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REVIEW

Challenges and prospects of plastic waste management in Nigeria

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Abstract
The combined properties of low cost, lightweight, and resistance to chemicals and corrosion has increased the use of plastic materials for packaging and storage purposes in preference to other materials. Consequently, there is a continued increase in their proportion in domestic solid wastes worldwide as well as the concern of their impacts on the environment. Most developed and developing countries have put in place and continue to improve their plastic waste disposal, collection, and recycling methods to reduce these impacts. In Nigeria with a population of about 186 million, there are little or no available data on the use of plastic materials in relation to city populations, their disposal, collection, and recycling methods. There are a few numbers of plastic waste recycling companies in a fewer number of cities and disposal practices for the greater percentage of the plastic wastes that are not captured for recycling possess immediate and future danger for the environment. This work reviews the consumption of plastics, its waste generation, collection, and treatment in Nigeria and a few selected countries. The problems associated with inadequate management of the wastes were emphasized and recommendations were proffered to not only highlight research and investment opportunities that are inherent in plastic waste management in Nigeria, but also provide a background for the formulation of sustainable regulatory policies by the government to address the problems.

Keywords Plastic waste · Disposal · Recycling · Environment · Investment · Waste management

Introduction

Plastics are synthetic organic materials that can easily be molded into the desired shape when soft and then set into rigid forms that are slightly elastic. They are used in various applications such as packaging, electronics, medicals, aerospace, transportation, building, and construction [1]. Their preference in these areas to other types of material is encouraged by their low cost, lightweight, and resistant to chemicals, and this has consequently led to the recent increase in the proportion of plastic wastes in both domestic and industrial solid wastes. Plastic wastes also increase further as the human population increases. The Nigerian population growth rate from year 2000 to 2017 is at the average of 2.37 [2], and this can be related directly to the rate of increase in Municipal Solid Waste (MSW) generally and, by extension, plastic wastes.

In the year 2007, the world plastic production was estimated to be 260 million metric tons per annum with thermoplastic resins alone contributing about 67% [3, 4]. This estimate increased to 348 million metric tons in 2017 [5]. The authors further estimated that about 50% of plastic produced is employed for single-use disposable applications such as packaging and other dispensable consumer items. Most of these materials are not biodegradable and are not part of the food chain. Thus, they end up in landfills and our water bodies where there is an absence or inefficient management of wastes, a situation that is more prevalent in developing countries.

There are inadequate or lack of statistical data on the production and importation of plastic materials and their resulting wastes in Nigeria. Majority of the consumers lack the awareness of immediate and remote consequences of their generated and mismanaged plastic wastes.

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The level of the well-being of a people may be linked to the extent to which they treat their plastic wastes. Rukina and Filatov [6] put this in another perspective by stating that the general state of the culture of a people can be mirrored in their ability to properly dispose and recycle their plastic wastes.

The theme for the 2018 world environmental day hosted by India was 'Beat Plastic Pollution' [7]. Several developed and developing countries had, before now keyed into this call with policies, strict regulations and technological advancement in the treatment plastic wastes. An insight into this global trend is provided here for the nation to urgently and critically re-assess her position and be guided in formulating policies and enforceable regulations that would help in protecting the environment.

Types of plastics and their applications

Thermoplastics

These types can be melted back into their liquid state on application of heat and remolded into the same or different shape for the same or different use. Thermoplastics contribute roughly 80% to the total plastic consumption [8]. Some examples of thermoplastics, their properties, and application are shown in Table 1.

Thermosets

Thermoset types of plastic cannot return to their original form once cured (cooled and hardened). They are produced by crosslinking of similar or different polymer chains through chemical bonding. They are harder, stronger, and more durable than the thermoplastic but generally non-recyclable. It has been found in recent studies, however, that certain thermosets can be recycled via bond exchange reactions [9] or by further reactions of the active sites in the already cured thermoset [10]. Examples of thermosets include epoxy resin, polyurethanes, and phenolic and polyester resins. They are used for auto parts, electrical fittings, aircraft parts, tires, etc. Thermosets contribute 20% of the world total plastic consumption.

Plastic consumption/waste generation

The packaging sector is one of the major consumers of plastics as the use of packaged materials has become part of our daily lives. It has been approximated that 30% of plastics produced worldwide are used for packaging application [11, 12]. In their own report, Hopewell et al. [3] posited that approximately 50% of the plastics used are single-use disposables for packaging, agricultural films, etc. The statistics of plastic consumption and its concomitant waste generation will generally vary from country to country and from city to city. The global Municipal Solid Waste in 1997 was put at 0.49 billion tons with an estimated annual growth of 3.2–4.5% and 2–3% in developed and developing countries, respectively [13]. By 2016, the global MSW was reported to have hit 1.47 billion metric tons [14]. Table 2 shows the population, quantity of solid waste, and percentage of plastic waste generation in some developed and developing countries or cities.

In Nigeria, there are few or no records of plastic waste generation rates in the cities. The composition of solid wastes generally depends on the location (residential, institutional, industrial, and markets) as well as the season. For example, while it is expected that waste collection points near markets will contain more fruits and vegetables, that of high-income residential areas will contain more of used plastic bags and bottles. Table 3 shows the average solid-waste generation against the population of some cities in Nigeria [32]. Tobore [33] further stated that a study carried out by the Bayero University Consultancy Unit in 2012 estimated the waste composition to be 19% of Polythene, 12.7% of paper, 10% of metals, 8.7% of glass, 11.3% of plastics, and 38.3% of biodegradable and other miscellaneous waste. The

Table 1 Types, properties, and applications of thermoplastics

Type	Properties	Application
Polyethylene (PE)	Translucent, tough and semi-rigid, chemical resistance, waterproof and low cost	Packaging (plastic bottles, bags, wraps, and films), construction
Polypropylene (PP)	Translucent, tough and semi-rigid, chemical resistance, fatigue resistance, heat resistance and living hinge property	Packaging and containers, toys, medicine, automotive parts, tubing, furniture, Laboratory equipment
Polyethylene terephthalate (PET)	Wear resistance, Low coefficient of friction	Bottles, textiles, electricals, cosmetic containers
Polyvinyl chloride (PVC)	Fire retardant, durability, chemical resistance	Pipes, insulation, footwears, automotive parts
Polystyrene (PS)	Lightweight, rigid	Insulation, packaging
Polymethyl methacrylate (PMMA)	High UV light and chemical resistant, transparency, durability	Automotive lamp covers an alternative to glass in certain applications

Table 2 Population and plastic waste generation in some developed and developing countries or cities

Country/city	Population (million)	Year	MSW (million tons/year)	Average MSW (g/capita/day)	Ave. plastic waste (%)
Accra (Ghana)	4.0	2010	0.43	567	3.3[a,b,c]
Nairobi (Kenya)	2.3	1996	0.37	NA	12.6d[d]
Rashat (Iran)	0.5	2007	0.15	800	3.5[e]
Delhi (India)	8.4	2000	1.42	475	1.5[f,g]
Singapore	3.9	1999	1.36	960	5.8[h]
Malaysia	26.6	2007	25.70	800	18.9[i,j]
USA	269.4	1996	209.70	1950	12.3[k,l]
Libya	5.9	2014	1.61	1120	8.0[m]
Rajshashi (Bangladesh)	0.75	2014	0.14	400	4.7[n]
China	1330.0	2008	150.0	980	[o,p,q]

[a–q][15–31]

Table 3 Solid-waste generation in some urban cities in Nigeria [32]

City	Population	Tonnage/month	Density (kg/m^3)	kg/Capita/Day
Lagos	8,029,200	255,556	294	0.63
Kano	3,248,700	156,676	290	0.56
Ibadan	307,840	135,391	330	0.51
Kaduna	1,458,900	114,433	320	0.58
Port Harcourt	1,053,900	117,825	300	0.60
Makurdi	249,000	24,242	340	0.48
Onitsha	509,500	84,137	310	0.53
Nsukka	100,700	12,000	370	0.44
Abuja	159,900	14,785	280	0.66

percentage of plastic in that report did not capture the litters that hardly make it to the waste bins and collection points.

A preponderant percentage of plastic consumption in Nigeria is for short life products and this, if investigated, will most likely give rise to a low weighted average service life of all plastic products and, consequently, a high plastic component of waste streams. In Germany, a developed country, the weighted average service life of all plastic products is estimated to be 14 years while that of India is 8 years [34, 35].

Among the non-biodegradable components of solid wastes in Nigeria, plastic materials are perhaps to most dominant (see Fig. 1a). In an integrated waste management facility study done for six districts in Abuja, the capital city, the average percentage of all plastics in the waste streams was found to be 19.4%, second to food remnant, probably due to higher earning capacity and lifestyle of the households studied (Table 4).The reason for the high content of plastics in our wastes is essentially due to the fact that waste scavengers mostly prefer scraps of metals usually iron, aluminum, and copper materials, an indication that the demand and, hence, the recycling of these metals are by far higher than that of plastics. Another reason for the prevalence of the plastic wastes in the dumps is the common use of polyethylene shopping bags and the sachet water production and sales that evolved since the late 1990s. In a typical market for food items, almost every item is handed to the buyer in a mini polyethylene bag that is not re-used. In recent times also, there has been an increase in the packaging of common household items such as noodles, detergents, beverages, and germicides in sachets of plastic materials that are not recyclable. Children and adults alike consume certain snacks and beverages while on the move and most of them are packaged with plastic materials which the consumers deposit along the streets, major roads, and highways. As a result, litters of plastics materials ranging from sweet and biscuit wraps to PET bottles and sachet water packaging are common sights in the streets of most cities, public places, and some institutions. This is depicted in Fig. 1b, c. They eventually end up in nearby farmlands and drainages. It is worthy to note that the majority of the populace including the educated harbors this habit, ignorant of the adverse effects of plastic wastes in the environment. In some countries, there are laws or corrective work orders that do not permit people to litter without attracting fines and corrective punishment [22].

Fig. 1 **a** A roadside waste collection point showing more of plastic materials. **b** A typical untarred urban residential street with litters of plastic materials. **c** A drainage system in a city capital filled with all forms of plastic wastes. **d** An overfilled waste dumpsite with scavengers searching for some recyclable materials

Table 4 Average composition (%) of household wastes in Apo, Asokoro, Garki, Gwarimpa, Maitama, and Wuse districts of Abuja

Type of waste	Average composition (%)
Paper	11.41
Metal	5.20
Glass	4.65
All plastics	19.34
Food remnants	54.77
Textile	2.53
Others	2.10

Adapted from [36, 37]

Recovery of plastic waste

With a population of about 186 million people, the country generates an average of 0.58 kg solid waste per person per day [38]. This translates to over 100,000 tons of solid waste per day, making it one of the largest in Africa. Abila and Kantola [39] estimated the country's MSW to be 25 million tons per year. At a conservative value of 10% plastic content, this will further suggest that over 10,000 tons of plastic waste are generated daily. Sadly, with the improper disposal methods and inherent management challenges, more than half of these wastes are either buried in the farmlands or are in the drainages and the waterways (Fig. 1c).

In general, as in the case of most developing countries, solid-waste management in Nigeria grapples with many challenges ranging from lack of technical capacity to very poor financing and mismanagement [19, 39–42]. The federal government of Nigeria, through an act in 2004, established the Federal Environmental Protection Agency (FEPA), to design, regulate, and enforce rules for waste management and other environmental issues nationwide. Most states also established their agencies to compliment that of FEPA. Examples include Lagos State Environmental Protection Agency (LASEPA), Enugu State Waste Management Agency (ESWAMA), Rivers State Waste Management Agency (RIWAMA), and Kano State Environmental Protection Agency (KASEPA). For a better-articulated responsibility, the FEPA was replaced with the National Environmental Standards and Regulations Enforcement Agency (NESREA) through another act in 2007. It was designed to focus her regulatory work on individuals and organizations (except oil and gas) whose activities pose a threat to the environment [43]. In all, there is still a huge gap in the management and the output of these agencies as the appointment of the managers and the operators are based more on political affiliations than on qualifications or experience. NESREA has up to 30 regulatory statements, but seemed to be lacking in the compliance monitoring and enforcement aspects. At their best, most states could only evacuate wastes from the residential areas regularly to designated dumpsites. Ogwueleka [32] reported waste collection efficiency to be between 5% in semi-urban and 50% in urban areas. There are cases of seeming dispersal of the wastes from the collection points to dump sites by the supposed disposal (open and uncovered) trucks due to overloading. To this end, litters of the lightweight plastic materials trail the trucks en-route to the dumpsites.

In nearly all the states in Nigeria, waste collection services are provided for the cities only. The rural dwellers deal with their wastes generally as it suits them. Some of the plastic wastes are either burnt or thrown into nearby farmlands within and around their residences. However, it is worthy to note that complete recovery of plastic waste is not easily achievable even in some developed countries with increased improvement in plastic waste collection and recycling methods. Hopewell et al. [3] recorded that Western Europe achieved only 39% of the total recovery rate out of the 21.1 million tons of plastic waste generated in 2003. They added that any expected gains in the recovery trends will be counterbalanced by the concomitant increasing trend in the generation of the waste.

Over the years, the cumulative effects of unrecovered plastic wastes in Nigeria lead to low crop yields in the farmlands. It has been identified that flooding of the major roads and some residential areas in the cities are caused by clogging of the drainages and sewage systems by these plastic wastes (Fig. 1c). With time, the ones that end up in the oceans and water bodies degrade to microplastics and water-soluble components with their attendant consequences including exposure of the aquatic environment to toxins which may eventually find their way into our food chain [44, 45]. This implies, therefore, that coastal countries with an inadequate plastic waste management system may have a fair share of the contributions to the worldwide marine plastic pollution. Jambeck et al. [46] had estimated that over 4% of 275 metric tons of plastic wastes generated by 192 coastal countries in 2010 entered the ocean. In a prediction with global river plastic inputs model that used geospatial data of population density, rates of mismanaged plastic waste production, and other parameters, three Nigerian rivers were listed among world top 20 polluting rivers [47]. Investigation of the cause of a recent boat mishap in a riverine area of Port Harcourt metropolis revealed that the engine was suddenly knocked off by shreds of plastic wastes that tangled with the propeller blades.

Whether in the ocean, farmland, or buried underground, it goes that plastic wastes are like seeds sown by man, who will eventually reap the ugly 'fruits' that it bears whenever and wherever it ripens.

Management of plastic materials and wastes

Degradation

Plastics may be degraded by one or more of the following: heat (thermodegradation), Light (photodegradation), micro-organisms (biodegradation), and chemicals (chemodegradation) [12]. Biodegradable plastics are plastics that can be completely degraded by the action of naturally occurring micro-organisms depending on the environmental condition [48].

Going by the method of our management (or rather, mismanagement) of plastic materials in the country, we ought to rely heavily on micro-organisms for the degradation of our plastic wastes. However, it may take several years for nature to completely degrade a piece of plastic. Shimao [49] stated that a number of polyesters have been found to be biodegradable due to the easily hydrolysable ester linkages and polyhydroxyalkanoates (a bacterial polyester) which can now be incorporated in the production of biodegradable plastics. Plastic shopping bags which are the most dominant in our waste streams can be produced with polylactic acid. Polylactic acid is a polymer that biodegrades easily under composting conditions without toxic residue.

A strain of *Rhodococcus* rubber has been found to significantly degrade Polyethylene films [50, 51]. There are few available reports on the biodegradability of polyvinylchloride and polystyrene [12]. However, several works have established that Polyethylene which is more prevalent in our waste dumps can be modified at the production stages to enhance its biodegradability. This is achieved by modifying one or more of its mechanical properties that are responsible for its resistance towards biodegradabilities such as crystalline level and molecular weight [52]. In this view, Evangelista [53] and Bikiaris et al. [54] increased the hydrophilicity of polyethylene by blending with starch. Johnson et al. [55] also demonstrated that compounding polyethylene with starch and transition metal additives promotes its degradation in the natural environment. To avoid or reduce the impact on food grade starch, efforts of research and innovative technologies have been shifted to the use of non-edible biomass waste which contains a large number of cellulosic by-products [48, 56, 57]. Plastics' biodegradability has been exploited in their waste management strategy via anaerobic digestion by converting the bio-waste into methane which is resourceful for energy production [58].

Reuse, reduce, recycle, recover, and reject

A synoptic management method of plastic materials and their wastes will be best considered under the 5 Rs of Reduce, Reuse, Recycle, Recover, and Refuse (Fig. 2). Reusable as well as recyclable plastics should always be preferred. Reduction strategy can be applied using or accepting plastic packages only when it is necessary as well as using only one re-useable bag for typical market purchases instead of packaging every item with a mini-plastic bag. Rejection should be applied when one is not sure of getting the resulting plastic waste to a collection point for recycling or when the plastic packaging is non-recyclable.

Plastic wastes can be significantly reduced if the populace imbibes the culture of re-using plastic materials. Unfortunately, most of the packaging materials are designed for single use, especially the polyethylene bags that come in miniature of sizes. Some polypropylene bags are designed for reuse; however, most consumers do not reuse them, either due to impromptu shopping that requires a fresh bag or out of habit. With the accumulation in their homes, they all soon end up in the waste bins, leading to a high proportion of plastic wastes (Fig. 1b). In other to discourage the use of plastic bags and associated materials or encourage their reuse, some developed (Ireland, Australia, and San Francisco) and developing (China, Rwanda, Botswana, Bangladesh, Kenya, South Africa) countries/regions have banned the use of plastic bags or imposed some form of tax in their use [59–65]. The law in Kenya which is today regarded as the world's toughest plastic ban attracts a fine that may be up to $40,000 or a 4-year jail term for production, sale, or use of polyethylene plastic bags.

Except in facilities owned by some corporate and multinational companies, sorting of wastes into their various types is non-existent at the households as well as at the collection points. Existing recycling plants may be discouraged by the cost of sorting and cleaning heterogeneous plastic wastes taken directly from the mixed waste dumps. Some recycling outfits in Lagos operate an incentive-based scheme in which recyclable materials are collected from post consumers and rewarded.

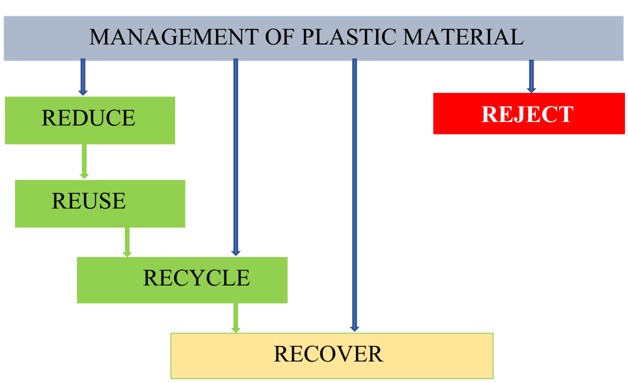

Fig. 2 A synoptic management method of plastic materials

Landfills

Modern landfills are professionally designed to hold a large volume of wastes with proper underlays and leachate collection systems that prevents contamination of the adjourning environment, especially the underground water. The dumpsites around the country are far from being a modern landfill. They are usually borrow pits that had previously served as laterite excavation sites for road construction (Fig. 1d). For years, the use of dumpsites has been the traditional approach of solid-waste management in Nigeria. With time, seepages from these unprotected sites get to underground water and resulting to its contamination. Substantial quantities of plastics end up in the dumpsites due to lack of segregation, thus, resulting in both waste management and environmental issues [1, 26]. In some dry seasons, heaps of these dumpsites will be set on fire for the purpose of reducing the volume to accommodate more wastes. As a consequence, toxic gases such as dioxins and other polychlorinated biphenyls (PCBs) are released into the environment.

Recycling

Considering the high demand for plastic materials and the corresponding wastes generated, recycling is presently the most viable method that could be used for its minimization. Recycling is the process of converting materials that could have been considered as waste into new products. This waste management strategy helps to reduce the amount of waste sent to landfills as well as reduce greenhouse gas emissions that contribute to climate change, thereby helping to sustain the environment. This strategy also helps to reduce the requirement for plastic production, saves energy, and conserves fossil fuels, since plastic production is dependent on non-renewable sources [3, 66, 67]. According to Stanford University Peninsula Sanitary Service Incorporation, recycling 1 ton of plastics is equal to saving 5774 kilowatts/hour of energy, 16.3 barrels of oil, and 30 cubic yards of landfill space.

Plastic recycling technologies can be grouped into four categories:

1. Primary recycling—involves waste processing into a product of similar characteristics.
2. Secondary recycling—involves the processing of waste into products of different characteristics.
3. Tertiary recycling—involves the production of basic chemicals and fuel from segregated municipal waste.

4. Quaternary recycling—involves energy extraction by partial or complete oxidation of the material [1, 66].

Plastic recycling can be difficult considering the components used in its production process, such as different polymers, pigments, adhesives, paper, etc., and also if not sorted and separated from the sources [3]. While most cities in Nigeria do not have plastic recycling plants, existing ones in cities like Aba, Abuja, Kano, Lagos, and Onitsha have capacities that may take less than 30% of all recyclable plastics if they were all recovered and they are mostly engaged in the secondary methods of recycling. In comparison, a country like India has a record of recycling 50–80% of all plastic used, while Germany, adjudged to have the largest market of recycled plastic in Europe, has a record of 100% all plastic waste recycling [11, 21]. To promote mechanical recycling of PET bottles alone in the municipalities of the capital city, Japan established a council for PET bottle recycling in 1993 [66].

However, when plastic wastes are heterogeneous or consist of mixed resins, they are unsuitable for reclamation. In this case, thermal cracking into hydrocarbons which is termed chemical recycling may provide a suitable means of recovery [68]. This falls into the category of tertiary recycling. It involves their conversion into the smallest molecules (liquids and gases) that can be employed as suitable feedstocks for the production of new petrochemicals and plastics [69]. Pyrolysis is the major method of chemical recycling and has attracted several research efforts [67, 70–73].

Quaternary recycling methods are employed where other recovery routes are not feasible. It involves subjecting the PSW to integrated incineration to recover the inherent energy in the form of heat, steam, or electricity. Plastic materials are known to have calorific values that are comparable to that of major crude oil products [66, 74]. This method commonly referred to Waste To Energy (WTE) method can be applied directly to MSW to produce steam and/or electricity. Themelis [75] estimated that 300 million tons of MSW are combusted annually in over 600 WTE facilities worldwide. Though WTE requires high capital investment compared to other MSW management methods, it has the advantage of requiring little or no pre-treatment of waste and is more environmentally friendly [30]. Nigeria with the largest economy in sub-saharan Africa and challenges in power generation is yet to advance to this level of waste treatment. Out of her current capacity to generate 12,522 megawatts (MW) of electric power, only about 4000 MW is generated daily which is grossly insufficient for the over 186 million population [76]. In another advanced recycling method, plastic wastes can be blended with bitumen for road tarring and the blends have shown to have better resistance to rainwater, cracking, and deformation of bituminous layers as well as decreased consumption of bitumen [77–80].

Recommendations and conclusions

Nigeria and most other countries are already at the receiving end of the effects of plastic waste mismanagement for several years now and this is, unfortunately, still on the increase. Urgent and robust policy framework in the production, use, and recycling of plastics and its wastes (cradle-to-grave) need to put in place to save the environment. The following set of recommendations that may help in formulating sustainable policies in plastic management is advanced.

1. A strong public education program on the need for proper disposal of plastic materials should be instituted by environmental agencies at all levels of the government, starting from the primary schools.
2. Households should be encouraged to sort their wastes at source before disposal to central collection centers. This can be done by rewarding or paying for recyclable materials such as metals and plastics, while minimal fees should be imposed on unsorted wastes.
3. Plastic waste collection centers should be set up at several points in the urban areas and at least one center in the rural Local Government Areas which can also serve as pre-treatment centers.
4. Private partner participation should be encouraged with adequate incentives in both the collection and recycling of plastic wastes.
5. Records of plastic consumption (companies' local production and importation data) as well as plastic wastes and the capacities of recycling companies should compulsorily be domiciled with the Federal Ministry of Environment and updated regularly.
6. There should be legislation against the use of non-recyclable plastics for packaging, while more research efforts should be directed towards the production and application of biodegradable plastics in the country.
7. Considering the grave energy requirements of the country, investing in WTE will increase power generation, provide employment at the time, and drastically reduce the volume of plastic wastes that may require alternative methods of treatment.
8. To help some developing countries that may not have adequate mechanism to sensitize its citizens on the proper use of plastics and management of the resulting wastes, bodies like United Nations through the W.H.O. may need to have some set of rules and policies on the use of plastics and management of its wastes for all its member nations to strictly adhere to.

This generation and subsequent generations should take the environment as a loan from future generations which must be paid back with interest by bequeathing it better than we found it. We can only be close to achieving this by making conscious efforts in preventing these plastic wastes that may last hundreds of years, from getting to the environment. Policy statements on the use of plastic and management of its wastes will also help the country towards the efforts of achieving some of the Sustainable Development Goals (SDGs), especially 13–15.

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