Toxics Link
for a toxics-free world

Is Plastic Recycling SAFE?

Testing recycled plastic products for Chemicals

A report by Toxics Link

About Toxics Link

Toxics Link is an Indian environmental research and advocacy organization set up in 1996, engaged in disseminating information to help strengthen the campaign against toxics pollution, provide cleaner alternatives and bring together groups and people affected by this problem. Toxics Link's Mission Statement - "Working together for environmental justice and freedom from toxics. We have taken upon ourselves to collect and share both information about the sources and the dangers of poisons in our environment and bodies, and information about clean and sustainable alternatives for India and the rest of the world." Toxics Link has a unique expertise in areas of hazardous, plastic, medical and municipal wastes, international waste trade, and the emerging issues of pesticides, Persistent Organic Pollutants (POPs), hazardous heavy metal contamination etc. from the environment and public health point of view. We have successfully implemented various best practices and have brought in policy changes in the aforementioned areas apart from creating awareness among several stakeholder groups.

Toxics Link has been working extensively on the issue of plastics for the last couple of decades, focussing both on upstream as well as downstream aspects.

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Introduction

Plastics have become so ubiquitous that their magnitude, distribution, and collateral effects suggest the advent of a new era in the Anthropocene: "The Plasticene". This signifies an age where humans have become overly reliant and fond of plastic[1]. However, the Plasticene age has become a source of concern, as plastics permeate Earth's cycles (geological, water, and atmospheric) due to mass production, use, disposal and long-term persistence throughout the entire environmental realm. Accumulation of plastic in the ecosystem has given rise to the global challenge of plastic pollution, posing a significant transboundary threat to natural ecosystems, human health, and sustainability.

1.1 GROWING CONCERN OF PLASTIC POLLUTION

The global plastic production has risen from 2 million tonnes (Mt) in 1950 to more than 390 Mt in 2021, with a projected increase to 2600 Mt by 2050[2,3]. The rise in plastic production has invariably led to an increase in the generation of plastic waste. According to the CPCB report for 2020-2021, India's total plastic waste generation has escalated from 3.36 Mt in 2018-2019 to 4.12 Mt in 2020-2021[4]. A significant factor contributing to this surge in plastic waste, apart from the heightened demand for plastic usage, is the substantial proportion of plastic produced for single-use purposes. Because these products have a low reusability, this has led to an unprecedented amount of plastic trash and contamination.

1.2 PLASTIC WASTE MANAGEMENT

Plastic waste management strategies include recycling, incineration, and landfills[5]. However, global statistics reveal that a significant portion of generated plastic waste (approximately 79%) ends up in landfills or the environment, with only 9% being recycled and the remaining 12% undergoing incineration or open burning globally[6]. Incineration and landfill dumping are conventional disposal methods that not only consume significant resources but also give rise to significant pollution issues. Consequently, plastic recycling stands out among these three methods as the most advantageous approach due to its environmental and economic benefits.[7]

Given the magnitude of openly discarded plastic waste and its detrimental impacts, recycling is gaining attention as a viable approach to tackling the growing issue of plastic waste management. In contrast to the methods of landfilling and incineration, the recycling process diminishes air and land pollution associated with these practices. Additionally, it contributes to the conservation of rapidly depleting landfill space.

The Plastic Waste Management Rule 2022 in India emphasizes the significance of recycling plastic, along with banning 19 categories of single-use plastics. These regulations mandate that a designated percentage of produced plastic must be recycled by importers, manufacturers, and brand owners. However, even though the rules highlight recycling as a key strategy for managing plastic waste, they do not establish specific standards or norms for the recycling process.

1.3 TYPES OF PLASTIC RECYCLING

Currently, the predominant methods of recycling can be categorized into mechanical and chemical.

1. **Mechanical recycling** involves the processing of plastic into secondary raw material without substantial alteration to its chemical structure[8]. This method, also referred to as closed-loop recycling, is the most common method of reprocessing plastic into products with performance characteristics equivalent to those of virgin plastic. Both primary and secondary recycling fall under the umbrella of mechanical recycling. Primary recycling involves the conversion of recycled plastic into a product that serves a similar function, involving physical processes without significant chemical reactions. Because of this, primary recycling involves little to no use of chemicals. An example of this is Polyethylene Terephthalate (PET) plastics recovered from post-consumer bottles, undergoing a primary recycling process, and being transformed into new bottles[9]. On the other hand, secondary recycling entails the modification of the recycled materials to create an entirely new product. While the product is made of the same material, its purpose may serve an entirely new function. For example, in the case of tires, the recovered rubber is turned into various new products such as rubber mulch or carpet. PET bottles are often transformed to make yarns, which is also a form of secondary recycling. Contrary to primary recycling, secondary recycling involves chemical transformations.

2. **Chemical recycling,** also known as tertiary recycling, pertains to the process of converting polymeric waste by altering its chemical structure. This process involves transforming the waste into substances that can serve as raw materials for manufacturing new products[10]. This method is also known as feedstock recycling.

1.4 IS RECYCLING A PART OF CIRCULAR ECONOMY?

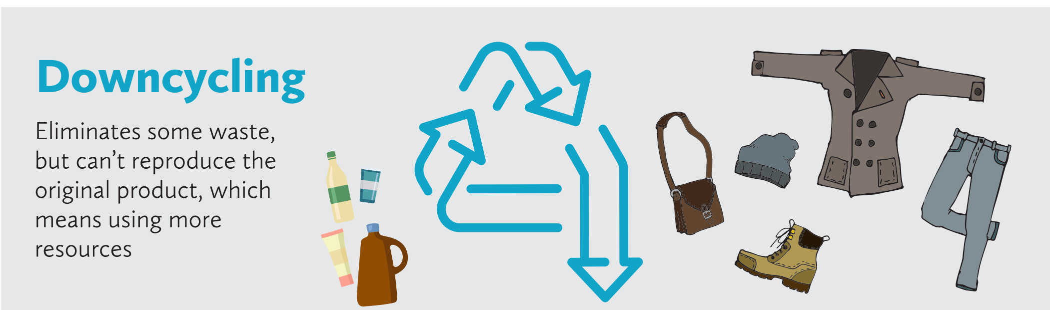
As the current plastic crisis garners increasing attention from governments, industries and stakeholders, there is a growing global focus towards bringing in a circular economy (CE) across different sectors. CE can help move plastics away from an unsustainable linear system where materials are used and discarded, to a more sustainable, cyclic system where materials are produced, used, reused and recycled in a way that limits extraction of natural resources, energy use and pollution.

In recent times, CE in plastic has become synonymous with plastic recycling. The plastic industry has also promoted recycling as a solution to plastic pollution. Through plastic recycling, plastics are broken down to their basic materials to produce plastic of similar value and quality as the original plastic. Ideally, this should allow recycled materials to be manufactured into new products, reducing the need for virgin plastic production. Thus, the energy, time and labor which goes into producing the raw materials would be conserved.

In reality, most plastics are downcycled. Downcycling begins the same way as recycling: plastic products are broken down into their constituent materials, resulting in the creation of plastic pellets. However, these downcycled materials are of lesser quality. While the plastic is processed in both of these methods, in the recycling process the quality and hence the value of the product is reserved. In contrast, during the downcycling process, the product formed after the process is of lesser quality. Generally, plastic can be recycled once or maybe twice before it starts losing its structural integrity. With every recycling process, the length of the polymer decreases, causing it to have structural weakness and lower value.

Studies indicate that only 9% of all the plastic waste ever produced has been recycled. However, it is difficult to assess how much of this 9% was actually recycled and how much was downcycled. A report by the Ellen MacArthur Foundation tried to assess this using plastic packaging data from 2013. The foundation found that only 14% of global plastic packaging waste was collected for recycling that year. Of that amount, 8% was downcycled and 4% was lost during the process. Only 2% was effectively recycled into a product of equal or higher value.

Figure 1: Downcycling of plastic



Though there has been a global push to promote recycled or downcycled plastics, it is crucial to recognize that recycled plastics are a ***cocktail of toxic chemicals***. These chemicals persist through the recycling and transformation process, meaning that the products contain high levels of toxicity that may render them unsuitable for consumer use.

The recycling process and its resultant products have the potential to induce ecotoxicity (toxicity to the ecosystem). This issue arises due to the release of contaminants, such as chemical additives or residual catalyzers, during the recycling processes or from the recycled pellets themselves. All plastics inherently contain toxic chemicals which are transferred directly or indirectly into recycled plastic products during manufacturing. It is noteworthy that recycled plastic products tend to harbor more impurities and potentially more chemical contaminants than those made from virgin plastic pellets[11]. Plastics in current recycling processes are thus incompatible with the circular economy.

1.5 CHEMICAL PATHWAYS DURING RECYCLING

All plastics contain chemicals; they can be added intentionally to deliver material functionality, or they can be unintentionally created during the plastic manufacturing stages. A recent collaborative study by International Pollutants Elimination Network (IPEN) states the presence of more than 13000 chemicals in plastic, with approximately 7000 of those identified as highly hazardous[12]. Given their abundance, it is relatively easy for these chemicals to find their way into recycled plastic. Certain pathways through which these chemicals can get into the recycled plastic products include:

1 Direct transfer

Virgin plastics constitute a complex amalgamation of chemicals, and when recycled, there is a direct transfer of toxic chemicals into the recycled plastic.

2 Adsorption to transfer:

Plastic waste has a distinct ability to adsorb poisonous chemicals through direct adsorption. Plastics become tainted with chemicals in waste streams or elsewhere in the environment, resulting in recycled plastic products containing a stew of toxic chemicals.

3 Generation of new chemicals during recycling

When plastics are recycled, new toxic chemicals are released/produced into the recycled plastics. For example: when plastics containing brominated flame retardants (BFR) are recycled, brominated dioxins are formed. Likewise, the mechanical recycling of PET plastic has the potential to produce benzene, a carcinogen[13].

2
Chemicals in Recycled Plastic

2.1 CHEMICALS OF CONCERN IN RECYCLED PLASTIC

Plastics are extremely complex and poorly characterized materials that pose significant challenges. Their primary components include organic compounds, a polymeric matrix, and a variety of chemicals. Specifically, over 13000 chemicals have been linked to plastics and plastic production across a wide range of sectors and applications, with 3200 of these being monomers, additives, processing aids, and unintentionally added substances. These chemicals raise concern due to their ecotoxicity, carcinogenicity, mutagenicity, and reproductive toxicity[14]. Some examples include Plasticizers, metals and Metalloids, stabilizers, anti-oxidants, flame retardants, biocides, bisphenol, and per and polyfluoroalkyl substances.

> 13000
chemicals have been linked to plastics and plastic production across a wide range of sectors and applications

2.2 CHEMICALS OF RESEARCH INTEREST FOR THE PRESENT STUDY

The current study focuses on **5 major chemicals** that are known for their detrimental impact on human health: phthalates, Chlorinated Paraffins [Single Chain Chlorinated Paraffins (SCCPs) and Medium Chain Chlorinated Paraffins (MCCPs)], heavy metals (Pd, Cr, Cd and As), Bisphenol A (BPA) and Nonylphenol (NP).

1 Phthalates

Phthalates or phthalic acid ester (PAEs) are diesters of 1,2-benzenedicarboxylic acid used in industrial plastics, personal care products, and pharmaceuticals. Phthalates of higher molecular weight are used as plasticizers, whereas phthalates of lower molecular weight are used as solvents in personal care products. This process makes the material softer and flexible, increases plasticity and reduces viscosity during the process of manufacturing, thus making plastic more durable[15,16].

Phthalates are emitted or migrated throughout a plastic's entire life cycle, from product manufacturing to consumption of a phthalate-containing product. Phthalates of low molecular weight are highly susceptible to migration from plastics and thus can cause toxicity in humans. The European Union Food Contact Material (FCM) regulation (EU No. 10/2011) restricts certain phthalates in materials that come into contact with food.

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2 Chlorinated Paraffins

Chlorinated Paraffins (CPs) constitute a class of chlorinated n-alkanes which are used in many products and applications. CPs are classified into three groups based on their carbon chain length: Short Chain CPs (SCCPs), Medium Chain CPs (MCCPs) and Long-chain CPs (LCCPs). These versatile chemicals find extensive use in high-temperature lubricants, metal cutting fluids, and sealants. Furthermore, they are utilized as plasticizers and flame retardants in plastics[17].

CPs, considered among the most hazardous and high production volume chemicals globally, possess persistent and bioaccumulative properties, rendering them toxic. Due to their abundance in plastics, however, they are continuously released into the environment throughout their life cycle. Consequently, SCCPs were banned under the Stockholm Convention on Persistent Organic Pollutant in 2017, while MCCPs are presently under evaluation for a potential global ban.

India was estimated to produce approximately 375,000 tonnes of SCCPs annually in 2008, making it the second largest producer of CPs[18]. However, despite this significant production volume, there are currently no regulations or legislation in place in India to regulate the utilization and distribution of SCCPs.

3 Heavy metals (Cd, As, Pb and Cr)

The incorporation of heavy metals aims to enhance the physicochemical property of plastics through the recycling process. As a result, heavy metals emerge as primary contaminants in plastic pellets. Additives required in the production of pellets of recycled plastic, such as catalysts, antioxidants, and light and heat stabilizers, leave residues of Pb, Cd, Cr, and As[19]. Metal based compounds are also used as heat stabilizers and are extensively used in thermoplastics such as Poly Vinyl Chloride (PVC).

Notably, these heavy metals are not chemically bound to the plastic polymer and leach out under the influence of several physicochemical factors (sunlight, temperature, types of solvents, and pH of the product). Thus, to regulate and mitigate potential hazards, the Bureau of Indian Standards (BIS) has established national standards for the permissible use of heavy metals in plastic. According to these standards, metal concentration should not exceed 1 ppm, with a stricter limit of 0.1 ppm for Cd.

The EU also has stringent regulations on heavy metals in plastics under the REACH (Registration, Evaluation, Authorization and Restriction of Chemicals) regulation. REACH restricts the use of certain hazardous substances in all materials, including plastics. The Restriction of Hazardous Substances (RoHS) Directive limits the use of specific hazardous materials (including Pb, Hg, Cd and Cr) in electrical and equipment. Additionally, the Toys Safety Directive sets limits for heavy metals in toys.

4 Bisphenol A

Bisphenol A (BPA) serves as an industrial monomer utilized in the production of polycarbonate (PC) plastic and epoxy resin. Widely employed in various applications, BPA is commonly found in epoxy paints and glue, food chain linings, and thermal paper receipts. It is also used in PC for imparting clarity, hardness, thermal stability[20] and resistance to acids and oils. Additionally, BPA functions as a stabilizer and antioxidant in the manufacturing of PVC.

Despite having a low bioaccumulation rate in the human body, BPA possesses a distinctive ability to mimic certain hormones, particularly estrogens, thereby interfering with the functioning of estrogen activity. As a result, BPA is rendered highly toxic[21].

Till now, there are no specific regulatory policies on the use of BPA in plastics, even in materials that come into contact with food. However, in response to growing concerns, the Bureau of Indian Standards (BIS) revised the baby feeding bottle standard (IS 14625:2015) in 2015, prohibiting the use of BPA in baby feeding bottles. This regulatory measure was implemented to safeguard infants and address potential health risks associated with BPA exposure[22] .

The EU has restricted the use of BPA in baby bottles and has set specific migration limits for BPA in FCM under Regulation (EU) No 10/2011. The European Safety Authority (EFSA) continues to evaluate the risks of BPA and has significantly lowered the temporary tolerable daily intake. BPA is also identified as a substance of very high concern (SVHC) under the REACH regulation due to its reproductive toxicity.

5 Nonylphenol

Nonylphenol (NP), a widely utilized industrial chemical, is introduced into the environment as a byproduct of the degradation of NP ethoxylates (surfactants)[23]. These surfactants find application in industrial, institutional, commercial, and household settings. Another source of NP involves the hydrolysis of the antioxidant tris(nonylphenyl) phosphite (TNPP), which are used as heat stabilizers in the manufacturing of polymeric food packaging materials.

Many plastics intended to come into contact with food have been detected with NP, such as polycarbonate tableware and baby bottles, polystyrene disposable cups and food cases, and PVC stretch films and gloves. NPs exhibit high resistance to biodegradation, which leads to bioaccumulation. Because of this, they are considered one of the most toxic chemicals found in plastic. Studies have documented the presence of NPs in water and milk, proving that the toxins leached out from plastic bottles such as HDPE and PVC[24]. As of today, there are no rules and standards for the use of NP in plastics anywhere in the world, including India.

2.3 ROUTE OF EXPOSURE TO CHEMICALS IN RECYCLED PLASTIC

There are several routes of exposure to these chemicals including:

- the digestive system ingestion: through contaminated food and water,
- vertical transmission: maternofoetal (of or pertaining to both mother and foetus),
- the respiratory system: inhalation,
- integumentary system: skin and eye contact

2.4 IMPACTS OF CHEMICALS IN RECYCLED PLASTIC ON HUMAN HEALTH

The following is a summary of some of the most significant epidemiological studies conducted in order to understand the impact of these chemicals on human health.

i. **Reproductive health:** Exposure to chemicals in plastics has been associated with adverse reproductive effects, as evidenced by various studies. Phthalates such as DEHP, DEP, DMP and DnBP have been linked to early menarche and accelerated breast development in young girls, as well as an increased risk of breast cancer and endometriosis[25]. Phthalates also exhibit anti-androgenic properties, inhibiting the activity of male hormones such as testosterone.

   BPA and NP have been identified to reduce the anogenital distance in males, leading to a decline in male fertility[26]. BPA, specifically, is known to disrupt the function of both male and female sex hormones[27]. Pb has the capacity to alter sex hormones and destabilize chromatin, potentially causing congenital disabilities. Cd can reduce the sperm motility in males, disrupt the morphology of the ovary, and decrease the egg count, ultimately impacting the female fertility. Additionally, CPs have been found to damage the reproductive system, causing premature breast development in females and leading to poor semen quality in men.

ii. **Pregnancy and foetal development:** BPA has also been known to impact child brain development, prompting regulatory controls on its usage in baby bottles and other containers for food and drinks intended for children. Pb can pass through the placenta and cause miscarriages or low birth weight of foetuses Cd may disturb the growth and development of follicles, leading to spontaneous abortion and birth defects in infants. CPs can cause preterm birth in humans. Parental exposure to DEHP, DBP and DiBP is also associated with child verbal comprehension, processing speed, perceptual reasoning, working memory, neuropsychological disorders and mental retardation[28].

iii. **Respiratory illness:** Phthalates are known to trigger respiratory illness such as asthma, causing impairment and deterioration of the lungs[29].

iv. **Dermal and skin issues:** Heavy metals found in plastics can exhibit toxicity that manifests in skin-related issues. Accumulation of heavy metals in the body can cause skin pigmentation and skin cancer[30]. Exposure to CPs, can lead to dermal irritancy and related dermatological issues[31].

v. **Endocrine Disruption:** In young children, exposure to phthalates has been linked to effect on metabolic activity, as well as disruptions in the endocrine and reproductive system. Similarly, BPA and NP are endocrine-disrupting chemicals. These chemicals are known to mimic estrogen and bind to endocrine receptors, leading to endocrine disruption.

vi. **Carcinogenicity:** Phthalates, CPs, BP and NP and heavy metals (Pb, Cd, As and Cr) found in plastic are mutagenic and carcinogenic.

vii. **Cardiovascular system:** Phthalates are known to cause cardiovascular risks such as increases/decreases in blood pressure, coronary heart diseases, and atherosclerosis. A specific study conducted in the Uppsala community, focusing on individuals aged 70 years or more, revealed a close association between phthalates and BPA to induce coronary heart disease[32].

viii. **Erythrocytes (Red blood cells):** Phthalates, including DEHP, affect the plasma membrane of erythrocytes, causing osmotic fragility by making them more flexible. This ultimately deforms the shape of the erythrocytes, thus impairing the entire cell[33].

ix. **Apoptosis (programmed cell death) and DNA damage:** NP may induce apoptosis and chromosomal damage, eventually affecting the DNA[34]. BPA also causes DNA damage in human blood cells.

Apart from these health effects, these chemicals can also cause liver impairment and immunotoxicity, neurological and renal damage, tissue lesions and skeletal retardation.

3

Past Studies, Regulations and Sustainable Development Goals Associated with Plastic Recycling

3.1 PAST STUDIES

Numerous studies have stated the presence of toxic chemicals in recycled plastic products. Some of these researches are listed below:

In a 2022 IPEN report, data on 73 recycled plastic products from China, Indonesia, and Russia were summarized, and it was discovered that all of the products contained toxic chemicals (POP-BFRs, i.e., penta-, octa-, deca-BDE, and Hexabromocyclododecane (HBCD)) that are prohibited under the Stockholm convention [IPEN 2022 report how plastic poison]. Another global study, published in 2022, discovered that recycled plastic bottles contained more toxic chemicals (aldehydes, antimony (Sb), BPA, and phthalates) than new plastic bottles, indicating that the recycling process can exacerbate chemical threats[35]. Toxic chemicals (common and novel BFR, tetrabromo BPA, Polybrominated diphenyl ether (PBDE) and HBCD, Brominated dioxins, tetrabromo BPA (TBBPA)) were discovered in recycled plastic toys, kitchen utensils, and other products in a 2022 study conducted in collaboration between IPEN, Arnika, and partners in 11 African and Arabic countries[36].

A study by IPEN in 2021 on recycled pellets collected from 23 countries (Argentina, Bangladesh, Cameroon, Congo, Egypt, India, Kazakhstan, Malaysia, Mauritius, Mexico, Nepal, Nigeria, the Philippines, Rwanda, Senegal, Serbia, Sri Lanka, Taiwan, Tanzania, Thailand, Ukraine, Vietnam, and Zambia) claimed the presence of toxic chemicals in recycled plastics. The report also stated that these chemicals were not removed during recycling, but instead were carried over to new products and/or generated new toxic chemicals after recycling. The study assessed the presence of BFR, BPA and UV stabilizers in recycled plastic products[37]. According to a study conducted in over 26 different countries, on four continents (Africa, North America, Asia and Europe), recycled plastic toys contained high levels of toxic dioxins. It also estimated that the daily toxic chemical ingestion from children's mouthing habits is significantly higher than the recommended tolerable daily intake[38].

A 2013 study carried out in China discovered harmful air-polluting chemicals (Poly Aromatic Hydrocarbons (PAHs), Volatile Organic Compounds (VOCs), phthalate esters (PAEs)) around and inside Chinese plastic recycling facilities, with potential health consequences for workers and local residents. The concentrations of hazardous chemicals near the facilities were higher than at the associated control site[39]. Two more studies from China discovered high levels of plastic flame-retardant chemicals in soils, sediment, and road dust near plastic recycling facilities, and compared them to lower levels in samples from areas where plastic recycling is not carried out[40,41]. Hazardous chemicals such as Poly Aromatic Hydrocarbons (PAHs), SCCPs, phthalates, adipates, vulcanized additives, and antioxidants have been detected in recycled tire crumbs, which are used in children's playgrounds and recreational sports surfaces in 17 countries (Albania, Chile, Croatia, Finland, France, Germany, Greece, Italy, Netherlands, Poland, Portugal, Spain, Sweden, Thailand, Turkey, United Kingdom and United States)[42]. In China, the presence of SCCPs, MCCPs, and LCCPs has been observed in recycled rubber granules and playground tiles[43].

A study of 21 plastic flakes and pellets collected from Canadian recycling companies found the presence of more than 280 chemicals (organic chemicals and metals)[44].

Several studies have documented the detection of chemicals in recycled toys. For instance, a study conducted in Belgium reported finding flame retardants (FR), such as polybrominated diphenyl ethers and phosphate FRs, as well as phthalate esters in 106 recycled plastic toy samples[45]. Another study carried out in Canada detected the presence of brominated/chlorinated flame retardants, organophosphorus ester FR, and perfluoroalkyl acids (PFAAs)[46]. A different study conducted on recycled consumer products (children's toys, FCM) purchased from retailers in Texas, United States found the presence of flame retardants, plasticizers and biocides[47]. In a recent investigation conducted by the Danish Environmental Protection Agency, it was discovered that as much as 45% of recycled plastic toys exhibited phthalate levels exceeding the prescribed limit for toys intended for children aged 0-3 years, in accordance with the standards set by the Danish EPA[48].

A recent study conducted by IPEN identified the presence of SCCPs and MCCPs in end-of-life car tires, which were recycled into rubber granules for use on artificial soccer fields and playground tiles.[49] Another recent study in China reported the presence of heavy metals (Cd, As, Pb and Cr) in recycled plastic pellets, emphasizing the associated health risks for workers[50].

3.2 REGULATIONS REGARDING RECYCLING OF PLASTIC IN INDIA

(a) Plastic waste management (PWM) Rules, 2016 India

The Govt. of India, through the Ministry of Environment, Forest and Climate Change notified the new Plastic Waste Management Rule in 2016 (through a gazette notification dated 18th March 2016). With a special focus on recycling, this ruled that any plastic waste that can be recycled should be channelized to registered plastic waste recyclers, and all recycling of plastic shall conform to the Indian Standard: IS 14534:1998.

BIS has issued standards (IS 14534: 1998 and IS 14535: 1998) for the recovery and recycling of plastic waste, as well as the products that can be manufactured using recycled materials.

(b) Plastic Waste Management (Amendment) Rules, 2021; Plastic Waste Management (Amendment) Rules, 2022; and Plastic Waste Management (Amendment) Rule 2023

Plastic Waste Management (PWM) Rules, 2016, was superseded by the Plastic Waste Management (Amendment) Rules, 2021, and Plastic Waste Management (Amendment) Rules, 2023. These amendments bring out certain details regarding the management of plastic waste, particularly related with the idea of Extended Producer Responsibility (EPR).

The major change that was brought into the amendment of 2021 regarded the use of recycled plastic for storing, carrying, dispensing or packaging FCM, , which was earlier prohibited in Plastic Waste Management Rule of 2016. This was subject to appropriate standards and regulations under the Food Safety and Standards Act, 2006, by the Food Safety and Standards Authority of India (FSSAI).

The 2023 amendment introduced a new category, Category V, for biodegradable plastics; in which biodegradable and compostable plastics can be distinguished. A noteworthy development is the inclusion of gutka, pan masala, and tobacco packaging in the biodegradable plastics category. However, it is important to note that the recycling process was only elucidated in the 2021 amendment.

(c) IS 14534: 1998: Guidelines for the recovery and recycling of plastic waste

This standard specifies procedures for selecting, sorting, and processing plastic waste/scrap. It also provides guidelines to plastic product manufacturers regarding the marking used on the finished product. This is intended to facilitate identification of the basic raw material, and also aid in determining whether the material used on the finished product is virgin, recyclates, or a blend of the two.

(d) IS 14535: 1998: Indian Standard for recycled plastics for the manufacturing of products-designation

This standard lays out the guidelines for identification and classification of recycled plastic materials (intended for normal use with no further modifications) on the basis of its basic properties and applications. These include information on the source of the recycled material (eg. Post-consumer or post-industrial), the type of plastic (eg.- PET, HDPE), etc.

3.3 SUSTAINABLE DEVELOPMENT GOALS ASSOCIATED WITH RECYCLING

(1) Sustainable Development Goal 3: good-health and well-being

This places an emphasis on producing and consuming toxic-free recycled plastic materials, and aligns with the goal of ensuring good health and well-being.

(2) Sustainable Development Goal 6: Clean water and Sanitation for all and Sustainable Development Goal 14: Life below water

Plastics play a major role in polluting water systems as well as affect the living system. Their degradation leads to the formation of microplastics and the release of harmful

chemicals, which adversely affect aquatic environments. Protecting these habitats and ecosystems requires the implementation of rigorous controls on the chemical components of all plastics, encompassing both virgin and recycled plastics.

(3) Sustainable Development Goal 12: ensure sustainable production and consumption

Ensuring sustainable production would mean producing and consuming recycled plastic materials, which are toxin free, in turn bringing recycled products into the ambit of the circular economy.

(4) Sustainable Development Goal 9: Industry, innovation and infrastructure

This goal aligns with the promotion of industries and innovations which address harmful chemicals in plastic. Building resilient infrastructure and fostering sustainable industrialization involves developing technologies and practices that mitigate the negative environmental and health impacts of plastic use.

(5) Sustainable Development Goal 11: 'Sustainable cities and Communities'

This goal promotes industries and innovations to reduce harmful chemicals in plastics and contributes to creating sustainable cities and communities. It encourages the development of eco-friendly practices and alternatives that can be implemented at the community level, aligning with the broader aim of sustainable urban development.

Interconnectedness of various SDGs and an emphasis on the need for a holistic approach can address the environmental and health challenges associated with recycled plastic use. By integrating these goals into plastic production, consumption, and recycling, there is a potential to create a future that is healthier and sustainable.

4 Objectives, Study Area and Methodology

4.1 RATIONALE OF THE STUDY

While India is currently ranked 12th among countries with low provisions for managing plastic waste, the country is committed to achieving the 5th position in effective plastic waste management by 2025[51]. Consequently, there is an urgent need to find sustainable options. Recycling or reprocessing plastic waste remains one of the key mechanisms of addressing plastic mismanagement issues. It also immensely helps in reducing the adverse environmental effects of plastic consumption and utilization. As India transitions to CE, there is a growing emphasis on plastic recycling, but chemical aspects of the recycling process are often not recognized.

There have been limited studies to date that focus on chemical contamination during recycling. Unfortunately, there is a lack of comprehension regarding the transfer and/or transformation of toxic chemicals from virgin to recycled plastics and their potential impact on human health, especially in India.

This research is a component of Toxics Link's initiative to comprehend and evaluate chemical contamination in recycled plastic products and advocate for policy and management actions that restrict increased reliance on recycling, and mandates safe recycling, while concurrently addressing the growing plastic production concerns.

4.2 OBJECTIVES OF THE STUDY

- To assess the toxic contaminants in recycled plastic products
- To increase the amount of data available about toxic chemicals transferred from plastic waste into recycled plastic pellets
- To use this data to raise awareness of the problem of non-circular plastics entering the recycling system, especially in developing countries like India
- To understand the current recycling process in the informal sector and how chemical contamination are handled over these sectors
- To highlight the need for transparency and right-to-know for chemicals in products made both from virgin and recycled plastic
- To advocate for stricter standards on plastic recycling, especially related to chemical contamination

4.3 STUDY AREA

For the current investigation, the samples were selected from different areas of New Delhi (latitude 28°24'17"N to 28°53'00"N and longitude 76°50'24"E to 77°20'37"E). Figure 2 shows the map of India, highlighting the current research area (New Delhi).

Figure 2: Location map of Sample site (New Delhi) >

4.4 METHODOLOGY

(a) Identification of recycled product manufacturing units

Initially, recycled product manufacturing areas were identified to comprehend the supply chain of recycled plastic, products manufactured using recycled pellets, and the processes involved in recycling.

(b) Scope of the Study

The Indian plastic recycling market achieved a total market volume of 54.7 Mt in 2023 and is poised for strong growth in the future, with a projected Compound Annual Growth Rate of 10.57% through 2029[52]. The informal sector/marginalized groups play a pivotal role in recycling in India, contributing a substantial 70% to the overall recycling efforts. Itinerant waste buyers collect approximately 6.5 to 8.5 tonnes of plastic waste per day, with household waste collectors accounting for a significant portion. Remarkably, 50-80% of this waste is projected to be recycled[53]. Recycled plastic products have a huge market in India in terms of consumption, especially in the marginalized population. The significant dependency and consumption of recycled plastic products by marginalized groups can be attributed to several factors:

(i) Affordability

Recycled plastic products are often less expensive than those made from virgin materials. For marginalized groups, who typically have limited financial resources, affordability is a crucial factor.

(ii) Availability

Recycled plastic products are widely available, partly due to the extensive informal recycling networks in many regions. Marginalized communities often have more access to these recycled plastic products than to virgin, costlier alternatives.

(iii) Income Generation

In many cases, marginalized groups are directly involved in the collection, sorting and recycling of plastic waste. This not only provides them with income but also with access to recycled plastic. This creates a cycle where the waste these groups collect can be turned into affordable products for their use.

Various types of recycled plastic products were accessible in the market. For the current study, materials highly prone to susceptibility, such as toys, FCM, tooth brushes, and tobacco boxes, were examined for the presence of BPA, Chlorinated Paraffins (SCCPs and MCCPs), phthalates ((DBP, BBP, DEHP, DNOP, DINP, DIDP and DIBP), heavy metals (As, Cd, Cr and Pb) and NP. The selection of chemicals for the current study was based on specific properties, listed below in Figure 3:

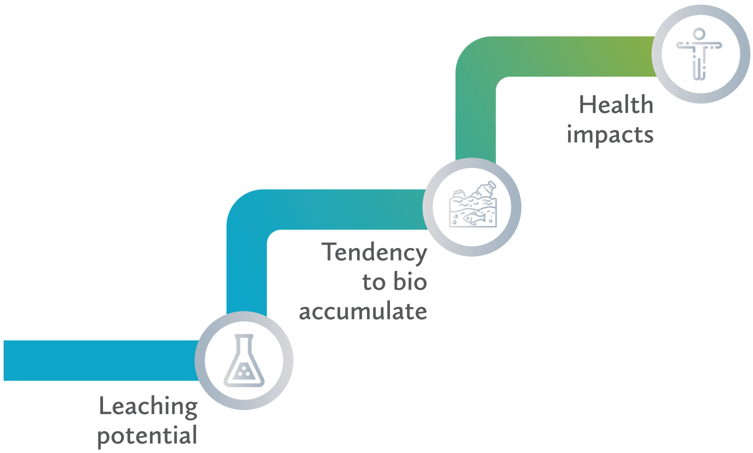

Figure 3: Properties of listed chemicals that can have adverse impacts

(c) Sample Collection

Stratified sampling was the adopted sampling method.

(a) From recycling units: Several specific manufacturing areas (strata), that are indulged in manufacturing recycled plastic items, were identified. Following identification, each stratum was randomly surveyed, and samples were gathered from various units based on the product of interest as determined by the research need.

(b) From weekly and local markets: Samples were also collected from local and weekly markets and then assessed.

Samples were collected between 11th October 2023 and 12th December 2023 from all the units and local markets. The type of plastic (virgin, semi or recycled) along with the polymer type of each sample were also identified with the help of experts, and the semi and recycled products were selected and sent for testing to an accredited lab.

Thereafter all samples were packed, labelled and listed before they were dispatched to the testing laboratory for chemical analysis. Detailed information of products is summarized in Table 1. As listed in Table 1, a total of 15 samples (S.N 1 – S.N. 15) were sent for testing.

Table 1: Details of sample collected from recycling units and local markets

S.No.	Sample No.	Sample Name
1.	Sample No. 1 (S.N. 1)	Sauce Bottle
2.	Sample No. 2 (S.N. 2)	Soft Toy Duck
3.	Sample No. 3 (S.N. 3)	Milk Drum
4.	Sample No. 4 (S.N. 4)	Masala box
5.	Sample No. 5 (S.N. 5)	Casserole
6.	Sample No. 6 (S.N. 6)	Kitchen set
7.	Sample No. 7 (S.N. 7)	Fruit set
8.	Sample No. 8 (S.N. 8)	Rattle Toy (locally known as Jhunjhuna)
9.	Sample No. 9 (S.N. 9)	Mouth Organ
10.	Sample No. 10 (S.N. 10)	Tobacco Box
11.	Sample No. 11 (S.N. 11)	Water Bottle
12.	Sample No. 12 (S.N. 12)	Tooth Brush
13.	Sample No 13 (S.N.13)	Food Container
14.	Sample No. 14 (S.N. 14)	Rubik's Cube
15.	Sample No. 15 (S.N. 15)	Bingo blocks

(d) Testing methodology

(i) Sample Preparation

To measure the concentration of each chemical, plastic products were weighed before sample collection.

(ii) Measurement techniques used for testing of chemicals

Table 2: Measurement techniques and test methods followed for the testing of chemicals.

S.No.	Chemicals	Testing Technique	Type of test method followed
1.	Bisphenol A	HPLC-MS	In house method (developed by testing lab where the sample was sent.)
2.	Chlorinated Paraffins (SCCPs & MCCPs)	GC-MS-NCI	ISO 18219-1/2:2021
3.	Heavy metals (As, Cd, Cr and Pb)	ICP-MS/ICP-OES	EN 16711-1: 2015/Acid Digestion
4.	Phthalates (DBP, BBP, DEHP, DNOP, DINP, DIDP and DIBP)	GC-MS	ISO 14389:2014
5.	Alkyl Phenol (Nonylphenol)	HPLC-MS	ISO 18254-1:2016

Bisphenol A

The measurement of BPA contents involved weighing approximately 1 g of sample, followed by digestion and extraction with Tetrahydrofuran/methanol (THF/Methanol) in an ultrasonic bath at 60°C for (60 ± 5) minutes. After the extraction, it was cooled to near room temperature, and approximately 20 ml of the solution was filtered into HPLC vial, using a disposable syringe equipped with a membrane filter. Detection and quantification were performed using HPLC.

Chlorinated Paraffins

For the measurement of CP in plastic samples, 2g of each sample was utilized. The sample underwent digestion and extraction in a KOH/Acetone/hexane solvent, employing 1/15 hour of sonication at 90°C. Following the cooling of the extract to room temperature, approximately 40 ml was filtered and subsequently detected and quantified using GC-MS.

Heavy metals (As, Cd, Cr and Pb)

To detect all heavy metals, 0.2 g of sample was weighed. 3 ml of conc. HNO_3 was added, followed by a small quantity of HCl. The sample was filtered and the volume was adjusted to 100 ml with an ultrapure water, maintaining an acid concentration of 10%. Microwave digestion was employed for sample extraction (10ml), with each sample's temperature reaching 170 ± 5°C for 10-20 minutes of the remaining digestion period. After the microwave digestion, the sample was allowed to cool for a minimum of 5 minutes before removing them from the microwave system. When the vessels were cooled to near room temperature, the sample was ready for ICP-MS/OES analysis.

Phthalates

Approximately 0.3 g of the cut plastic sample was extracted with THF/Hexane in an ultrasonic bath at 60°C for (60 ± 5) minutes. After cooling the extract to room temperature, about 20 ml of the extraction solution was filtered into a vial using a disposable syringe equipped with a membrane filter. The detection and quantification were conducted using GC-MS.

Nonylphenol

Approximately 1 g of the cut plastic sample was subjected to extraction with methanol in an ultrasonic bath at 70°C for (60 ± 5) minutes. Following the cooling of the extract to room temperature, approximately 10 ml of the extraction solution was filtered into an HPLC vial using a disposable syringe equipped with a membrane filter. Detection and quantification were carried out using HPLC-MS with gradient elution and an ESI mass spectrometer.

5
Results and Discussions

5.1 PLASTIC RECYCLING IN DELHI

The informal recycling areas for plastic in Delhi were visited between October - December 2023. The field visits showed that recycling or downcycling of plastic is extensive in Delhi, and that the city receives plastic waste from all over the country. The prime areas dedicated to manufacturing recycled products have been listed in Table 3. Most of the units in the identified recycling areas produced new products from recycled pellets. Each of these areas were dotted with many plastic grinding and moulding units, with many of these units dealing in different types of resins and producing a diverse range of recycled products.

Table 3: List of recycling units identified across Delhi

S.No.	Area	Moulded Products from recycled plastic
1.	Anand Parvat	Automobiles
2.	Badli	Combs
3.	Bawana	Tubs, flower pots (Semi-recycled)
4.	Daya Basti	Torches, flour strainers, serving bowls, food containers, toy cars, toy guns
5.	Inderlok	Toys, toothbrushes, spectacle frames
6.	Jhilmil & Friends colony	Cables and engineering
7.	Karwal nagar	Helmet, broom handles
8.	Khyala Village	Home theater cabinets, capacitor covers, fan parts, helmet, wall clips, electric toy cars, electric boxes, auto parts, torches, press handles, washing machine trolleys and e-rickshaw parts
9.	Kirti Nagar	thinner cans, battery part, horns
10.	Narela	Mugs, buckets, tubs, crates, paints & chemical containers

S.No.	Area	Moulded Products from recycled plastic
11.	Okhla	Flower pots, speakers, electric items, auto parts
12.	Sadar Bazar	Toys, lens frames

**Semi-recycled- Here, "semi" refers to plastic products that are made by blending virgin and recycled plastic pellets. Plastic product manufacturers prefer to manufacture semi-recycled plastic products rather than pure recycled plastic ones because the latter lack the sheen and texture that only virgin plastic can offer. As a result, mixing/blending of virgin and recycled plastic is far glossier and more durable than pure recycled plastic.*

Following an extensive field survey across various recycled plastic product manufacturing sites, Daya Basti, Inderlok, and Narela were identified as the key locations of interest, because of their relevance to the considered recycled plastic products. Some of the samples tested during the study were picked up from the units in these areas, and the remaining samples were bought from different market areas in Delhi.

5.2 TEST RESULTS

Samples are grouped in their respective classes (FCM, Toys and Miscellaneous) to facilitate better understanding of the study. Results of testing are segregated and presented in accordance with each sample category. Samples were tested for the presence of BPA, Heavy metals (As, Cd, Cr and Pb), NP, CP and Phthalates. As outlined in the methodology, a total of 15 samples were scrutinized; these comprised of 6 samples categorized under FCM, 7 samples designated as toys, and the remaining 2 grouped under miscellaneous. The analysis measured the concentration of all chemicals during the testing expressed in mg/kg.

For all the samples, the Limit of Detection (LOD) for the chemicals: BPA, CPs, Heavy Metals (As, Cd, Cr and Pb), Phthalates and NPs were 0.1 mg/kg, 100 mg/kg, 5 mg/kg (As, Cd, Cr and Pb), 50 mg/kg and 10 mg/kg.

Table 4: Sample details

Sample No.	Category (FCM/ Toys/ Miscellaneous	Sample	Type of plastic (virgin/ semi/ recycled)	Resin type	Susceptible Population	Possible Exposure pathway
Sample No. 1 (S.N. 1)	FCM	Sauce Bottle	Semi	HDPE	People of all age groups	Ingestion and Dermal
Sample No. 2 (S.N. 2)	Toy	Soft Toy Duck	Semi	PVC	Children of age < 5 years	Dermal and ingestion (when is put in mouth)
Sample No. 3 (S.N. 3)	FCM	Milk Drum	Semi	HDPE	People of all age groups	Ingestion
Sample No. 4 (S.N. 4)	FCM	Masala Box	Semi	PP	People of all age groups	Ingestion
Sample No. 5 (S.N. 5)	FCM	Casserole	Semi	PP	People of all age groups	Ingestion
Sample No. 6 (S.N. 6)	Toy	Kitchen Set	Recycled	PP	Children of age < 5 years	Dermal and ingestion (when is put in mouth)
Sample No. 7 (S.N. 7)	Toy	Fruit Set	Recycled	PP	Children of age < 5 years	Dermal and ingestion (when is put in mouth)
Sample No. 8 (S.N. 8)	Toy	Rattle Toy	Recycled	PP	Children of age < 5 years	Dermal and ingestion (when is put in mouth)
Sample No. 9 (S.N. 9)	Toy	Mouth Organ	Recycled	HIPS	Children of age < 5 years	Dermal and ingestion (when is put in mouth)
Sample No. 10 (S.N. 10)	Miscellaneous	Tobacco Box	Recycled	PP	People of age > 15 years	Ingestion and Dermal
Sample No. 11 (S.N. 11)	FCM	Water Bottle	Recycled	PP	People of all age groups	Ingestion and Dermal
Sample No. 12 (S.N. 12)	Miscellaneous	Tooth Brush	Recycled	PP	People of age group ≥ 1 year	Ingestion when used for cleaning the teeth
Sample No 13 (S.N.13)	FCM	Food Container	Semi	PP	People of all age group	Ingestion and Dermal
Sample No. 14 (S.N. 14)	Toy	Rubik's Cube	Semi	PP	Children of age < 5 years	Dermal and ingestion (when is put in mouth)
Sample No. 15 (S.N. 15)	Toy	Bingo Blocks	Semi	PP	Children of age < 5 years	Dermal and ingestion (when is put in mouth)

Laboratory analysis of the recycled plastic samples showed that 10 out of 15 samples contained positive results, indicating the presence of one or more chemicals including BPA, CPs (SCCPs), heavy metals (As, Cd, and Cr), phthalates (DEHP and DINP) and NP. Out a total of 15 samples, 8 samples contained BPA at concentration ranging from 0.30 mg/kg to 161 mg/kg; 4 samples contained SCCPs at concentration ranging from 111 mg/kg to 338 mg/kg and 4 samples contained NP at concentration ranging from 38.5 mg/kg to 522 mg/kg. Only 2 out of 15 samples detected the presence of heavy metals. One of these samples contained Cd at a concentration of 89 mg/kg, while the other showed the presence of both Pb and Cr at concentrations of 121 mg/kg and 33.9 mg/kg, respectively. Furthermore, 3 out of 15 samples were identified with phthalates. All three of these samples contained DEHP at concentration ranging from 85 mg/kg to 220000 mg/kg. Notably, one of these samples also disclosed the presence of DINP at a concentration of 8000 mg/kg.

Furthermore, within these 10 samples, 6 were found to contain more than one chemical, and among them, 2 samples revealed an exceptionally high rate of chemical detection, with 4 different kinds of chemicals found in each of the samples.

Figure 4: Percentage of tested samples detected with toxic chemicals

A. Food Contact Materials (FCM)

Out of 15 samples, 40% (6 samples-S.N. 1, S.N. 3, S.N. 4, S.N. 5, S.N. 11 and S.N. 13) fell within the category of FCM. FCM are designed to store, package, or process food, often coming in direct contact with this food for extended periods. This prolonged exposure time increases the likelihood of chemical migration, resulting in a higher potential for direct ingestion by humans. When people consume food that has been in contact with plastic, there is a possibility of ingesting any migrated substances.

The products that are chosen and classified under FCM in this study include sauce bottles, milk drums, masala boxes, caseeroles, water bottles and food containers. Within this subset of 6 samples, 67% (4 samples) exhibited the presence of chemicals, while the remaining 33% (2 samples) were not detected with the chemicals considered during the study. Table 5 displays the concentration of each chemical in every sample categorized under FCM.

Table 5: Concentration of each chemical found in samples categorized under FCM

Sample No.	Chemicals														
	BPA (mg/kg)	CP (mg/kg)		Heavy metals (mg/kg)				NP (mg/kg)	Phthalates (mg/kg)						
		MCCPs	SCCPs	As	Cd	Cr	Pb		DBP	BBP	DEHP	DNOP	DINP	DIDP	DIBP
S.N. 1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
S.N. 3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
S.N. 4	161	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
S.N. 5	40.9	ND	111	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
S.N. 11	0.34	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
S.N. 13	2.14	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND: Not Detected

S.N. 4, S.N. 5, S.N. 11 and S.N. 13 were detected with tested chemicals. BPA was present in all four of these samples, which constitutes worry as BPA is known to have huge health impacts. It's noteworthy that one of the samples also showed presence of SCCPs. S.N. 1 and S.N. 3 were not detected with any of the tested chemicals.

Figure 5: Pictures of S.N.1 (Sauce bottle) and S.N.3 (Milk bottle) *(L to R)*

Figure 6: Pictures of S.N.4 (Masala boxes), S.N. 5 (Casserole), S.N. 11 (Water Bottle), S.N. 13 (Food Container) *(L to R)*

Of the concentrations detected in the samples, S.N. 11 (0.34 mg/kg) and S.N. 13 (2.14 mg/kg) exhibited lower concentrations of BPA in comparison to other samples that were detected with BPA. The concentrations were significantly high in S.N. 5 (40.9 mg/kg) and in S.N. 4 (161 mg/kg). Due to potential risks linked to BPA, about 40 countries have implemented strict restrictions on its use in FCM, especially those designed for young children. The European Commission (EC) states that the migration of BPA from plastic materials and articles shall not exceed a specific migration limit of 0.05 mg/kg of food. The current permissible limit of BPA as per Environment Food Safety Authority (EFSA) is a Tolerable Daily Intake (TDI) of 0.2 ng/kg/bw/day (nanogram per kilogram of body weight per day). It is noteworthy that developing countries like India are lagging in adopting stringent policy measures to regulate the use of BPA in FCM.

S.N. 5 also harbored elevated concentrations of prohibited chemical SCCPs with a concentration of 111 mg/kg. The presence of SCCPs in S.N. 5 raises significant concerns, due to their potential health impacts. None of the samples detected MCCPs.

Detection of chemicals in the testing products raises concerns as several studies across the globe have reported leaching of chemicals from plastic FCM. In Malaysia, a study identified the leaching of chemicals such as styrene and antimony trioxides from water containers made of PP, PET, PS and PE[54]. Additionally, a separate study detected the leaching of chemicals, including benzene, styrene, and BPA from recycled PET plastic containers into beverages[55]. Furthermore, another study found the leaching of BPA in water that had come into contact with plastic containers[56].

B. Toys

47% of the samples tested, i.e. 7 samples-S.N. 2, S.N. 6, S.N. 7, S.N. 8, S.N. 9, S.N. 14 and S.N. 15, have been classified under the Toys category. Within this subset of 7 samples, 86% (6 samples) showed the presence of tested chemicals. The samples which were detected with the toxic chemicals are in S.N. 2, S.N. 6, S.N. 7, S.N. 8, S.N. 9, and S.N. 14. Table 6 displays the detected limits of each chemical in every sample categorized under toys.

Table 6: Detected limits of each chemical found in S.N.2, S.N. 6, S.N. 7, S.N. 8, S.N. 9, S.N. 14 and S.N. 15 categorized under toys

Sample No.	Chemicals														
	BPA (mg/kg)	Chlorinated Paraffins (mg/kg)		Heavy metals (mg/kg)				NP (mg/kg)	Phthalates (mg/kg)						
		MCCPs	SCCPs	As	Cd	Cr	Pb		DBP	BBP	DEHP	DNOP	DINP	DIDP	DIBP
S.N. 2	ND	ND	338	ND	89	ND	ND	522	ND	ND	220000	ND	8000	ND	ND
S.N. 6	3.37	ND	ND	ND	ND	ND	ND	38.9	ND	ND	ND	ND	ND	ND	ND
S.N. 7	ND	ND	138	ND	ND	ND	ND	38.5	ND	ND	ND	ND	ND	ND	ND
S.N. 8	0.3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
S.N. 9	1.08	ND	ND	ND	ND	ND	ND	41.1	ND	ND	121	ND	ND	ND	ND
S.N. 14	12.7	ND	120	ND	ND	33.9	121	ND	ND	ND	85	ND	ND	ND	ND
S.N. 15	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND: Not Detected

Figure 7: Pictures of S.N. 2 (Soft toy duck), S.N. 6 (kitchen set), S.N. 7 (Fruit set), S.N. 9 (Mouth Organ), S.N. 14 (Rubik's cube) and S.N. 8 (Rattle toy) *(Clockwise from top left)*

Among these 6 samples, 67% (4 samples) exhibited the presence of BPA, with S.N.14 demonstrating the highest concentration (12.7 mg/kg) followed by S.N. 6 (3.37 mg/kg) and S.N. 9 (1.08 mg/kg). S.N. 8 had only minimal traces of BPA, with a concentration of 0.3 mg/kg.

Remarkably, within this group of 6 samples, none tested positive for MCCPs, while 50% showed the presence of SCCPs. In terms of SCCP levels, S.N. 2 displayed the highest concentration (338 mg/kg), followed by S.N. 7 at 138 mg/kg. Although S.N. 14 had a lower SCCP concentration (120 mg/kg) in comparison to S.N. 2 and S.N. 7, its concentration is still very high, and could lead to potential health impacts.

50% of the samples in this subset were found to contain DEHP, i.e., in S.N. 2 (with concentration 220000 mg/kg), S.N. 9 (with concentration 121 mg/kg) and S.N. 14 (with concentration 85 mg/kg). Additionally, S.N. 2 was also detected with DINP phthalate (8000 mg/kg). All of the samples tested negative for the five phthalate congeners (DBP, BBP, DNOP, DIDP, and DIBP).

Presence of heavy metals was detected in two of the samples: S.N. 2 and S.N. 14. Cd was found in S.N.2 at a concentration 89 mg/kg, while S.N.14 contained Cr with concentration 33.9 mg/kg) and Pb with concentration 121 mg/kg.

Nonyphenol, an emerging chemical of concern, was detected in four of the tested samples. S.N. 2 displayed the highest concentration at 522 mg/kg, trailed by S.N. 9 with concentration of 41.1 mg/kg. In contrast, S.N. 6 (38.9 mg/kg) and S.N. 7 (38.5 mg/kg) had the lower concentrations when compared to other toy samples detected with NP, with marginal disparity between them.

Figure 8: Picture of S.N. 15 (Bingo blocks)

Except for Bingo blocks, all toys were found to contain various chemicals. The soft toy duck (S.N. 2), in particular, exhibited high concentrations of almost all chemicals, excluding BPA. The levels of these chemicals in the soft toy duck were significantly higher. Similarly, traces of all chemicals, except for NP, were identified in the Rubik's cube (S.N.14). Past research has brought attention to the presence of chemicals like BFR and heavy metals in toys. Both the soft toy duck and Rubik's cube are deemed highly contagious and pose potential harm when used by children. Other toys detected with chemicals are also known to have potential health impacts.

C. Other Items (Miscellaneous)

The two plastic products classified under this category were not detected with any of the tested chemicals.

Table 7: Detected limits of each chemical found in S.N.10 and S.N. 12 categorized under miscellaneous

Sample No.	Chemicals														
	BPA (mg/kg)	CP (mg/kg)		Heavy metals (mg/kg)				NP (mg/kg)	Phthalates (mg/kg)						
		MCCPs	SCCPs	As	Cd	Cr	Pb		DBP	BBP	DEHP	DNOP	DINP	DIDP	DIBP
S.N. 10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
S.N. 12	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND-Not detected

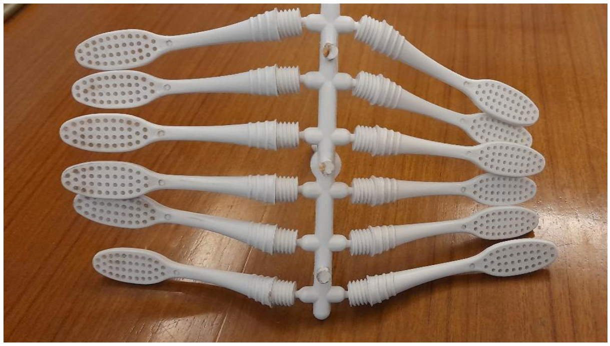

Figure 9: Picture of S.N. 10 (Tobacco box) and S.N. 12 (Tooth brush)

Category wise comparison

When comparing the sample categories, it is notable that toys exhibited the highest concentration of chemicals, highlighting the vulnerability of children to these substances. Specifically, 86% of toy samples contained chemicals, while 67% of FCM were detected with chemicals.

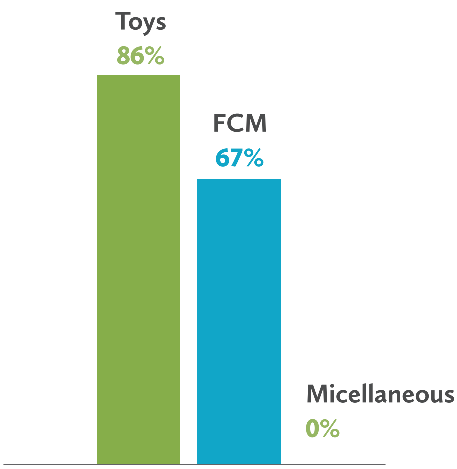

Figure 10: Proportion of chemicals (%) found in each sample category

Comparative analysis based on the presence of chemicals in each sample

When analyzed based on chemical presence (Figure 11), BPA was a major culprit, as it was detected in 53.3% of the tested samples. The proportion of the samples detecting NP and CPs was identical, each accounting for 26.6%. Phthalates constituted 20% of detected chemicals, while heavy metals had the lowest percentage at 13.3%.

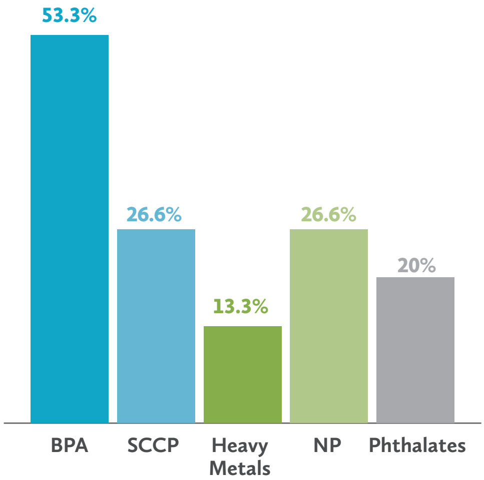

Figure 11: Proportion of chemicals (%)

Out of 15 samples tested, only two revealed the presence of heavy metals. One sample indicated the presence of both Cr and Pb, while the other sample showed the presence of Cd. However, the concentration of all three heavy metals were significantly higher, with Pb reporting to be the highest value (121 mg/kg) followed by Cd (88.9 mg/kg) and Cr (33.9 mg/kg). Heavy metals are known to have major health impacts, especially on growing children.

When samples were tested for CPs, none of them contained MCCPs, with 26.6% (4 samples) detected the presence of SCCPs.

The recycled plastic underwent testing for the presence of phthalates (DINP, DIDP, DNOP, DEHP, DBP, BBP, DIBP). 3 of the samples were found to contain DEHP, while 1 sample detected DINP. Of the two, DEHP displayed the highest concentration.

6 Conclusions and Recommendations

As plastic recycling effectively mitigates the pollution arising from incineration and diminishes the adverse effects associated with landfilling, it simultaneously generates new opportunities for both small- and large-scale commercial and recycling units in various countries. However, despite these advantages, plastic recycling contains various challenges. One notable issue commonly encountered is the downcycling of recycled plastic products, resulting in a lower quality compared to virgin plastic.

Another significant concern, often overlooked, pertains to the chemical aspect of the recycling process. The use of recycled plastic without any regulations is emerging as a major cause of concern across multiple sectors. This is due to the presence of often toxic chemicals in these plastics, which remain through the recycling process and are evident in the finished products.

Our field study clearly showed that plastic recycling is extensively carried out in the informal sectors. Though the present study was carried out in Delhi, our previous work on this issue has indicated that such informal plastic recycling exists in most cities across the country. As indicated in the earlier sections, recycling units visited during the study were not following any established safety norms or standards related to the recycling process. In moulding units, where recycled pellets are used for manufacturing new products, quality and safety checks are not being conducted on the possible chemicals in the recycled pellets nor their suitability for manufacturing. When these units recycle plastic material into pellets, there are no processes to remove any chemical additives, so these chemicals end up in these pellets. These are then used to make a range of new consumer products, such as toys, food containers or kitchen utensils. This raises serious concern as these products thus contain huge exposure risks. Food contact materials, toys or other products made of these recycled pellets have the possibility of exposing the users to many toxic chemicals, especially when these products have a high likelihood of coming into contact with the mouth. Most of these recycled plastic products are cheaper than branded products of similar nature, and hence are likely to be bought and used by lower income groups or marginalized populations. These populations are more susceptible to health impacts, as their nutrition levels might be lower and access to good healthcare might be limited.

The present study demonstrates that there is significant chemical contamination in the recycled plastic products. Out of 15 samples examined, over 60% were found to contain the tested chemicals. Majority of these products were picked up from various markets, indicating their widespread availability. Most of the chemicals detected were higher than the permissible limits (either by Indian or global standards, as India does not have standards for any aforementioned chemicals). These chemicals have associated human health impacts, including disruption to endocrine, immune, and reproductive systems. Despite the complete bans on certain chemicals such as SCCPs and BPA, their presence in FCM poses a high risk of contamination for both children and adults, raising questions about the effectiveness of these bans. The presence of chemicals in toys, particularly, was very worrisome as this would mean exposure to children in their developing years, and many of the chemicals detected are known to cause development impacts. Although presence of these toxic chemicals in FCM was lower than toys, detection of even minute traces of these substances in contact with food is alarming and means risk to a much higher population.

Most countries, especially developing countries like India, are pushing for plastics recycling as the best option for dealing with large amounts of plastic waste generated. These countries are pushing this as the main measure within the Global Plastic Treaty discussion as well. The current study findings indicate that the policy makers should be concerned about the toxic nature of plastics, especially in recycled pellets. Chemical additives and contaminants are not labelled or monitored, and with large amounts of plastic recycling occurring in the informal sector, this is a big concern. Though the study only tested 15 chemicals and heavy metals in these common products, there could also be other harmful chemicals present.

The presence of toxic chemicals also points out the fact that uncontrolled use of toxic chemical additives in plastic products renders plastic recycling as an unviable option in some cases, especially for making new products with direct human contact, like toys or FCMs. These new products can be a cause of exposure to humans and the environment.

The study findings also clearly spell out the need for a reevaluation of 'recycling' within CE in plastic. The current recycling systems are certainly not safe and need to be monitored. Absence of labels in these low quality, recycled products also are a reason for concern.

Recommendations

Based on the current study findings, the following could be recommended to prevent or reduce chemical exposure from plastic recycling:

1. **Quality Control:** Quality control measures are essential in the recycling process to minimize the presence of contaminants and ensure that the recycled plastic meets specific standards.
2. **Regulatory Compliance:** Government and regulatory bodies should set more guidelines and standards for recycled plastic to ensure its safety and sustainability for various applications. Compliance with these regulations helps in mitigating health and environmental risks associated with recycled plastic. The same chemical safety standards should be applied to materials made with recycled plastics and to those made from virgin plastics.
3. **Manufacturing:** The manufacturers should be encouraged, through policy and other measures, to redesign products to allow for a toxics-free circular economy, including the phase-out of toxic chemical additives.
4. **Application-specific considerations:** The suitability of recycled plastic for specific applications depends on the level of purity and the presence of certain chemicals. For example, food grade recycled plastic requires proper testing and evaluation to be deemed safe.
5. **Transparency and Traceability-** There is a need for plastic producers and plastic product manufacturers to list plastic ingredients, including additives, on labels. Chemical contents of plastics also need to be traceable throughout their entire lifecycle.
6. **Awareness campaigns:** Initiating awareness campaigns is essential to enhance public consciousness about the health impacts associated with recycled plastics.
7. **In-Depth Research and studies:** The promotion of research and studies is crucial to heighten awareness and transparency concerning the chemicals present in recycled plastic.

In conclusion, the chemicals present in recycled plastic are a complex mix of the original plastic materials, contaminants and potential by-products of the recycling process. Advances in recycling technologies and transparency as well as awareness of the importance of recycling quality control may contribute to improving the overall quality of recycled plastic. Pathways associated during chemical transfer over the course of the recycling process underscore the intricate challenge associated with the recycling of plastic. This emphasizes the need for careful consideration and implementation of mitigation strategies to address the potential hazards arising from the presence and generation of toxic chemicals in recycled plastic products.

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