World Journal of Advanced Research and Reviews

eISSN: 2581-9615 CODEN (USA): WJARAI

Cross Ref DOI: 10.30574/wjarr

Journal homepage: https://wjarr.com/

(REVIEW ARTICLE)

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Microplastic pollution in India-Evidence of major health concern

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World Journal of Advanced Research and Reviews, 2025, 26(01), 1420-1436

Publication history: Received on 25 February 2025; revised on 02 April 2025; accepted on 5 April 2025

Article DOI: https://doi.org/10.30574/wjarr.2025.26.1.1134

Abstract

According to the new study published in Nature, India has secured the top spot as biggest plastic polluter in the world, releasing 9.3 million tonnes (Mt) annually. Plastic pollution remains a global challenge and this alarming trend of rising plastic waste in India has severe consequences for the environment, wildlife, and human health. The Indian government has launched initiatives like the **Swachh Bharat Abhiyan** to improve waste management, but more needs to be done to address the plight of waste pickers. Microplastics in water sources and food chains pose significant risks to human health, affecting the respiratory and reproductive systems and contributing to conditions like cancer. Studies link plastic pollution to an increased risk of cancer, male and female sterility, cardiovascular diseases, diabetes, and obesity. Microplastic has been found in food and beverages. Microplastic are also found in disposable plastic cups for drinking and single-use food containers for home delivery of tea, coffee, and hot beverages. Hence it is recommended that avoid drinking tea, coffee and hot beverages in the plastic cups. Since microplastics do not degrade, those particles which enter the human body through ingestion, inhalation or touch, but are not excreted, can be expected to accumulate in tissues of the human body. Tissue accumulation of microplastics has been demonstrated in marine organisms and mammals. Additives to plastic of major health concern include toxic metals, such as lead, cadmium, arsenic and chromium, bisphenol A (BPA). phthalates, brominated flame retardants (BFR) and endocrine- disrupting chemicals (EDCs). The three main methods for detecting and quantifying microplastic concentrations in water are FTIR Spectroscopy, py-GC/MS, and Raman Spectroscopy.

Keywords: Bisphenol A (BPA); Cancer; Microplastic; Phthalates; Plastic pollution; India; Endocrine- disrupting chemicals (EDCs)

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1. Introduction

Plastic pollution is a global challenge requiring immediate action owing to its environmental persistence and negative impact on ecosystems, infrastructure, society and the economy [1-53, 168]. Plastic pollution remains a major problem, necessitating collective efforts at both national and international levels to mitigate its far-reaching consequences [1-53]. India being highest population of 1.5 billion in world leads the world in generating plastic waste, producing 10.2 million tones a year, far more than double the next big-polluting nations, according to a new study [5, 6]. India has secured the top spot as biggest plastic polluter in the world, releasing 9.3 million tonnes (Mt) annually, according to a new study [1-5, 6]. This amounts to roughly one-fifth of global plastic emissions [5, 6]. Overall, this study published in Nature estimated that 56.8 Mt $year^{-1}$ [40–77, 168] of municipal solid waste is open burned in India, of which 5.8 Mt $year^{-1}$ [4.1–7.9] is plastic [1-5, 6].

India has emerged as the largest plastic polluter globally, generating a staggering 9.3 million tones of plastic waste annually, contributing a fifth of global plastic waste [1-53]. A recent study by the University of Leeds, published in the journal *Nature*, reveals that the country's waste generation rate is approximately 120 grams per capita per day [1-5, 6]. However, these figures are considered undervalued as they do not account for waste generated in rural areas, such as open burning of uncollected waste and recycling by the informal sector [1-5, 6]. The last edition of the same study ranked China as the highest polluter globally, but it has now dropped to the fourth spot due to its waste management progress and controlled landfills [1-5,6]. With India topping the list, Nigeria and Indonesia take second and third places, respectively [1-53].

On the basis of literature survey [1-54], India as a whole, the annual per capita consumption of plastics stands at approximately 11 kg [1-54]. India plays a significant role in the generation of plastic waste, contributing approximately 26 million metric tons annually [1-53]. India is at the forefront of the global community involved in plastic waste generation [1-54]. The sources of this plastic production are multifaceted [1-53]. Firstly, during industrial production, plastics are generated, and there is also a risk of accidental spillages that can release plastics into the environment [1-54]. Secondly, during the use phase of products, microplastics are intentionally incorporated into items such as cosmetics, and these microplastics are subsequently discharged into sewage systems or directly into the environment [1-53]. Thirdly, synthetic products undergo wear and tear during their continued use, resulting in the release of microfibers, such as those from textiles during washing, tire wear particles from road transport, and the chipping of paint from buildings [1-53]. For instance, it is estimated that around 22 million tones of microfibers from synthetic textiles will enter the environment by 2050 due to this phenomenon [1-54].

This alarming trend of rising plastic waste has severe consequences for the environment, wildlife, and human health [1-54,168]. The Indian government has launched initiatives like the **Swachh Bharat Abhiyan** to improve waste management, but more needs to be done to address the plight of waste pickers [1-54]. Providing them with proper equipment, training, and social protection can help to reduce the health risks associated with plastic waste [1-54]. The Indian government has taken steps to address the plastic pollution crisis. The Plastic Waste Management Rules, 2016, and the Solid Waste Management Rules, 2016, aimed to regulate plastic waste generation and disposal [1-54]. However, implementation and enforcement remain significant challenges. Governments, corporations, and individuals must work together to promote reusable bags, reject single-use plastics, and encourage recycling to create a plastic-free future [1-54]. The Indian government's 2022 ban on single-use plastic items and its door-to-door segregated waste collection initiative have been steps in the right direction, but when these initiatives will be fully optimized remains uncertain [1-54]. Awareness campaigns like cleanup drives and waste segregation initiatives can help to build a community that understands the importance of reducing plastic waste [1-54]. "Social media can play a pivotal role in making this information accessible [1-54, 168].

Single-use plastics, such as plastic bags, straws, and water bottles, are major contributors to India's growing problem [1-54]. These items are used for mere minutes but take hundreds of years to decompose [1-54]. Additionally, the lack of waste management infrastructure and the indiscriminate dumping of plastic waste exacerbate the situation, with plastic bags alone accounting for 15% of global waste, as the world consumes nearly 5 trillion bags annually [1-54, 168].

The plastics industry in India is rapidly expanding, with Western India emerging as the largest consumer, accounting for 47% of the total consumption [1-54]. This substantial usage is primarily concentrated in states such as Karnataka, Gujarat, Maharashtra, Madhya Pradesh, Daman and Diu, Chhattisgarh, and Dadra and Nagar Haveli [1-54]. Various pathways such as ingestion, inhalation and dermal contact were identified as a major route through which microplastics can be encountered [1-120]. Notably, ingesting microplastics has been associated with gastrointestinal issues, endocrine disruption, and the potential transfer of harmful bacteria [1-130]. Inhalation of airborne microplastics is particularly concerning, as it may impact respiratory and cardiovascular health [1-100]. While dermal contact though less frequently studied, it raises concerns about possible skin irritation and allergic reactions [1-100]. Although research concerning the influence of microplastics on marine life and ecosystems remains ongoing, their deleterious effects on marine environments are well-established [1-120].

In India, waste pickers, or rag pickers, are the primary collectors of all types of waste. The International Alliance of Waste Pickers estimates there are approximately 1.5 million waste pickers in India, with the majority coming from marginalized communities [1-54]. Most are women and children, many of whom belong to lower castes or tribes. Among waste pickers, 70-75% are women, and 50% are children under age of 18 [1-54]. They are exposed to toxic chemicals such as lead, mercury, and cadmium, which can cause respiratory problems, cancer, and other health issues [1-54]. Inhaling plastic dust and particles can lead to respiratory conditions like asthma and bronchitis, and the rag pickers are also vulnerable to skin infections, cuts, and bleeding. [1-53]. Female waste pickers face social exclusion and ridicule due to their occupation while suffering daily injuries from sharp plastic edges [1-54]. These vulnerable groups often lack access to healthcare, sanitation, and social security, despite being disproportionately affected by the health hazards of plastic waste [1-54].

Plastic is valued for its flexibility to be utilized in different applications, yet it poses a significant threat to our environment because of mismanaged plastic waste [1-54]. India's compound annual growth of plastic consumption has been around 7% for a decade. Despite this significant growth, there has not been a comprehensive study of Indian plastic follows since 2000 [1-54]. The analysis reveals a total plastic production of 19.3 Mt, 22% of which is Polyethylene as the most wildly used plastic [1-54]. The total mass of plastic in products distributed in various applications is 23.9 Mt. Key sectors for plastic consumption are packaging (30%), textiles (17%), and buildings and construction (16%) [1-54]. Plastic waste generation is 15.5 Mt, primarily from packaging and textiles. Only 13% of this plastic gets recycled, 46% is mismanaged, and the rest incinerated or dumped [1-54]. The study's unique nationwide, mass-balanced, transparent approach offers a rigorous reference point for decision-makers [1-120]. Yet, the lack of reliable data is the main barrier to design, implement, and monitor of policy interventions [1-54].

Plastic pollution has permanently damaging effects on marine life, soil, and human health [1-120]. Plastic waste in oceans harms marine life, contaminates the food chain, and ultimately impacts human consumption. In soil, it reduces soil fertility, in turn affects food production [1-120]. Over 800 species of marine life are harmed by plastic waste, leading to lifelong impairment and even extinction [1-120]. Microplastics in water sources and food chains pose significant risks to human health, affecting the respiratory and reproductive systems and contributing to conditions like cancer [1-120]. Studies link plastic pollution to an increased risk of cardiovascular diseases, diabetes, and obesity [1-120].

Plastics have become one of the most prevalent and enduring pollutants, infiltrating oceans and beaches globally through various channels, including river transport, atmospheric dispersion, beach littering, and direct introduction at sea via aquaculture, shipping [1-120]. The principal contributors to plastic pollution stem from both sea-based and land-based sources [1-120, 168]. Sea-based sources encompass shipping, fishing, and transportation activities, while land-based sources involve tourism, industrial discharges, and riverine inputs into coastal and oceanic regions [1-120]. In general, minute plastic particles, either intentionally manufactured to be microscopic (known as primary microplastics) or resulting from the breakdown (through physical, chemical, and biological degradation) of larger plastic items, find their way into marine environments [1-120, 168].

India has shown increasing interest in bio-plastics due to growing environmental concerns and a focus on sustainability [1-54, 87,152-153-167]. The Indian government has been taking steps to promote sustainable practices, and initiatives supporting bio-based products, including bio-plastics, have gained attention [1-53, 152-166]. Incentives, subsidies, and regulations promoting environmentally friendly alternatives that influence the Indian Bio Plastics market. India has a significant agricultural sector, providing a potential source for bio-based feed stocks used in the production of bioplastics [1-54, 87, 152-153-167]. Growing environmental concerns and increased awareness of the impact of traditional plastics on ecosystems have driven interest in bio-plastics as more sustainable alternatives [1-54, 87, 152-153-167]. Consumers and businesses are seeking eco-friendly solutions, contributing to the demand for bio-degradable and bio-based materials [1-54, 87, 152-153]. The Indian government has been implementing policies and initiatives to promote sustainable practices and reduce environmental pollution [1-54, 87,152-153-167]. Crops such as sugarcane, corn, and other biomass materials are utilized in bio plastics manufacture, contributing to the growth of the industry [1-54, 87,152, 153-167]. In the following section, the evidence of exposure to microplastic, then toxicity of chemicals used in the plastic production on human health has been discussed and updated.

2. Microplastics: Detection Methods

Microplastics are any solid plastic or synthetic polymer particle insoluble in water with the largest dimension between 1 µm and 5 mm. Researchers have found microplastics in marine and terrestrial life. It invades the food chain, and it is even been found in salt, sugar, tea bags, beer, alcohol, and honey [1-149]. Primary microplastics are directly released into the environment as small plastic particles. These are intentionally engineered particles, like those found in some consumer and industrial products. Cosmetics have used microplastics as abrasives [1-148]. Secondary microplastics are the result of the degradation of large plastic waste, like plastic bags and bottles, into smaller plastic fragments when exposed to our environment [1-149, 168]. Microplastics are tiny fragments (less than 5 mm in diameter) of plastics that end up in nature from sources like cosmetics, clothing, car tires, and industrial processes [1-149]. There is rising concern about microplastic pollution in lakes, oceans, and drinking water, which in turn increases the demand for laboratory analyses that detect microplastics in water samples [1-149]. Manufacturers engineer primary microplastics because of the unique physical and chemical properties created by its small scale. Those properties include durability, rigidity and abrasiveness [1-149]. Density, size, shape and composition influence its properties. Scientists use microplastics in many areas, including cosmetics, personal care, detergents, paints/coatings/inks, industrial abrasives, agriculture, pharmaceuticals, wastewater treatment and construction [1-149]. But these particles often weather, degrade or abrade from environmental or physical events, ending up in oceans and elsewhere [1-149]. Microplastics are now recognized to be a global contaminant of concern, with the volume of both public attention and academic research on the topic steadily increasing. With a life span of up to 450 years, microplastics materials can persist in the environment for centuries and will eventually degrade into smaller pieces referred to as micro- and nanoparticles, entering the ecosystem and causing harm to marine life [1-149].

Microplastics contribute significantly to the pollution of natural environments, from which they eventually end up in the human body [1-149]. The concrete effects of microplastics on human health are still largely unknown, but preliminary evidence suggests that high concentrations of microplastics in the body can provoke stress and immune responses [1-149]. Testing for microplastics in samples including bottled water, groundwater, and wastewater is an important way to minimize the negative environmental effects of manufacturing and waste disposal processes. As consumers become more environmentally conscious and wary of the possible health effects that microplastics can cause, testing will also become increasingly beneficial from a business perspective [1-149, 168].

The three main methods for detecting and quantifying microplastic concentrations in water are FTIR Spectroscopy, py-GC/MS, and Raman Spectroscopy [1-149, 168]. FTIR and Raman can determine the number of microplastic particles by plastic type and size range, whereas py-GC/MS can quantify concentrations of specific types of microplastics in mg/l [1-149]. These methods can also be used to detect microplastics in sludge and soil samples. Raman spectroscopy plays a key role in identifying the types and origins of microplastics. It is a part of the efforts to develop policies and procedures for controlling the amount of microplastics introduced into ecosystem [1-149, 168].

Micro- and nanoplastics are in our food, water and the air we breathe. They are showing up in our bodies, from testicles to brain matter [150]. Nano and microplastics are byproducts of degrading plastic materials such as lunch boxes, cups and utensils. As very small particles with a large surface area, nanoplastics are particularly concerning to human health due to their increased ability to absorb toxins and penetrate biological barriers within the human body. Detecting these plastics typically requires skilled personnel and expensive equipment [150]. Now, UBC, Vancouver, Canada researchers have developed a low-cost, portable tool to accurately measure plastic released from everyday sources like disposable cups and water bottles [150]. The device, paired with an app, uses fluorescent labeling to detect plastic particles ranging from 50 nanometres to 10 microns in size – too small to be detected by the naked eye – and delivers results in minutes. They created a small, biodegradable, 3D-printed box containing a wireless digital microscope, green LED light and an excitation filter [150]. To measure the plastics, they customized MATLAB software with machine-learning algorithms and combined it with image capture software [150]. The result is a portable tool that works with a smart phone or other mobile device to reveal the number of plastic particles in a sample. The tool only needs a tiny liquid sample – less than a drop of water – and makes the plastic particles glow under the green LED light in the microscope to visualize and measure them [150]. The results are easy to understand, whether by a technician in a food processing lab or just someone curious about their morning cup of coffee [150]. The tool is currently calibrated to measure polystyrene, but the machine-learning algorithm could be tweaked to measure different types of plastics like polyethylene or polypropylene [150]. Next, the researchers aimed to commercialize the device to analyze plastic particles for other real-world applications [150]. To reduce plastic ingestion, it is important to consider avoiding petroleum-based plastic products by opting for alternatives like glass or stainless steel for food containers [149]. The development of biodegradable packaging materials is also important for replacing traditional plastics and moving towards a more sustainable world [150].

In one of the study in India by Mohan et al., (2023) [151] the Nile red staining, a simple and alternative approach to organic solvent stains, successfully identified the presence of microplastics in twenty commercial bottled water samples [150]. The microplastics of different shapes, types, and sizes were identified by FTIR, and polyethylene/polystyrene were the most abundant [151]. This study by Mohan et al., (2023) [151] estimated the presence of microplastics in different brands of bottled water available in India using the Nile red (NR) staining method [150]. The FTIR examination revealed the presence of polystyrene (PS), polyethylene (PE), and polyamide (PA) in the bottled water samples with PE being the most prevalent one [151]. Zebrafish embryos exposed to different concentrations of fluorescent-tagged polyethylene microplastics (PE-MPs) (10–150 μm) showed accumulation patterns at different time points in various organs [151]. The exposure to PE microplastic induced a concentration-dependent ROS activity. The expression of first-line antioxidative defense marker genes were significantly down regulated in embryos exposed to varying concentrations of PE- microplastic, suggesting concentration and time-dependent effects on zebrafish [151]. The results of this study suggest that the potential negative consequences on human health could be due to the oxidative stress and time dependent toxicity of microplastics [151].

Bottled water manufacturers may also be interested in microplastic testing, which can helped to reduce the amount of particles in the final product [1-149, 151, 167]. The same goes for textile manufacturers, as microplastics released from textiles during laundering are another significant source of microplastic pollution. In addition to industry needs, microplastic analysis can be utilized in research projects to study the concentrations of microplastics in lakes, seas, and oceans [1-149-151]. This may interest public officials as well as researchers, as awareness of high microplastic concentrations in specific water areas can help plan efforts to reduce such pollution [1-149, 151,167].

3. Microplastic: Evidence of Exposure

Belmaker et al., (2024) [101] reported that microplastic have wide dispersion in the environment [101]. They have been found in the atmosphere, oceans and rivers, rain and snow, dust and soil, wastewater of sewage treatment plants and in the air surrounding plastic recycling facilities [1-145]. Plastics have become one of the most ubiquitous materials in use world-wide over the past 70 years [1-120]. Rather than decompose, many plastic objects and waste break into smaller and smaller fragments of varying geometrical forms, called microplastic if they are 1 micron to 5 mm in diameter and nanoplastic if they are between 1 to 1000 nm (< 1 micron) [1-120]. Plastic waste can form mats which float in aqueous environments [101, 167]. Belmaker et al., (2024) [101] indicated that the plastic mats tend to accumulate contaminants, including persistent organic pollutants (POPs), heavy metals, algae, fungi and bacteria, including pathogenic bacteria [100]. On the basis of literature survey, the contaminants can potentially affect a variety of species, especially marine ones [100-147], yet literature with empirical data documenting the extent and health consequences of exposure to contaminants of plastic in humans is scarce [1-120]. Data on human exposure to microplastis are an essential part of risk-analysis of possible adverse health effects from exposure to microplastic [1-120]. Microplastic are found in both out-door and indoor air, with higher concentrations in indoor air [1-120]. Up to 60% of plastic particles in indoor air are microfibers, primarily from synthetic fabrics in clothing, textiles and padded furniture [101].

Microplastic has been found in food and beverages [101, 168]. A thorough review in 2023 and 2024 presents several factors which contribute to the contamination of food with microplastic [1-140, 168]. Industrial processing of food; Contact of food with plastic packaging or storage bins [101]; Atmospheric microplastic; Contact of agricultural crops with soil, fertilizer, and/or irrigation water contaminated with microplastic; Contamination of the environment of marine and fresh-water fish and shellfish with water contaminated with microplastic; Contact with contents of the GI tracts of animals [1-140]. Beverages are another source of exposure to microplastic [1-140]. In a study of 11 global brands of drinking water bottled in plastic containers. 93% contained microplastic, with an average of 325 microplastic particles/liter. 95% of the microplastic were 6.5–100 microns in size [1-141]. The concentration of microplastic in the bottled water was double that in tap water, indicating that microplastic contamination can be produced by the process of bottling, or the release of microplastic upon opening the plastic cap on the bottled water [1-141]. Another source of microplastic in beverages are tea bags, which when steeped in hot water, release 2.3×10^6 microplastic and 14.7×10^9 nanoplastic per cup of tea [148]. The literature survey by Belmaker et al., (2024) [101] reported that another biggest problem of microplastics, heating the water used to make infant formula in the polypropylene bottle, heating the water in an electric kettle with a polypropylene lining, sterilization, and repeated use of the same bottle, all increased the release of polypropylene microplastics into the infant formula [1-147]. The literature work by Belmaker et al., (2024) [101] reported that microplastic are also found in disposable plastic cups for drinking and single-use food containers for home delivery of food, tea, coffee, and hot beverages [1-148]. Therefore, paper cups are often considered to be a safe alternative to plastic cups when drinking hot beverages [1-148]. Hence it is recommended that avoid drinking tea, coffee and hot beverages in the plastic cups. However, paper cups have an interior lining, usually made of polyethylene plastic, which degrades into microplastic when exposed to water over 85 °C [1-148].

On the basis of literature survey by Belmaker et al., (2024) [101], dermal exposure to microplastics can occur through use of personal care products (PCP) such as cosmetics, soap, skin conditioners, toothpaste, lip balms, exfoliants, glitter, and artificial plastic eye lashes particularly those which include plastic microbeads as exfoliants [1-147]. Glitter is manufactured from microplastics and its use in cosmetics causes direct dermal exposure to microplastics [1-147]. Exposure of fetuses in utero and newborn infants to microplastics is documented by the findings of microplastics on the fetal side of the human placenta [1-147]. Belmaker et al., (2024) [101] also mentioned that children ingest and inhale more liquids, food, and air than adults per body weight (BW) and are thereby exposed to a higher dose level of microplastics / kilogram BW [1-147]. Older children can be exposed to microplastics at playgrounds, as well as in their homes, daycare, and schools. Infants and children are not only directly exposed to microplastics, but also to toxic additives that can leach from the microplastics into body tissues [101]. On the basis of literature survey by Belmaker et al., (2024) [101], microplastics do not degrade, those particles which enter the human body through ingestion, inhalation or touch, but are not excreted, can be expected to accumulate in tissues of the human body [101]. Tissue accumulation of microplastics has been demonstrated in marine organisms and mammals [101]. The literature survey by Belmaker et al., (2024) [101] confirmed that during their lifespan, infants and children will be expected to accumulate a larger body burden of microplastics than adults, given their longer expected years of exposure and the current exponential rate of increase in production of plastic [101]. However, microplastics have not yet been found in the human brain [101].

4. Microplastic: Major Health Problems

On the basis of literature survey by Belmaker et al., (2024) [101], the adverse health effects of human exposure to microplastics from inhalation, ingestion or touch are influenced by the size, shape and chemical composition of the plastic, additives, and chemical, bacterial and heavy metal contaminants that adsorb onto the microplastics [101]. Microplastics, with their large surface area-to-volume ratio, cause toxicity by mechanical damage to cell membranes, DNA, and the cellular mechanisms that replicate and repair DNA [101-149, 167]. On the basis of literature survey by Belmaker et al., (2024) [101], the accumulation of intracellular microplastic can cause oxidative stress, chronic inflammation, with activation of the cytokine system and negative effects on the immunological systems of the body [1-101-147]. Intracellular exposure to microplastic can induce creation of reactive oxygen species and activation of inflammatory cells, leading to DNA damage, genotoxicity and abnormal gene expression, which is turn can contribute to carcinogenesis [101-149, 167]. There are studies documenting increased risk of respiratory disease and lung cancer among workers exposed occupationally to plastic dust [1-148]. Belmaker et al., (2024) [101] also reported that respiratory exposure to both microplastics < 10 microns (PM10) and PM < 2.5 microns (PM2.5) is associated with increased risk of asthma, chronic obstructive pulmonary disease (COPD), cardiovascular disease (CVD), and lung cancer, with causal associations between both short-term and long-term exposure and over-all mortality [54-100-149]. Those with microplastic in their carotid artery plaques had elevated levels of biomarkers of inflammation: interleukin- 18, interleukin- 1β, interleukin-6 and tumor necrosis factor alpha (TNF-α) [54-100-148]. The recent findings of microplastic in human reproductive organs (the maternal and fetal sides of placentas, testes and semen), as well as in breast milk, are a cause for concern [101-149].

5. Microplastic-Toxic chemicals

Additives to plastic of major health concern include toxic metals, such as lead, cadmium, arsenic and chromium, brominated flame retardants (BFR) and endocrine- disrupting chemicals (EDCs) [54-147, 168]. Although there are many other additives to plastic which may have adverse health effects, endocrine- disrupting chemicals affect not only the reproductive system, but also other aspects of our endocrine, metabolic and neuro-developmental systems and some are carcinogenic [54-100-147, 168]. Some of the chemical additives used in the manufacture of plastic are, (1)

- **Bisphenols:** Bisphenols are used in the manufacture of single-use and multiple-use polycarbonate bottles for beverages, containers for the storage of food, kitchen utensils, toys, dental sealants and even water pipes [1-22, 101-149, 168]. They are used in the manufacture of epoxy resins which are used to line food and beverage cans [1-22, 54-100-147]. They can leach from food and drink containers into the food that we eat and the beverages we drink [54- 101-149]. The vast majority of the population of the world is exposed to bisphenol A (BPA). The half-life of BPA in the human body is short (approximately 6 h) [54-101-149, 168]. In a study by the US Center for Disease Control (CDC), over 92% of Americans were found to have detectable levels of BPA in their urine, reflecting ubiquitous exposure to BPA [54-101-149, 168]. Measurable levels of BPA have been found in maternal and fetal blood and placenta and in the milk of nursing mothers [54-100-149]. **Phthalates** are plasticizers, *i.e.* they make plastic easy to mold into various shapes [54-101-149, 168]. They do not chemically bind to the plastic to which they are added, allowing them to migrate from a plastic item and leading to exposure via ingestion, inhalation and skin exposure [54-101-149, 168]. Exposure to phthalates is ubiquitous since they are found in a wide variety of products, including children's toys, packaging for food and drinks, roofing, flooring, shower curtains and the plastic parts of cars [54-101-149, 168]. The source of phthalates in meat and dairy products can be from exposure to phthalates in animals from which meat and dairy products are made, thereby allowing phthalates to enter the human food chain through the food itself, as well as through phthalates in the plastic packaging in which meat, fish and dairy products are marketed [54-101-149, 168]. The phthalate DEHP is widely used in medical care products since DEHP is an integral part of the PVC which is used for the manufacture of intravenous bags, tubing, dialysis equipment, and surgical gloves [54-100-149]. Phthalates have a short half-life in the human body since they are rapidly metabolized and excreted in the urine [54-101-149]. Surveys in the US have found that virtually everyone is exposed to phthalates on a daily basis [54-101-149, 168]. DEHP and its metabolites are present in 90–100% of samples of second- trimester amniotic fluid and are also found in cord blood of newborns, breast milk and ovarian follicular fluid [54-101-149]. Phthalates affect estrogen and testosterone levels and function, and block thyroid action [54-101-149, 168]. Therefore, considered to be reproductive toxicants and classified by the EU as SVHC [54-100-149]. Prenatal exposure to phthalates is associated with preterm birth, low birth weight, childhood obesity, and impaired glucose tolerance in the mother (gestational diabetes) [54-100-147]. On the basis of literature survey by Belmaker et al., (2024) [101], in adult men, chronic exposure to phthalates (especially benzyl and butyl phthalates) is associated with decreased testosterone levels, decreased sperm counts and sperm quality, resulting in a decrease in male fertility [54-101-149, 168]. In adults, both male and female, exposure to phthalates is associated with obesity, diabetes, and other risk factors for CVD, including elevated blood pressure, insulin resistance and elevated levels of triglycerides [54-101-149, 168].

- **PFAS**, Per-and Polyfluoroalkyl Substances, are persistent organic pollutants (POPs), chemicals that can bio-accumulate [54-101-149, 168]. They are known as "Forever Chemicals" due to their high resistance to chemical, physical, or biological degradation [54-101-149, 168]. PFAS chemicals include PFOA, PFOS, and many other fluorinated compounds. They are not found in nature, cannot be degraded by any natural organism [54-101-149,168]. They cannot be metabolized in human tissues [54-101-147]. Due to widespread environmental contamination, PFAS can be found in meat, seafood, dairy products, vegetables, fruit and water sources [54-101-149]. PFAS have grease- and water-resistant properties and are therefore found in many consumer products as additives to plastics such as polyester, nylon and vinyl fabrics, which are widely used for the manufacture of clothes, rugs, cushions, drapes and textile-covered furniture [54-101-149]. Disintegration of these plastics allows for the creation of microfibers containing PFAS, which can be a source of human exposure to PFAS via inhalation or oral contact [54-101-149,168]. On the basis of literature survey by Belmaker et al., (2024) [101], PFAS can often be found in coatings of non-stick cookware, wrappers for take-away food, as well as many other consumer items [54-101-149]. Four PFAS chemicals (PFOA, PFOS, PFNA, PFHxS) are almost universally detectable in the blood of pregnant women, neonates and children around the world, as well as in human breast milk [54-101-149, 168]. These chemicals can also cross the placental barrier and enter the fetus [54-101-149]. Prenatal exposure to PFAS is associated with low birth weight and childhood obesity [54-100-149,168]. Belmaker et al., (2024) [101] reported that exposure during pregnancy is also associated with impaired glucose tolerance, insulin resistance and gestational diabetes in the mother [54-101-149,168]. Exposure of adults, both male and female, to PFAS is associated with obesity [54-100-149]. In adult males, PFAS exposure is associated with lower semen quality and semen counts [106]. Some of the PFAS chemicals are carcinogenic [101]. PFOS was classified in 2023 as a possible human carcinogen [101]. Increasing blood levels of PFOS, taken before the onset of illness, are associated with increased risk of testicular cancer [54-101-147]. In women, elevated levels are associated with increased risk of hormone-receptor positive breast cancer [54-101-147, 168].
- **Bisphenol A** (BPA), F (BPF) and S (BPS) are those bisphenols for which there is the most evidence of adverse health effects [54-100-149, 168]. On the basis of literature survey by Belmaker et al., (2024) [101], there is growing evidence that BPA, BPF, and BPS, along with other bisphenols, can bind to estrogen, progesterone and androgen receptors and, in addition, disrupt thyroid hormone function, even at low concentrations, thereby disrupting reproduction, metabolism and neurodevelopment [54-100-149,168]. Exposure to BPA is associated with altered cell division and quality of oocytes and increased incidence of polycystic ovary syndrome in women [54-101-149,168]. In men, exposure to BPA and BPS is associated with decreased sperm count, concentration, quality and motility [54-100-149, 168]. In both sexes, steroidogenesis is adversely affected by exposure to BPA [54-101-149,168]. In adults, exposure to BPA and BPS is associated with increased risk of diabetes [54-100-147,168]. In children, prenatal exposure to BPA is associated with increased levels of body fat, ADHD and behavior problems [101]. Exposure to BPA and its analogs (BPF, BPS, BPAF, TBBPA) negatively affect reproductive health of women [101]. BPA exposure is associated with lower female fertility [54-100-147, 168].

- **Endocrine- disrupting chemicals (EDCs)**: There is a vast and rapidly growing body of literature on adverse health effects of endocrine- disrupting chemicals (EDCs) [54-101-149, 168]. They are chemicals called xenohormones whose structure is similar to that of naturally occurring human endocrine hormones (*e.g.* estrogen and testosterone) [54-100-149,168]. They can therefore, cause endocrine-like effects in people exposed to them [54-100-147]. The sources of endocrine disruptors are many and varied, including additives to plastics [54-100-149, 167,168]. Edocrine- disrupting chemicals (EDCs) have biological effects throughout the life cycle, from the fetus, throughout infancy and childhood, adolescence, adulthood and aging [54-101-147, 168]. However, the most vulnerable period to exposure to endocrine- disrupting chemicals (EDCs) is the fetal period, indicating the importance of reducing maternal exposure to endocrine- disrupting chemicals (EDCs) [54-100-149]. Exposure to endocrine- disrupting chemicals (EDCs) early in life is associated with childhood obesity and disorders of neurodevelopment [54-101-147,168]. The Endocrine Society's Authoritative Guide emphasizes that adverse health effects of exposure to Edocrine- disrupting chemicals (EDCs) can occur at very low doses [54-100-149]. Therefore there is likely no "safe" dose of exposure to edocrine- disrupting chemicals (EDCs) [54-100-149, 168]. The Guide also emphasizes that there can be a long latency between exposure to Edocrine- disrupting chemicals (EDCs) and adverse health effects, indicating the difficulty of identifying all the late effects of exposure [54-100-149, 168]. The Endocrine Society and The Lancet both published comprehensive reviews of literature on adverse health effects of many endocrine- disrupting chemicals (EDCs), including bisphenols, phthalates and PFAS, all of which are known additives to plastic [54-100-147, 168]. Vegetables and fruits are generally thought by the public to be free from endocrine- disrupting chemicals (EDCs) [54-100-147, 168]. However, ready-to-eat vegetables, when packaged in plastic wrap, have been found to be a source of exposure to phthalates [54-100-147,168]. In addition, canned fruits and vegetables can be a source of exposure to endocrine- disrupting chemicals (EDCs) due to food contact with the lining of the cans [54-100-149]. Fast foods, as well as restaurant food, can be a source of exposure to EDCs [54-100-147, 168]. They can migrate into ingredients of food during their manufacture, storage or shipping in plastic containers, or during their preparation in the restaurant [54-100-147, 167]. On the basis of literature survey by Belmaker et al., (2024) [101], endocrine- disrupting chemicals (EDCs) can also be found in food packaging used for takeaway food, such as plastic food containers and wrappers [54-101-147]. Increased migration of phthalates and bisphenols from plastic into food and beverages is associated with heating, duration of heating, and prolonged use of plastic containers, as well as use of plastic items that are not certified as food-safe [54-100-147, 168]. Belmaker et al., (2024) [101] also indicated that migration of PFAS into food is promoted by high fat content of the food, low pH (i.e. acidic food), high salt concentration and emulsified food [54-101-147, 168].

6. Biodegradalbe plastic

The environmental problems caused by discarded synthetic plastics have paved the way for the search for substitutes, that is biodegradable plastic [87, 152-153-167]. Bioplastics, in general, are derived from renewable resources, such as plants, and are considered more environmentally friendly than traditional petroleum-based plastics [152-153-166]. Renewable biomass, or plants, is used to make biobased polymers. Sugarcane, cassava, and corn are some of the most popular plants utilized to produce bioplastics [87, 152-153-167]. Embracing bioplastics in the food packaging industry offers several advantages [87, 152-153-167]. Firstly, the manufacturing process of bioplastics emits fewer greenhouse gases compared to their conventional counterparts, which is a considerable step towards mitigating climate change [87,152-153-167]. The base materials for bioplastics, such as corn, food waste, and other plant-based raw materials, are renewable, offering both sustainability and the possibility of a more circular economy. Some bioplastics are also biodegradable under certain conditions, potentially reducing the volume of waste destined for landfills [87, 152-153]. Biodegradable plastics decompose in environments such as soil or water, or in compost. In other words, creating an environment conducive to microbial activity is crucial for plastics to decompose effectively [87, 152-153-167]. Biodegradable plastic bags are made from all-natural plant-based raw materials that enable the natural decomposition process which is achieved when the bacteria and fungi present in the surrounding environment naturally metabolizes the plastics and helps to further breakdown the structure of a biodegradable plastic [87, 152-153-167]. The end result of which is less harmful to the environment as compared to regular plastic bags [87, 152-153-167].

7. Conclusion

New research published in the journal Nature has said that India is responsible for around one-fifth of global plastic emissions of around 9.3 million metric tonnes (Mt) per year. This alarming trend of rising plastic waste has severe consequences for the environment, wildlife, and human health. The Indian government has launched initiatives like the **Swachh Bharat Abhiyan** to improve waste management, but more needs to be done to address the plight of waste pickers. Additionally, the lack of waste management infrastructure and the indiscriminate dumping of plastic waste exacerbate the situation, with plastic bags alone accounting for 15% of global waste, as the world consumes nearly 5 trillion bags annually. The concrete effects of microplastics on human health are still largely unknown, but preliminary evidence suggests that high concentrations of microplastics in the body can provoke stress and immune responses.

Microplastic spread throughout our environment, contaminating the atmosphere, water, and land of the earth, allowing microplastic to work its way up through the food chain, disrupting global ecology. Microplastic has been found in food and beverages. Humans can be exposed to microplastic via inhalation, ingestion and touch, while fetuses can be exposed via maternal exposure and infants can be exposed through breast milk. The growing number of studies documenting the presence of microplastic in various organs of the human body are a cause for concern, since they are indestructible by any biological process. Therefore, once present in human tissue, they are likely to persist. The recent findings of microplastic on the fetal side of the human placenta, meconium of new-born infants, breast milk, the circulatory and digestive systems, lungs, liver, spleen, kidneys, testes, and sperm are particularly worrisome. Over their lifespan, infants and children will accumulate a much larger body burden of microplastic than adults who were born decades ago, given the current exponential rate of increase in production of plastic and their longer potential years of exposure. The toxic of exposure to endocrine- disrupting chemicals (EDCs) have been widely researched, in epidemiological studies and animal models. Those studies in which exposure is measured before the adverse outcome (such as those studying the association between levels of endocrine- disrupting chemicals (EDCs) in pregnant mothers and various measures of health, growth and development of her infant) strengthen the evidence of a causal relationship between exposure to endocrine- disrupting chemicals (EDCs) and adverse health effects.

As the consequential environmental impact of traditional plastics becomes increasingly apparent, the introduction of bioplastics has ignited a ray of change. Consumers and businesses are seeking eco-friendly solutions, contributing to the demand for bio-degradable and bio-based materials. The Indian bio plastics market is still in its early stages, with only a handful of companies (EcoBharat, Adsum Eco Solution Pvt. Ltd, J&K Agro Industries Ltd, Envigreen, Ecolastic, Plastobags, Earthsoul India Truegreen, Environmental XPRT, Corbion India PL, Envigreen Biotech India Private Ltd, TORAY INDUSTRIES, INC. Biogreen, **Green Tech Bio Products**) currently operating in this segment. The Indian government has been implementing policies and initiatives to promote sustainable practices and reduce environmental pollution. Moreover, the rising demand for biodegradable plastics for medical and personal care packaging applications is anticipated to fuel the market in the country. Crops such as sugarcane, corn, and other biomass materials are utilized in Bio Plastics manufacture, contributing to the growth of the industry.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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