and testing to increase their efficiency in dealing with complex mixtures of pollutants found in e-waste. Future research could explore genetically engineered plants or microorganisms capable of absorbing or breaking down multiple contaminants at once. Additionally, the development of nanotechnology-based remediation solutions could be explored, particularly for the removal of heavy metals and micro plastics from contaminated soils.

9.2.3 Impact of E-Waste on Biodiversity

Further investigation into the impacts of e-waste on soil biodiversity, particularly on soil microorganisms, is essential. Research could focus on the role of e-waste contaminants in altering the functional diversity of soil microbial communities and how this affects ecosystem processes like nutrient cycling, organic matter decomposition, and plant health. Understanding the specific microbes that are most affected by e-waste and developing strategies to protect beneficial soil bacteria will be vital for maintaining soil health.

9.2.4 Development of Policy Frameworks and Public Awareness

For effective management of e-waste contamination, robust policy frameworks are essential. Future research could explore the effectiveness of existing policies and propose new strategies to regulate e-waste disposal and promote responsible recycling practices. Collaboration between governments, industry, and local communities will be crucial to creating and enforcing regulations that prevent the release of hazardous e-waste components into the environment. Additionally, public awareness campaigns aimed at educating the public about the dangers of improper e-waste disposal and the benefits of recycling should be intensified.

9.2.5 Use of Advanced Analytical Tools for Contaminant Detection

To improve the detection and monitoring of e-waste contaminants in soil, future studies should focus on developing and applying advanced analytical techniques, such as portable sensors, molecular markers, and isotopic tracing that can detect low concentrations of hazardous substances. These tools will be crucial for early identification of contamination hotspots and will aid in assessing the effectiveness of remediation efforts.

CHAPTER 10

CONCLUSION

The paper aims to define and analyse the main areas of research on electrical and electronic waste, while offering a broader analysis of the relevant literature in order to summarize the information available and to create common knowledge. Based on this few key points were observed. Firstly, many countries don't have any standardized method to estimate e-waste generation. Further, there is a need to implement and frame polices for proper e-waste management in developing countries so as to solve environmental issues related to informal recycling practice. There is a need for developing a legal framework for the management of this waste fraction is one of the challenges for the policy makers in developing countries. Awareness programs should be generated and training should be provided in handling e waste. E-waste has emerged as perhaps the most critical waste disposal issue of the twenty-first century. The problem is exacerbated by the increasing rate of computer and television production in the world including India, and by relatively short life spans of recent computer models. Additionally, the number of computers currently in storage would result in a massive influx of toxins to the municipal waste stream if they were land filled. The presence of lead, mercury, BFRs, and chromium along with other hazardous chemicals may lead to potentially severe negative health effects if exposed to the environment through conventional disposal. Although there is some debate about the specific type and level of risk involved with each substance, there is little doubt that these hazardous chemicals will cause significant harm over the course of the twenty first century if they are not disposed of properly. The potential risks to the developing nervous systems of babies and children are particularly significant.

The present article summarizes that e-waste contains a number Hazardous substances. Heavy metals and halogenated compounds are of particular concern. Improper handling and management of e-waste during recycling and other end-of-life treatment options may develop potentially significant risks to both human health and the environment. Current simple recycling carried out in many developing countries is causing risks that could to a large extent, be avoided through the use of improved treatment methods. Bio hydrometallurgical techniques allow metal cycling by processes similar to natural biogeochemical cycles. Using biological techniques, the recovery efficiency can be increased whereas thermal or physico-chemical methods alone are less successful, as shown in copper and gold mining where low grade ores are biologically treated to obtain metal values, which are not accessible by conventional treatments. Bioremediation methods can improve scenario of current treatment practices available for e-waste. Besides, management practices for e-waste there is a need of doing more research in the area of bioremediation so that these techniques can be used for the treatment of E-waste.

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