

Urban Mining: Recovering Critical Raw Materials and Foreign Exchange from Waste Rechargeable Batteries in Nigeria

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Abstract

Urban mining involves extracting raw materials from waste as a sustainable approach to resource recovery. In Nigeria, waste rechargeable batteries (WRB) represent a major prospect for urban mining, particularly within the framework of recovering critical raw materials (CRM) and foreign exchange value. Improper disposal of WRB not only poses environmental risks but also results in the loss of valuable resources that could be recycled and reused. Urban mining provides a feasible solution by converting waste into wealth, thus contributing to a circular economy. The process of urban mining involves collection, disassembly, and chemical processing of WRB to extract metals. In Nigeria, this practice could reduce the dependency on raw material imports or virgin material mining and provide a new revenue flow through the sale of recovered metals on the international market. This study mined data from the UN Comtrade database for battery importation into Nigeria from 1999 – 2022 and used the mean metal levels determined in WRB (Co, 28.9 g/t; Li, 66 g/t; Mn, 18.3 g/t; and Ni, 24.3 g/t) to estimate recoverable CRM. Data from UN Comtrade showed importation of 2.63 Mt of WRB into Nigeria. If the WRBs are collected and recycled, 76 t of Co, 174 t of Li and 48.3 t of Mn and 64.1 t of Ni can be recovered from the batteries considering results of this study. Considering the CRM unit prices in the mineral market (Co, US\$28550/t; Li, US\$15343/t; Mn, US\$1690/t and US\$16863 for Ni) the recoverable metals are worth US\$6 Million. This shows that much forex can be obtained from WRB if collected and recycled, stimulating economic growth. However, if disposed with municipal waste, they will contaminate the environment; endangering the lives of plants, animals and humans.

Keywords: Urban mining; resource recovery; circular economy; recycle; foreign exchange.

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1. Introduction

Electronic Waste or e-waste has become a pressing issue as a result of the speedy advancement of technology and the widespread use of electronic devices [1, 2]. E-waste is generated when electronic device is discarded and it can include everything from cell phones and computers, to refrigerators and washing machines [3]. According to the United Nations, the world generates approximately 53 million tons of e-waste annually, and this number is expected to double by 2050. The UN fourth Global e-waste monitor, 2024, reveals that a record 62 million tonnes (Mt of e-waste) was produced in 2022, up to 82 % from 2010; on track to rise another 32 % to 82 million tonnes in 2030. Billions of dollars' worth of strategically-valuable resources squandered. Less than one-quarter (22.3 %) of the year's e-waste mass was documented as having been properly recycled in 2022, leaving US\$ 62 billion worth of recoverable natural resources unaccounted for and increasing pollution risks to communities worldwide [4].

Compared to conventional municipal wastes, certain components of electronic products contain toxic substances which can generate a threat to the environment and human health. This is a major concern that stems from improper disposal of these electronic devices. For instance, television and computer monitors usually contain hazardous materials such as lead, mercury, brominated flame retardants and cadmium which can contaminate the environment and pose a threat to human health. For example, when electronic devices are burned, toxic fumes are released, which can cause respiratory problems and other health issues. When these products are placed in landfills, or incinerated, they pose health risks due to the hazardous materials they contain. As more e-waste is placed in landfills, exposure to environmental toxins is likely to increase resulting in elevated risks of cancer and developmental and neurological disorders. A major cause of e-waste problem is the short lifespan of most electronic products — less than two years for computers and cell phones. This high obsolescence rate spells a major issue [1]. On the other hand, e-waste may contain precious metals such as gold, copper, nickel, cobalt, lithium and beryllium, rare metals of strategic value such as indium and palladium can be recovered, recycled and used as valuable sources of secondary raw materials [5, 6]. This is to say that in addition to the environmental and health concerns associated with e-waste, there is also a significant economic impact. Many of these materials used in electronic devices, such as gold, lithium, cobalt, nickel, copper, palladium, etc. are valuable resources that could be re-used if the devices were properly recycled. However, much of the e-waste generated in developed countries is shipped to developing countries, where it is often dismantled in unsafe and unregulated conditions, exposing workers to hazardous materials and releasing pollutants into the environment. To address the e-waste problem, there have been efforts to promote responsible management and disposal of electronic devices such as recycling and designing devices that are more easily repairable and recyclable [7], including awareness on sustainable practices [5, 6, 8].

This aim of this study is to discuss the WRB management issues in Nigeria and estimate recoverable metals and the forex that can be earned from it. This study mined data from the UN Comtrade database [9] for battery importation into Nigeria from 1999 – 2022 and used the mean metal levels determined in WRB. Data on metal contents of WRB is from [10, 11].

2. Materials and Methods/Approach

2.1 Data sources

Data was mined from UN Comtrade Database for the importation of batteries into Nigeria [12]. This provided data on the quantities of rechargeable batteries imported into Nigeria from various countries [10, 11]. It was assumed that at some points, these batteries became waste and were disposed. Since the waste rechargeable batteries (WRB) contain valuable scarce critical raw materials (CRM), the study estimated the recoverable metals from the WRBs.

Information on the market values of the recoverable metals were obtained from international raw material sites/market and thereafter used to estimate the recoverable values (in monetary terms) of the valuable metals using the average metal contents of the batteries as determined using AAS [10, 11].

Estimation of Recoverable CRMs from WRBs

For a given year, the recoverable values were estimated using the relationship:

$$R_m = Q_b \times Mc \dots\dots\dots 1$$

Where R_m is the recoverable metal; Q_b is the quantity of battery imported; and Mc is the mean metal concentration (a given metal).

The amount of recoverable metals and their value (in Dollars) are presented in this section. For a given year, the recoverable values were estimated using the equation:

$$Value_{\$} = R_m \times Unit\ Market\ Value_{\$} \dots\dots\dots 2$$

3. Results and Discussion

3.1 CRM Contents of Waste Rechargeable Batteries

The summaries of the metal contents of Li-ion batteries, Li-polymer batteries and NiMH batteries are presented in Table I, Table 2, Table 3 and in Figure 1. The mean concentrations (range) of the sample lithium-ion batteries are 28899 mg/kg (33397-14076 mg/kg) for Co, 65961 mg/kg (81159-47132 mg/kg) for Li, 18310 mg/kg (32549-8821 mg/kg) for Mn and 24329 mg/kg (35857-3808 mg/kg) for Ni. The mean concentrations (range) of the sample lithium-polymer batteries are 29753 mg/kg (33555-177436 mg/kg) for Co, 65477 mg/kg (73284-55494 mg/kg) for Li, 21287 mg/kg (30260-8461 mg/kg) for Mn and 20159 mg/kg (32706-2766 mg/kg) for Ni. The distribution of mean concentrations (range) of the sample nickel metal hydride batteries are 66287 mg/kg (71581-60993 mg/kg) for Co, 13851 mg/kg (15587-12115 mg/kg) for Li, 32899 mg/kg (54605-11192 mg/kg) for Mn and 82735 mg/kg (84580-80889 mg/kg) for Ni.

Table 1: Summary of metal levels of lithium-ion sample batteries

Parameter	Co	Li	Mn	Ni
Mean	28899	65961	18310	24329
Standard deviation	5227	8490	4961	12271
Maximum	33397	81159	32549	35857
Minimum	14076	47132	8821	3808
Geometric mean	28264	65409	17671	19513

Table 2: Summary of metal levels of lithium- polymer sample batteries

Parameter	Co	Li	Mn	Ni
Mean	29753	65477	21287	20159
SD	4649	5293	6628	10120
Maximum	33555	73284	30260	32706
Minimum	17743	55494	8461	2766
Geometric mean	29337	65280	20129	16803

Table 3: Summary of metal levels of NiMH sample batteries

Parameter	Co	Li	Mn	Ni
Mean	66287	13851	32899	82735
Standard deviation	7487	2455	30698	2610
Maximum	71581	15587	54605	84580
Minimum	60993	12115	11192	80889
Geometric mean	66075	13742	24721	82714

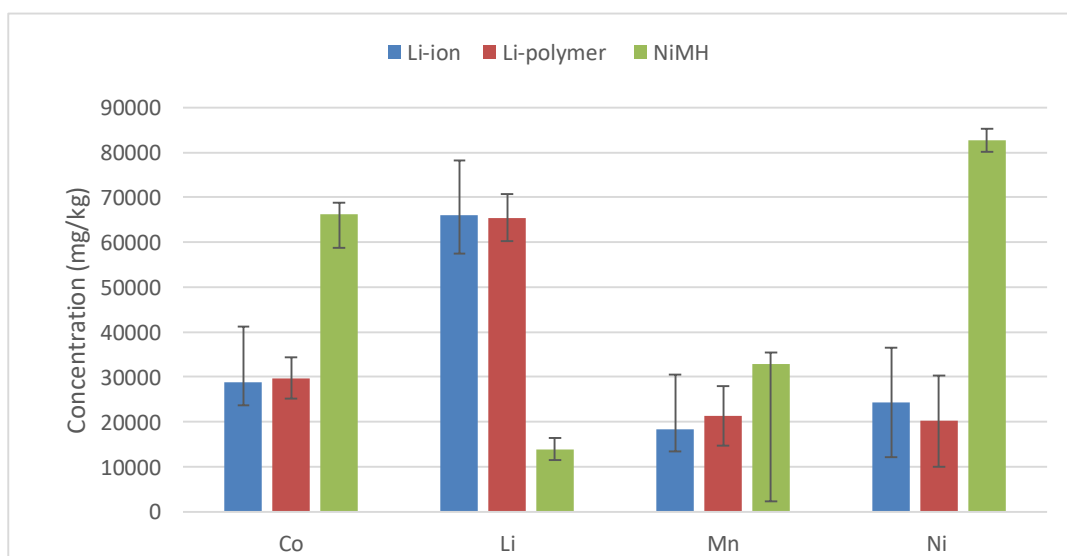


Figure 1: Summary of metal levels of waste rechargeable batteries

Data for rechargeable batteries used in other devices that are imported as separate items (not installed in any electronic devices) from 1999-2022 are presented in Table 4. Recoverable metals and values from these batteries also show that lithium batteries imported into Nigeria from 1999-2022 had 75.9 tonnes of recoverable Co with an estimated recoverable value of \$2.2 Million at a unit price of \$28,550 [37]. Also, 173.7 tonnes of recoverable Li, which at a unit price of \$15,343.30 [36] was estimated at a recoverable value of \$2.7 Million. Furthermore, 48.3 tonnes of recoverable Mn, having a unit price of \$1,690 [38] was estimated at a recoverable value of \$81,347. In addition, 64 tonnes of recoverable Ni, at a unit price of \$16,863 [39] was estimated at a recoverable value of \$1.1 Million. Li had the highest recoverable value followed by Co, then Ni and Mn. The total recoverable value of the metals was \$6 Million.

Presented in Table 5 is the recoverable quantities of CRM from waste batteries that were imported fixed in mobile phones and the values (in Dollars) for the period 1999-2022. The percentage weight of battery in a mobile phone is estimated at 5.304 % [13]. 5.304 % of 82,100 tonnes [10] being the quantity of mobile phones imported gave 4351.3 tonnes as the quantity of battery in the mobile phones produced from 1999-2022. Table 2 shows that 0.1 tonne of Co is recoverable from 4351.3 tonnes of the mobile phones imported from 1999-2022 which had a recoverable value of \$3,590 at the mineral market. Also, 0.3 tonne of Li was estimated which had a recoverable value of \$4,406. Mn was estimated at 0.08 tonne which had a recoverable value of \$135 while Ni was estimated at 0.1 tonne and its recoverable value was \$1,783. The total recoverable value of these metals was \$9,914.

Table 4: Recoverable values of WRB’s imported from 1999-2022

Metal	Qty of battery imported (t)	Recoverable metal (t)	Average metal content (g/t)	Market value (\$/t)	Total value (\$M)
Co	2630319	75.9	28.9	28550	2.17
Li	2630319	173.7	66	15343	2.66
Mn	2630319	48.3	18.3	1690	0.08
Ni	2630319	64	24.3	16863	1.08
Sum					5.99

Table 5: Recoverable value (in \$) from batteries installed in mobile phones imported between 1999 to 2022

Quantity of battery (t)	Metal	Concentration (g/t)	Recoverable metal (t)	Unit price (\$/t)	Market value (\$)
4351.3	Co	28.9	0.1	28550	3,590
4351.3	Li	66	0.3	15343	4,406
4351.3	Mn	18.3	0.08	1690	135
4351.3	Ni	24.3	0.1	16863	1,783
Total value					9,914

3.2 Discussion

Waste Rechargeable Batteries (WRB) – a cause for concern

Among the key components of rechargeable batteries are valuable metals such as lithium, cobalt, nickel, and rare earth elements [14]. These metals play a pivotal role in the functionality and performance of batteries, making them indispensable for various applications [3]. However, the conventional disposal methods of e-waste, often characterized by incineration and landfilling, not only squander these precious resources but also contribute to environmental pollution and resource scarcity [5, 15]. As society moves towards more sustainable practices, there is a pressing need to develop efficient and environmentally sound methods for the recovery of valuable metals from waste rechargeable batteries [14]. The field of battery recycling and metal recovery has gained momentum in recent years, driven by concerns over resource depletion, environmental impact, and the economic potential of recycling these materials [16, 17]. Also, health problems such as central nervous disorder, prostate and lung tumors, kidney disorders, pre-mature births, cardiac hypertrophy and illnesses of anaemia and osteomalacia which are prevalent in Nigeria at large are linked but not limited to environmental pollution due to the presence of lithium, nickel and manganese [18]. Despite the growing importation of batteries in Nigeria, there is a lack of comprehensive data on the metal levels present in discarded rechargeable batteries [19]. The absence of recycling facilities exacerbates the issue, hindering the recovery of valuable metals from these batteries [20].

Global Depletion of CRMs and Importance of Urban Mining

Some of the key battery tech manufacturing countries include China, Japan, South Korea, the United States, Germany and India. Chile has the largest known reserves of lithium in the world, with a total of 8 million tons. This puts it ahead of other countries with significant reserves, such as Australia (2.7 million tons). In Europe, Portugal also has smaller deposits of lithium. The global battery technology market size is expected to grow from \$95.7 billion in 2022 to \$136.6 billion by 2027 at a compound annual growth rate of 7.4 % [21].

It is projected that between 2020 and 2030, the global demand for lithium-ion batteries will increase eleven-fold reaching over two terawatt-hours in 2030. The global lithium-ion battery market, while valued at about 40.5 billion U.S dollars in 2020, the market should reach the size of around 91.9 billion U.S. dollars in 2030. The production capacity, worldwide is thus projected to significantly grow from almost 300 gigawatt-hours in 2018 to over two terawatt-hours in 2028 [22].

Urban mining aligns with the urgent need to address resource scarcity by recycling and recovering valuable metals from discarded batteries, minimizing the pressure on natural resources and mitigating environmental impact. Secondly, urban mining contributes to a sustainable waste management approach, reducing the burden of e-waste and promoting responsible disposal practices. Thirdly, it encourages the concept of a circular economy which emphasizes the importance of retaining the value of products and materials by promoting reuse, recycling, and resource recovery. Furthermore, it aligns with regulatory goals, complies with current environmental standards and responsible resource management.

Local Production of Rechargeable Batteries & WRB Management in Nigeria

The Federal Government of Nigeria, on October 12, 2023 inaugurated a \$250 Million Lithium Battery factory in Endo Community, Nasarawa Local Government Area, Nasarawa State to encourage local production of batteries and to end the of exportation of raw materials. The plant will handle 18,000 metric tons of lithium per day with annual processing capacity of 4.5 Million tons providing 2,500 jobs directly and 15,000 jobs indirectly [23]. One of the major challenges in waste management in Nigeria is the prevalence of informal waste disposal practices, such as open dumping and indiscriminate burning. The burning of waste releases harmful pollutants into the air, contributing to air pollution and posing serious health risks to residents, especially children and the elderly causing respiratory illnesses, skin conditions, and other health issues.. Furthermore, the lack of public awareness regarding waste disposal, leads to littering and improper waste segregation. However, empowering local residents through education and capacity-building initiatives can help promote sustainable behavior change and mitigate the adverse impacts of informal waste disposal on both the environment and public health [24]. Despite the challenges, Nigerian cities are increasingly turning to innovative solutions to address the waste management crisis and pave the way for a cleaner and more sustainable future. One such approach is the implementation of integrated waste management systems used by the Lagos Waste Management Authority (LAWMA) initiative that encompass waste reduction, recycling, and resource recovery. This involves the promotion of waste segregation at the source, whereby households and businesses separate recyclable materials from non-recyclables. This reduces the volume of waste sent to landfills and facilitates the recycling process, thereby conserving valuable resources and mitigating environmental pollution. By embracing innovative solutions, fostering collaboration, and promoting civic responsibility, we can overcome these challenges and pave the way for a future where waste is no longer a burden but a valuable resource for sustainable development [24].

Review of Options in WRB Recycling

To ensure a circular economy and protect the environment, collection and recycling of WRB should be prioritized. This starts with collection and pre-treatment of WRB. The ultimate goal of pretreatment is to separate as much as possible, the components of the battery, so these materials do not interfere with the leaching process [25]. It is necessary also to passivate the batteries [26]. Pre-treatment reduces impurities, facilitates the subsequent recovery process and enhances overall efficiency [27].

Discharge or Passivation: Battery discharge before dismantling prevents short-circuiting and self-ignition of battery rolls of anodes and cathodes [27]. Discharge is achieved by soaking the spent rechargeable batteries in a salt solution, with NaCl being the most popular. Na₂SO₄ is also common, but leaching efficiency has been shown to be as effective as NaCl [28].

Dismantling or Disassembly: There are two possible mechanisms for dismantling: manual and automatic disassembly. In manual disassembly, operators usually need to wear masks, protective glasses and gloves throughout the process and adopt scissors, knives and pliers to disassemble the batteries into different components. Manual operation is more developed, resulting in a higher purity of separated product [28]. Manual dismantling is not suited to large-scale industrial applications. During dismantling, toxic products can be

produced that must be taken into consideration. Metals like cobalt and nickel are toxic to human health, especially as a respiratory hazard. Electrolytes can produce many toxic compounds like fluorophosphates, fluoro-ethanol, hydrogen fluoride and fluoroethylene [28]. In the process, different metal components of the battery cell including outer metal casing, plastic materials, separators, cathode, anode and other materials (glue, binders, electrolytes, wires, etc.) are separated and taken for further treatment wherever necessary [28, 29]

As an alternative to dismantling, crushing and shredding the battery can be employed to make the process simple. Shredding or crushing the battery in an inert atmosphere has been used in the industry to combine the discharging step and dismantling step to make the process cheaper as well. Fire and emission of toxic gases are also dangers associated with crushing and shredding of batteries [25].

Component Separation: This may involve solvent dissolution which entails the use of alkalis or organic solvents to separate the components [30]. On the other hand, heat treatment using decomposition temperature of 350°C-600°C can be applied. Researchers often apply organic solvents to dissolve binders such as dimethyl formamide (DMF), N-methyl-2-pyrrolidone (NMP), dimethyl sulfoxide (DMSO), ethanol and ionic liquids.

Processing/Extraction Methods for WRBs

Pyrometallurgy (Thermal Processing): Pyrometallurgy (thermal processing) is a high temperature (500 °C – 1000 °C) thermal treatment which converts metal-containing battery components into metallic alloy [34]. Here, metals are converted into metal oxides. The pyrometallurgical process involves three main steps including pre-heating, plastic burning and metal reducing [25]. Although pyrometallurgical process is industrially viable for large scale recycling of spent batteries (Li-ion, Li-polymer and Ni-MH), it shows poor performance towards lithium recovery. Other drawbacks of pyrometallurgy are high temperature and energy consumption, high capital cost [14], hazardous gas emissions [31] and high cost of recovering elements from slag.

Hydrometallurgy (Aqueous Processing): In hydrometallurgical method (aqueous processing), the valuable metals present in the battery are dissolved into a liquid at low temperature of about 60 °C, followed by separation and purification to recover valuable metals [28]. In the metal leaching, various types of inorganic acids (HCl, HNO₃, H₂SO₄ and H₃PO₄) or alkaline e.g. (NaOH) are employed [28, 32]. It results in recovery of highly pure-grade Li but it produces a high amount of waste water which could damage the receiving water bodies if discharged without proper treatment [28]. A recent study from a research group on metal recovery from spent NMC type battery using 1 mol/L H₂SO₄ at 90 °C and solid – to- liquid ratio 1:10 without addition of a reducing agent achieved 100 % extraction of Co, Li, Ni and 93% extraction of manganese [33]. Among the pyrometallurgical and hydrometallurgical processes, hydrometallurgical is more advantageous because of less green house gases (GHGs) (e.g CO₂) emissions and low energy consumption [30]. In addition, hydrometallurgical processing results in recovery of highly pure-grade Li but it produces a high amount of waste water which could damage the receiving water bodies if discharged without proper treatment [28]. In hydrometallurgical process, H₂O₂ is mostly used as a reductant [26]. The highest recovery of various metals (Co: 99.5 %, Li: 99.9 %, Ni: 99.4 % and Mn: 99.9 %) was obtained under low concentration acid leaching condition (1 mol/L H₂SO₄) with a liquid – to- solid ratio of 20 : 1, reaction temperature of 60 °C and reaction

time of 1hr. Metals recovered can be purified by precipitation, solvent extraction or selective adsorption [27].

Bioleaching (Bio hydrometallurgy): Bioleaching is a microbial-based process used in the mining industry to extract valuable metals from ores and concentrates [25]. However, it can also be applied to the recovery of valuable metals from spent portable rechargeable batteries, such as lithium-ion batteries, which contain materials like lithium, cobalt, nickel, and other valuable metals. The process involved are outlined below. First, spent portable rechargeable batteries are collected and sorted based on their type and chemistry [26]. This step is essential because different battery chemistries contain varying metal compositions. The collected batteries are disassembled to access the inner components, including the cathodes, anodes, and electrolytes. This disassembly can be done manually or through automated processes [29]. The cathodes and anodes of the batteries are typically the most metal-rich components. These metal-rich parts are separated and processed further for bioleaching [31]. Specific types of bacteria or microbial consortia such as *Acidithiobacillus ferrooxidans* or *Acidithiobacillus thiooxidans* are selected for their ability to selectively leach metals from the battery components [14]. These microorganisms are often acidophilic, meaning they thrive in acidic environments, which is suitable for bioleaching. Fungi such as *Aspergillus niger* can also be used [34, 25].

The metal-rich battery components are exposed to the selected bacterial culture and a suitable leaching solution. This solution is typically acidic and contains nutrients to support microbial growth [35]. The bacteria then interact with the metal components, facilitating the dissolution of valuable metals into the solution. Once the metals have been leached into the solution, they can be recovered using various techniques, such as precipitation, solvent extraction, or electrodeposition. These techniques aim to separate and purify the metals from the leaching solution [25].

Bioleaching is a more environmentally friendly method compared to traditional chemical processes, as it reduces the need for harsh chemicals and minimizes hazardous waste generation. It allows for the efficient recovery of valuable metals, promoting resource conservation and reducing the demand for mining of virgin ores [14]. Bioleaching typically requires lower energy inputs compared to traditional smelting and refining processes. However, bioleaching may not be suitable for all types of battery chemistries and may require optimization for specific materials and conditions.

Electrochemical Extraction: This method can achieve high recovery efficiency without producing impurities. When a potential is provided by the external energy source and applied to the two electrodes of the electrolyser, a redox reaction of ions in the leaching solution is induced which results in the reduction of metal ions to metal on the cathodes [25].

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