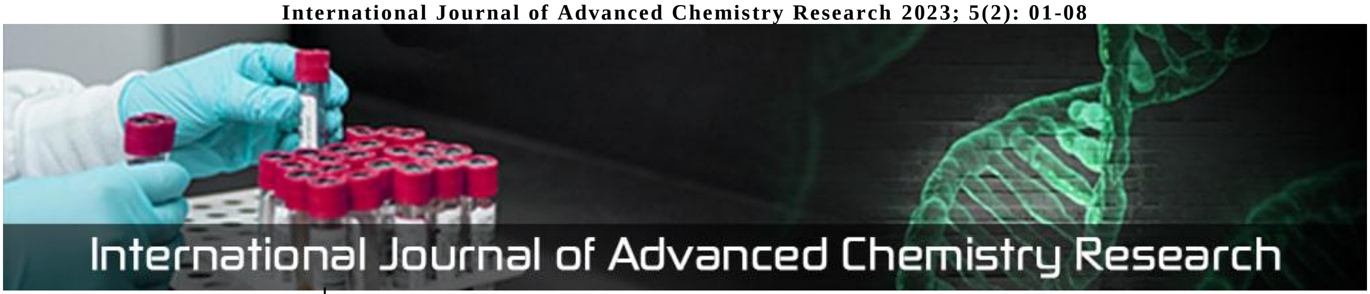

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Occurrence, distribution, characteristics, toxicity, human health effects and removal techniques of microplastic: A review

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Abstract
Since the inception of commercial plastic production around 1950, modern society's reliance on plastics has surged dramatically. This growing dependence is attributed to the remarkable advantages of plastics, including their versatility, stability, lightweight nature, and cost-effectiveness, all of which have propelled their global demand to unprecedented levels. These materials find applications in packaging, construction, electronics, textiles, medical devices, and more, owing to their capacity to be moulded into a wide array of shapes and sizes. Regrettably, the prevalent pattern involves utilizing plastics briefly before discarding them on land, exacerbating environmental and sustainability challenges. However, the disposability of plastics after single-use applications has led to the generation of Microplastic (MPs), an emerging class of contaminants, in our environment. MPs are plastic particles less than 5 mm in size and could originate due to primary and secondary sources. MPs size range which are generated as such are the primary ones while the secondary MPs are a result of fragmentation of larger plastic particles which eventually enters the aquatic, terrestrial, atmospheric environments and human consumables affecting human health a lot. MPs have been found in biological samples such as faeces, sputum, saliva, blood and placenta. Cancer, intestinal, pulmonary, cardiovascular, infectious and inflammatory diseases are induced or mediated by microplastics. Overcoming these issues necessitates collaborative efforts to innovate, regulate, and raise awareness, ultimately steering society towards a more sustainable relationship with plastics starting with prevention, followed by reducing, reusing, recycling, recovering, and ending with disposal as the least preferable option. This study seeks to, review the sources, formation, occurrence, toxicity, effects of Microplastic on the environment and human health, and remediation methods of microplastics (like coagulation, membrane bioreactors, sand filtration, adsorption, photocatalytic degradation, electrocoagulation and magnetic separation) and comprehensively examine scientific literature pertaining to Microplastic research across various environmental domains.

Keywords: Microplastic (MPs), emerging contaminant, aquatic systems, atmosphere, terrestrial systems, human consumable, human health, reducing, reusing, recycling

Introduction
Over the past 70 years, global plastic production has surged, creating a pervasive "plastic world" due to their cost-effectiveness, versatility, water resistance, strength-to-weight ratio, and insulation properties. They are integral to clothing, storage, transport, packaging, construction, and consumer goods etc. in modern life because of their properties like low manufacturing cost, adaptability, water-resistant nature, high strength-to-weight ratio and high thermal and electrical insulation properties [1]. Due to massive production and improper disposal of plastics escalating concerns arise about environmental and human health risks [2]. The COVID-19 pandemic exacerbated these issues due to heightened plastic usage. How a single-use plastic item like disposable face masks can impose variable levels of problems in our environment like wildlife deaths and hazardous emissions from incineration. Research highlights the far-reaching consequences, as aquatic organisms suffer entanglement, injury, accidental ingestion, and fatalities including harm to the ecosystem and impairment of human body functions due to plastic exposure [3]. Urgent action is imperative to curb the threats posed by plastic proliferation on diverse ecosystems and organisms.
Due to highly persistent in nature degradation of Plastics occurs at a very slow rate and their accumulation at a faster pace [4].

Today worldwide prevalence of smaller fraction of plastics, i.e. Microplastic (MPs) and nano plastics (NPs), is gaining significant attention of the researchers globally due to their serious environmental consequences**.** Their small size allows them to easily penetrate living cells and reach remote locations, exacerbating their potential harm They can be primary (that are intentionally made for products like cosmetics, dermal exfoliators, etc.) or secondary (resulting from fragmentation of larger plastic items like food packaging, plastic bottles, fishing gear, synthetic textiles, car tyres, paints etc.) [5]. MPs have pervaded aquatic systems, land surface, inside biological organisms, human consumables and even in the air. Their widespread presence is due to huge plastic product demand. The USA is the top plastic waste producer trailed by the EU, India, China, Brazil, Indonesia. Russian Federation, Germany and others, contributing to MP generation. Gradual accumulation and subsequent fragmentation of plastics lead to MP formation. As pollution from microplastics are becoming a serious problem around the world, and many studies on microplastics such as distribution, toxicity, analysis, and removal are being conducted by many researchers still research on MPs is limited, with only 22.9% of countries investigating this aspect [6].

Production of plastics and microplastics

Global plastic production has risen from 1.5 million tonnes to approximately 359.0 million tonnes during the last 70 years, and is expected to reach 500 million tonnes by 2025. China in 2013, produced approximately 63.0 million tonnes of plastic, accounting for most plastic production worldwide. After combining with the plastic production of other Asian countries, the total plastic production reaches approximately 114.0 million tonnes [7]. The second-largest region was European Union for plastic production, with nearly 50.0 million tonnes produced. North America also contributed significantly, with 49.0 million tonnes of plastic produced. While, Latin America, Commonwealth countries, Africa, and the Middle East collectively produced only 37.0 million tonnes of plastic. Most of plastic waste is being incinerated, dumped in landfills, and released into the environment, causing significant environmental and health problems**.** Unfortunately, plastic wastes constitute more than 75.0% of marine waste materials, owing to their rigid and non-biodegradable nature**.** Mediterranean Sea region has unfortunately become one of the most highly polluted areas with plastics and Microplastic contributed by five countries, with Turkey being the largest contributor of approximately 144.0 tonnes per day of plastic waste, followed by Spain at 126 tonnes, Italy at 90.0 tonnes, Egypt at 77.0 tonnes, and France at 66.0 tonnes [8]. India is consuming plastic approximately 11 kg per capita and being a major consumer, it generates approximately 26 million metric tons of plastic wastes annually thereby holding an important position in the plastic waste generation community**.** In recent years, the production of microplastics has significantly risen in our ecosystems and is expected to double in next few years but lack of reliable and accurate sampling techniques, leads to a potential underestimation of the problem**.**

Characteristics and classification of Microplastic

Microplastic (MPs) are plastic particles measuring 5 mm to 1 µm in their longest dimension and can be categorised into five major types: fragments, fibres, foam, pellets, and films [9]. Furthermore, Microplastic can be classified into six categories based on their chemical composition: PET (polyethylene terephthalate), PU (polyurethane), PS (polystyrene), PVC (polyvinylchloride), PP (polypropylene), polyester, PE (polyethylene) [10]. As shown in the Fig.1 [11]

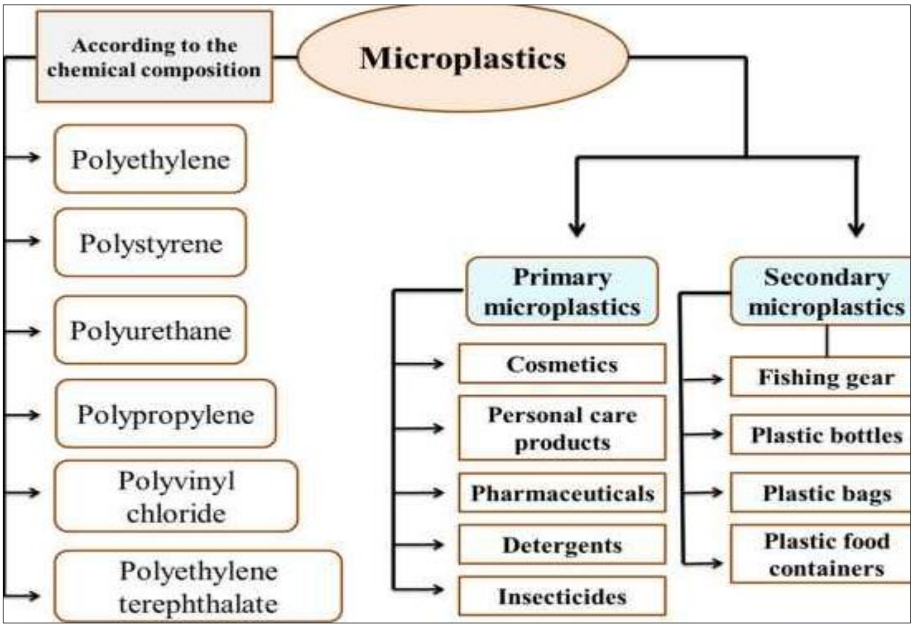

Fig 1: Different classifications of microplastic.

Microplastics, small plastic particles less than 5mm in size, possess various physical properties that profoundly impact their environmental behaviour and potential toxicity. These attributes, including size, density, colour, shape, and crystallinity, are often assessed using microscopic techniques. Size, a crucial metric, varies with sampling and separation methods, influenced by filter membrane pore sizes. Size determines the accuracy of counting; smaller Microplastic yield larger counting errors while larger ones reduce errors

Density, dependent on polymer type and production process, influences microplastic buoyancy. For instance, PP, PE, and

PVC densities are 0.85-0.94 g/cm³, 0.92-0.97 g/cm³, and 1.38 g/cm³, respectively. Microplastics less dense than water float, risking ingestion by surface and mid-level aquatic organisms [12].

Colour serves as a tool to identify microplastic sources; their varied colours such as pink, blue, or black hint at origins. Colour also indicates residence time and degradation, aiding exposure assessments.

Crystallinity, reflecting the proportion of crystalline regions in polymers, influences mechanical properties. Crystallinity varies (30% to 85%) and divides polymers into crystalline, semi crystalline, and amorphous types. Notably, no polymers fall solely within the crystalline category. High crystallinity in PE, PP, and PA contributes to strength, while amorphous polymers like PC, PS, PVC, and PMMA offer flexibility. Environmental microplastics' crystallinity shifts with aging due to preferential degradation of amorphous polymers or molecular rearrangement [13].

Microplastics' chemical properties encompass composition, surface groups, and potential release of polymers, additives, dyes, and pollutants. Environmental impact arises from leaks, particularly harmful with chlorine-rich PVC due to dioxin release. Leaching is tied to polymer porosity, size, degradation, and aging-induced additive release, dependent on concentrations. Surface group diversity crucial for interactions, influenced by artificial modifications and environmental oxidation, like increased carbonyl groups in weathered Polypropylene [14].

Occurrence and distribution of Microplastic

Improper plastic waste management, including inadequate handling of plastic waste in towns, tourism, agriculture, and industry, along with ship transportation and fishery activities, directly contribute to significant plastic pollution in aquatic environments. Synthetic textile and personal care product residues discharged in wastewater are major sources of microplastic fibres and pellets in freshwater. Poor landfill practices exacerbate microplastic pollution. Rainfall and floods can transport microplastics from landfills into water bodies, while atmospheric deposition also introduces microplastics. These pollutants accumulate in ice and snow, eventually entering seawater upon melting. Studies show alarming levels of microplastics, with implications for ecosystems [15].

Microplastic contamination in soil originates from diverse sources like sewage irrigation, agricultural practices, plastic waste mishandling, and atmospheric deposition**.** These sources introduce various microplastic types, including films and fibres, such as polyethylene and polyvinyl chloride. Sewage irrigation and agricultural mulch are major contributors**.** Improper plastic waste disposal and atmospheric deposition exacerbate soil pollution, posing global environmental and health risks.

Microplastics in the atmosphere originate from various sources including industrial emissions, daily life activities, and plastic waste stacking, burning etc. They include fibres, fragments, and films, with fibres being a significant contributor**.** Microplastics in air is present indoor as well as outdoor indicating the ubiquitous reach of these particles [16]. These are lightweight and can be carried by air over long distances, primarily through wind currents, settling during transportation**.**

Contamination of hydrosphere, atmosphere, and lithosphere with microplastics (MPs) is a fact today. Organisms in these ecosystems consuming MPs pose risks to humans through ingestion and inhalation [17]. MPs have been found in consumables like seafood, salt, and drinking water, drawing attention to pollution concerns. Plastic use in food packaging contributes to microplastic presence in human consumables.

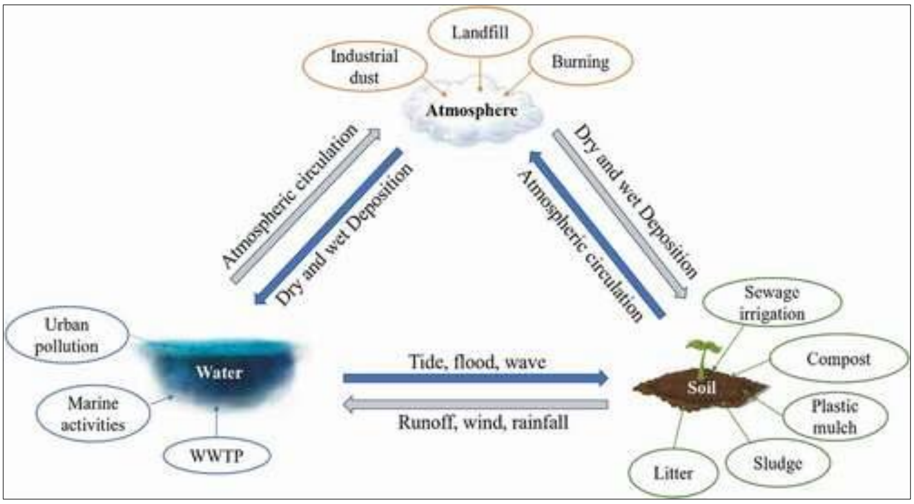

Fig 2: Occurrence and distribution of Microplastic in the ecosystem

Microplastics and Human health

A. Microplastics in Human Body

Understanding the origin, circulation, and susceptibility of microplastics in humans is essential for maintaining good health. As the evidence of microplastic exposure and the toxicity effect is prominent, it is necessary to assess the presence of microplastics in the human body through biological samples such as faeces, sputum, and placenta. Clinical studies found microplastics in human stool with high-density polyethylene. Placenta and foetal meconium contained polyethylene, polypropylene, polystyrene, and polyurethane [18]. Microplastics in faecal samples obtained from infants and adults, fifteen different types of microplastics were identified with polyethylene terephthalate and polyamide being the most frequently detected. Recent researches also indicate a strong correlation between the severity of inflammatory bowel disease and faecal microplastics [19].

Microplastics in the respiratory tract have triggered the release of reactive oxygen species, which may lead to alterations in lung cell metabolism, proliferation, and cohesiveness**.** Research conducted in 21 kinds of microplastics in sputum samples, with polyurethane constituting the majority. This research suggests that inhalation is a potential entry point for microplastics**.** FTIR spectroscopy and scanning electron microscopy-energy dispersive spectroscopy proved the presence of microplastics in human broncho alveolar lavage fluid and possibly damaged and decreased lung function [20].

In Human blood of 22 healthy participants, researchers found four high polymers used in plastics, such as polyethylene terephthalate, polyethylene, polymers of styrene, and methyl methacrylate. They used steel syringe needles and glass tubes to avoid contamination and evaluated for background levels of microplastics using blank samples.

Scientists have discovered microplastics for the first time in the human placenta, raising concerns that the compounds may interfere with embryonic development. Raman micro spectroscopy was used to evaluate six human placentas collected from women who agreed to have their pregnancies monitored for microplastics. The sample was processed in a confined and controlled environment to avoid cross-contamination, revealing the presence of 12 microplastic fragments [21].

B. Impact of Microplastic - induced diseases on human health

Ingestion of food containing plastic particles may pose potential health risks to humans, including cancer, immune toxicity, intestinal diseases, pulmonary diseases, cardiovascular disease, inflammatory diseases, as well as pregnancy and maternal exposure to progeny. This section summarises the toxic mechanisms and effects of microplastics potentially causing harm to humans. Shown in Fig. 3 [22].

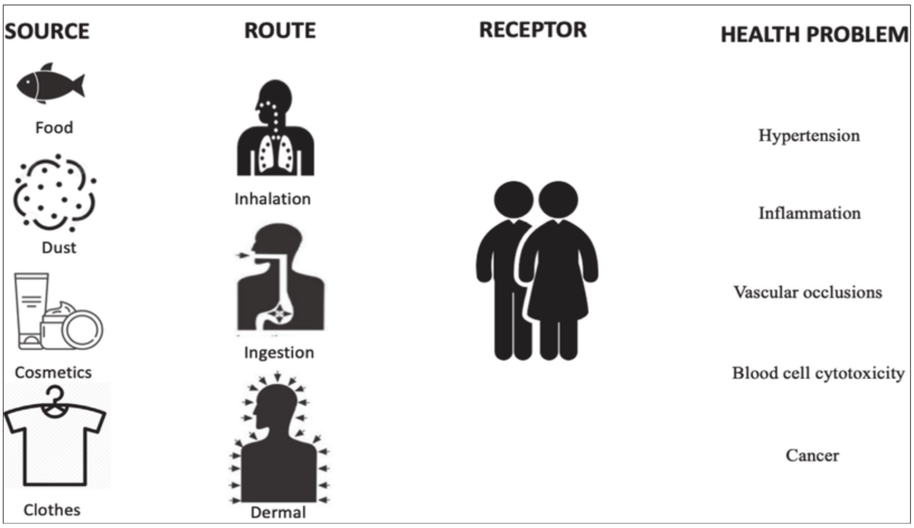

Fig 3: Effects of micro-plastics on human health

Immunotoxicity

The term used to describe the negative effects of pollutants on the immune system is Immunotoxicity. Immune cells underneath the intestinal epithelium response by presenting antigens, generating antibodies, and releasing cytokines, which defend quickly to infectious threats and toxins. Several mechanisms support this sensitive effort, including myeloid cells, innate lymphoid cells, and T cells. Microplastics have been shown to have various immune system problems, such as immune cell death, altered surface receptor expression, interleukin production including immunosuppression (Decreased host resistance to infectious agents and tumours), immune activation (increased risk of developing allergic and autoimmune Diseases), and abnormal inflammatory responses (Chronic inflammation, tissue or organ damage and dysfunction)**.** New research has identified several crucial immunomodulatory substances, including interleukin-27 and interleukin-28B, as immunotherapeutic agents for inflammation and lesions caused by polycyclic aromatic hydrocarbons [23]. Thus, ingestion of microplastics may affect the human body in various ways, such as altering intestinal homeostasis or altering immune cell recruitment or cytokine production levels. The vulnerability of the immune system to microplastics adds to the dangers to human health.

Intestinal diseases

Microplastic particles after inhalation can enter the gastrointestinal system through food contaminated with microplastics leading to various negative health effects, including increased gut permeability, alterations in gut microbiome composition, and changes in metabolism. Microplastics with a dimension greater than 150 µm are not absorbed. They remain bound to the intestinal mucosal layer and directly in contact with the apical part of the intestinal epithelial cells. The smaller nanoparticles (dimension less than 150 µm) can cross the mucous barrier and infiltrate deep into organs. This effect could lead to gut inflammation and a local impact on the immune system**.** Microplastics can change human microbial colonic community composition, and the colonic microbiota could attach to the microplastics surface to induce biofilm formations [24].

A study on the impact of microplastics on lipid digestion demonstrated that five types of microplastics (i.e. polystyrene, polyethylene terephthalate, polyethylene, polyvinyl chloride, and poly (lactic-co-glycolic acid) significantly inhibited lipid digestion using an *in vitro* gastrointestinal system. Polystyrene showed the highest level of inhibition at 12.7%, and the study also found that lipid digestion decreased with increasing concentrations of polystyrene indicates that microplastics can negatively impact lipid digestion, posing a human health [25].

Carcinogenic diseases

Recent studies show that microplastic is a very prominent source of cancer, when consumed by humans. Microplastics, due to the small size have a high ratio of surface area to volume. Materials with a high surface area are highly cytotoxic to cells and tissue and can damage deoxyribonucleic acid (DNA) inside the cells. Due to this damage mutations occurs that can lead to cancer. Also, uncontrolled waste of microplastics in water tends to absorb hydrophobic organic pollutants from water which are carcinogenic, and long-term exposure can cause DNA mutations that causes cancer [26]. Use of heavy metals in the production of plastics like arsenic (As), cadmium (Cd), chromium (Cr), mercury (Hg), and lead (Pb) are carcinogenic, according to the International Agency for Research on Cancer (IARC). Microplastics can be directly consumed by various marine organisms and contaminate the human food chain via the bioaccumulation process**.** Once consumed by humans, the particles of microplastics with sizes less than 2.5 mm can enter the digestive tract and gastrointestinal level via a cellular process called endocytosis by the microfold cells of Peyer's patches which is validated by microplastics in the human stool samples. These studies provide direct evidence of plastic consumption in humans that may lead to the development of various cancers [27].

The research highlighted the potential harm of microplastic ingestion, indicating that it could lead to chronic inflammation, irritation, and DNA damage**.** This is particularly concerning due to the release of pro-inflammatory agents, potentially causing angiogenesis and promoting malignancies [54] evaluated microplastics' cancer risk and found that they adsorbed significant levels of PAHs, indicating that the risk of microplastic leaching is substantially higher than benzo [a] pyrene.

Using bisphenol A as a plasticiser and its nano-scale size exposure could lead to local inflammation and affect colon cell permeability. This process was mediated by elevated levels of interferon-g, interleukin-17 and immunoglobulin A. Interleukin-17 promotes cancer cell survival and induces resistance to conventional chemotherapeutic agents, while Interferons are proteins that are part of human nature and defences. They signal the immune system when germs or cancer cells are detected in the body [28]. One of the isomers of plasticisers, the tri-o-cresyl phosphate is reported to have neurotoxic effect and cause liver and reproductive toxicity. Investigations on the impact of tri-o-cresyl phosphate on human breast cancer cell line (MCF-7) and oestrogen receptor α human embryonic kidney-oestrogen receptors (HEK-ESR) cells demonstrated that the coordination of tri-o-cresyl phosphate to oestrogen receptor α in silico had a high tendency to induce tumour growth by overexpressing angiogenesis and nutritional supply. This action promoted invasion and metastasis, affecting the cell cycle and endocrine system as oestrogen receptor α cells HEK-ESR and MCF-7 breast cancer cells [29].

Pulmonary diseases

Studies have identified micro plastics in both indoor and outdoor air, raising concerns about potential inhalation and their subsequent impact on human health**.** Occupational exposure in industries such as synthetic textiles, vinyl and polyvinyl chloride has been linked to respiratory diseases, supported by *in vivo* studies replicating associated lesions. Microplastics have been detected in human lung tissues from autopsies. Research indicates that exposure to polystyrene nano spheres triggers lung inflammation and gene expression changes, possibly due to their large surface area causing oxidant activity. Microplastics alter lung surfactant behaviour, surface tension, and membrane structure, with stronger adsorption of phospholipids compared to proteins [30]. Polystyrene microplastics inhibit proliferation of alveolar cells, leading to reduced metabolic activity and altered cell morphology. The uptake of 1-µm microplastics can lead to systemic toxicological effects inhibiting the proliferation of human alveolar A549 cell lines.

Cardiovascular diseases

Exposure to airborne microplastics poses health risks, including asthma, cardiac disease, allergies, and autoimmune disorders**.** Microplastics adhering to red blood cell membranes can impede oxygen transport, causing symptoms like shortness of breath and weakness [31]. Research on human umbilical vein endothelial cells (HUVEC) reveals that microplastics of different sizes damage cell membranes and disrupt autophagy, impacting cardiovascular health. Plasticizer additives such as bisphenol A and phthalates, leached from plastics, raise concerns. Biomonitoring shows detectable levels of these additives in most people. Long-term exposure to bisphenol A is associated with a hazard ratio of 46-49% for heart diseases, while increased urinary phthalate and bisphenol A levels link to hypertension and reduced heart function**.** Drinking water from bisphenol A-containing bottles rapidly increases bisphenol A levels in urine, correlating with high blood pressure. Phthalates like DEHP can impair coronary circulation, causing atrial dysfunction, bradycardia, and cardiac conduction issues [32].

Microplastics found first time in human heart tissues, both before and after surgical procedures

Kun Hua, Xiubin Yang and colleagues wanted to investigate whether these particles have entered people's cardiovascular systems through indirect and direct exposures. Then the team analysed 15 samples before surgery with laser direct infrared imaging and identified 20 to 500micrometer -wide particles made from eight types of plastic, including polyethylene terephthalate, polyvinyl chloride and poly (methyl methacrylate). This technique detected tens to thousands of individual microplastic pieces came from more diverse types of plastics which accumulate and persist in the heart and its innermost tissues in varied amount between participants but after surgery their average size decreased. The researchers conclude invasive medical procedures are an overlooked route of microplastics exposure, providing direct access to the bloodstream and internal tissues [33].

Inflammatory diseases

Exposure to microplastics in contaminated food has been shown to activate the immune system and reduce gut microorganisms, potentially harming human health [49]. Microplastics can induce cellular toxicity and increase inflammatory cytokine production, leading to chronic inflammation, oxidative stress, and toxicity. Larger microplastic particles can trigger the production of proinflammatory cytokines like interleukin-6 and tumour necrosis factor-α. Researchers found that microplastics can interact with the surface of SARS-CoV-2 pseudo virus, increasing infection rates and influencing inflammatory markers. Inhalation of plastic particles may cause lung reactions such as alveolitis, persistent pneumonia, and fibrotic changes, potentially leading to cancer due to DNA mutations and prolonged inflammation [35]. Synthetic textile workers with prolonged exposure to microplastics have shown a higher cancer incidence, linked to exposure intensity and duration. Studies also demonstrate a correlation between microplastics and inflammatory bowel disease occurrence in faecal samples.

Treatment techniques for microplastics

Treatment strategies for microplastics in aquatic ecosystems focus on their removal. Conventional methods like coagulation, membrane bioreactors, and adsorption, along with innovative techniques like photocatalytic degradation and magnetic separation, are employed. Each of these techniques has both positive and negative aspects and its efficiency depends on factors like microplastic size, concentration, flow rate, and pH. Shown in table 1.

Table 1: Summarises the different treatment techniques used for the removal of micro plastics, reactions, and factors influencing their efficiency [11].

Treatment technique	Positive aspects	Negative aspects	Controlling factors	Reactions involved	Reference
Coagulation	Simple and fast operation, different coagulants can be used, remove various pollutants, relatively low cost	With a large volume of produced sludge, additives addition increases the cost and difficulty of dealing with different pollutants simultaneously	Type and dose of coagulant, pH level, pollutant charge, concentration	Charge neutralisation, adsorption, sweep flocculation	[36]
Membrane bioreactor technology	Removing different pollutants with various concentrations, high effluent quality, good removal efficiency	Aeration limitations, membrane fouling, the need to add nutritious materials to microorganisms, high cost	Pollutant load, membrane characteristics, flow rate, microorganism	Combination of membrane filtration, including micro or ultrafiltration	[37]
Rapid sand filtration	Removing various pollutants, including viruses, small land area, low sensitivity to water quality parameters, high flow rate	Low efficiency, requires expensive flocculating materials, frequent maintenance, high cost	Flow rate, contact time, pollutant concentration	Flocculation, sand filtration	[37]
Adsorption	High removal efficiency, no sludge waste formation, various adsorbents could be used	Non-selective adsorption	Type and composition of adsorbent, coexisting pollutants	Electrostatic interactions, hydrogen bond interactions, π-π interactions	[38]
Photocatalytic degradation	Eco-friendly, sustainable, high removal efficiency	High energy requirement (ultraviolet light)	Type and dose of photocatalyst, pH level, reaction temperature, pollutant concentration, light intensity	Electron transfer, formation of free radicals	[39]
Electrochemical oxidation	High efficiency, degradation of several organic pollutants, no need for adding chemical agents, no sludge formation	High cost of electrodes	Surface area and the material of the anode used, current intensity, type, the concentration of the electrolyte used, degradation reaction time	Anodic oxidation, indirect cathode oxidation	[40]
Electro-coagulation	No need for chemical coagulant materials, reduced operation time and cost, reduced amount of generated sludge, high efficiency with various water qualities	Need for frequent change of electrodes	Electrode efficiency, applied electricity, pollutant charge and concentration	Flocs formation, micro-coagulants formation, pollutant destabilisation	[41]
Magnetic separation	High removal efficiency, various magnetic separators use to remove microplastics from sediment, freshwater, and seawater samples	on-selective pollutant removal	Size and shape of the target pollutant	Electrostatic interaction, hydrogen bond formation, complexation	[42]
Conventional strategies for microplastic removal have been used for many years in water treatment plants and involve physical and chemical processes. In contrast, innovative microplastic removal techniques are still being developed and tested but hold promise for more efficient and effective removal of microplastics. It's important to note that while these techniques can be effective at removing microplastics from water, prevention is still the best solution. This includes reducing our use of plastic products and properly disposing of them to keep them out of the environment treatment technique.					

Recommendations and Effective measures to be taken

Microplastics have garnered increasing attention as a concerning category of pollutants. Addressing their growing impact requires sustainable solutions short-term and long-term cost-effective strategies should be made considering factors such as a country's infrastructure, economic conditions, types of microplastics released, alternative options, and public readiness to transition to a non-plastic dependent economy. The most effective strategy is 7 R's strategy that is reducing, reusing, recycling, refusing, rethinking, regifting, recovering (7 R's), and ending with disposal [43]. To minimise plastic production media sources such as television shows, journals, and social media platforms can play important role to improve the general knowledge and awareness of microplastics. Implementing these waste minimisation strategies on a governmental and individual level is essential to effectively control microplastic pollution [44]. People should bring change in their behaviour and opt for natural things like clothes made of cotton and wool instead of synthetic fibres, natural materials in cosmetics and personal care products, avoiding single-use plastic items like bags, cups, and bottles and using alternatives made from natural materials can be a viable strategy [45, 46, 47].

Additionally, use of eco-friendly polymers and Bioplastic which is biodegradable in nature gives a promising solution in food and pharmaceutical packaging industry, electric and electronic appliances, such as touch screens for smartphones and laptops, circuit boards, and data storage and in automotive industry for airbags and seat covers [48].

Conclusion

The development of risk assessment for microplastics (MPs) in ecosystems requires several key steps. Firstly, a clear definition of MP types and size ranges is crucial. Standardization and internationalization of sampling, processing, identification, and quantification procedures are needed. Strategies to reduce MP presence, such as emission prevention and sustainable plastic use, are vital. Reliable methods for assessing MP pollution levels and innovative technologies to prevent plastic discharge must be developed, including eco-friendly polymers.

Microplastics, particularly those under 150 μm, can be absorbed by biota at various levels, posing risks to human health. These risks encompass acute and chronic toxicity, carcinogenicity, developmental and genotoxicity. Nano plastics further raise concerns about chronic toxicity and developmental effects.

Although toxicity and analysis methods for MPs are summarized, the establishment of a robust dose-response model necessitates more research.

This study comprehensively examines MP definitions, characterizations, ecosystem levels, detection methods, and risk assessment strategies. It serves as a foundational resource for future investigations into human and ecosystem health impacts. Effective prioritization of high-risk MPs through appropriate risk assessment approaches is crucial for guiding future research. This study thus lays a strong foundation for understanding and mitigating the impact of MPs on ecosystems and human well-being.

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