14 Chemical Leaching into Food and the Environment Poses Health Hazards

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14.1 Introduction

The quest for urbanisation and economic advancement globally has resulted in a more significant proportion of people living in townships; hence, more plastic substances are littered indiscriminately into the environment daily, leading to plastic pollution (Mngomezulu et al. 2020). More than 8 billion tonnes of plastic have been manufactured by humanity since 1950; more than half of this plastic ended up in landfills, and only approximately 9% was recycled (World Population Review 2022). Nigeria is the highest producer of plastic waste in Africa (about 18,640 tonnes) and is ranked tenth globally (World Population Review 2022). A section of plastic dump in a landfill located in Aba, Abia State, Nigeria (Fig. 14.1), indicates that landfills and aerial deposition are a major nexus for plastic leachates dispersal into the ecosystem. Plastic may harm the ecosystem by releasing poisonous compounds into the soil and groundwater that suffocates or kill animals who unintentionally swallow it. Finding waste management strategies and technologies that are environmentally friendly, economical, and socially feasible has been a continual desire for both leaders and technocrats as the manufacturing of plastic garbage has become unavoidable (Cohen 2018). The majority of our food, drink, packages, toys, clothing, sporting goods, and electrical components are manufactured or packaged using plastic components, which poses a serious health risk if inhaled or consumed. Plastic leaching and build-up of component monomers, endogenous additives, and absorbed ambient contaminants are all potential causes of chemical toxicity. The majority of tools used at home and work are made of plastic. Organic monomers are used to create plastics partly or entirely, making them strong, lightweight, and durable to create plastics (Mohanty et al. 2022). Cellulose, coal, natural gas, salt, and crude oil are some natural materials that may be processed by a polymerisation or polycondensation process and can be moulded or shaped in various ways according to their intended use (Jem and Tan 2020). Numerous varieties of plastic are produced using a range of chemicals. For instance, only a container made of plastic might contain more than 4000 distinct compounds. Chronic leachate exposure is considered very hazardous due to the potential accumulation and health impart over time (Wright and Kelly 2017). Their migration in the soil is also affected by physical processes such as volatilisation, adsorption, and dissolution in soil pore

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Fig. 14.1 A cross section of a plastic-polluted area in Aba, Abia State, Nigeria

water, and these alongside the time of human intervention determine the extent of impact in the soil (Ahmed et al. 2022). Most places, however, lack proper waste management, and the plastic pollution risk is anticipated to be exposure levels dependent, although there is a dearth of cogent evidence about the exposure levels (Chang et al. 2022). The local population is at severe health risks such as hormone-related cancers, infertility, and neurodevelopment disorders like ADHD and autism. Research has also confirmed that plastic wastes are carriers of pathogenic bacteria and viruses, further hampering the spread of diseases (Niyobuhungiro and Schenck 2021; Meng et al. 2021). The classification of plastics, sources, mode of exposure, effects of additives, the health implications of plastic leachates to aquatic and soil organisms and humans, remedies to the effect of plastic leachate pollution, and alternatives to plastic are emphasised in this chapter.

14.2 Plastics Are Classified According to Physical and Chemical Properties

14.2.1 Polyethylene Terephthalate (PET or PETE)

One of the most commonly used plastics is PET. It is robust, translucent, lightweight, and frequently used in textiles and food packaging (polyester). Examples include beverage and food bottles (for salad dressing, peanut butter, honey, and others) and polyester clothes. The properties include a moisture barrier, toughness, transparency, solvent resistance, and gas softening at 80 °C. It results in cancer, nausea, and diarrhoea (Mikhailovich and Fitzgerald 2014).

14.2.2 High-Density Polyethylene (HDPE)

The world's most widely used plastic is polyethene, divided into three types: linear low-density, low-density, and high-density. Due to its solid nature and resistance to moisture and chemicals, HDPE is perfect for use in pipelines, cartons, and other building supplies. Examples include rigid pipes, toys, buckets, park chairs, detergent bottles, cereal box liners, and milk cartons. It has a waxy surface, is opaque, softens at 75 °C, is hard to semi-flexible, is resistant to chemicals and moisture, and can cause stomach ulcers (Eriksen et al. 2019).

14.2.3 Polyvinyl Chloride (PVC or Vinyl)

Polyvinyl chloride can resist chemicals and weathering, making it suitable and highly desirable for building and construction applications. The fact that it is a poor conductor of electricity, tough and rigid, makes it popularly used for high-tech like lines and cables. It is also used in healthcare systems because it is impermeable to germs, simple to clean, and offers single-use applications that prevent infections. However, PVC, commonly employed in medical applications, is the plastic that poses the greatest threat to human health as it is known to release harmful leachates (e.g., lead, dioxins, vinyl chloride). Plumbing pipes, credit cards, toys for people and animals, rain gutters, teething rings, IV fluid bags, medical tubing, and oxygen masks are a few examples. Properties include durability, robustness, softening at 80 °C, transparency, weldability plastic, elasticity, and flexibility (Made Safe 2016).

14.2.4 Low-Density Polyethylene (LDPE)

Low-density polyethylene is a softer, more transparent, and more malleable HDPE variant. It is frequently used as a liner in beverage cartons, corrosion-resistant work surfaces, and other items. Examples include drinking cups, bubble wrap, sandwich and bread bags, plastic wrap, waste bags, and cling wrap. Properties: LDPE is a transparent, waxy surface that softens at 70 °C, easily scratched, and not recyclable (Guo et al. 2020).

14.2.5 Polypropylene (PP)

One of the strongest kinds of plastics available is PP. This is because it can withstand greater heat than other plastics. It is also perfect for food storage and packaging. Although it is slightly bendable due to its flexibility, it holds its strength and form for a long time. Straws, bottle caps, prescription bottles, hot meal containers, packing tape, disposable diapers, and DVD/CD boxes are some examples of PP. Its characteristics include hardness and translucence, resistance to solvents, and versatility. PP is generally a less toxic plastic, according to FDA, although its adverse effect on organisms has also been indicated (Jemec Kokalj et al. 2022).

14.2.6 Expanded Polystyrene and Polystyrene (PS or Styrofoam)

Polystyrene, often known as Styrofoam, is inexpensive and excellent at insulating, making it a standard in the building, packaging, and food sectors. Polystyrene, like PVC, is hazardous because it is easy to leach toxic substances like styrene, a neurotoxin, into the food people consume. Some of the properties are semi-toughness, glassy, rigidness, and transparency. It also softens at 95 °C; is influenced by fat, acids, and solvents; is resistant to salt solutions and alkalis; has low water absorption capacity; is clear; and is odourless and tasteless when unpigmented (Hahladakis and Iacovidou 2018). Examples include cups, takeaway containers, packaging materials for shipping and delivery, egg crates, cutleries, and insulation materials for building.

14.2.7 Polycarbonate and Other Materials

Polycarbonates and other plastic types are included in this category, especially if they fall outside one of the other six categories mentioned above. Other plastics formed from the combination of different types are also classified into this group. This plastic group cannot be recycled. Some examples include translucent plastic flatware, infant and sports bottles, gadgets, CDs and DVDs, lighting fixtures, cooler bottles, automotive and appliance parts, all resins, and multimaterials (such as laminates) with qualities reliant on plastic or a mixture of plastics. Leachates from this plastic group may result in endocrine issues in foetuses and children, such as obesity and cancer (Khan et al. 2019).

14.3 Plastics Are Classified According to Size

Plastic debris of size less than 5 mm is known as microplastic, while plastic debris of 5 mm to 20 mm and 20 mm and above is called meso debris and macro plastic, respectively. Larger plastic materials like plastic bags and fishing nets are the prime sources of macro-plastics. A substantial proportion of these plastic materials persist in the environment, contributing seriously to environmental pollution. Plastics are degraded due to exposure to ultraviolet (UV) radiation, which catalyses plastic's photooxidation, causing it to become brittle. Plastics are degraded into smaller fragments of the micro- (0.1–1000 μm) and potentially nano-sized (≤0.1 μm) particles, referred to herein as micro- and nanoplastics, respectively. When abandoned in the ocean, marine animals continuously get trapped in them (Andrady et al. 2022). Microplastics (MPs) and nanoplastics (NPs) often start as macro or meso debris, larger plastic polymers that break down into smaller pieces over time due to chemical degradation. Therefore, MPs and NPs that persist in the environment likely originate from the pre-weathering of plastics released into the biosphere.

14.4 Sources of Plastic Leaching

14.4.1 Plastic Leachate Is Released through Personal Care Products

Exposure to plastic leachate is possible through a variety of domestic and industrial applications, such as the use of plastic materials as abrasive exfoliants used in the preparation of personal care products [microbeads, alumina, sodium tetraborate decahydrate particles, and polyethylene (PE) beads] (Sun et al. 2020) and other products like hand sanitiser, soap, shower gel, cleansing products, makeup cosmetics, facial cleansers, toothpaste, and shaving cream (Nizzetto et al. 2016). Most producers of personal care products defy the use of natural materials, probably due to their high cost and availability. These natural products include pumice, oats, apricots, powdered fruit cores, or walnut shells (Decker and Graber 2012; Napper et al. 2015).

14.4.2 P*lastic* L*eachates* A*re* R*eleased* F*rom* W*astewater* T*reatment* P*lants*

Municipal wastewater contains plastic fibres from machine-washed garments that are copiously released into the environment (Wright and Kelly 2017). Most home wastewater, especially in developing nations, contains microplastics. Some microplastics can escape wastewater treatment plants (WWTPs) and seep through the land surfaces into aquatic environments or agricultural fields (Onyedikachi et al. 2018). Recently, it was noted that despite the wastewater treatment plant reduction of the microplastic content by about 98%, close to 44 million plastic leachates (microplastics) were still discharged into the receiving water per day. Also, approximately eight trillion microbeads are discharged into aquatic and other biological ecosystems every day in the United States via WWTPs, constituting a significant source of plastic pollution (Wright and Kelly 2017). Due to the discharge of industrial effluents, sludge by-products from wastewater treatment plants, and wastewater treatment plant effluents, plastic leachate has entered agricultural land, which could wind up in aquatic habitats and agricultural areas. It has been found that synthetic (plastic) clothing fibres are found in these habitats, and they persist for up to five years post-application (Ragoobur et al. 2021).

14.4.3 *Marine Debris Are Carriers of Plastic Leachate*

Plastic predominates among marine trash, including glass, metals, paper, textiles, wood, and rubber, but MPs are frequently the most prevalent (Novikov et al. 2021). MPs are pervasive and have been found in several environments around the planet, from the poles to the equator. Global sea surface pollution is estimated to be 5.25 trillion plastic particles, while the deep Indian Ocean floor is contaminated by four billion fibres per square kilometre (Sharma and Kaushik 2021). According to the fugacity study by Jang et al. (2022), marine invertebrates living on the island contaminated by marine debris accumulated more plastic concentrations than those living on the island less affected by marine debris. Therefore, marine trash contaminated with plastics are carriers and sources of leachates which are seriously injurious to health (Jang et al. 2022).

14.4.4 Plastic Leachate Released in Common Household Products

Nanoplastics are also delivered through various items, including electronics, paints, adhesives, and medical delivery systems. For example, 3D printing can release polymeric nanoparticles in a printing press. Their diminished size may bring on their potential toxicity due to environmental deterioration. The quality of the ecosystems' microbiota and the entirety of the food chain may be altered by these micro- and nano-pollutants, which must be regarded as environmental contaminants of rising concern (Garcia-Muñoz et al. 2023).

14.4.5 Plastic Leachates' Unique Properties Make Them Vectors for Various Priority Contaminants

Microplastics are implicated in negative health impacts due to their ability to traject priority pollutants listed in the Stockholm Convention as chemicals of concern (Rahman et al. 2021). Hydrophobic organic contaminants (HOCs) such as polycyclic aromatic hydrocarbons (PAHs), organochlorine pesticides, and polychlorinated biphenyls (PCBs) can be concentrated and adsorbed by microplastics due to their hydrophobic surface (Jin et al. 2020; Jiménez-Skrzypek et al. 2021). These HOCs act as chemical additives since they are adsorbed and incorporated into plastic goods. Thus, they become vulnerable to leaking into the external media because they are not chemically linked to the plastic polymer matrix (Wright and Kelly 2017). Heavy metals, including lead, cadmium, zinc, and nickel, get accumulated on the microplastics and continue breaking apart, creating a chance for inherent compounds to migrate up the surface in a concentration gradient continually. Such contaminants may be ingested and discharged into the environment, such as on agricultural lands (Onyedikachi et al. 2019a, b). If microplastics accumulate over time, they may be a source of chemical leachates in tissues, fluids, and the entire environment, resulting in serious health risks.

14.4.6 Plastic Leachate through some Agricultural Practices

Plastics are increasingly used in agricultural practices worldwide (PlasticsEurope 2018). For example, plastic mulching is often used in agriculture to maintain heat, retain water and fertiliser, enhance soil quality, and inhibit weed growth (Liu et al. 2017; Gao et al. 2021). Other applications for plastic in agriculture include plastic crates for harvesting crops, plastic crates for greenhouses, plastic fittings and spray cones, plastic irrigation pipes, plastic water storage tanks, plastic films to store silage, woven polypropylene bags of synthetic fertilisers, and compost (PlasticsEurope 2018). Unfortunately, plastics are left in agricultural areas since removing the thinner plastic films takes a lot of time and effort after the crop cycle (Steinmetz et al. 2016), hence promoting the breakdown of plastic additives which seep through the soil-water-air affecting the health of various organisms inhabiting them.

14.5 Pathways of Exposure to Plastic Pollution

14.5.1 Inhalation

Recently, reports of atmospheric dispersion of plastic material have surfaced, suggesting a potential exposure pathway through breathing (Sridharan et al. 2021). Humans are exposed to microplastics and their additives through product application and inhalation (Fig. 14.2). When building finishes, such as paints and other materials, are used, large amounts of plastic leachate are discharged (Testai et al. 2016). When plastics and plastic products are exposed to high temperatures and indiscriminately disposed of on land or burnt in the open air, toxic chemicals can leach into food, drinks, and water, releasing toxic

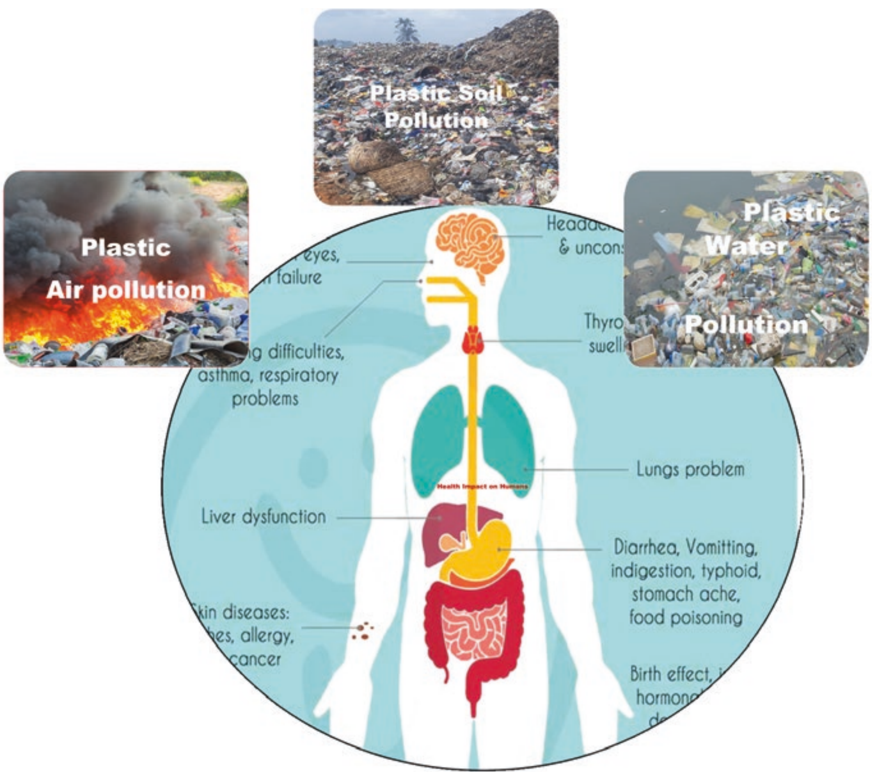

Fig. 14.2 Plastic pollution is a pathway for air, water, soil, and health pollution impact (Bansal and Sharma 2021)

chemicals into the air, inhaled into the biological system (Fig. 14.2), and resulting in public health hazards (Alabi et al. 2019). The risk to human health should be evaluated, especially the potential risk to the respiratory tract. Due to its small weight, air-driven plastic leachate can travel long distances accumulating large amounts of plastic waste before entering sewage systems. In addition, other sources of plastic pollution through the inhalation pathway include agricultural polyethylene sheets, the release of fibres from drying clothing outside, and they can also be blown from sludge-based fertiliser, which might potentially cause airborne plastic release (Koutnik 2022). Through inhalation, these plastic leachates enter biological systems and are a source of severe health problems.

14.5.2 Oral

Plastic leachates gain entry into the biological systems through the mouth, that is, through food and water consumption (Fig. 14.2). Human exposure to plastic additives like BPA is commonly anticipated to come primarily from consuming plastic-contaminated food and drinks (Kumar 2018). According to research by Vandenberg et al. (2007), groundwater can get contaminated when plastic additives like BPA are liberated from plastic polymers in landfills.

14.5.3 Dermal

The skin is a pathway through which plastic leachates can reach biological systems. They are extensively discharged using products such as electronics, building materials, toys, CDs, paints, and medical devices, which results in exposure through dermal absorption (Geens et al. 2012; Testai et al. 2016). Workers at thermal paper companies, particularly those engaged in the production of coating material and operating coating machines, as well as those exposed to thermal paper containing BPA, such as cashiers, have been shown to have dermal contact exposure to plastic leachates (Ndaw et al. 2016; Heinälä et al. 2017).

14.6 Additives Used in Plastic Production Are a Major Factor in Chemical Leaching

The most popular materials used by producers to enhance the quality of plastics are Bisphenol A (BPA), plasticisers, flame retardants, antioxidants, acid scavengers, lubricants, light and heat stabilisers, pigments and dyes, antistatic and anti-inflammatory agents, slide compounds, and thermal stabilisers (Hahladakis et al. 2018; Galloway et al., 2018). Emerging priority contaminants such as BPA, polybrominated diphenyl ether (PBDE), phthalates, flame retardants, and others are not chemically bound to the plastic polymer and hence possess the tendency to migrate within the substance, reach its surface, and then leach out into the environment. Leachates are mixes of additives, some of which are developing pollutants or those that might be dangerous for the environment and people's health (Gunaalan et al. 2020). Plastic additives are usually added to plastics to improve their softness, harden them, or add colour, which has generated concerns. Plastics break down into little pieces, and addivtives leak into meals, bodies of water, and the environment (Gunaalan et al. 2020). Numerous of them have been connected to harmful health impacts, ranging from disturbing our sensitive endocrine system to problems in reproduction. Obesity, early puberty, and adult-onset diabetes have all been connected to exposure to chemical leachates. These additives are invariably the most expensive components of plastic formulations and the minimum quantity required to produce a plastic product. However, the endocrine system may be modulated if the biological system is exposed to these plastic leachates. They are thus classified as EDCs, or endocrine-disrupting compounds (Andersen 2019).

14.6.1 Effect of Bisphenol a

Bisphenol A is a synthetic chemical that is widely used in the production of tough, long-lasting plastics like polycarbonate and epoxy resins. In the manufacturing of polyvinyl chloride (PVC), it also functions as a stabiliser. BPA in the plastic product might disintegrate and leak into any food it comes into contact with. Exposure to BPA is critical and common. Research indicated that it is found in the urine in more than 90% of Americans (Ye et al. 2015). Also, research has demonstrated that BPA is a systemic toxicant even at low concentrations and polymerises to produce a hard plastic (Kumar 2018). The health risk implication brought on by BPA exposure has been challenging to manage. Hence, the "European Human Biomonitoring Initiative" (HBM4EU) recently developed human biomonitoring guiding values (HBM-GVs). An HBM-GV is a biomarker concentration in the biological matrix and serves as a guideline value below which unfavourable human health consequences caused by drug exposure are not anticipated (Apel et al. 2020). Increased temperature, duration of contact, and pH may trigger hydrolysis and breakdown at the polymer surface, which might lead to BPA being released from polycarbonate (Pedersen et al. 2015). Despite its widespread use and manufacture, few studies have looked into BPA occupational hazards in Europe (Ribeiro et al. 2017). These substances are often leached into water or food through container lining in pregnant women's blood, amniotic fluid, placental tissue, and cord blood, indicating foetal exposure to BPA. According to Sayıcı et al. (2019), BPA can also be passed from mothers to their infants through breast milk or feeding bottles. Due to the growing concerns of BPA accumulation in organs and tissues and also its reduced ability to be detoxified, pregnant women are more at risk than other adults who are subjected to the same levels of exposure (Sayıcı et al. 2019). Generally, the main route of BPA exposure is through food consumption (Kumar 2018). Although, there was a belief that bisphenol-A at low amount is safe since it can break down however, a recent study has projected its potent toxicity in the body as this chemical additives can be biotransformed into a compound that may induce metabolic diseases like obesity (Kumar 2018).

14.6.2 Phthalates

Many consumer items use phthalates as plasticisers, but because they are not covalently attached to plastic, they can migrate or seep out, exposing people to them (Kumar 2018). They are quickly digested, have a short half-life (hours), and are eliminated in urine and faeces. Flexible vinyl, which is utilised in consumer items, flooring and wall coverings, food contact applications, and medical equipment, is created from plastics by adding higher molecular weight phthalates (Wright and Kelly 2017). Lower molecular weight phthalates are used in personal care goods like coatings, solvents, lacquers, and varnishing, as well as in some medications to offer scheduled releases (Kahn et al. 2020). For the general population, exposure by ingesting, inhalation, and skin contact are all regarded as significant exposure pathways. Phthalates metabolise quickly, do not build up, and are primarily eliminated through urine. According to Bamai et al. (2016), children had greater daily phthalate intakes than their parents based on estimates from urine metabolites. Due to their hand-to-mouth activity, babies and toddlers consume up to ten times more household dust than adults, making floor dust one of the most significant sources of phthalate consumption in these age groups. Studies have revealed that the levels of maternal pre- and post-natal phthalate metabolites varied greatly and were often not substantially correlated. These connections have been incredibly understudied in humans to date compared to the enormous body of evidence in laboratory animals confirming phthalate reproductive or developmental harm (Rahman et al. 2021). Phthalates have been labelled as reproductive toxins in humans due to research demonstrating altered male genital development and decreased semen quality (Kumar 2018). Males have only been included in the majority of human research examining reproductive or developmental health consequences linked to prenatal or newborn exposure to phthalates. They have concentrated on pronounced modifications such as hypospadias; shortened anogenital distance (a sensitive and non-invasive indicator of potential androgen deficiency during foetal development); and malformations of the epididymis, vas deferens, seminal vesicles, and prostate (the "phthalate syndrome"). To produce congenital defects, foetal testosterone production must be reduced during the key period for the development of these structures (Kumar 2018). Phthalates primarily change the gene expression of several enzymes and transport proteins involved in typical testosterone production and transport in the foetal Leydig cell, which impairs the development of androgen-dependent structures. This phenomenon closely matches the condition of human testicular dysgenesis (Kumar 2018).

14.6.3 Brominated Flame Retardants

Brominated flame retardants (BFRs) are synthetic less flammable chemicals made from various materials for human usage. They are used by industries for the production of plastic textiles and electrical/electronic equipment. BFRs are distributed into five main classes:

(1) Polybrominated diphenyl ethers (PBDEs) for plastics, textiles, circuitry, and electronic castings; (2) hexabromocyclododecanes (HBCDDs) used by building industries for thermal insulation; (3) tetrabromobisphenol A (TBBPA) and other phenols used as thermoplastics in TVs and printed circuit boards; (4) polybrominated biphenyls (PBBs) for plastic foams, consumer appliances, and textiles; and (5) other brominated flame retardants (OBFR) used for various insulation purposes. The European Union has restricted the use of certain BFRs due to their persistence in the environment and the risks these chemicals pose to public health. This is because BFR-treated products leach BFRs into the environment and contaminate the air, soil, and water. These contaminants may then enter the food chain, disrupting the health and well-being of man and his environment (EFSA) 2021). All plastic materials, from waiting room chairs to intravenous pumps, must be fire-resistant. Manufacturers of healthcare items must include flame-resistant chemicals, or "flame retardants", in their products in order to comply with fire safety regulations. BFRs, a subgroup of these flame retardants, are currently under close examination because of mounting evidence that they bioaccumulate in the food chain and human bodies and have negative effects on children through processes that target various levels of the hypothalamic-pituitary-gonad/thyroid axis, Thus, exposing them to certain plastic additives may change endocrine function. As a result of the generated molecular epigenetic changes, many organs may experience transgenerational effects (Kumar 2018).

14.7 Soil Physical and Chemical Properties Influencing Plastic Leaching

The characteristics of the soil determine how badly microplastics harm terrestrial ecosystems and human health (Lehmann et al. 2019; Liu et al. 2017). Changes in soil bulk density, water-holding capacity, soil aggregate stability, and soil water repellency occur when soils are exposed to microplastics. Microplastics can change soil bulk density, an important factor in predicting soil carbon storage, because they generally have a lower density than soil particles. In soils, microplastics in the form of plastic film have the ability to change the porosity, which would hasten water evaporation and cause soil cracking. Studies have shown that the use of polyester fibre can greatly improve the soil's capacity to store water while drastically reducing the proportion of water-stable aggregates in the soil.

Soil enzymes assist in the breakdown of organic matter and the cycling of different elements (C, N, P, etc.). (Trasar-Cepeda et al. 2008; Allison and Jastrow, 2006). Urease and phosphatase are engaged in the cycle of nutrients in the soil and act as indicators of soil quality during times of stress (Hagmann et al. 2015; Xiao et al. 2017). Fluorescein diacetate hydrolase (FDAse), a significant indicator of soil microbial metabolic activity, may quickly reflect changes in soil quality (Muscolo et al. 2015). Fei et al. found that 1% and 5% (w/w) additions of PVC and PE to soils reduced FDAse activity and increased urease and acid phosphatase activity. Although PE microplastics had a greater impact on urease activity in the soil, PVC microplastics had a greater impact on acid phosphatase and FDAse activities in the soil (Fei et al. 2020). More proof was presented by Yi et al. (2021) showing the kind and shape of microplastics that affected the activity of soil enzymes. Recent studies, however, discovered that introducing soil microplastics at lower concentrations [0.2 and 1.0% (w/w)], which are more indicative of their real amounts in the soil environment, had no appreciable influence on the activities of soil enzymes (Xu et al. 2020).

In addition, microplastics have an effect on the soil nitrogen cycle. Recent studies have shown that the carbon and nutrient cycles may be affected by soil-dissolved organic matter (DOM), which is altered by microplastics (Liu et al. 2017). Ecosystems on farms have received increased attention recently since they account for 20% of global greenhouse gas emissions (Verge et al. 2007). Microplastics in the soil might change microorganism-controlled soil greenhouse gas emissions (Liu et al. 2019; Liu et al. 2017). According to research by Gao et al., soils with 18% microplastics might increase soil CO_2 emission flow by 28.67%. CO_2 emissions were also found to have a strong positive correlation with microplastic-resistant microbial species such as Mycobacterium, Aeromicrobium, and Amycolatopsis (Gao et al. 2021).

Nitrogen is a nutritional element that is necessary to support a number of significant biological processes in soils, including nitrification, ammonification, and denitrification. Excess plastic mulch may reduce soil inorganic nitrogen, according to long-term plastic mulching studies. The influence of polyethylene microplastics on the nitrogen cycle was established by the rise in urease activity in their presence (Huang et al. 2019). Polystyrene and polyethylene microplastics also inhibited leucine aminopeptidase and N-acetylglucosaminidase, two critical enzymes impacting the soil nitrogen cycle (Awet et al., 2018; Bandopadhyay et al. 2019).

14.8 Health Issues Associated with Plastic Leaching

14.8.1 Humans

The health concerns associated with plastic polymers are often thought to be caused by various sorts of plastic additives and leftover monomers that are apparently retained from these polymers, despite the fact that they are widely believed to be safe and barely endanger society. According to Fucic et al. (2018), the majority of plastic additives are recognised endocrine disruptors and carcinogens, and they damage people mostly when they come into contact with their skin (leading to dermatitis), mouth (swallowing), or by inhalation (Aalto-Korte et al. 2019). When ingested by a variety of marine and freshwater species, microplastics are important poisons that can create complexes in the food chain and cause severe health issues (Wright and Kelly 2017). Animals exposed to plastic additives and microplastics can be detrimental to people if consumed in food. Biomonitoring studies on human tissues have shown that plastic components are present in the human species through the detection of environmental pollutants (Smith et al. 2018). The biological system exposure to plastic leachates is associated with diabetes, heart disease, and several health concerns (Gopinath et al. 2022). In foetuses, newborns, children, and pregnant women, high levels of this endocrine disruptor (BPA) have a deleterious impact on the brain, behaviour, and prostate gland (which may result in foetal or neonatal death, congenital impairments, or lower birth weight in their kids) (Kahn et al. 2020). Additionally, studies revealed that both men and women's free and total testosterone levels had high levels of BPA (Kumar 2018). The idea that the human body can break down BPA into a harmless product was refuted in a study by (Kumar 2018), since the bi-product BPA-glucuronide (BPAG) stimulates adipogenesis and may significantly contribute to obesity.

14.8.2 Aquatic Organisms

Diverse aquatic organisms, including coral, polychaete worms, sea cucumbers, crustaceans, molluscs, fish, reptiles, water birds, and sea mammals, all contain plastic leachates. Some of these species are able to excrete or eat plastic waste, while others retain, accumulate, and immobilise it in their bloodstream (Anderson et al. 2017; Li et al. 2019; Maaghloud et al. 2020). The three mechanisms that make up the plastics' toxicity seem to be (1) ingesting stress (physical obstruction, energy expenditure during egestion); (2) additive leaks from plastic (plasticisers); and (3) exposure to contaminants linked to microplastics (such as persistent organic pollutants) (Anderson et al. 2017). By changing light penetration into the water column and sedimentation properties, plastics can also have an impact on the environment's abiotic attributes (Eerkes-Medrano et al. 2015). Recent studies on plastic leachates have mostly focused on aquatic creatures. Both micro- and macroplastics have an influence on larger creatures (such as large fish, reptiles, birds, and mammals), but microplastics primarily have an impact on smaller organisms (such as zooplankton, worms, coral, crabs, molluscs, and tiny fish). However, because they are commensals whose primary victims are typically the smaller creatures in aquatic environments, bigger species in the water environment are more impacted by microplastics than macroplastics. Macroplastics have a detrimental impact on these species by restricting actions in vertebrates, including mammals, reptiles, and aquatic birds (such as swimming, breathing, and eating), lowering their ability to survive, and impeding growth and reproduction (Beer et al. 2018). According to Ramesh et al. (2019), the entanglement of fish nets and plastic waste discharged into the water had a significant negative impact on two sea turtles. The fish's arm tissues were ripped, and a person died as a result. Some turtles eat macroplastics because they mistake plastics for food and become caught in fishnets and huge pieces of plastic. This makes it difficult for them to eat and conceal from predators (Li et al. 2019; Nelms et al. 2016). The presence of plastic particles in the digestive systems of several seabirds, fish, and mammal species from tropical, temperate, and polar climates is linked to the polymer's attachment to the exterior surface, which obstructs and harms the digestive system. Inflammation, hepatic stress, and reduced development are further impacts (Auta et al. 2017). The clogged gut and cloaca, respectively, also have an impact on the female's capacity to reproduce (Nelms et al. 2016; Li et al. 2019). The leaching of contaminants, such as trace metals and other toxins (such as persistent organic pollutants), through the plastics into the digestive tracts would result in developmental and reproductive abnormalities in animals. This is one of the secondary effects of macroplastic consumption in large animals (Nelms et al. 2016). Plastics on beaches also cause the sand temperature to drop, which has a significant impact on the change in sex ratios of reptiles (such as turtles) that lay their eggs on beaches (Nelms et al. 2016). There are several ways that microplastics might infiltrate the aquatic biota, including filter feeding, suspension feeding, eating of prey that has been exposed to microplastics, or direct ingestion (Anderson et al. 2017). Microplastics can bind to organic pollutants such as polycyclic aromatic hydrocarbons, polybrominated diphenyl ethers, polychlorinated biphenyls, and dichloro diphenyl trichloroethane because they are hydrophobic and have vast surface areas (Anderson et al. 2017). In aquatic environments, plastics could act as a substrate for bacterial colonies and as vectors for infections (Anderson et al. 2017). Microplastics therefore affect organisms on a wide range of levels, including genetic structure and expression; biochemical activities (such as immune response, oxidative and energy-related enzyme activities); behavioural changes (such as swimming, feeding, olfactory senses, inflammatory responses, and other daily activities); alteration of life history traits (such as development, survival, reproduction, size, and weight); and health impairment such as lung problems, liver dysfunction and skin diseases (Auta et al. 2017; Barboza et al. 2018).

14.8.3 Soil Organisms

In recent years, plastic leachates have become pervasive pollutants that are a source of growing worry due to their toxicity and other health impacts, not just in aquatic and terrestrial ecosystems. Despite the fact that soil is a significant reservoir and a means of microplastic leaching and spreading to other ecosystems (Monkul and Özhan 2021), microplastics may alter the ecosystem where soil creatures live, indirectly impacting such species (Selonen et al. 2020); and this connotes a rippling effect that in turn affects other organisms. The effects of microplastics on earthworms have received the most significant attention since they are a model species in the soil ecosystem and their development rates and immune systems are impacted by the types and quantities of microplastics (Hodson et al. 2017). According to research by Cao et al. (2017), earthworm adaptation had no discernible effects when exposed to 0.25–0.5% of polystyrene microplastics. Growth inhibition only occurred at exposure concentrations higher than 1% Cao et al. (2017). Earthworm mortality rose by 8% and 25%, respectively, when exposed to microplastic concentrations of up to 28% and 60% (Lwanga et al. 2016). Microplastics have also been shown to alter the intestinal microbiota of soil organisms, suggesting that these communities may be involved in the cycling of critical elements and the consumption of organic materials (Zhu et al. 2018a). Landfills, soil supplements, agricultural films, tyre abrasion, and atmospheric deposition are the main entry points for microplastics into the soil ecosystem. Microplastics incorporated into the soil may change its composition and interact with other soil components, impacting how well the soil functions and how many organisms exist (Wang et al. 2019). Most of the time, microplastics are accidentally consumed by species that cannot break down the plastic into smaller pieces (Wang et al. 2019). According to studies conducted on marine organisms (Setälä et al. 2016; Lahive et al. 2019), the ingestion of MPs may cause growth loss, reproduction reduction, and mortality of terrestrial organisms due to nutritional imbalance, organ damage, and disorders of immune responses and metabolisms (Hodson et al. 2017; Wang et al. 2019). Furthermore, as humans are the top predators in the terrestrial food chain, the bioaccumulation and subsequent trophic transfer of MP leachates might potentially harm their health (Guo et al. 2020) The composition and diversity of the microbial population, notably of rhizosphere microorganisms like N-fixers, mycorrhizal fungi, and pathogens, might be impacted by the presence of MPs, which modify soil structure and function (Rillig et al. 2019). Numerous studies have shown that the presence of MPs has an impact on a variety of soil microbial enzymes, including dehydrogenase, leucine-aminopeptidase, alkaline phosphatase, glucose-glucosidase, cellobiohydrolase, and fluorescein diacetate hydrolase. The microbiota that resides in their stomachs is also impacted by microplastics, in addition to the organisms that dwell in the soil. *Caenorhabditis elegans*' body length, survival rate, reproduction rate, and genes for oxidative stress were all shown to be influenced by the size of polystyrene (PS). PS might also significantly alter these characteristics (Lei et al. 2018). In addition to affecting the bacterial diversity and microbiota in the gut of collembolan (*Folsomia candida*), Zhou et al. (2020) found that exposure to 0.1% PVC microplastics reduced the growth and reproduction of collembolan (Zhu et al. 2018b). The consumption of PETs by snails induced changes in their TAOC (comprehensive index representing oxidative stress), GPx antioxidant enzyme activity, and malondialdehyde (MDA) concentration. These changes resulted in lipid peroxidation and digestive system impairment in the snails (Song et al. 2019). Snails ingesting infected leaves may modify the histology of their digestive systems as well as the growth, behaviour, and viability of the microbiota that inhabits their intestinal tracts (Chae and An 2020).

14.9 Plastic Pollution and Sustainable Development Goals: A Nexus for Human and Economic Development

Plastic leachates into foods, water bodies, and agricultural lands through various routes can impair human and economic development in connection to the SDGs (Fig. 14.3), and it is a growing concern globally:

1. The well-being and health of man and other organisms. The poisonous particles can cause local inflammation and all kinds of physiological effects which should be combated (Fig. 14.3) to prevent the health concerns associated with plastic pollution (SDG 3).
2. Clean water and sanitation are essential for the existence of man and other living things; for example, without clean water free from contaminants, living organisms are exposed to different disorders (Fig. 14.3). Contaminated water affects the growth of plants and also affects the organisms in the soil whose activities enhance plant growth and degrade pollutants (SDG 6). This is aimed at promoting the quality of freshwater by remediation processes and reduction in the plastic pollution loads.
3. Sustainable cities and communities (SDG 11): By the effective collection and processing of waste, reusability, and ensuring cleanup of our cities and communities especially in densely populated regions where plastic waste is abundant, hence avoiding health risks associated with plastic pollution.
4. Responsible consumption and production (SDG 12): The abundant production of plastics for different purposes and the single-use practice, that is, non-recycling of plastic

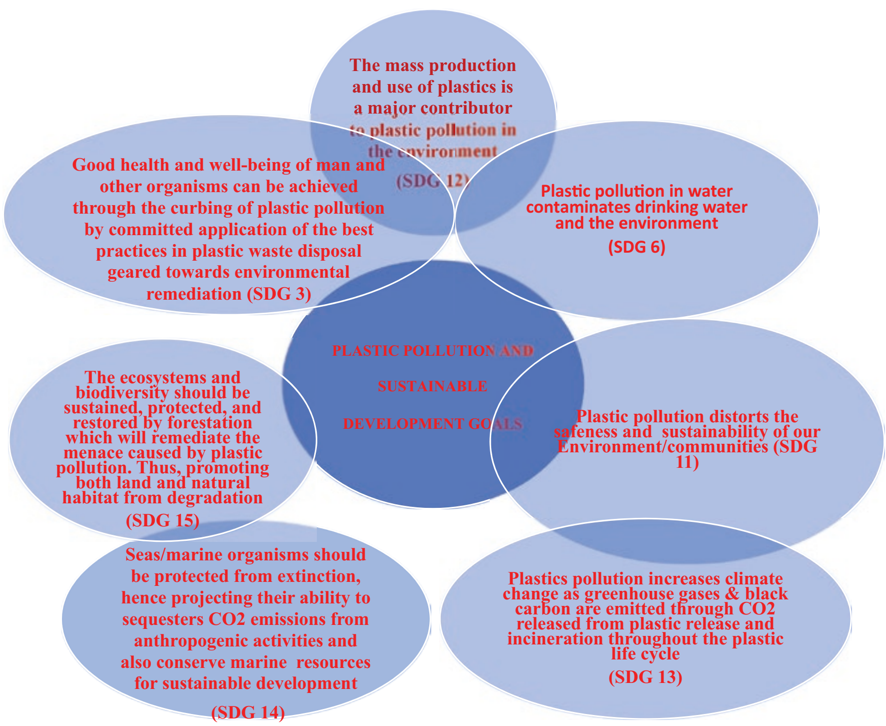

Fig. 14.3 The relationship between plastic pollution and target sustainable development goals (SDGs) (United Nations 2015)

materials, are major contributors to plastic pollution in the sea and on land. This pollution has a negative influence on the functioning of ecosystems and endangers animal lives as well as the food supply of large groups of people. Also, the consumption of plastics via several exposure pathways has promoted the observable link in health challenges (Fig. 14.3) caused by plastic pollution. Hence, the best way to promote SDG 12 is through an absolute reduction in plastics, improved effectiveness of recycling, and safer alternatives.

5. Climate Action (SDG 13): Most plastic materials are made from fossil fuels which use lots of energy and when incinerated cause global warming and the release of carbon dioxide (Fig. 14.3). The reduction of CO2 emissions would prevent an average temperature increase of two degrees is an extremely urgent SDG goal.
6. Protection of seas and oceans (SDG 14): This SDG is aimed at reducing and preventing pollution in the sea, especially from waste that originates on land (Fig. 14.3). This is because 80% of marine waste comes from the land and most of the waste dumps and drainages are infested with plastics which find their way in the water bodies. Huge benefits can be reaped if effective waste collection systems are put in place everywhere to assuage plastic pollution.
7. Repair ecosystems and retain biodiversity (SDG 15): Ecosystems in the sea and on land are threatened by plastic leachates which seep through into the ecosystems, causing severe diversity losses and suffocation of animals, making them unable to feed well, and also endangering their species and health.

14.10 Remedy for Plastic Leaching Health Effect

14.10.1 Bioplastics

Due to the mounting environmental strain on global warming and plastic waste, bioplastics have drawn a lot of attention. One of them, poly (lactic acid) (PLA), is both bio-based and biodegradable and has been extensively employed in numerous applications involving throwaway/takeaway packaging. According to Jem's law, the demand for PLA in the worldwide market doubles yearly when compared to the demand for conventional petroleum-based plastics. PLA often has fewer mechanical and physical qualities and is more costly. PLA's mechanical and thermal properties might be enhanced for high-end applications by recent compounding work and commercialisation of D-lactic acid and its polymer, PDLA (e.g. by making stereocomplex PLA). PLA is still used in other applications, although. Poly (glycolic acid) (PGA), which has a structure comparable to PLA and promising qualities including strong biodegradability and barrier properties, may be a useful addition to PLA. Co-polymerisation, physical mixing, and multilayer lamination can all be used to modify PLA with PGA. PGA and its combination with PLA have received a lot of attention in biomedical applications, but because of their relatively expensive manufacturing costs, they have not been extensively developed at a large scale. The emergence of new government rules and the development of novel manufacturing technologies are, in this case, the primary forces behind a global shift towards bioplastics. Numerous government rules that limit the use of conventional plastics and promote the use of biodegradable polymers have recently been published. Industrial waste gases may be converted into PGA using cutting-edge production equipment, which lowers production costs and carbon emissions. PGA and PLA may be coupled to play a crucial role in the sustainable and ecologically friendly plastic industry by advancing the production and compounding technologies, especially for single-use items needing quick disintegration at room temperature or in the natural environment.

14.10.2 Alternatives to Plastics

Although it is hard to imagine living without plastics, the hunt for alternatives has been sparked by growing knowledge of the health risks. On the horizon, several excellent options are:

1. Increasing the use of glass materials, notably for storage and microwave use.
2. Prefer paper, jute, or cloth-based reusable bags over plastic ones.
3. Compared to their petrochemical equivalents, the use of bioplastics, which are largely produced from sustainable resources like biomass, can result in production energy savings of up to 40%.
4. Biodegradable plastics include those made of polyhydroxyalkanoate (PHA) polyesters, starch-based polymers, and aliphatic polyesters.
5. A promising material is one manufactured from milk casein and chicken feathers.
6. Produced from biodegradable lignin, a by-product of the paper industry, is liquid wood.
7. By ensuring the protection and enhancement of the environment, avoiding environmental pollution in all its forms, and addressing special environmental issues unique to different nations, government initiatives programmes might support the strict reforms in plastic waste management.

14.10.3 Plastic Recycling

Recycling of plastic materials like bags and containers instead of single-use practices often used in packaging can reduce the adverse effects of plastic pollution and packaging costs, as waste materials can find a secondary route to obtain value rather than being disposed of. This will reduce dumping in oceans and rivers, and as well protect marine organisms and asides reduce global warming which are important goals in the world leaders' SDG plans. Restaurants, stores, and events can purchase, use, refill, and wash them hundreds of times, before returning them to recycling or reshaping when they are not needed anymore. This is one of the preferred routes as less energy and resources are required to carry it out. However, reused plastic packaging may be contaminated from their former use. hence, to avoid migration of contaminants to food, it is important to wash first before reusing plastic packaging to ensure health safety (Ncube et al. 2021). Examples of plastic recycling products and methods include Waterhaul, used in making sunglasses from plastic waste; WasteAid, a Gambian initiative for converting LDPE plastic waste to plastic tiles; Kkplascticroads, an Indian initiative using recycled plastic waste as binders in making asphalt roads; and Plastic Fantastic, an initiative that uses litters to reprocess plastic litters into new products for scaffolds, benches, and facing materials. Plastic collective shrudder is also equipment for recycling plastic waste, and the Byfusion method also reuses plastic in making building materials (Plastic soup foundation 2023). These beautiful recycling processes actually go a long way to reduce the accumulation of plastic in the environment. This chapter encourages its application in achieving SDG goals come 2030.

14.10.4 Technological Tools for Detecting and Cleaning up Plastics

Technology tools for detecting and cleaning up include the following: (a) the detection method involves: (1) WASSER 3.0 PE-X, a project developed for the removal of microplastics and micropollutants from water using hybrid silica gel that binds to plastic materials thus forming lumps that can be separated easily on the surface of the treatment basin; (2) MAGNET, developed by some Spanish scientists which uses a system of hybrid material that absorbs microplastics from water. It can be used to clean small samples and monitoring of water pollution; (3) DRAPER, developed by an American company which uses fluorescent dye on water samples from the sea, making plastics easily identifiable around small organisms such as plankton and organic material; and (4) Marine Litter Detective, a floating tracker giving insight into the sea currents that carry plastic along (Plastic Soup Foundation 2023).

(b) The cleaning up process involves: (1) SeeHamsters, which are compact catamarans with a length of about 4.5 meters and a width of 2 m and a low draught, equipped with fold-down nets or fishing gear to collect debris from inland waters such as lakes and rivers. (1) the Versi-Cat's function is the collection of plastic litter and debris from the water surface to a removable basket, which can be lifted and tipped directly into a skip or shoreside receptacle for disposal. (3) the Aqua Pod are waste-collecting modular floating docks of 2.4 × 6 meters that capture plastic waste from marinas and other waterfront areas by creating a water flow into a net, thereby trapping waste for easy removal. (4) Clear Rivers is also another initiative that uses Litter Traps to collect plastic waste from rivers and port areas and use it to produce platforms that can be assembled to form a floating park (Recycled Islands). (5) the Cleaning Drone V1 is a fully electric, autonomous surface vehicle designed to remove marine plastic waste in and just below water surfaces in ports, canals, rivers, river mouths, and other marine and aquatic environments. It is designed as a robust catamaran with a collection unit and a unique system for self-emptying in a specially designed stationary waste pool. (c) Microplastic removal system (1) a static charge filtration screen used to remove microplastic from beaches. The screens are loaded with dry sand and plastic, and through a back-and-forth motion users manually filter the sand through the screen. (2) Hoola One is a machine that uses a buoyancy separation method to recover plastic particles as small as 50 um. It is made out of three different modules to allow access to hard-to-reach places, and it uses a separation technology to put natural matter back on the beaches. (3) Vroom suction installations provide suction technologies that can be used to remove waste and pollutants from the soil, sand, gravel, and water. It is very useful to remove green and residual waste from hard-to-reach places. (4) The Marina Trash Skimmer collects trash and removes oil and floating debris from the surface of the water. It works with the natural currents of the installation sites, tides, and prevailing winds to collect trash and oil sheen into one easy-to-access location, for quick removal and disposal. (5) The Manta is a plastic-eating catamaran that collects trash on an industrial scale, up to 3 tons of ocean garbage per hour. It has nets along the stern to collect plastic and garbage, along with sustainable energy sources like solar panels and wind turbines to power the onboard collection and recycling centre. (6) Eco-Mobile Robot is developed to clean up the ocean on a big scale. The floating deck, looking like an oil platform, can suck up trash. Connected to satellites, they can be monitored and controlled (Plastic Soup Foundation 2023).

(c) Natural organisms like *Aspergillus tubingensis*, a mould that enhances quicker breakdown of polyester polyurethane; *Phanerochaete chrysosporium*, contributes to the breakdown of polycarbonate (PC); and *Galleria mellonella*, a caterpillar that has the ability to eat and digest this kind of plastic (Plastic Soup Foundation 2023).

14.11 Conclusion

There is a great need to use healthy alternatives that are biodegradable in order to curtail the adverse health implications as a result of exposure to plastics. The effects of plastic additives, especially their disruptive effects on the endocrine glands, intestinal obstructions, injuries, and deaths, are a severe concern. Although plastics and their additives have significant uses that assist daily life, their environmental and significant health risks outweigh their benefits. The only way out is to look for natural alternatives, a more efficient plastic recycling process, discourage the use of plastic materials in building roads and other infrastructure, and reduce usage in the food and beverage industry. Governments, stakeholders, and technocrats should make policies that control plastic usage and its indiscriminate release into the environment in industrial and anthropogenic activities.

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