

Plastic Waste Challenges in Nigeria: A Review on Pollution, Sorting, and Recycling Approaches

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Abstract

Plastic waste has become one of the most persistent environmental challenges in Nigeria, rather driven by continuous growth in population, urbanization, industrialization, increasing consumption of packaged goods, and inadequate waste-management infrastructure. The widespread use of plastics has become an integral part of modern life, with applications spanning household products, packaging materials, electrical and electronic appliances, structural components, medical devices, and advanced scientific equipment. In Nigeria, plastic consumption has increased substantially without a corresponding improvement in the collection, treatment, and disposal of the resulting waste. The problem is particularly pronounced in major commercial centers such as Lagos, Kano, Port Harcourt, Aba in Abia State, Onitsha in Anambra State, and other densely populated commercial areas across the country. Common plastic wastes include polyethylene bags, polyethylene terephthalate (PET) bottles, high-density polyethylene (HDPE) sachets used for packaged water, polystyrene disposable food containers and cutlery, polypropylene products such as broken chairs, low-density polyethylene (LDPE) shrink wraps, and numerous other materials belonging to the polymer family. The indiscriminate disposal of these materials has created serious environmental challenges in many communities. Plastic waste often accumulates in streets and drainage channels, obstructing water flow and providing suitable breeding grounds for mosquitoes, thereby contributing to environmental and public-health concerns. This article examines the environmental and ecological hazards associated with plastic waste and reviews both immediate and long-term strategies for reducing plastic pollution, highlighting sustainable approaches for improving waste management, safeguarding the environment, and protecting the lives of plants and animals. This review is more of a narrative review than other types, as this work mostly dwells on discussions on plastic pollution, sources, sorting, recycling, environmental impacts, economic value and recycling approaches by selecting relevant studies and discussing them systematically with findings synthesized qualitatively and research gaps highlighted.

Keywords: Plastic waste, recycling, environment, pollution, Nigeria.

1.0 Introduction

Plastics are polymers containing additives. Polymers are derived from crude oil. Plastics are used daily everywhere and thus an integral part of every community as a result of their wide range of applications across numerous sectors. Designers and engineers increasingly patronize plastics as a result of their unique combination of properties that may rather be difficult to obtain from other materials such as metals or ceramics. These properties include low weight, durability, corrosion resistance, colour stability, transparency, and ease of processing, among others. Although plastics have certain limitations, their potential applications are largely constrained only by the creativity and ingenuity of designers. Since the emergence of plastics, their production has continued to increase steadily in comparison with ceramics and it is always applied across different industries[1]. Products from plastic can be sourced and can be found everywhere around the world showing that the demand for plastics is significantly high. For example, in China alone, are more than 15000 plastic industries [2]. Nigeria is among the countries with plastic waste challenge as a result of its large and still growing population with urbanization and subsequent high dependence on packaging materials. Figure 1 shows a heap of waste plastic bottles (beverage bottles = Polyethylene terephthalate (PET), cap = Polypropylene (PP).



Figure 1: A heap of waste beverage bottles at a location in Ekiti State, Nigeria

Plastics can broadly be categorized into two major groups based on their thermal and mechanical properties: thermoplastics and thermosetting plastics. Thermoplastics can be softened and remoulded repeatedly via an application of heat and pressure, making them recyclable, and they are generally more widely used than thermosetting plastics. Common recyclable thermoplastics include polypropylene (PP), low-density polyethylene (LDPE), high-density polyethylene (HDPE), polyvinyl chloride (PVC), and polystyrene (PS). Table 1 presents some commonly used plastics and their respective applications. As indicated in Table 1, low-density polyethylene (LDPE) and polyethylene terephthalate (PET) are among the plastics that are extensively used and consequently contribute substantially to plastic waste generation. LDPE is commonly employed in the production of plastic bags, shrink films, sachet-water bags, and related packaging materials, whereas PET is widely used for beverage containers, including soft-drink and bottled-water.

Table 1: Some common plastics and their common applications

Plastic name	Acronym	Class of plastic	Applications
Low density polyethylene	LDPE	Thermoplastic	Plastic bag, Cling films, bread bags, shrink wrap
High density polyethylene	HDPE	Thermoplastic	Cream containers, detergent bottles, shopping bags
Polypropylene	PP	Thermoplastic	Plastic chairs, accelerator pedal, car bumpers, straw, microwave containers
Polyvinyl chloride	PVC	Thermoplastic	Plumbing pipes for drainage, credit card(uPVC), pipes
Polystyrene	PS	Thermoplastic	Packaging material, thermal insulator, fast food boxes
Polymethyl methacrylate	PMMA	Thermoplastic	Sauce pan handle
Polyethylene terephthalate	PET	Thermoplastic	Beverage bottles
Polyamide(nylon)	PA	Thermoplastic	Bearing, slide rollers
Polyurethane	PU	Thermoset	Rigid foam for insulation and flexible foam for cushion
Urea Formaldehyde	UF	Thermoset	Electric switches
Epoxy resin	ER	Thermoset	Polymer castings, adhesives

Common plastics encountered in Nigerian waste streams include PET, HDPE, LDPE, PP, PS and PVC. PET is widely used for bottled water, carbonated beverages and other drinks. HDPE is used for containers, bottles and household products, whereas LDPE is commonly found in shopping bags, packaging films and other flexible applications. PP is used in food containers, household products, chairs, packaging and other durable goods. PS is used for disposable food packs, cups and other lightweight products, while PVC occurs in pipes, cables and construction applications. Numerous studies have identified plastic waste as one of the major contributors to the increasing volume of solid waste generated worldwide. The indiscriminate disposal of plastic materials has resulted in the obstruction of waterways and drainage channels, contributing to the accumulation of debris, soil erosion, and leaching. This environmental challenge is partly attributed to the non-biodegradable nature of plastics, which are predominantly produced from petroleum-derived raw materials [3]. Polyethylene terephthalate (PET) has emerged as one of the most widely utilized plastics in the industry because of its diverse applications and outstanding mechanical strength[4]. PET bottles are particularly durable and may persist in the environment for approximately 450 years [5]. The relatively high degree of crystallinity of PET contributes to its rigidity and thermal

resistance, with a melting temperature of approximately 250 °C, which is comparatively higher than that of several other commonly used plastics[6].

PET is a linear-chain polymer with favourable processing characteristics that allow it to be repeatedly softened by heating and solidified upon cooling. Consequently, it belongs to the thermoplastic class of polymers and can be mechanically or thermally recycled. PET resin can be processed into various products and forms, as illustrated in Figure 2, with PET fibres and PET bottles representing being the most commonly used.

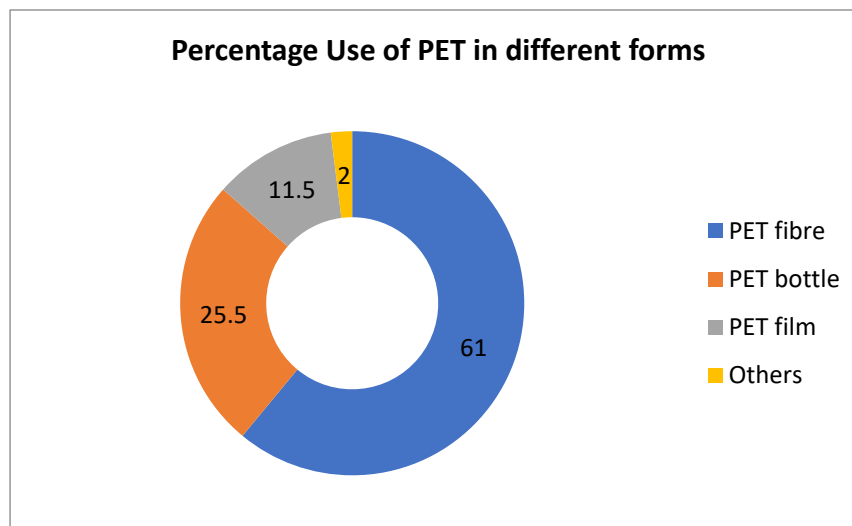


Figure 2: Percentage use of PET in varying forms Adapted from [4]

A major factor responsible for the substantial generation of PET waste from beverage containers is their predominantly single-use nature [7]. The growing accumulation of plastic waste poses a serious threat to the environment, particularly in the context of climate change, which is influenced by patterns of consumption and the inadequate reuse, recovery, and recycling of plastic materials. The persistence of non-biodegradable plastics in the environment contributes to different types of pollution [8], with potential consequences for food safety and economic activities. Improperly discarded plastics can obstruct drainage systems and waterways, increasing the risk of flooding and soil erosion, which may subsequently contribute to the displacement of affected communities. Furthermore, plastic production, use, and disposal contribute to climate change through the emission of greenhouse gases, including carbon dioxide. Plastic waste also poses significant threats to aquatic ecosystems, where it can endanger marine and freshwater organisms through ingestion, entanglement, and habitat degradation.

Nigeria is endowed with numerous water bodies that provide important habitats for aquatic organisms, including major rivers such as the Niger and Benue Rivers. However, the increasing accumulation of plastic waste in drainage systems and waterways has become a significant environmental concern. The obstruction of channels intended for water flow can impede drainage, thereby increasing the incidence of flooding, soil erosion, and alterations to the natural landscape. Large quantities of plastic waste are also transported into aquatic environments, including oceans, seas, rivers, and lakes, where they contribute to water pollution and pose serious threats to aquatic ecosystems and biodiversity, including the decline or loss of some aquatic species. A substantial proportion of plastic waste originates from packaging materials, as illustrated in Figure 3, with packaging accounting for more than one-quarter of the total plastic waste generated.

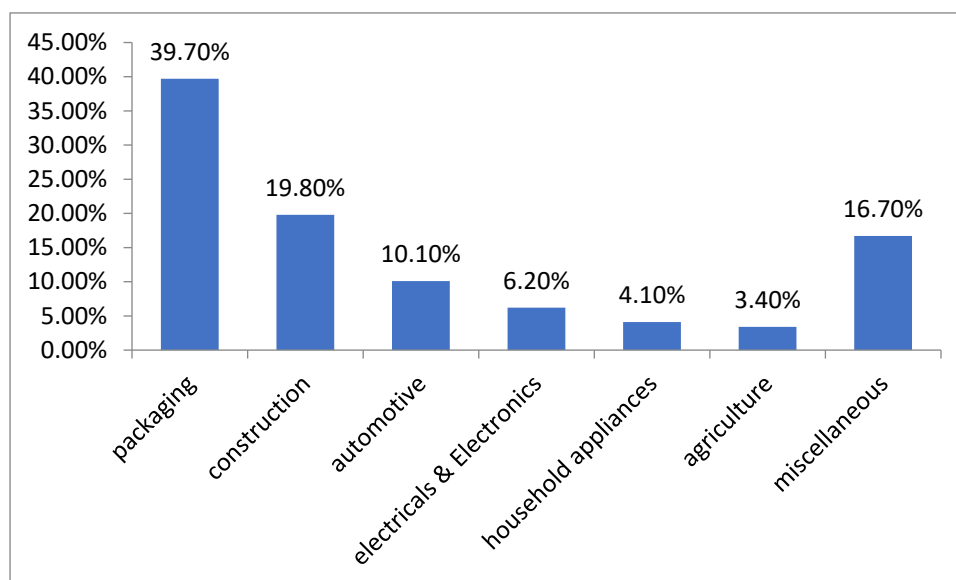


Figure 3: Percentage of plastic waste generated from different sectors [9]

The accumulation and indiscriminate disposal of plastic materials, including beverage bottles, carrier bags, and various packaging products, constitute major sources of environmental pollution. The widespread adoption of plastics can be attributed to their lightweight nature, ease of handling, convenience, versatility, and relatively simple manufacturing processes, which have enabled them to replace many conventional materials and consequently increased the volume of plastic waste generated. Inadequate collection, recycling, and disposal systems further result in substantial quantities of plastic waste being deposited in landfills and other uncontrolled locations, thereby exacerbating environmental pollution. The persistence and improper management of these waste pose significant risks to environmental quality and can adversely the health and well-being of both humans and animals.

2. Plastic pollution in Nigeria

2.1 Land and soil pollution

Soil contamination or pollution is the introduction and accumulation of chemical substances, waste, or other pollutants in soil at concentrations that can adversely affect soil quality, ecosystems, human health, or agricultural productivity. Improperly discarded plastic waste are widespread in urban, semi-urban and even rural areas within the environment. Plastics may accumulate along roadsides, vacant plots, markets and drainage systems. Their low density enables wind and surface runoff to transport lightweight plastics from their original disposal locations to other areas. Accumulation in drainage channels is particularly significant in Nigerian cities. Plastic bags, bottles, sachets and packaging films can obstruct water flow, increasing the risk of localized flooding during heavy rainfall. This problem is intensified in densely populated urban areas, as a result of poor waste management [10], waste generation is high and drainage systems already under pressure can be clogged. Plastic accumulation on land can alter soil characteristics and interfere with ecological processes. Large plastic materials may physically cover soil surfaces, while fragmented plastics can become incorporated into soil. Plastic-associated chemicals and contaminants may also interact with soil organisms and plants. However, compared with aquatic plastic pollution, written papers and evidence on the distribution and ecological effects of plastics in Nigerian soils are still insufficient.

2.1.1 Sources of soil contamination associated with plastic waste

Several pathways can contribute to plastic-related soil contamination; these pathways include but are not limited to:

(a) **Indiscriminate disposal as well as open dumping**

Plastic bags, bottles, sachets, packaging materials and other plastic products discarded on land can accumulate directly in the soil. Poorly managed general or municipal waste is therefore an important source of plastic pollution.

(b) **Landfills and waste disposal sites**

Plastic-containing municipal waste can accumulate in landfill environments. Rainwater passing through waste may lead to leaching, which can transport dissolved chemicals and other contaminants into surrounding soil and potentially groundwater.

(c) **Agricultural plastics**

Agricultural films, irrigation pipes, fertilizer bags, pesticide containers and other plastic materials can leave residues in agricultural soils. Repeated use of plastic mulch and inadequate removal after cultivation can contribute to the accumulation of plastic fragments and microplastics.

(d) **Wastewater and sewage sludge**

Microplastics originating from domestic and industrial wastewater can enter wastewater-treatment systems. Some particles may subsequently accumulate in sewage sludge, which, when applied to agricultural land, can introduce plastics and associated contaminants into soils.

(e) **Atmospheric deposition of plastic waste**

Soils could be polluted when small plastic particles and fibres are transported through the atmosphere and deposited onto the soils. This provides an additional pathway by which plastic contamination can reach areas distant from the original source. Plastic particles can alter soil structure, porosity, water-holding capacity, bulk density and aggregate stability. Their effects depend on particle size, shape, polymer type and concentration. Microplastics may also influence the movement of water and air through soil and can interact with soil organisms[11]. Plastics may have been produced with some additives which can affect soil structure and nutritional value. Weathering can facilitate the release of additives and can also modify plastic surfaces, allowing them to interact with other pollutants [12]. Plastic particles may carry heavy metals and hydrophobic organic pollutants, onto soil surfaces. Consequently, plastics can influence the transport and distribution of contaminants within soil, although the importance of plastics relative to naturally occurring soil particles and organic matter varies with environmental conditions [13]. Hence effective plastic-waste management is paramount for preventing soil contamination.

2.2 Aquatic and marine Pollution

Plastic waste transported through drainage systems, streams and rivers eventually gets to larger water bodies and coastal regions. Nigeria's extensive network of rivers and coastal areas therefore provides pathways for land-based plastic waste to penetrate aquatic ecosystems. Once in aquatic environments, plastic materials can fragment into smaller particles through ultraviolet radiation, mechanical abrasion, oxidation and other environmental processes. These fragments can form microplastics, which may be ingested by aquatic organisms and potentially enter food chains[10].

2.3 Air pollution as a result of burning plastics

Open burning [2,10,14] is another important plastic-waste management problem. Where collection and disposal systems are inadequate, households and communities may burn accumulated waste to reduce its volume. Burning plastics under uncontrolled conditions can release particulate matter and potentially hazardous gaseous and chemical emissions. It also destroys material resources that could otherwise be recovered through recycling. Hence it is imperative to educate citizens on the proper disposal of plastic waste.

3.0 Environmental impacts of plastic pollution

Plastic pollution produces interconnected environmental, social and economic impacts. Environmentally, plastic waste contributes to landscape degradation, drainage blockage, flooding, aquatic contamination and habitat disturbance. Persistent plastic materials can also fragment into microplastics, increasing the complexity of pollution management. The socioeconomic consequences include increased municipal cleaning costs, reduced aesthetic quality of urban environments, damage to drainage and infrastructure, reduced productivity of affected communities and potential losses to fisheries and tourism. Plastic pollution also represents a loss of potentially valuable materials. PET, HDPE and PP waste, for example, can be recovered and converted into secondary raw materials when properly collected and sorted. Plastic waste management can therefore be viewed not only as an environmental problem but also as an economic opportunity. Recovery and recycling can generate employment for waste collectors, sorters, transporters, processors and manufacturers. A circular plastics economy can further create markets for recycled materials and reduce dependence on virgin polymer feedstock.

3.1. Chemical Leaching as a result of plastic contaminations

The process by which some chemical substances are released from virtually solid materials and transferred into a surrounding liquid or other environmental medium can be termed 'chemical leaching'. In the context of plastic waste, leaching occurs when water or other fluids come into contact with plastic materials and dissolve, mobilize, or extract chemicals present in or associated with the plastic. These substances may include plastic additives, such as ; stabilizers, plasticizers and other contaminants [12,15]. Chemical leaching is an important environmental concern because plastics discarded in landfills, open dumps, drainage channels, rivers and coastal environments can remain in contact with rainwater, groundwater or surface water for extended periods. As water passes through or over plastic waste, chemicals can migrate from the plastic matrix into the surrounding environment. The extent of leaching depends on factors such as the type of polymer, chemical composition of the plastic, temperature, pH, contact time, moisture content, particle size and degree of weathering [16]. Plastic

products contain numerous chemical substances that can potentially migrate into the environment. Some are intentionally added during manufacturing, while others may be residual chemicals from polymer production or degradation. For example, plasticizers are commonly associated with flexible plastics, while stabilizers, antioxidants, flame retardants, pigments and processing aids are used to improve specific properties of plastic products. Because some additives are not chemically bonded to the polymer chains, they may gradually migrate out of the plastic under favourable environmental conditions[12]. The degradation of plastic waste can enhance chemical leaching. Ultraviolet radiation, heat, oxygen, mechanical abrasion and biological processes can alter the polymer structure and increase its surface area. Weathered plastics may therefore release chemicals more readily than intact plastics. Smaller particles, including microplastics and nanoplastics, can have a relatively large surface area and may facilitate greater interactions with surrounding water and sediments. Factors that may influence the rate of chemical leaching include: type of polymer (PVC, PP, PE,PC), type of additive, particle size, temperature, weathering condition (UV radiation, oxidation) and temperature.

3.2 Human exposure and ecotoxicological effects of plastics

Plastics contain chemical additives that may be released during their use, degradation, disposal and recycling, therefore plastic pollution is increasingly recognized as an environmental and public-health concern. Human exposure and ecological effects can arise from both the physical presence of plastic particles, particularly microplastics and nanoplastics, and from chemicals associated with plastics, including plasticizers, flame retardants, stabilizers, pigments and residual monomers[12,17]. Ecotoxicology examines the effects of pollutants on organisms, populations and ecosystems. Plastic pollution can produce ecotoxicological effects through both physical particle effects and chemical toxicity, this can be detailed in subsequent work.

3.3 Categories of plastics and some other factors contributing to plastic pollution

3.3.1 Microplastics

Microplastics (denoted as: MPs) could be said to be those small plastic particles that are usually less than 5 mm in size. They are plastics with very small dimensions, the small dimension could be as a result of the breakdown of larger plastic materials. Microplastics could be of various shapes and they can come in form of fragments, fibres, films, foams and pellets, and may consist of polymers such as polyethylene (PE), polypropylene (PP), polystyrene (PS), polyvinyl chloride (PVC) and polyethylene terephthalate (PET) [18]. Exposure to sunlight, particularly ultraviolet radiation, together with oxidation, mechanical abrasion and weathering can progressively weaken plastic materials and cause them to fragment into smaller particles [19]. Once released into the environment, microplastics can be transported through rivers, wastewater, wind and ocean currents. They have been detected in marine, freshwater and terrestrial environments, including sediments and soils. Their small size makes them difficult to recover using conventional waste-management systems, allowing them to persist and accumulate in environmental compartments [11,20]. Microplastics are also of concern because they can interact with organisms throughout the food web. Aquatic organisms, including plankton, fish, shellfish and other invertebrates, may ingest microplastics because of their small size or similarity to food particles. Ingestion can potentially cause physical effects, including reduced feeding, digestive disturbances and impaired growth, although the magnitude of these effects varies with polymer type, particle size, concentration and exposure conditions [21]. Microplastics are particularly relevant to plastic-waste management and recycling because inadequate collection, sorting and disposal of plastic waste can increase the amount of plastic exposed to environmental weathering. Consequently, effective source reduction, collection, segregation, recycling and appropriate disposal of plastic waste are important measures for reducing the formation and release of secondary microplastics.

3.3.2 Nanoplastics

Nanoplastics (denoted as: NPs) are extremely small plastic particles generally considered to have at least one dimension in the nanometer range (1–1000 nm).. Nanoplastics can be as a result of production of nanoscale plastic materials or, via the progressive fragmentation and degradation of larger plastic particles and products [18,22]. Nanoplastics can be classified as primary or secondary particles. Primary nanoplastics are intentionally manufactured or released directly at nanoscale dimensions, whereas secondary nanoplastics are generated when larger plastic materials undergo continuous degradation. Processes such as ultraviolet radiation, oxidation, thermal degradation, mechanical abrasion and biological activity can progressively break down plastic waste into microplastics and eventually smaller particles, including nanoplastics [22,23]. The extremely small size of nanoplastics distinguishes them from conventional plastic waste and microplastics. Their small dimensions provide a large surface-area-to-volume ratio, which can influence their interaction with environmental contaminants, microorganisms and biological tissues. Some examples of polymers associated with nanoplastics include polyethylene (PE), polypropylene (PP), polystyrene (PS), polyethylene terephthalate (PET) and polyvinyl chloride (PVC) [22,24]. Nanoplastics can enter the environment through several pathways. The weathering of plastic waste, degradation of packaging materials, abrasion of synthetic textiles, breakdown of plastic products and

fragmentation of microplastics can contribute to their formation. Once released, their small size allows them to be transported through water, wastewater, soil and atmospheric systems. They have therefore become an emerging contaminant of concern in marine, freshwater and terrestrial environments. Nanoplastics are of particular concern because their small size may allow them to interact more readily with biological membranes and cellular structures than larger plastic particles. Laboratory studies have reported that nanoplastics can be taken up by aquatic organisms and may cause oxidative stress, inflammation, changes in metabolism and other cellular effects, although the magnitude and ecological significance of these effects depend strongly on particle size, polymer type, surface characteristics, concentration and exposure conditions [24,25]. Nanoplastics may also interact with other substances present in the environment. Their surfaces can adsorb chemicals, metals and other pollutants, potentially influencing the transport and bioavailability of these substances. However, the environmental importance of nanoplastics as vectors for contaminants remains an active area of research, and their behaviour can differ considerably from that of larger microplastics[22]. Another major challenge is their detection and quantification. Because nanoplastics are considerably smaller than microplastics, conventional methods used for identifying larger plastic particles may not adequately detect them. Advanced analytical techniques, including electron microscopy, atomic force microscopy, spectroscopy and mass-spectrometric approaches, are increasingly being investigated for their characterization. The absence of standardized analytical methods and agreed definitions remains a major obstacle to accurately determining their environmental concentrations and risks. Nanoplastics represent an important downstream consequence of inadequate plastic-waste management. When plastic bottles, packaging, bags and other products are improperly discarded, prolonged exposure to sunlight, heat, moisture and mechanical forces can cause progressive fragmentation. Thus, effective plastic collection, sorting, recycling, reuse and controlled disposal can help reduce the amount of plastic available for environmental degradation and subsequent formation of micro- and nanoplastics. Table 2 shows the categories of plastics with major differences between macroplastics, microplastics and nanoplastics.

Table 2: Categories of plastics with their examples

S/N	Category of plastic	Approximate size	Examples
1	Macroplastics	>5mm	PET bottles, plastic containers and drums, nylon fishing rod
2	Microplastics	<5mm	Fragments of plastics, fibres, films and pellets
3	Nanoplastics	<1 µm	Fragments that are of nanoscale

3.3.3 Plastic Additives

Plastic additives are those substances that are introduced into polymers to boost their mechanical or physical properties or both and enhance their performance especially in composites applications. Unlike the polymer itself, many additives are not chemically bound to the polymer chains and can therefore migrate or be released from plastic products during their use, disposal, recycling, or environmental degradation. Their presence in plastic-waste management can influence both the environmental behaviour and recyclability of plastics [12,16]. Plastic additives are used in almost all major polymer types such as polycarbonates (PC) polyethylene terephthalate (PET), polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), and polystyrene (PS). Depending on the intended application, additives may be present at concentrations ranging from trace levels to substantial proportions of the plastic product. Some examples and functions of these plastic additives are shown in Table 3.

Table 3: Plastic additives and their uses

S/N	Additive	Function
1	Flame retardants	Flame retardants are incorporated into plastics to reduce their flammability and slow the spread of fire. An example of flame retardant is Bromine
2	Plasticizers	Plasticizers are added for improved flow or flexibility and hence workability of polymers.
3	Antioxidants and stabilizers	Antioxidants protect polymers from degradation caused by oxygen, heat and processing conditions. Stabilizers can also protect plastics from ultraviolet (UV) radiation and other environmental stresses. These additives extend the service life of plastic products and help maintain their mechanical properties during processing and use.
4	UV stabilizers	UV stabilizers reduce degradation caused by exposure to ultraviolet radiation from sunlight. Without adequate stabilization, prolonged UV exposure can cause discoloration, embrittlement, cracking and fragmentation of plastic products. UV

S/N	Additive	Function
		stabilizers are therefore important in outdoor applications such as agricultural films, construction materials and packaging
5	Colorants and pigments	Colorants are used to provide plastics with specific colours, opacity and visual characteristics. They may include organic dyes or inorganic pigments. Some pigments can contain metals or other substances that require consideration during recycling and disposal
6	Fillers and reinforcing agents	Fillers are incorporated to modify mechanical properties, reduce production costs or improve dimensional stability [26]. Examples include calcium carbonate, talc, clay and glass fibres. Although fillers are sometimes distinguished from conventional chemical additives, they form an important component of many commercial plastic formulations.
7	Lubricants and processing aids	These additives improve the flow and processing behaviour of polymers during processing such as extrusion, injection moulding and other manufacturing processes. They can reduce friction between the polymer and processing equipment and improve the quality of finished products
8	Antistatic agents	Antistatic additives reduce the accumulation of static electrical charges on plastic surfaces.

Plastic additives can become environmental contaminants because they may migrate from plastic products into surrounding media. Release can occur during the normal use of products, washing, weathering, recycling, landfilling and incineration. Factors such as temperature, sunlight, mechanical abrasion, polymer composition and the chemical properties of the additive influence their release[12]. When plastic waste is exposed to environmental conditions, degradation of the polymer matrix can also increase the accessibility of additives. Consequently, plastic waste can act as a source of chemicals in soil, sediments, freshwater and marine environments. Some additives are persistent, bioaccumulative or toxic, while others may have lower environmental persistence or toxicity. Therefore, the environmental risk depends strongly on the specific additive and its concentration. Plastic additives are particularly important during mechanical recycling. When plastics are recycled, additives originally incorporated into the material may remain in the recycled polymer. Furthermore, plastics of different ages and compositions may be mixed during collection and processing, potentially resulting in variable additive concentrations in recycled products.

3.3.4 Particulate matter (PM)

Particulate matter (PM) refers to solid particles and liquid droplets suspended in the air. In plastic-waste burning, PM may consist of soot, ash, unburned or partially burned plastic, and condensed organic compounds. Fine particles of $\leq 2.5 \mu\text{m}$ are of particular concern because they can penetrate deeply into the respiratory system. Open burning generally produces substantial particulate emissions because combustion is incomplete and there is little or no filtration of the resulting smoke. PM exposure is associated with respiratory and cardiovascular effects and can transport toxic substances such as metals and organic pollutants[27].

3.3.5 Carbon monoxide (CO) and Carbon dioxide (CO₂)

Carbon monoxide (CO) is a colourless and odourless toxic gas formed mainly by incomplete combustion of carbon-containing materials. During uncontrolled burning of plastics, insufficient oxygen, fluctuating temperatures and poor mixing can prevent complete conversion of carbon to CO₂, thereby increasing CO formation. CO is hazardous because it binds strongly to hemoglobin, reducing the blood's ability to transport oxygen. Consequently, high exposure can cause headache, dizziness, impaired consciousness and, at sufficiently high concentrations, death. Carbon dioxide (CO₂) is the principal carbon-containing product of the complete combustion of organic materials, including most plastics. Plastics are largely derived from fossil hydrocarbons; therefore, combustion releases their carbon predominantly as CO₂. Unlike CO, CO₂ is not primarily an indicator of incomplete combustion. Rather, it is an important greenhouse gas and represents a direct transfer of fossil carbon from plastic products to the atmosphere. The climate impact of plastic combustion therefore needs to be considered when evaluating waste-to-energy options. [27].

3.3.6 Volatile organic compounds (VOCs)

Volatile organic compounds (VOCs) are carbon-containing chemicals that readily evaporate into the atmosphere. Plastic combustion can generate VOCs when polymers undergo thermal decomposition and

incomplete oxidation. Depending on the plastic and combustion conditions, VOC emissions may include hydrocarbons, aldehydes, ketones, aromatic compounds and other organic substances. VOCs are important because some are directly toxic, while others participate in atmospheric photochemical reactions that contribute to the formation of ground-level ozone and secondary organic aerosol. Poorly controlled plastic burning can therefore contribute to both local toxicity and wider air-quality problems. Recent reviews of plastic-waste treatment identify VOC emissions as an important concern associated with improper plastic disposal and combustion [28].

3.3.7 Polycyclic aromatic hydrocarbons (PAHs)

Polycyclic aromatic hydrocarbons (PAHs) are a group of organic compounds containing two or more fused aromatic rings. They are formed primarily during incomplete combustion and pyrolysis of carbon-rich materials. Plastic waste burning can generate PAHs, particularly under oxygen-deficient or low-temperature conditions. Some PAHs are carcinogenic, mutagenic or otherwise toxic. They can be emitted in the gaseous phase or attached to particulate matter, allowing them to persist in smoke and subsequently deposit onto soil, vegetation and water. WHO specifically identifies PAHs among pollutants associated with open waste burning [27].

3.3.8 Heavy metals associated with plastic waste and pollution

Plastic waste can contribute to heavy-metal contamination because some metals are used as pigments, stabilizers, catalysts, fillers or other additives during plastic production. For example, compounds containing lead, cadmium and chromium have historically been used in some plastic formulations, particularly as pigments and stabilizers. Consequently, certain plastic products can contain metals that may be released during weathering, disposal, recycling or combustion [12,29]. Heavy metals may also become associated with plastic surfaces after plastics enter the environment. Weathered plastics can develop cracks, increased surface area and altered surface chemistry, which can facilitate the adsorption of metals from contaminated water or sediments. Microplastics are therefore capable of interacting with metals such as lead, cadmium, copper and zinc in aquatic and terrestrial environments [30]. Heavy metals are naturally occurring elements that can become hazardous environmental contaminants when present at excessive concentrations. In plastic-waste systems, they may originate from metal-containing additives, pigments and stabilizers, or become attached to plastic surfaces after environmental exposure. Their persistence, potential toxicity and ability to accumulate in environmental compartments make them important considerations in plastic disposal, recycling and environmental risk assessment. Effective collection, sorting, controlled recycling and environmentally sound disposal can help reduce the release and redistribution of heavy metals associated with plastic waste.

4.0 Major and common sources of plastic waste

The **major sources of plastic waste** can be broadly classified according to the activities or sectors that generate them as shown in Table 4.

Table 4: Major sources of plastic waste

S/N	Source	Plastic type
1	Household and domestic activities	Plastic wrap bags, water sachets, PET/beverage bottles, food containers, disposables
2	Commercial and retail activities	Shopping bags, Packaging films and wraps, Food-service containers, plastic packaging
3	Industrial and manufacturing activities	plastic scraps and off-cuts, condemned (with defects) plastic products, plastic packaging materials, process residues, damaged containers and components
4	Agricultural activities	Fertilizer and pesticide containers, irrigation pipes and plastic tubing, mulching films, greenhouse plastics, animal-feed plastic containers and agricultural-product packaging
5	Construction and demolition sites	PVC pipes and fittings, Plastic insulation materials, Packaging from construction materials, Plastic sheets, films and flooring materials
6	Healthcare and medical facilities	Syringes and medical tubing, Gloves and disposable protective equipment, IV bags and tubing, Medicine and chemical containers, Disposable medical packaging
7	Transportation and automotive sectors	Plastic vehicle components, bumpers and dashboards, used tires and synthetic materials, packaging of spare parts.

8	Institutional sources: E. g Universities, secondary schools	PET bottles, food packaging plastics, plastic wrapping bags, stationery and disposable item.
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4.0 Plastic Recycling

Plastic waste has emerged as a major environmental challenge in Nigeria since the widespread introduction and adoption of plastic materials. One effective approach to addressing the plastic waste challenges is plastic recycling, which involves the collection, recovery, and reprocessing of discarded plastic materials into new and useful products that may differ substantially from their original forms. Recycling converts used materials into new products, thereby minimizing the wastage of potentially valuable resources, reducing dependence on virgin raw materials, lowering energy consumption, and decreasing air and water pollution associated with incineration and landfilling. Discarded plastics can be transformed into a variety of useful products, including hangers, shopping bags, and reinforcement materials for construction and building applications. The recycling of plastic waste offers several environmental and economic benefits, including the conservation of non-renewable fossil-fuel resources. Plastic production is estimated to account for approximately 8% of global oil consumption, with about 4% used as feedstock and another 4% consumed during manufacturing. Recycling can also reduce energy requirements, minimize the quantity of solid waste sent to landfills, and lower emissions of greenhouse gases and other pollutants, including carbon dioxide (CO₂) [4]. Plastic materials are ubiquitous in Nigerian communities and include polyethylene carrier bags, polypropylene containers, polyethylene terephthalate (PET) bottles used for water and beverages, discarded plastic furniture such as chairs, and various plastic components and scraps generated from automobiles, electrical equipment, and electronic devices. Effective collection, sorting, and recycling systems could significantly reduce the environmental burden associated with these materials. However, the commercialization of recycled plastics (recyclates) continues to face several challenges. These include limited and inadequate markets for recycled products, the comparatively lower quality of some recyclates, and the substantial capital investment required to establish and operate large-scale plastic recycling facilities [31]. However, their durability and resistance to temperature remain their downsides [32].

4.1 Ways of recycling plastics waste

There are several ways of recycling plastic waste or converting plastic waste into some useful products. These include: mechanical recycling, chemical recycling [4], and biological recycling [1]. Chemical recycling of plastics involves the conversion of these plastic waste into their constituent substances or monomers (depolymerisation using cracking agent) that could be introduced as raw materials for new products, with glycolysis being the most widely used method [5,6]. Chemical recycling is very expensive and much more expensive than mechanical recycling [9] and it emits carbon dioxide (a greenhouse gas) more than others [33]. Thermochemical conversion involves straight conversion of useful products via the application of heat and some chemical reactions. Biological recycling though still emerging and being researched, involves the use of enzymes to depolymerize plastic under certain conditions [6]. Upcycling involves reconfiguration or conversion of polymer chain into high value added via chemical, biological or physical approach [6]. Mechanical recycling being less expensive and achievable in Nigeria is therefore discussed in subsequent section.

4.1.1 Mechanical recycling

Mechanical recycling is a widely adopted approach for managing plastic waste and involves the recovery, processing, and conversion of discarded plastics into new and useful products. It is regarded as one of the most practical and effective methods of plastic waste management [7]. Through mechanical recycling, waste plastics can be converted into a wide range of products, including plastic lumber, waste bins, benches, stationery, tiles, paving blocks, concrete products, sanitizers, perfumes, graphene, electrode materials, carbon nanotubes, and construction materials such as asphalt mixtures [7,33]. The mechanical recycling process generally consists of several stages, beginning with the collection of plastic waste. Before further processing, the collected plastics are sorted according to their polymer type using the Resin Identification Code (RIC). The RIC system was developed by the Society of the Plastics Industry as a means of identifying and categorizing different types of plastics. The identification number is commonly displayed within a triangular symbol formed by three arrows, usually located at the bottom or base of plastic containers. The various plastic categories and their corresponding resin identification codes are presented in Table 5. Accordingly, collected plastic wastes are separated based on their respective resin identification codes to facilitate appropriate recycling and subsequent processing.

Table 5: Some common plastics and their Resin Identification Code

S/N	Plastic name	Resin Identification Code (RIC)
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1	Polyethylene terephthalate (PET)	1
2	High density polyethylene (HDPE)	2
3	Polyvinyl chloride (PVC)	3
4	Low density polyethylene (LDPE)	4
5	Polypropylene (PP)	5
6	Polystyrene (PS)	6
7	Others such as acrylonitrile butadiene styrene (ABS), polycarbonate (PC)	7

4.1.1.1. Stages in mechanical recycling

4.1.1.1.1 Collection

Specially designed waste plastic collection bins are usually placed at designated locations in the communities, market places, institutions etc. especially in developed countries. From these places, the waste plastics are taken to depots for sorting and washing.

4.1.1.1.2 Sorting

Before processing, the collected plastics are sorted. There are a couple of methods used in sorting of plastic waste, however the choice of method is highly dependent on the type of plastic, physical properties, colour, size, and intended recycling process. The major types of plastic-waste sorting include:

- (a) **Manual sorting:** Workers visually identify and separate plastics based on type, colour, shape, product, or contamination level. Manual sorting is mostly adopted in developing countries. This adoption can be attributed to the facts that this method is simple and inexpensive, suitable for small-scale recycling facilities. However, it is labour-intensive and relatively slow, it can often be used as a preliminary sorting stage. Manual pre-sorting is highly suitable because it requires relatively little capital investment and can remove obvious contaminants before PET bottles enter the crusher.
- (i) **Sorting by polymer/resin type:** Plastics are separated according to their polymer composition, usually using the Resin Identification Code (RIC): (see Table 5). This is particularly important because different polymers have different melting temperatures and processing requirements
- (ii) **Sorting by colour:** Plastic wastes are separated into clear, transparent, white, coloured, and dark/black plastics. For example, clear PET bottles are commonly separated from green, brown, or other coloured PET because clear PET generally has a wider range of recycling applications
- (iii) **Sorting by shape and size:** Plastics can also be sorted according to the size, weight and shape of the plastic, putting into consideration the type of shredder or processing equipment available as well as the end use. However Size alone cannot reliably distinguish polymers because different plastics can have similar dimensions. Therefore, size sorting is normally used as a supporting technology rather than a complete polymer-identification method.
- (b) **Air or pneumatic sorting** [3]: A controlled airflow separates plastics based on differences in weight, shape, and aerodynamic properties. Light materials such as plastic films can be separated from heavier materials such as rigid plastic pieces.
- (c) **Magnetic and eddy-current sorting:** These methods are mainly used to remove metal contaminants from plastic waste. Magnetic separators remove ferrous metals such as iron and steel. Eddy-current separators can remove non-ferrous metals such as aluminum. Although they do not primarily distinguish one polymer from another, they are important for preparing plastic waste for recycling.
- (d) **Optical sorting:** Optical sorting systems use cameras, near-infrared (NIR) sensors, or other spectroscopic techniques to identify plastics according to their polymer type and colour. For example, an NIR sorter can distinguish PET from HDPE, PP, and other polymers and automatically direct them into separate streams.
- (e) **Electrostatic sorting**[33]: Plastic particles are electrically charged and separated according to differences in their electrical properties. It can be useful for separating polymers that have similar densities and are difficult to distinguish by conventional density separation.
- (f) **Sensor-based/automated sorting** [6]: Modern recycling plants combine NIR spectroscopy, colour cameras, artificial intelligence, robotics, and machine-learning algorithms to automatically identify and sort different plastic materials.
- (g) **Density-based sorting:** Density-based sorting has to do with the differences in the specific gravity of different materials, in order to separate them. Several polymeric materials have different densities. For example, PET has a density of approximately 1.38 g/cm^3 , while common polyolefin such as HDPE and PP have densities below water, these could be separated under suitable environment.

For “Plastic Waste Challenges in Nigeria: the most relevant methods would be manual sorting, resin/polymer identification, colour sorting, density separation, size screening, optical/NIR sorting, and automated/AI-based sorting, as these directly affect the quality and efficiency of recycled PET, HDPE, PP, LDPE and other plastics

4.1.1.1.3 Pre-washing

The sorted plastic materials are thoroughly washed to remove dirt, contaminants, and other unwanted particles. The cleaned plastics are subsequently dried to prepare them for further processing.

4.1.1.1.4 Shredding into flakes

The pre-washed plastics are introduced into a crusher or shredder, where they are reduced into smaller flakes. The shredded materials are then subjected to a second washing process to eliminate any remaining contaminants before being dried.

4.1.1.1.5 Pelletization

The dried plastic flakes are transferred into a hopper and processed through a pelletizer, where they are converted into uniform plastic granules or pellets suitable for subsequent processing.

4.1.1.1.6 Extrusion

The recycled plastic pellets are fed into an extruder, where they are melted and, when required, blended with virgin polymer materials. The molten material is then shaped through an appropriate die to produce new plastic products or articles.

5.0 Some specific areas where recycled plastics can be applied

Recycled plastics have found applications in several areas. When molten plastic waste was used instead of cement and then mixed with broken glasses as partial substitution of aggregate in addition to fine river sand, roof tiles and hollow plastic tiles were achieved, solving to an extent, some environmental and ecological problems[34]. Recycled PVC can be processed into a variety of useful products, including flexible electrical cables, hoses, traffic cones, and other applications where flexibility and durability are required. HDPE, identified by resin code number 2, is commonly down-cycled into durable products such as plastic lumber, tables, roadside curbs, benches, truck cargo liners, waste receptacles, stationery items such as rulers, and other long-lasting plastic products. Recycled HDPE remains relatively valuable and is widely sought after for these applications. Table 6 gives a summary of some areas of applications of recycled plastics.

Table 6: Present and upcoming areas of utilization of recycled plastics from research works (especially in construction materials)

S/N	Recycled component	Plastic/other	Area of use	References
1	PET+PU (binder)		Non-load bearing masonry brick/Interlocking bricks/ partition wall	[35]
2	PET + foundry sand		Bricks	[36]
3	Glass + waste plastics (molten)		Roof tiles, hollow blocks, floor tiles	[34]
4	Expanded polystyrene (EPS)		Back up for electrical appliance such	[2]
5	Low density polyethylene (LDPE) +High impact polystyrene		Light-weight concrete	
6	Scraps of recycled plastics		Composites with cement	[32]
7	HDPE(high-density polyethylene) or number 2		Bin, pallets, crates	[2]

6.0 Energy Recovery through plastic waste and other economic values of recyclable plastics

Energy recovery is a broader term describing the recovery of useful energy from waste. It can involve incineration with heat/electricity generation, or the use of products from pyrolysis or gasification as fuels. Therefore, energy recovery is not a separate combustion mechanism in the same sense as pyrolysis or gasification. It describes what happens to the energy contained in the waste or its conversion products. Recyclable plastics have significant economic value because they can be collected, sorted, processed and converted into secondary raw materials and new products. Instead of being treated solely as waste, materials such as PET, HDPE, LDPE, PP and some PVC can become valuable inputs for manufacturing. These other economic values include:

(i) Generation of revenue from recovered materials: Recyclable plastics have a market value at different stages of the recycling chain. Waste collectors and aggregators can sell collected bottles, films and other plastics to recyclers, while recyclers generate additional value by producing flakes, pellets and recycled resin. The Organization for Economic Cooperation and Development (OECD) notes that revenues from recycling can encourage the collection of valuable materials and support improved waste-management systems[37].

(ii) Substitution for virgin plastic raw materials: Recycled PET, HDPE, PP and other polymers can substitute, wholly or partly, for virgin resin in many applications. This creates economic value by turning discarded plastics into secondary raw materials and reducing dependence on newly produced polymers. The OECD identifies recycled plastics as an important source of secondary material that can reduce demand for primary plastics [37].

(iii) Employment and income generation: Plastic recycling creates employment throughout the value chain, including collection, sorting, transportation, washing, shredding, pelletizing, manufacturing and marketing. This is particularly relevant in developing countries where informal waste collectors and small recycling enterprises participate extensively in plastic recovery.

(iv) Development of recycling industries and businesses: Recyclable plastics provide feedstock for businesses producing products such as: recycled plastic pellets, fibers and textiles, plastic furniture, bins and containers, paving blocks and tiles, construction materials (see Table 8)

(v) Contribution to the circular economy: Recycling retains the economic value embedded in plastics by keeping materials in productive use rather than disposing of them after a single use. Globally, secondary plastics production has increased substantially, although recycled plastics still represented only about 6% of total plastics production in 2019, indicating considerable room for expansion [37].

(vi) Growth of the recycled-plastics market, reduction in waste-management costs and economic opportunity in Nigeria: The economic importance of recycled plastics is reflected in the expanding global market. A recent market estimate valued the global recycled-plastics market at about US\$60.19 billion in 2025, with a projection of approximately US\$126.3 billion by 2034 [38]. Recovering plastics reduces the quantity of waste requiring disposal through landfilling or other waste-management methods. This can reduce pressure on landfill capacity and associated collection and disposal costs. The economic potential is particularly significant in Nigeria because of the country's large and growing plastic-waste stream and relatively underdeveloped recycling capacity. A 2026 report citing the Green Cities Infrastructure and Energy Programme (GCIEP) estimated Nigeria's plastic-recycling sector at approximately US\$10 billion, highlighting substantial opportunities for investment, recycling enterprises and waste-to-value activities[39].

7.0 Approaches towards minimizing plastic waste in Nigeria

Plastic waste could be drastically reduced in Nigeria by the following ways:

- (i) Industries that are into plastic manufacturing and packaging should take the lead of establishing post-consumer recycling project that should collect, recover and recycle their plastic containers. Extended producer responsibility (EPR) is vital in curbing the menace of plastic waste. They should set up recycling infrastructure and encourage consumers to recycle their beverage packaging.
- (ii) Plastic packaging companies should increase as much as possible the usage of the recycled material.
- (iii) Companies that are into plastic packaging should endeavor to use exclusively only thermoplastic materials for packaging, for recyclability.
- (iv) Reducing to the barest minimum, the quantity of packaging used is one of the most significant ways to reduce its environmental impact. In addition to using less material, this helps to reduce the carbon footprint of packaging throughout its lifecycle: from manufacture to transportation to disposal or recycling
- (v) More and effective policies and regulatory frame work should be developed: Nigeria has established policy initiatives aimed at improving plastic-waste management. The Federal Ministry of Environment has published a National Policy on Plastic Waste Management, reflecting the need for coordinated interventions across the plastic life cycle.
- (vi) Furthermore, standards for recycled content can stimulate demand for secondary plastics.
- (vii) Advancements/new areas in developing polymer-matrix composites for various applications
- (viii) Public awareness and change in behaviour: Educational institutions are particularly important locations for behavioural interventions. Schools, universities and polytechnics can establish separate collection points for PET bottles and other recyclable plastics, introduce recycling education and support student-led environmental Programmes
- (ix) Buy back of plastic materials is not encouraged; the buyback scheme should be extended in all parts of the country.
- (x) Many waste plastic collection centers and points should be enacted and visibly advertised.

8.0 Research Gaps

Although several works have been carried out on plastics and the consequences of plastic waste in Nigeria, reliable data on plastic production, waste generation, collection and recycling cannot be guaranteed. The functionality in terms of efficiency and output of locally developed recycling equipment need to be researched on. Investigations should be carried out on the quality of recycled materials in comparison with the efficiency of sorting. More research is necessary on the areas of recycling facilities and marketability of recycled products.

9.0 Conclusion and Recommendation

Plastic waste is a significant environmental, technological and socioeconomic challenge in Nigeria. Rapid urbanization, increasing consumption of packaged products, inadequate waste collection, indiscriminate disposal and limited recycling infrastructure have contributed to the accumulation of plastics in communities, drainage systems, terrestrial environments and aquatic environments. As one of the outstanding barriers in recycling is collection and sorting, all levels of government should be highly appreciative and supportive of sorting and recycling in various scales recognizing that it represents a major milestone in curbing the menace of plastic pollution. People should be highly sensitized to the responsibility of sorting and recycling through awareness campaigns via posters, flyers, media houses and even house to house. There is the need to build an efficient and functional nation-wide recycling economy that would ensure that our environment (drainages and dumpsites in particular) is free from plastic waste. A sustainable solution requires a transition from a disposal-oriented system towards an integrated circular plastics economy. This transition should combine waste reduction, reuse, source segregation, efficient collection, improved sorting, mechanical and other appropriate recycling technologies, market development, producer responsibility, public education and formal integration of informal recyclers. Ultimately, the plastic-waste challenge in Nigeria should be addressed across the entire life cycle of plastics. Stronger institutional coordination, investment in appropriate technologies, effective policy implementation, reliable data and sustained behavioural change are essential for transforming plastic waste from an environmental burden into a valuable secondary resource, plastic waste management should be included as one of the courses at all levels in the school curriculum.

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