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EVALUATION OF HEAVY METAL CONTENT IN SOIL AND SURFACE WATER AROUND E-WASTE BURNING SITES IN LAGOS STATE

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Abstract

This study evaluated the heavy-metal contamination in soils and surface water at three informal e-waste burning sites in Lagos State: Alaba International Market, Ikeja Computer Village, and Abule-Egba scrapyard. The study objective was to evaluate the heavy metal pollution indices of soil and water and. A descriptive cross-sectional design was used. Soil samples were collected at two depths (0–15 cm and 15–30 cm), while surface-water samples were taken from nearby drainage channels. The heavy metal concentrations (Pb, Cd, Cr, Cu, Zn, and Ni) were determined using Atomic Absorption Spectrophotometry. Pollution indices (CF, PLI, NPI, WQI) and ANOVA was applied to interpret the results. The soils at the three sites were strongly acidic compared with the control soil, showing the long-term effect of e-waste burning and dismantling. Heavy-metal concentrations were extremely high in the surface soils, with lead reaching 432 mg/kg at Alaba, and remained elevated in deeper layers, indicating downward movement over time. Water samples also exceeded WHO limits, and the Water Quality Index rated the sites as poor to very poor. A notable finding was the unusually high zinc level at Abule-Egba, showing that even small scrapyards can become serious contamination hotspots. Overall, the study provides a clearer understanding of how heavy-metal pollution develops and spreads at informal e-waste sites and highlights the need for stricter controls, safer recycling practices, improved testing, and continuous monitoring to reduce long-term environmental risks.

Keywords:

Heavy Metal, Soil, Surface Water, E-Waste Burning Sites, Lagos State.

1. Introduction

The rapid growth of technology has made electronic devices a normal part of daily life. Phones, laptops, televisions, and other gadgets are replaced more quickly than ever, and this constant cycle of upgrading has created a huge and fast-growing stream of electronic waste, commonly called e-waste. Unfortunately, only a small portion of this waste is properly recycled. Most of it ends up stored in homes, dumped in open spaces, or handled through informal recycling methods, especially in developing countries (Baldé *et al.,* 2017).

Nigeria, and Lagos in particular, receives large volumes of used electronic equipment every year. Many of these items arrive damaged or become waste shortly after use. Because formal recycling systems are limited, thousands of people survive by dismantling and burning discarded electronics to recover valuable metals. Over time, places such as Alaba International Market, Ikeja Computer Village, and the Abule-Egba scrapyard have become major e-waste processing hotspots (Isimekhai *et al.,* 2017). The challenge is that these activities are carried out in the open, on bare ground or next to drainage channels, using crude methods such as open burning, manual dismantling, and acid washing. Burning cables and circuit boards releases heavy metals like lead, copper, cadmium, zinc, and nickel. These metals do not break down and can remain in the environment for years. They settle in the soil, wash into surface-water bodies during rainfall, and continue to build up with each cycle of burning. In many cases, the acidic fumes from burning plastics lower soil pH, allowing these metals to migrate deeper into the soil or toward groundwater.

Previous studies in Lagos have reported extremely high concentrations of heavy metals in soils and drainage channels around e-waste sites, often far above international safety guidelines. Yet despite this evidence, informal recycling continues to grow because it provides income for many families. Existing regulations and policies have also not been fully effective, partly due to weak enforcement and the complex social and economic realities surrounding e-waste recycling. Another ongoing problem is the lack of comprehensive and comparable environmental data. Many earlier studies examined only the surface soil, focused on a single site, or assessed soil and water separately. This makes it difficult to understand how metals move between soil and water, how deep they travel, or how widespread the contamination truly is.

This study was therefore designed to fill these gaps. It provides a coordinated assessment of heavy metals in both soils and surface waters across three major e-waste burning locations in Lagos. By examining different soil depths, analyzing water bodies that receive runoff, and applying recognized pollution indices and statistical tools, the study offers clearer evidence of how e-waste activities are affecting the environment. Ultimately, the goal is simple: to give policymakers, environmental agencies, and community stakeholders reliable information that can guide practical, realistic, and long-term solutions for managing e-waste pollution in Lagos.

Building on the background that shows how informal e-waste recycling has become a major source of heavy-metal pollution in Lagos State, the central problem this study seeks to address is the absence of clear, reliable, and comprehensive data on the actual levels of heavy-metal contamination in both the soils and surface waters of these burning sites. Despite the obvious environmental risks associated with open burning and crude dismantling at Alaba International Market, Ikeja Computer Village, and the Abule-Egba scrapyard, there is still no solid understanding of how much contamination has occurred, how deeply the metals have penetrated the soil, or how far they have spread into nearby surface-water channels that collect runoff from these sites. Existing studies provide useful clues but remain fragmented, with many limited to surface soils, single locations, or isolated water assessments. This lack of integrated and multi-depth data makes it difficult for environmental authorities to judge the real severity of pollution, identify the worst-affected zones, or design practical and targeted remediation measures. Therefore, this research aims to close this critical information gap by systematically quantifying heavy metals across multiple e-waste burning sites in Lagos, examining both soil and surface water, and applying standardized pollution indices to produce a clearer and more complete picture of contamination levels in the region.

2. Material and Methods

2.1 Study Area

The study was carried out in Lagos State, Nigeria, which is the country's main commercial and industrial center. Lagos is located in the southwestern part of Nigeria, along the Atlantic coastline. It lies approximately between latitude 6°23′N and 6°41′N and longitude 2°42′E and 3°42′E. The state covers about 3,577 square kilometers, and around one-fifth of this area consists of lagoons, rivers, and creeks (Lagos Bureau of Statistics, 2022). Lagos has a humid tropical climate characterized by two main seasons: the rainy season (April to October) and the dry season (November to March). The average annual rainfall ranges between 1,500 and 2,000 millimeters, while the average temperature varies from 24°C to 32°C throughout the year (NIMET, 2023). The combination of high rainfall, temperature, and humidity encourages rapid weathering of waste materials and the spread of pollutants into nearby soils and water bodies. During the dry season, contaminants tend to concentrate in the soil and drainage channels due to limited dilution and low water flow.

Even though Lagos is the smallest state in the country by land size, it is the most densely populated and one of the busiest. Over 20 million people live and work in Lagos. Every day, more people move into the city from other parts of Nigeria and from neighbouring countries, looking for better job opportunities, business, or education. As a result, the city is always growing, building, and changing. Lagos is also known for being the commercial and economic heart of Nigeria. It is home to major markets, industries, banks, ports, and technology hubs. Because of its large economy and strong trading connections, Lagos receives a huge amount of imported goods from all over the world. Among these are second-hand electronic items like computers, televisions, phones, printers, DVD players, and other gadgets. Some of these electronics are still usable, but many are already broken or damaged beyond repair. These unusable ones become electronic waste — often called e-waste (Osibanjo & Nnorom, 2007). The topography of Lagos is generally flat and low-lying, with elevations rarely exceeding 15 meters above sea level. Because of this, drainage is often poor, and floodwater or runoff can easily spread contaminants from one area to another. Lagos soils allow water to pass through easily, so heavy metals can move downward and contaminate groundwater, especially when the soil becomes acidic (Adewumi & Olofin, 2023). Hydrologically, Lagos has an extensive network of drainage channels, creeks, and lagoons. Some of the major water systems include the Lagos Lagoon, Ologe Lagoon, and Ogun River. These water bodies receive large volumes of waste from industrial and residential areas. Over time, they have become among the most polluted aquatic environments in West Africa, mainly due to the discharge of industrial effluents, domestic waste, and uncontrolled e-waste disposal (Babayemi *et al.,* 2017).

E-waste is a serious problem because many of these old devices contain toxic materials. Inside a single item like a phone or a television, there are small parts made with harmful metals such as lead, mercury, cadmium, and chromium. If these devices are not handled properly, these metals can be released into the air, soil, and water, and that can be dangerous for both people and the environment (Isimekhai et al., 2017; Babayemi et al., 2017). Lagos has become a major destination for this kind of waste, partly because it is a major port city and partly because there is high demand for second-hand electronics due to poverty and high costs of new goods. Over the years, many people have found ways to earn a living by working with e-waste. Some buy and sell usable parts. Others repair damaged electronics. Many more works informally, breaking down electronics by hand to collect valuable metals, especially copper, aluminum, and steel (Tchounwou et al., 2012).

The study focused on three locations in Lagos State where informal e-waste recycling is most common: Alaba International Market (Ojo LGA), Ikeja Computer Village (Ikeja LGA), and Abule-Egba Scrap Market (Alimosho LGA). Each of these locations is known as a hotspot for electronics trade and informal recycling activities. Thousands of people work in and around these markets every day, handling electronics in one way or another. from selling and repairing to dismantling and burning. While these activities provide income for many families, they also lead to serious environmental problems because they are not done in a safe or regulated way (Adediran & Abdulkarim, 2012). The three selected sites are:

1. **Alaba International Electronic Market (Ojo Local Government Area) –** This is one of the largest electronics markets in West Africa. It is located in the Ojo area of Lagos, close to the Badagry Expressway. The market has thousands of shops and stalls selling electronic items, including televisions, DVD players, satellite receivers, and home appliances. Many of these items are second-hand goods imported from Europe, Asia, and America. Within the market and in nearby spaces, people also work informally to extract parts from electronics that are no longer working. When something cannot be fixed, it is often dismantled on the spot. Workers remove useful parts and burn the remaining materials, especially wires, to get the copper inside. These burning activities are done in open spaces; on bare soil, next to shops, or even near food vendors. Thick black smoke fills the air when wires are burned. Ash and burnt materials cover the ground. During rainfall, this waste gets washed into open drains, flowing into nearby water channels. Over time, the soil and water around the area become heavily polluted (Adegoke *et al.,* 2020; Forti *et al.,* 2020) see Figure 1.

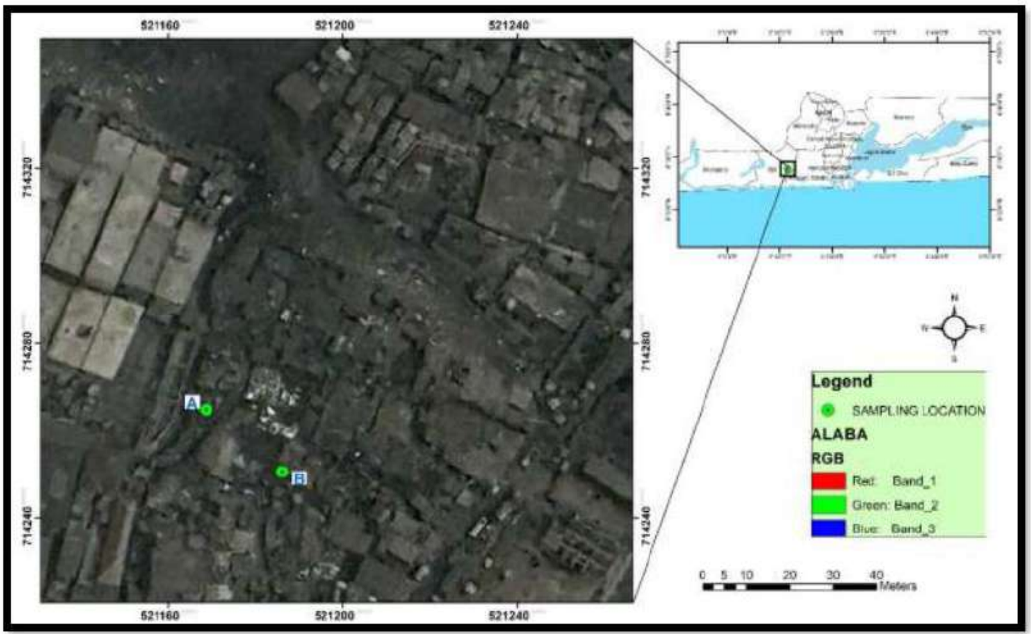

Figure 1: Lagos map showing Alaba sampling location

2. **Ikeja Computer Village (Ikeja Local Government Area)** – Located in the capital city of Lagos State, Ikeja. It is the biggest Information and Communication Technology (ICT) market in Nigeria and one of the largest in Africa. The area is filled with thousands of shops, roadside stalls, and kiosks. People buy, sell, and repair all kinds of electronic devices here; especially mobile phones, laptops, chargers, computer parts, and accessories. Although much of the activity in Computer Village is related to sales and repair, there is also a growing level of informal recycling. When devices cannot be fixed, they are broken apart to collect materials that still have value. Like in Alaba, this process is done on the streets or behind shops. There are no protective measures, no proper waste bins, and no clear disposal plan. Old phone batteries, broken screens, and metal parts are dumped on the ground. Sometimes these are burned in small piles to recover metal. The soil in the area has dark patches from burning, and the drains often carry oily or dirty water filled with tiny particles of waste. Because this area is in the city center, the pollution also affects a large number of people. Thousands of customers visit Computer Village every day. Many do not know they are walking through areas with high levels of toxic materials. Rainfall can wash the waste into underground drains, which later empty into rivers and other surface water bodies (Nnorom & Osibanjo, 2008).

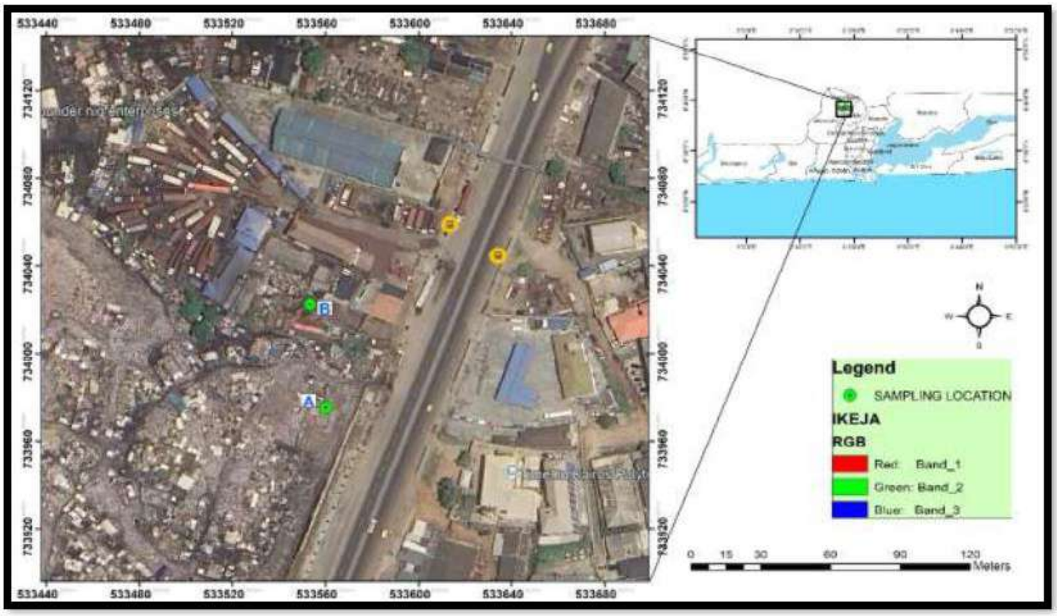

Figure 2: Lagos map showing Ikeja sampling location.

3. **Abule Egba Scrapyard (Alimosho Local Government Area)** – Located in Alimosho Local Government Area, is a well-known area for scrap trading. People bring in old electronics, metal parts, car batteries, electric cables, and other waste materials. Most of the work happens in open spaces. There are no roofs, no fences, and no safety rules. Workers, including young boys and men, use hammers, knives, or metal rods to break apart the waste. They sort useful parts and throw away the rest. Cable burning is very common here. You can often see smoke rising from several spots in the market. The ground is blackened with ash. Pools of dirty water collect after rain, and these often have oil and metal particles floating on top. Many of the workers wear no gloves or masks. Children walk around the site freely. Waste materials are dumped into nearby drains or left on the ground, where they can easily get washed into water channels during heavy rain (Oteng-Ababio, 2012) Figure 3.

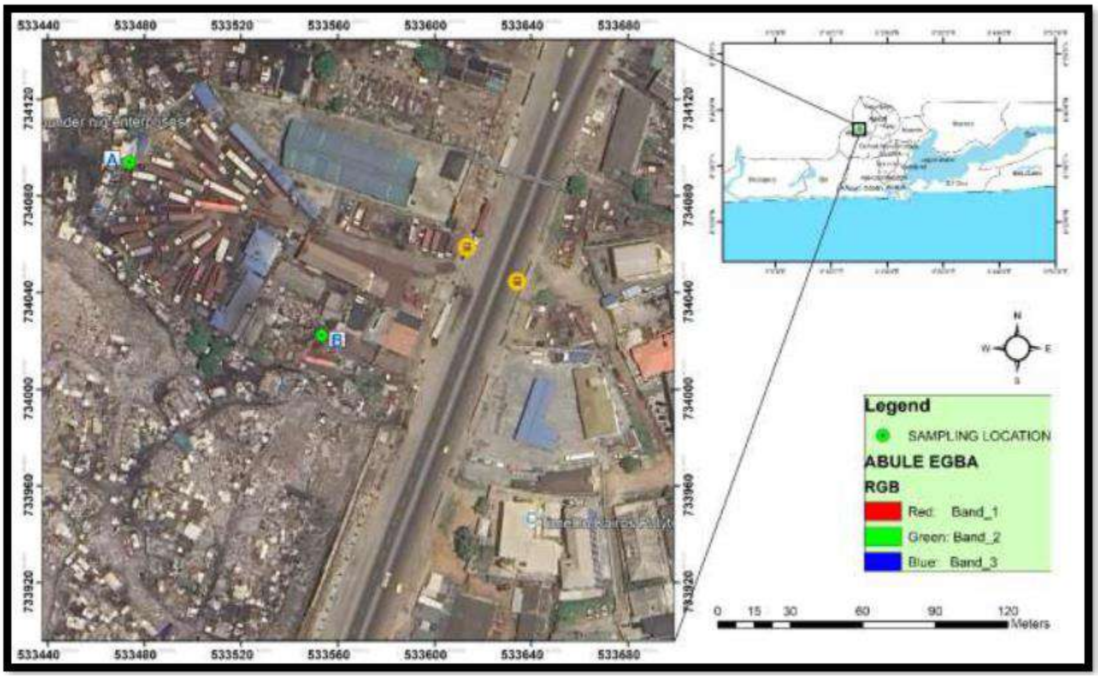

Figure 3: Lagos map showing Abule-Egba sampling location.

These three locations were chosen because they are some of the most active informal e-waste recycling zones in Lagos. They represent different parts of the city: from the commercial center (Ikeja) to a coastal trade hub (Alaba), to a low-income scrap site (Abule-Egba). Each has different patterns of recycling activity, and each presents unique risks to soil and water. Studying all three gave the research a fuller view of how informal e-waste activities affect the environment under different conditions. The geographical and environmental features of Lagos State therefore make it an ideal setting for this study. The combination of flat terrain, dense population, heavy rainfall, and widespread informal recycling creates perfect conditions for pollutants to spread and persist. Studying these areas provide useful data that can help local authorities, such as the Lagos State Environmental Protection Agency (LASEPA) and the National Environmental Standards and Regulations Enforcement Agency (NESREA), to design better management strategies for reducing heavy metal pollution.

2.2 Sampling and sample Technique

A stratified random sampling technique was adopted to collect soil and water samples from the selected e-waste burning sites. The method was chosen because each site contains different activity zones such as burning, dismantling, and storage areas, and pollution levels can vary across them. By dividing each site into smaller zones and collecting samples from each, the study ensured that every key area was properly represented, providing a more accurate picture of how pollution differs across the sites (Etikan *et al.,* 2016). The three chosen locations: Alaba International Electronic Market, Ikeja Computer Village, and Abule Egba Scrapyard, were subdivided into sampling zones based on their main recycling activities and layout, following approaches commonly used in similar environmental assessments (Reza & Singh, 2010; Bhutiani *et al.,* 2016).

2.2.1 Collection of Samples

For soil sampling, composite samples were collected from each zone using a systematic grid method. At every point, soils were taken at two depth levels: surface (0–15 cm) and sub-surface (15–30 cm). The surface layer captures direct contamination from burning and dismantling, while the sub-surface layer shows how far pollutants have migrated downward through leaching or infiltration. Several sub-samples were taken within a small radius, mixed to form a composite sample, and stored in clean, labeled polyethylene bags. This reduced local variation and improved accuracy. To establish background metal levels, control samples were collected about 200 meters away from each e-waste site, preferably upwind or upstream, where there were no visible recycling activities. These control soils provided baseline data for comparison.

For surface-water sampling, the grab sampling technique was used. Water samples were taken from nearby drains, channels, or ponds that receive runoff from e-waste areas using clean one-liter polyethylene bottles rinsed with sample water before collection. The samples were acidified with nitric acid to a pH below 2 to prevent metal precipitation and microbial growth, stored at 4°C in an icebox, and transported to the laboratory for analysis within 24 hours, following APHA (2017) and WHO (2022) standards. Background water samples were also collected from nearby clean areas to serve as control data.

In total, twenty-one soil samples and seven water samples were collected across the three sites, making twenty-eight samples altogether. The total number of soil samples was derived as follows: each of the three sites was divided into three activity zones (burning, dismantling, and deposition/runoff). Soils were collected at two depths from each zone, giving six samples per site (3 zones × 2 depths). For all three sites, this produced 18 samples, and when combined with one background soil sample per site (3 in total), the total became 21 soil samples. For surface water, two samples were taken from each site at runoff or drainage points (2 × 3 = 6), along with one control water sample, giving 7 water samples in total. (Figure 1 shows the schematic layout of soil and water sampling zones and depths at the different sites)

The heavy metals selected for analysis include lead (Pb), cadmium (Cd), chromium (Cr), copper (Cu), zinc (Zn), and nickel (Ni). These metals were quantified using Atomic Absorption Spectrophotometry (AAS). The raw concentration data obtained from laboratory analysis were subsequently used to compute pollution indices such as the Contamination Factor (CF), Pollution Load Index (PLI), and Water Quality Index (WQI), which provide a clearer assessment of contamination levels in soil and water samples (Tomlinson *et al.,* 1980; Bhutiani *et al.,* 2016).

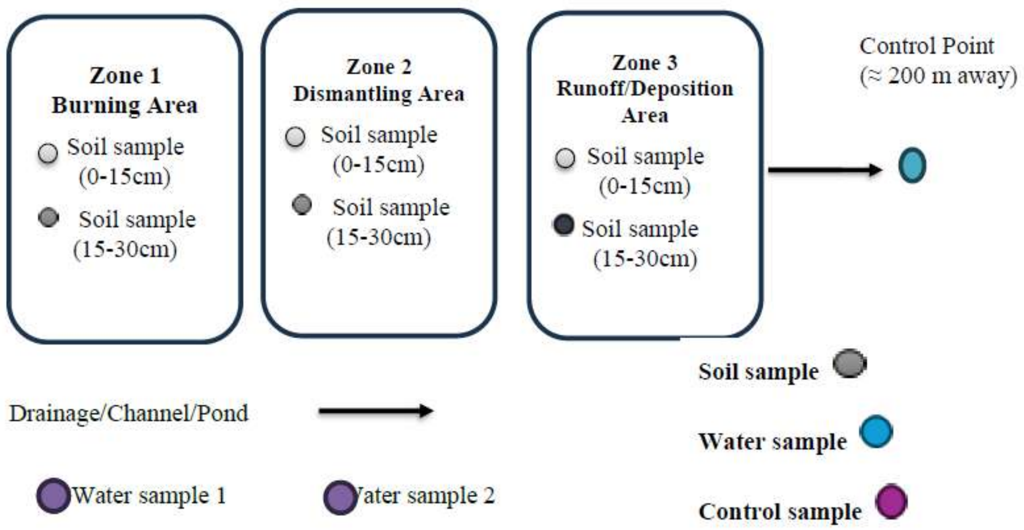

Figure 1: Soil and water sampling zones and depths at the different sites.

For heavy-metal analysis, both soil and water samples were subjected to acid digestion to release all metals into solution, following USEPA (2020) procedures. The digested samples were analysed using Atomic Absorption Spectrophotometry (AAS), a sensitive and reliable technique for detecting trace concentrations of metals. The metals analysed included lead (Pb), cadmium (Cd), chromium (Cr), copper (Cu), zinc (Zn), and nickel (Ni) (Bhattacharya *et al.,* 2012). The analytical results formed the basis for calculating contamination factors and pollution indices used in the study. To ensure data reliability, selected samples were analysed in duplicate, the AAS was calibrated using certified standard solutions, and blank samples were included to check for contamination (APHA, 2017; Bhattacharya *et al.,* 2012).
Overall, this systematic approach; combining careful field sampling, standardized laboratory methods, and basic quality-control measures, produced reliable datasets that accurately reflect the environmental conditions at the study sites and are suitable for statistical analysis and pollution-index evaluation.

2.3 Determination of pollution level of the soil and water sampled

Selected pollution indices (CF, PLI, NPI and WQI) were used to turn the metal values into simple contamination scores, using only reliable and practical methods.

2.3.1 Determination of pollution level in soil sample

Three indices were used for soils: Contamination Factor (CF), Pollution Load Index (PLI), and the Nemerow Pollution Index (NPI), following Hakanson (1980), Tomlinson *et al.* (1980), and Zhang *et al.* (2009).

1. **Contamination Factor (CF);** CF compares the concentration of a metal in soil with its natural background level. It is calculated with the formula:

$$CF = \frac{C_{sample}}{C_{background}} \qquad (2.1)$$

where: C_{sample} is the concentration of a metal in the soil sample. $C_{background}$ is the concentration of the same metal in control (uncontaminated) soil. (Hakanson, 1980): CF < 1 = low contamination. CF 1 – 3 = moderate contamination. CF 3 – 6 = considerable contamination. And CF ≥ 6 = very high contamination.

2. **Pollution Load Index (PLI);** PLI summarizes overall soil contamination by taking the geometric mean of all CF values. It is calculated with a formula:

$$PLI = (CF_1 \times CF_2 \times \ldots \times CF_n)^{1/n}$$
(2.2)

where: n is the number of metals analyzed, PLI > 1 indicates pollution, while PLI < 1 suggests no significant contamination. The geometric mean of CF values for each site was calculated in Excel. This single value summarizes overall contamination and supports comparisons across sites (Bhutiani *et al.,* 2016).

3. **Nemerow Pollution Index (NPI);** The NPI incorporates both the average contamination (CF-mean) and the highest contamination factor (CF-max) at each site. It is calculated with a formula:

$$NPI = \sqrt{\frac{CF_{mean}^2 + CF_{max}^2}{2}}$$
(2.3)

where: CF_{mean}= average CF across all metals, CF_{max}= highest CF value among the metals
An NPI > 1 generally indicates pollution pressure. Higher values point to more severe contamination and highlight pollution "hotspots" where certain metals (e.g., Pb or Cu) spike sharply due to specific e-waste activities (Zhang *et al.,* 2009; Islam *et al.,* 2015).

2.3.2 Determination of pollution level in water sample

The Weighted Water Quality Index (WQI) was used to assess the overall condition of surface water.

1. **Weighted Water Quality Index (WWQI);** WWQI was used to evaluate the overall quality of surface water at the study sites by combining the influence of each parameter into one score (Reza and Singh, 2010). In this method, each parameter is given a weight (Wi) based on its importance and toxicity. Metals such as Pb and Cd received higher weights because they are more harmful, while parameters of lower concern received lower weights. The quality rating (Qi) for each parameter was calculated using:

$$Qi = \frac{\text{Ci}}{\text{Si}} \times 100$$
(2.4)

where Ci is the measured concentration and Si is the WHO standard limit. The overall WWQI was obtained using:

$$WWQI = \frac{\sum(W_i \times Q_i)}{\sum W_i}$$
(2.5)

General interpretation: WQI < 50 = good water quality, 50–100 = moderate water quality, 100–200 = poor quality and 200 = very poor or unsafe
This method provides a balanced assessment by considering both the concentration of each parameter and its relative significance.

2.4 Methods of Data Analysis

Data obtained from field sampling and laboratory analyses were systematically organized, coded, and analysed using Microsoft Excel and SPSS Statistics. The analytical methods were chosen to address each research objective while remaining practical and scientifically sound. The statistical and interpretive approaches followed widely accepted environmental assessment procedures described by Bhutiani *et al.* (2016), Adriano (2001).

3 Results and Discussions

3.1 Heavy-Metal Concentrations in Soil Samples

Table 1 presents the concentrations of heavy metals in the surface soils (0–15 cm) across the study sites. The table summarizes the levels of Pb, Cd, Cr, Cu, Zn, and Ni for the control location and the three e-waste sites, providing an overview of metal accumulation at the soil surface. Table 2 presents the concentrations of heavy metals in the subsurface soils (15–30 cm) at the control site and the three e-waste locations. The table reports the levels of Pb, Cd, Cr, Cu, Zn, and Ni, giving an indication of metal accumulation below the soil surface.

The concentrations of Pb, Cu, Zn, and Cd in the surface soils were extremely high compared to the control site, showing the direct influence of open burning and dismantling activities. These metals are known to be released when cables, circuit boards, and batteries are burnt or broken open, and the pattern observed at Alaba, Ikeja, and Abule-Egba matches what other researchers have reported in informal recycling sites (Isimekhai *et al.,* 2017; Adegoke *et al.,* 2020). Alaba consistently recorded the highest concentrations, which is expected because of its large-scale operations and continuous recycling activity. The levels were far above natural background values, confirming that this contamination is man-made and not the result of natural soil composition. These high values show that the surface soil serves as the first and most heavily affected medium where metals settle, accumulate, and remain available for movement into deeper layers or nearby water bodies.

Although the concentrations of metals were lower at the deeper soil layers compared to the surface, they remained significantly above the control values, highlighting ongoing downward migration. This pattern is important because it shows that the contamination is not recent; rather, it has been happening long enough for metals to travel downward gradually. Acidic conditions, which were observed at both depths, make it easier for these metals to move, dissolve, and leach into deeper layers (Alloway, 2013). The presence of high metals at 15–30 cm suggests older contamination that has slowly diffused downward, while the higher surface concentrations reflect ongoing burning and dismantling activities. This combination shows that the soil profile is affected from top to bottom, raising concerns about long-term leaching and the possibility of reaching groundwater if the practices continue.

The comparison between the two soil depths shows a clear decline in metal concentrations as depth increases, which is the typical pattern in contaminated sites. However, the fact that metals remain significantly elevated at 15–30 cm shows that contamination has persisted long enough to move beyond the surface layer, especially in acidic soils that enhance downward mobility (Adriano, 2001). This suggests that the soil is acting as a long-term reservoir where contaminants from past burning events settle deeper while new contamination stays on the surface. This slow but steady vertical movement raises environmental concerns because deeper contamination tends to last longer and is much harder to remediate, and may eventually influence groundwater depending on the soil structure and rainfall patterns.

Table 1: Heavy Metals (Surface Soils, mg/kg) - (0–15 cm)

Site	Pb	Cd	Cr	Cu	Zn	Ni
Control	20.2	0.34	30.5	22.4	53.0	15.3
Alaba	432.4	2.93	83.9	339.1	542.8	67.6
Ikeja	259.2	1.78	54.3	201.0	294.5	39.4
Abule-Egba	349.9	2.54	69.5	248.8	418.5	53.5

Table 2: Heavy Metals (Subsurface Soils, mg/kg)- (15–30 cm)

Site	Pb	Cd	Cr	Cu	Zn	Ni
Control	20.3	0.32	30.5	22.4	53.0	15.3
Alaba	311.2	2.22	65.6	237.4	380.7	45.9
Ikeja	185.4	1.37	36.8	129.6	219.0	25.7
Abule-Egba	239.4	1.74	50.7	175.2	288.7	36.2

3.2 Heavy-Metal Concentrations in Surface Water

Table 3 presents the concentrations of the selected heavy metals in the surface water samples collected from the control site and the three e-waste locations. It shows the levels of Pb, Cd, Cr, Cu, Zn, and Ni, providing an indication of metal contamination in the surrounding drainage waters. The surface water around the e-waste sites was also found to be polluted. All samples tested showed metal levels above the limits set by the World Health Organization (WHO). This means the water is not safe for any kind of human or animal use. The pollution comes from rainfall that washes ash, dust, and small waste particles from the recycling areas into nearby gutters and drains (Bhutiani *et al.,* 2016). In Abule-Egba, zinc levels were especially high. This could be due to the burning of zinc-coated items, such as galvanized metals. Once metals enter the water, they can travel far from the source and affect other areas. This is especially dangerous in cities where many people rely on surface water for washing, farming, or even drinking during water shortages. The findings agree with similar work in Nigeria and elsewhere, where informal e-waste sites consistently show high metal levels in water bodies located close to burning and dismantling zones (Adegoke *et al.,* 2020). These results show that contamination is spreading beyond the soil and directly affecting water quality.

Table 3: Heavy Metals in Surface Water (mg/L)

Site	Pb	Cd	Cr	Cu	Zn	Ni
Control	0.006	0.004	0.005	0.025	0.081	0.005
Alaba	0.518	0.034	0.158	0.506	0.871	0.181
Ikeja	0.336	0.029	0.080	0.474	0.651	0.109
Abule-Egba	0.411	0.036	0.111	0.466	0.927	0.138

3.3 Pollution Indices for Soil

3.3.1 Contamination Factor (CF)

Table 4 presents the contamination factor (CF) values for the selected heavy metals at the three e-waste sites. These CF values help indicate the extent to which each metal exceeds background concentrations, offering a simple measure of soil pollution at each location. The contamination factor values recorded in this study were very high at all three e-waste sites. For most of the metals tested (Pb, Cd, Cu, and Zn), the CF values were greater than 6. According to the classification system, this level shows very high contamination (Hakanson, 1980). Lead and copper had the highest CF values across the sites. These metals are widely used in electronic components such as wires, batteries, and circuit boards. Alaba recorded the highest CF values overall. This result matches the high level of burning and dismantling activities observed at the site. When electronic waste is burned repeatedly in the same area, metals are released and settle into the soil. Over time, these metals build up and push CF values higher. The consistently high CF values show that the metals found in the soil are not natural. They are mainly from human activities linked to informal e-waste recycling (Alloway, 2013). High CF values are a strong warning sign. They show that the soil has exceeded safe limits and may pose serious risks. People who work or live near these sites may come into contact with contaminated soil through skin contact, dust inhalation, or food grown nearby.

Table 4. Contamination Factor (CF)

Site	Pb	Cd	Cr	Cu	Zn	Ni
Alaba	18.9	8.5	2.6	12.9	8.0	3.4
Ikeja	11.2	5.3	1.7	7.2	4.9	2.0
Abule-Egba	15.2	7.0	2.2	9.2	6.4	2.7

3.3.2 Pollution Load Index (PLI)

Table 5 presents the Pollution Load Index (PLI) values for the three e-waste sites. The PLI provides an overall indication of the combined pollution pressure from multiple heavy metals at each location. The Pollution Load Index values calculated for all three sites were greater than 1. This means that all the sites are polluted when the combined effect of all metals is considered (Tomlinson *et al.,* 1980). Unlike CF, which looks at one metal at a time, the PLI shows the overall condition of the soil. Alaba had the highest PLI value. This confirms that it is the most polluted site among the three locations studied. Ikeja and Abule-Egba also showed high PLI values, though slightly lower than Alaba. This shows that pollution is widespread and not limited to only one area. The PLI results are important because they show that pollution is not caused by just one metal. Instead, many metals are acting together. This combined pollution can increase risks and make soil recovery more difficult. High PLI values also suggest that the land may no longer be safe for farming, construction, or other uses without proper cleanup (Bhutiani *et al.,* 2016).

Table 5: PLI of the soil samples

Site	PLI
Alaba	7.97
Ikeja	5.02
Abule-Egba	6.59

3.3.3 Nemerow Pollution Index (NPI)

Table 6 presents the Nemerow Pollution Index (NPI) values for the three e-waste sites. The NPI gives an overall sense of how polluted each site is by combining both average and highest contamination levels. The Nemerow Pollution Index gave a clearer picture of pollution severity at each site. The NPI values showed that Alaba was the most polluted site. This result came from both high average contamination levels and very high maximum values, especially for lead and copper. The NPI is useful because it highlights not only general pollution but also extreme metal levels at specific points (Zhang *et al.,* 2009). Ikeja and Abule-Egba also had NPI values above the safe limit. This shows that all sites are polluted, even though the level of pollution differs. The NPI confirms that informal e-waste recycling has caused serious and long-lasting soil contamination at all locations studied.

Table 6: NPI

Site	NPI
Alaba	10.69
Ikeja	6.35
Abule-Egba	8.43

3.3.4 Water Quality Index (WQI) of the surface water samples

Table 7 presents the Water Quality Index (WQI) values for the three e-waste sites. The WQI gives an overall indication of how suitable the surface water is when all measured parameters are considered together. Appendix C shows how WQI was calculated. Table 8 presents the ANOVA results for the heavy metals across the study sites. The table shows the p-values and indicates whether the differences observed in metal concentrations are statistically significant.

The WQI classified the water at the e-waste sites as "poor" to "very poor," reflecting the combined influence of all measured parameters. Water in these locations is not functioning as natural drainage systems but has become heavily influenced by contaminated runoff, burnt residues, and dissolved metals from the surrounding soil (Reza & Singh, 2010). This condition poses risks, especially for communities that may use such water for informal washing or irrigation. The findings match what has been documented in other informal recycling regions where surface-water bodies quickly become polluted due to their proximity to burning activities (Adegoke *et al.,* 2020). The low WQI value of the control site supports the reliability of the index and emphasizes the severity of contamination in the study areas.

The ANOVA results showed statistically significant differences in heavy-metal concentrations across the sites, with p-values less than 0.05 for all metals. This means that the differences observed are not random and are likely caused by the recycling and burning activities taking place at each site. The statistical results support the earlier observations that Alaba, Ikeja, and

Abule-Egba each have unique activity patterns that influence how much contamination is present (Bhattacharya *et al.,* 2012). These findings strengthen the conclusion that the contamination is driven by human practices rather than natural variability in the soil.

Table 7 WQI of the surface water samples

Site	WQI
Alaba	186
Ikeja	142
Abule-Egba	173
Control	32

Table 8: Summary of ANOVA results on difference between the heavy metal content in the four sampled areas

Metal	p-value	Interpretation
Pb	0.000	Significant
Cd	0.003	Significant
Cr	0.021	Significant
Cu	0.000	Significant
Zn	0.000	Significant
Ni	0.012	Significant

4. Conclusions

Evaluation of heavy metal content in soil and surface water around e-waste burning sites in Lagos state has be carried out. Based on the findings of the study, it was concluded that; one, the soils at the e-waste sites have become strongly acidic, and this acidity helps metals move more easily into deeper layers. The higher EC, OM, and CEC values also show that burnt residues and dismantled materials have changed the natural condition of the soil. The nearby water bodies also reflected these changes due to runoff from contaminated areas. Two, the soil and water quality indices confirmed that all three sites are highly polluted. The CF, PLI, and NPI showed high to very high contamination, especially for Pb, Cd, Cu, and Zn, and the WQI placed the surface water in the poor to very poor category. Lastly, there are clear variations in metal levels across the three sites and between soil depths. The surface soils had higher levels, but deeper soils still contained significant amounts, showing that the contamination is already moving downward. Alaba recorded the highest levels, followed by Abule-Egba and Ikeja, and the ANOVA confirmed that the differences were significant.

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