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IRREVERSIBLE ENVIRONMENTAL IMPACTS OF PLASTIC USE AND ITS MITIGATION STRATEGIES

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Abstract

Plastic has revolutionized industries due to its affordability, durability, and versatility. However, its extensive use has led to severe and irreversible environmental damage. This paper explores the long-term ecological consequences of plastic pollution and presents mitigation strategies supported by scientific research and real-world examples.

Plastic pollution has become a global crisis, affecting terrestrial, aquatic, and atmospheric ecosystems. With annual production exceeding 400 million metric tons, plastics persist in the environment due to their resistance to degradation. The irreversible impacts range from biodiversity loss to disruptions in biochemical cycles.

Estimated that 8 million metric tons of plastic enter the oceans annually, causing significant harm to marine life. This paper explores the history of the Plastic revolution and associated impacts of Plastic usage over the years. Paper reviews the Plastic profile of Pakistan, its significance in terms of economic and GDP including associated environmental issues. Paper identifies the key irreversible environmental issues and explores the regulatory as well as voluntary strategies and efforts made in Pakistan at various level, wat are the existing challenges and way forward considering the size, scope and importance and current resources and technologies available at local level.

1 Introduction

Plastics are a wide range of synthetic or semisynthetic materials composed primarily of polymers. Their defining characteristic, plasticity, allows them to be molded, extruded, or pressed into a diverse range of solid forms. This adaptability, combined with a wide range of other properties such as low weight, durability, flexibility, chemical resistance, low toxicity, and low-cost production, has led to their widespread use around the world[1]. While most

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plastics are produced from natural gas and petroleum, a growing minority are produced from renewable resources like polylactic acid[2].

Evolved from 1862 when Parkesine was introduced by Alexander Parkes and finally the term Plastic was introduced in 1925. In between 1950 and 2017, 9.2 billion metric tons of plastic are estimated to have been made, with more than half of this amount being produced since 2004. In 2023 alone, preliminary figures indicate that over 400 million metric tons of plastic were produced worldwide[3]. If global trends in plastic demand continue, it is projected that annual global plastic production will exceed 1.3 billion tons by 2060. The primary uses for plastic include packaging, which makes up about 40% of its usage, and building and construction, which makes up about 20% of its usage.

The success and dominance of plastics since the early 20th century has had major benefits for mankind, ranging from medical devices to light-weight construction materials. The sewage systems in many countries relies on the resiliency and adaptability of polyvinyl chloride. It is also true that plastics are the basis of widespread environmental concerns[4] due to their slow decomposition rate in natural ecosystems. Most plastic produced has not been reused. Some is unsuitable for reuse. Much is captured in landfills or as plastic pollution. Particular concern focuses on microplastics. Marine plastic pollution, for example, creates garbage patches. Of all the plastic discarded so far, some 14% have been incinerated and less than 10% has been recycled[5].

In developed economies, about a third of plastic is used in packaging and roughly the same in buildings in applications such as piping, plumbing or vinyl siding. Other uses include automobiles (up to 20% plastic), furniture, and toys. In the developing world, the applications of plastic may differ; 42% of India's consumption is used in packaging[6]. Worldwide, about 50 kg of plastic is produced annually per person, with production doubling every ten years.

The world's first fully synthetic plastic was Bakelite, invented in New York in 1907, by Leo Baekeland[7], who coined the term "plastics"[8]. Dozens of different types of plastics are produced today, such as polyethylene, which is widely used in product packaging, and polyvinyl chloride (PVC), used in construction and pipes because of its strength and durability. Many chemists have contributed to the materials science of plastics, including Nobel laureate Hermann Staudinger, who has been called "the father of polymer chemistry", and Herman Mark, known as "the father of polymer physics"[9].

2 Plastic Pollution

Plastic pollution is the accumulation of plastic objects and particles (e.g. plastic bottles, bags and microbeads) in the Earth's environment that adversely affects humans, wildlife and their habitat[10]. Plastics that act as pollutants are categorized by size into micro-, meso-, or macro debris[11]. Plastics are inexpensive and durable, making them very adaptable for different uses; as a result, manufacturers choose to use plastic over other materials[12]. However, the chemical structure of most plastics renders them resistant to many natural processes of degradation and as a result they are slow to degrade. Together, these two factors allow large volumes of plastic to enter the environment as mismanaged waste which persists in the ecosystem and travels throughout food webs[13].

Plastic pollution can afflict land, waterways and oceans. It is estimated that 1.1 to 8.8 million tons of plastic waste enters the ocean from coastal communities each year[14]. It is estimated that there is a stock of 86 million tons of plastic marine debris in the worldwide ocean as of the end of 2013, with an assumption that 1.4% of global plastics produced from 1950 to 2013 has entered the ocean and has accumulated there. Global plastic production has surged from 1.5 million tons in the 1950s to 335 million tons in 2016, resulting in environmental concerns. A significant issue arises from the inefficient treatment of 79% of plastic products, leading to their release into landfills or natural environments[15].

Some researchers suggest that by 2050 there could be more plastic than fish in the oceans by weight. Living organisms, particularly marine animals, can be harmed either by mechanical effects such as entanglement in plastic objects, problems related to ingestion of plastic waste, or through exposure to chemicals within plastics that interfere with their physiology. Degraded plastic waste can directly affect humans through direct consumption (i.e. in tap water), indirect consumption (by eating plants and animals), and disruption of various hormonal mechanisms.

As of 2019, 368 million tons of plastic is produced each year; 51% in Asia, where China is the world's largest producer. From the 1950s up to 2018, an estimated 6.3 billion tons of plastic has been produced worldwide, of which an estimated 9% has been recycled and another 12% has been incinerated. This large amount of plastic waste enters the environment and causes problems throughout the ecosystem; for example, studies suggest that the bodies of 90% of seabirds contain plastic debris. In some areas there have been significant efforts to reduce the prominence of free range plastic pollution, through reducing plastic consumption, litter cleanup, and promoting plastic recycling[16].

As of 2020, the global mass of produced plastic exceeds the biomass of all land and marine animals combined. A May 2019 amendment to the Basel Convention regulates the exportation/importation of plastic waste, largely intended to prevent the shipping of plastic waste from developed countries to developing countries. On 2nd March 2022, in Nairobi, 175 countries pledged to create a legally binding agreement by the end of the year 2024 with a goal to end plastic pollution.

COVID-19 also had a significant impact on the use of plastic products resulting in plastic waste. Higher amounts of plastic ended up in the ocean, especially plastic from medical waste and masks. Several news reports point to a plastic industry trying to take advantage of the health concerns and desire for disposable masks and packaging to increase production of single use plastic[17]

3 Pakistan Plastic Context

Pakistan is one of the top ten (10) plastic polluters in the world, with the vast majority of the plastic not being disposed of properly[18]. Some 86% of the country's waste is mismanaged, which is well above the global average and the average in countries where SWITCH-Asia is active[19]. In absolute numbers this amounts to a total of almost 1.7 million tons of mismanaged plastic waste per year, or more than 7 kg per capita, compared to the global average of 12.5 kg per capita, as well as the average of 12.2 kg per capita in countries that are targeted by the SWITCH-Asia programme. Pakistan is among the 10 countries that have the largest amount of mismanaged plastic waste in absolute numbers[20].

The economic relevance of the plastic industry is high in Pakistan[21], and it is an important part of the manufacturing sector. Plastic-related trade data show that Pakistan imports most of the materials needed for manufacturing plastic products, and that it manufactures plastic products mainly for its domestic market. According to the latest estimates, in 2020 more than 11,000 small- medium- and large-sized plastic processing and manufacturing companies contributed more than 15% to Pakistan's gross domestic product (or roughly USD 45 billion) and likewise 15% to the national tax revenue (or more than USD 861 million). The workforce in the plastic industry numbers 500,000 individuals (direct) and 1,500,000 (indirect). The total annual production capacity of the four companies that produce plastic raw materials in Pakistan was 745,000 tons.

3.1 Key irreversible environmental Impacts

3.1.1 Soil and Land Degradation

Plastic pollution on soil and land poses a threat to the plants and animals – including humans who are based on the land products. Estimates of the amount of plastic concentration on land are between four and twenty-three times that of the ocean. The amount of plastic poised on the land is greater and more concentrated than that in the water[22].

Mismanaged plastic waste ranges from 60 percent in East Asia and Pacific to one percent in North America. It is estimated that between 1 million and 1.7 million tons of mismanaged plastic is transported to the ocean each year[23]. In 2021 a report conducted by the Food and Agriculture Organization stated that plastic is often used in agriculture. There is more plastic in the soil than in the oceans. The presence of plastic in the environment impacts the ecosystems and human health and pose a threat to food safety[24]. Chlorinated plastic can release harmful chemicals into the surrounding soil, which can then seep into groundwater or other surrounding water sources and also the ecosystem if not properly managed[25]. This can cause serious harm to the species that drink the water. A 2025 study confirmed that agricultural soil contains up to 23 times more plastic particles in comparison to the ocean. The particles can be absorbed by the crops through the roots and be eaten by humans. This create different health hazards, especially as the chemicals replacing BPA in the plastic can be more dangerous than BPA itself. Persistent microplastics alter soil composition, affecting microbial biodiversity and reducing agricultural productivity[26]. Toxic chemicals from plastics contaminate groundwater and disrupt nutrient cycling. A 2021 study in Punjab found high concentrations of microplastics in agricultural fields, reducing crop yield due to soil quality degradation[27].

3.1.2 Marine Ecosystem Disruption

Plastic pollution in Pakistan's marine environment has severe consequences, impacting marine life, habitats, and coastal communities. It leads to habitat destruction, biodiversity loss, and threatens fisheries and the livelihoods of those who depend on the sea. The accumulation of plastic waste, particularly in coastal areas like Karachi, is a major concern, with studies showing a high percentage of plastic waste on beaches and in the water.

Entanglement & Ingestion: Marine organisms suffer physical harm due to entanglement or ingestion of plastic debris, often leading to starvation or suffocation[28].

Deep-Sea Microplastic Accumulation: Microplastics are found in deep-sea sediments, altering the ocean's natural biological functions[29].

The Great Pacific Garbage Patch—covering 1.6 million square kilometers—harbors harmful pollutants, disrupting marine food chains.

3.1.3 Air Pollution & Climate Impact

Plastic pollution in Pakistan significantly contributes to air pollution and climate change, impacting both the environment and human health. Burning plastic waste releases harmful chemicals into the atmosphere, leading to respiratory problems and other health issues. Furthermore, the production, transportation, and disposal of plastic all contribute to greenhouse gas emissions, exacerbating climate change. The include:

Greenhouse Gas Emissions: Plastic production contributes significantly to CO_2 emissions, exacerbating climate change[30].

Microplastic Inhalation Risks: Recent studies indicate airborne microplastics infiltrate respiratory systems, posing long-term health hazard[31].

Burning plastic waste in developing countries releases toxic fumes, increasing local air pollution levels refer to Figure-1 below:



Figure-1: Air and Climate Impact due to Plastic Pollution

3.1.4 Toxicity & Bioaccumulation

Plastic pollution in Pakistan is causing significant toxicity and bioaccumulation issues, impacting both the environment and human health. The breakdown of plastics into microplastics and nano plastics introduces harmful chemicals into ecosystems, which are then absorbed by living organisms and can move up the food chain, leading to potential health problems.

Endocrine Disruption: Chemicals like Bisphenol A (BPA) mimic hormones, leading to reproductive abnormalities[32].

Bioaccumulation in Wildlife: Plastic toxins accumulate in organisms and magnify up the food chain, disrupting ecosystems. Studies on seabirds in the Arctic found plastic-induced toxicity affecting liver and kidney functions[33].

3.2 Pakistan Regulator Framework

Pakistan has several policies that include the plastic and plastic pollution. Overall, four bans on plastic products are in place at the provincial level, as well as two overarching policies that also address plastic waste while generally dealing with waste: the Environmental Protection Act and Solid Waste Management Act and the National Hazardous Waste Management Policy. The existing policies tackle the manufacture, consumption, waste management, and trade of plastic. Only the first stage of the plastics lifecycle, the production of primary plastic polymers, is left untouched.

The bans on the use of plastic that exist in three regions focus on the production, sale and use of certain single-use and avoidable plastic products. Already in 2006 for Sindh province, the manufacture, sale and use of black polythene bags including polythene bags below thirty-micron thickness were prohibited[34]. The ban of plastic bags that was introduced in Islamabad Capital Territory (ICT) in 2019 has led to more successful enforcement. In June 2024, the Punjab region also prohibited the sale of such bags. The Single Use Plastics Prohibition Regulations apply to the Islamabad Capital Territory, for phasing out and prohibiting the use of various single-use plastic items namely polythene bags, drinking straws, crockery, cutlery, and food and beverage containers for delivery and stirrers. In addition, the regulations require that from August 2028 beverage containers must include at least 50% environmentally safe recycled content.

The Islamabad Capital Territory also introduced a policy prohibiting non-degradable plastic products (Government of Pakistan 2013), banning the

manufacture, sale and use of non-(oxo-) degradable disposable plastic products made of polyethylene, polypropylene or polystyrene.

Two such regional awareness campaigns are the 'No to Plastic' campaign in Punjab and the 'Say No to Plastics' campaign in Islamabad. Both campaigns have been launched to raise public awareness about the severe health risks associated with plastic pollution. The initiatives are part of a broader effort to ban polythene bags in various regions of Pakistan.

In addition, a 10-year strategy to reduce plastic pollution was adopted in June 2023. Its aims are to reduce the consumption of disposable plastics including plastic bags, expand recycling efforts, and reduce waste. Finally, the Pakistan government adapted its procurement policies and is obliging all government institutions and divisions to use refillable water bottles and containers, and to ban all single use polythene items. There is no formal coordination channel on this subject publicly available; yet the fact that there has been an initiative to curb use of plastic water bottles through procurement policies, speaks in favor of this happening behind the scenes.

3.3 Challenges for Pakistan

Overall, the subject of waste management remains a challenge in Pakistan due to the lack of awareness, irresponsibly, lack of infrastructure, incentives for private and public sector and no political and public will towards the waste management including Plastic waste.

Masses still assume that waste management is purely a government responsibility, moreover, the plastic-related policies, rules and regulations are highly fragmented and vary across different provinces in Pakistan. Likewise, there is no functioning institutionalized or formalized interministerial coordination when it comes to plastic pollution.

Moreover, the regional bans of plastic bags failed because of the lack of enforcement combined with the absence of alternatives, plus an overall lack of awareness of policymakers and citizenry and involvement of major stakeholders i.e. the Plastic Product Manufacturers.

Segregation of waste at the source (e.g., households, businesses) is not being implemented in Pakistan, and residents are dumping all different types of waste into a single bin. This complicates collection and management efforts and is known to keep public awareness of wasteful practices and plastic pollution low.

Even though major cities have implemented waste management policies, they face issues such as inadequate equipment and technology, as well as

limited public awareness and inadequate infrastructure and urban planning coordination[35].

In rural areas, there is a lack of technological knowledge as well as lack of needed infrastructure for proper waste management, which are challenges that will need to be overcome.

Existing and "legacy" plastic pollution is another serious challenge, and its management needs to be urgently addressed, especially in already polluted waterways, to minimize further pollution of the marine environment.

3.4 Way Forward

In recent years no doubt, Pakistan has increased its efforts to fight plastic pollution due to global pressure. Furthermore, the country has recently joined the Global Plastic Action Partnership (GPAP) and thus aims to increase its environmental efforts[36].

In order to tackle the plastics challenge, in view of today's fragmentation of plastic-related policies, Pakistan would benefit from a more coherent, comprehensive and coordinated policy approach by following the suggestion as a way forward.

- Formulating a clear objective and commitment, as well as developing overarching national regulations, plans or strategies would improve governance by setting a common framework for addressing plastic pollution. This could lead to a more effective implementation of the diverse and interrelated polices in the provinces and at national level that aim at a reduction of plastic pollution.
- For example, a concerted policy at the national level could include bans on certain problematic and avoidable plastic products and also state recommendations on how to implement these bans at the provincial level.
- This would likely increase enforcement, thereby preventing a product from being prohibited in one province but allowed in another.
- Similarly, guidelines for environmentally sound waste management, as are currently discussed in the ongoing Treaty negotiations, could support the government in setting up a nationwide policy framework to guide provincial waste management legislations.
- A more coherent approach to policymaking should also target and improve institutional coordination. Ideally, it would establish an effective collaboration among federal, provincial, and local government entities

involved in waste management, as well as among key waste and water management institutions.

- It would also require a cultural shift, as plastics is often still considered as a premium product, signaling innovation and cleanliness; whereas, caring for the environment is branded as a luxury in a country where food and shelter are still an economic priority, as quoted by participants in a household survey[37].
- Equally important as a shift in governance towards a national, coordinated effort, is an improvement of the waste management system. Pakistan could benefit from expanding waste collection services as well as the country's sorting, treatment, recycling, and disposal facilities.
- The process could start with requirements for waste segregation at the source to improve the recycling potential of waste.
- Furthermore, it will be necessary to invest considerable amounts of money in adequate waste management infrastructure and capacity-building to improve services by local governments or waste management companies.
- Ideally, the expansion and improvement of the waste management system would be guided by a federal or regional waste management strategy, financed by multiple financing streams – by management fees levied from households and businesses, as well as from plastics manufacturers and users, supported by contributions from public authorities at different levels, and potentially, development cooperation or financing in support of international commitments.
- In addition, in Pakistan, as in many other developing countries, effective waste-management improvement will require collaboration with informal waste collectors, who contribute significantly to waste collection and recycling nationwide.

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