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Relationship between climate change and environmental microplastics: a one health vision for the platysphere health

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Abstract

The production, dispersal, and accumulation of microplastics (MPs) are interconnected with climate change. Plastic production, which involves fossil resources like oil, generates greenhouse gas emissions during extraction and processing, contributing to global warming. Simultaneously, climate change influences the dispersion, fragmentation, and accumulation of MPs; extreme weather events facilitate plastic transport to the sea and natural environments. The increasing environmental impact of MPs poses a global challenge. This review focuses on the dispersion of MPs due to climate change, with attention given to the "One Health" approach. This promotes interdisciplinary collaboration, recognizing the interrelationship of human, animal, and ecosystem health. Crucial for a broad perspective on global health, the "One Health" approach emphasizes the need to understand and address MPs in the environment. In conclusion, implementing protocols for health monitoring and educating the public on responsible plastic management are essential. These preventive indications can help mitigate the effects of MPs, promoting a sustainable lifestyle from a One Health perspective.

Keywords One health, Climate change, Microplastics, Carbon dioxide, Platysphere

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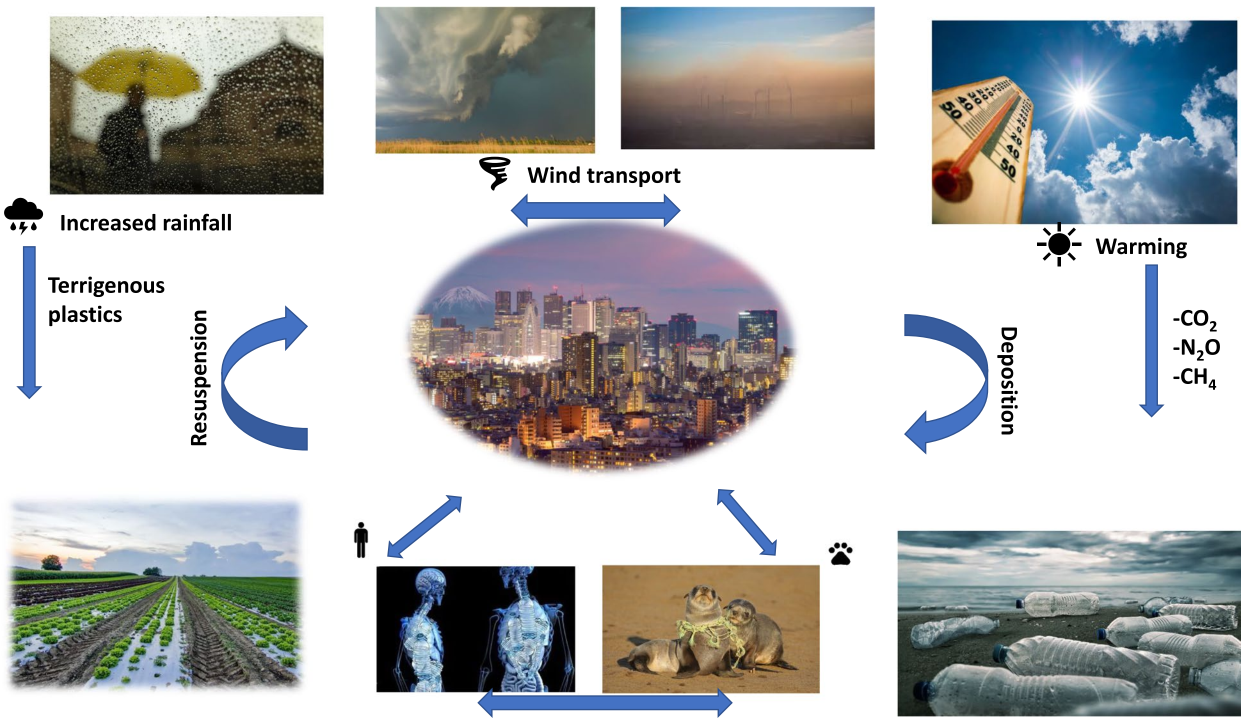
Graphical Abstract



Introduction

Global temperature has increased by 1.25 °C as a result of anthropogenic activities, and the current emission trend suggests that the 1.5 °C threshold may be surpassed within a decade [1]. "*Climate change refers to long-term shifts in temperatures and weather patterns*". Such shifts can be natural, due to changes in the sun's activity, large volcanic eruptions, and fires. However, in the industrial era (1800s – today), human activities have been the primary drivers of climate change due to the burning of fossil fuels such as coal, oil, and gas. Burning fossil fuels, energy production, industrial activities, deforestation, agricultural practices (including animal husbandry), and oil and gas operations are major sources of greenhouse gas emissions. These emissions can trap the sun's heat and raise planetary temperatures, thereby causing climate change [1].

Key contributors to global warming includes greenhouse gases—namely carbon dioxide (CO_2), methane, nitrous oxides, and fluorinated gases—with CO_2 constituting the predominant factor (79% in the USA), stemming from substantial releases in industrial processes [2–4].

In 1860, Alexander Parkes patented celluloid, a semi-synthetic plastic material. The evolutionary trend and utilization of this novel material have been both myriad and revolutionary. From the advent of bakelite in the early 1900s to the emergence of nylon in 1935, up to contemporary plastics such as PET, utilized for mineral water packaging, and PVC, synthesized in 1912 and definitively employed since 1939, these materials have found multifaceted applications [5].

Post-World War II, plastic assumed an increasingly prominent role in industrial production, agriculture, food packaging, and many other consumer products intertwined with human activities and the environment. Plastics, which are characterized by non-degradability and non-biodegradability, undergoes gradual breakdown into tiny fragments in natural environments, giving rise to microplastics (MPs) [6, 7]. According to the official definition by the European Commission, MPs are defined as "*extremely small pieces of plastic debris in the environment resulting from the disposal and breakdown of consumer products and industrial waste*" [8].

Plastics are acknowledged as emergent persistent pollutants that are capable (non-biodegradable) of causing contamination for extended periods in all environmental matrices [9].

Several studies have shown the circularity of actions and effects between climate change and MPs [10].

Hence, through a comprehensive review of existing literature, we believe that a One Health approach to addressing the active interelationships between climate change and MPs requires an integrated and cohesive strategy across various fronts (Fig. 1).

In fact, the One Health Approach:

- It consolidates human health, animal health, and environmental health considerations.
- It catalyzes collaborative, cross-sectoral, and multidisciplinary initiatives.
- It advocates for international cooperation to address global challenges, encompassing climate change and anthropogenic plastic pollution, specifically in the form of MPs.

This review primarily focused on MPs and climate change dynamics highlighting the dispersion of MPs and their ecological fate in diverse environmental compartments with a specific emphasis on terrestrial ecosystems, and their contributions to increasing climate change.

Climate change and MPs

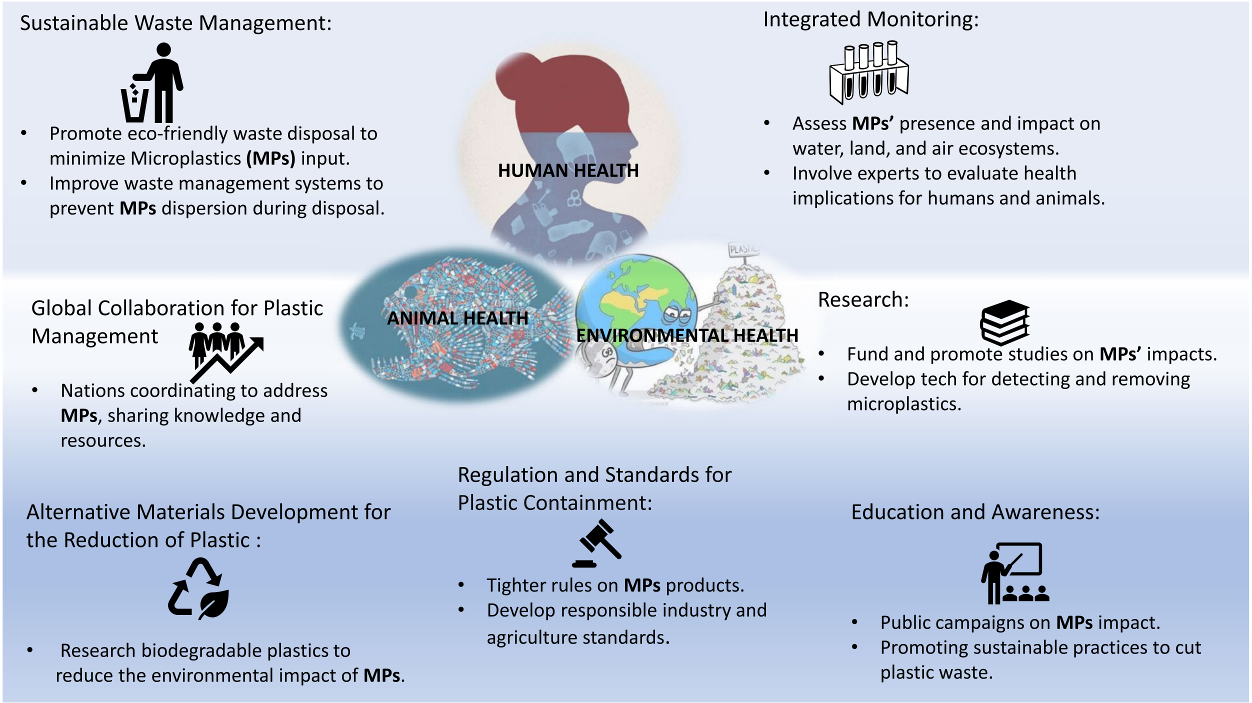
MPs play a pivotal role in climate change due to several factors: intensified plastic production (for the synthesis emissions), inadequate disposal methods, and their ability to release climate-altering gases during fragmentation [11, 12]. Approximately 99% of plastic is derived from non-renewable resources such as oil, natural gas, and coal. Projections indicate that by 2050, the plastics industry will contribute to 20% of global oil consumption [13].

The substantial impact on climate change is not limited only to the production phase, but encompasses the entire lifecycle of plastics, involving heightened CO_2 emissions [14, 15].

As a direct effect of climate change, rising temperatures increase the frequency of extreme weather events, which in turn accelerate sea-level rise and ocean acidification. These changes significantly contribute to the widespread dispersion of plastic litter in the environment and affect the ability of organisms to adapt to these changing conditions.

Furthermore, several authors have demonstrated that climate change has various effects on the fate of environmental MPs. Increasing environmental temperatures lead to the fastest degradation of plastic with the release of smaller microplastic particles due to the induction of contractions and expansions in plastics [16], but also increased their susceptibility to other deeper degradation processes [10].

In the environment, interactions between plastic waste and environmental components (wind, ice, floods, waves, sunlight, etc.) can catalyze the degradation of large plastic pieces into smaller plastic debris. Common plastics, such as Polyethylene (PE) (constituting 36% of production) or Polystyrene (PS), release methane and ethylene



Sustainable Waste Management:

- Promote eco-friendly waste disposal to minimize Microplastics **(MPs)** input.
- Improve waste management systems to prevent **MPs** dispersion during disposal.

Integrated Monitoring:

- Assess **MPs'** presence and impact on water, land, and air ecosystems.
- Involve experts to evaluate health implications for humans and animals.

Global Collaboration for Plastic Management

- Nations coordinating to address **MPs**, sharing knowledge and resources.

Research:

- Fund and promote studies on **MPs'** impacts.
- Develop tech for detecting and removing microplastics.

Alternative Materials Development for the Reduction of Plastic :

- Research biodegradable plastics to reduce the environmental impact of **MPs**.

Regulation and Standards for Plastic Containment:

- Tighter rules on **MPs** products.
- Develop responsible industry and agriculture standards.

Education and Awareness:

- Public campaigns on **MPs** impact.
- Promoting sustainable practices to cut plastic waste.

Fig. 1 One health approach on the topic of MPs into the atmosphere when fragmented by UV rays. Methane reacts with OH ions in the atmosphere, forming CO_2. This cyclical process exponentially amplifies greenhouse gas emissions, exacerbating climate change (Fig. 2) [17].

Both traditional plastics and contemporary bioplastics emit greenhouse gases, initiating enduring environmental impacts [18, 19].

The morphology and age of plastics can directly affect the quantities of emitted greenhouse gases. Plastic material with the largest surface area (increased by fissuring or breaking) enhances the total photodegradation exposure and effects. With the decomposition of plastics into MPs in the smallest nanoplastics, the rate of greenhouse gas release progressively increases [17]. We can also highlight an indirect contribution to the greenhouse gas emissions from plastics considering their manufacturing. Large quantities of oil are used globally in the plastic industry representing another important contributor to global gas emissions causing global warming [20].

Hence, a negative cycle is in motion, caused by a cascading reaction. As plastics undergo degradation, a process induced by factors such as sunlight, they expose an increased surface area to environmental elements, especially solar radiation.

Considering climate change, the global warming has increased the intensity and frequency of precipitation, glacial thawing, and intensified cyclones, all contributing to the enhanced dissemination of MPs.

MPs have been identified in nearly all aqueous and terrestrial ecosystems. Predominant polymers include several shapes such as fibers, particles, and films. Among the MPs, PE = Polyethylene, PP = Polypropylene, EPM = Poly (ethylene-propylene) copolymer, PVA = Poly (vinylalcohol), PS = Polystyrene, PET = Polyethylene terephtalate, PU = Polyurethane, PAN = Polyacrylonitrile, PA = Polyamide, PVC = Polyvinil chloride, PVAc = Polyvinyl acetate are the predominant chemical species (Table 1) [21, 22].

These circumstances suggest that, as plastic materials fragment and degrade, the emission of greenhouse gases into the atmosphere per unit of material amplifies, persisting throughout the material's very long lifecycle [13, 27].

Environment and MPs

Climate change, facilitated by meteorological phenomena such as winds, accelerates the dispersion of plastic particulates [28]. However, during humid events such

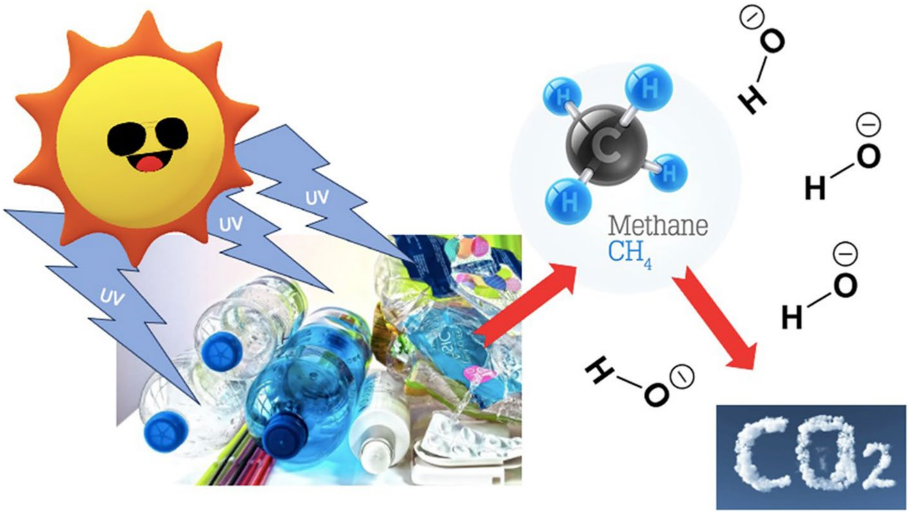


Fig. 2 CO_2 emissions from plastic due to sunlight

Table 1 Characterization and concentration of MPs in different geographic areas

Location	Sampling	Polymer types	Plastic microfiber deposition (mf m^{-2} day^{-1})	Reference
Central London	Urban	PP; PE; PS; PET; PU; PVC	575 – 1008	[23]
Ireland	Rural	PP; PE; PET; PA	12	[24]
Poland	Urban	PE; PP; EPM; PVA	0 – 30 $^{-1}$	[25]
China	Urban	PET; PA; PP	51178	[26]

as storms, larger MPs are deposited, likely originating from nearby urban areas. Conversely, smaller and lighter debris is transported over longer distances, and its deposition is linked to drier climatic conditions. The latter constitutes the predominant reservoir of deposited MPs [29, 30].

The formation of MPs is subject to diverse environmental factors. Acid rain, for instance, contributes to the deterioration of plastic materials. Acid precipitation, for instance, alters soil pH by reducing it leading to soil sterilization and consequential damage to crops [31].

The commonplace voluntary inclusion of small plastic particles in consumer products such as personal care items, which are subsequently discarded by washing after use (primary MPs) together with the debries that originate from plastic waste (secondary MPs), constitutes a significant direct source of plastic pollution in the environment including the soil and the sea, which represent the final acceptors (Fig. 3).

Soil and MPs

MPs have infiltrated intensive agricultural ecosystems through a combination of deliberate human activities and inadvertent releases, with the extensive utilization of plastic mulch film emerging as a direct prevalent source of MPs in soil ecosystems [32]. The agitated actions of farm workers, who are engaged in mowing and mulching activities, contribute to the dispersion of plastic fragments within the environment. The discarded grass, subjected to the mechanical forces of mower blades, undergoes fine fragmentation and subsequent dispersion on the soil surface. This plastic fraction, excluding collection, is progressively incorporated into the soil matrix, assuming a structural role over time [33, 34]. Moreover, 99% of MPs scattered on soils with wastewater sludges are dispersed by rain and irrigation water to reach rivers and seas. MPs leave a trail of various pollutants, including per- and poly-fluoroalkyl substances (PFAS), metals, and polychlorobiphenyls (PCBs), acknowledged as "eternal" chemical compounds [35, 36]. Consequently, water, air, and soil are currently heavily contaminated by MPs, which can have several adverse effects on plants, animals, and ultimately, human health [37, 38].

Table 2 shows how the concentration of MPs is present in different types of soil and countries.

Furthermore, irrigation practices employing wastewater serve as an additional way to introduce MPs into agricultural settings. Incidental sources include particles liberated through the abrasion of polymer materials in landfills and deposition from the atmosphere [35]**.** Due to their smaller size and relatively low density in comparison to natural sediments, MPs are susceptible to aerial transport by atmospheric currents [43]. Sewage sludge, which is rich in organic and inorganic nutrients, is widely repurposed as fertilizer in agricultural contexts and is presenting an economically advantageous means to

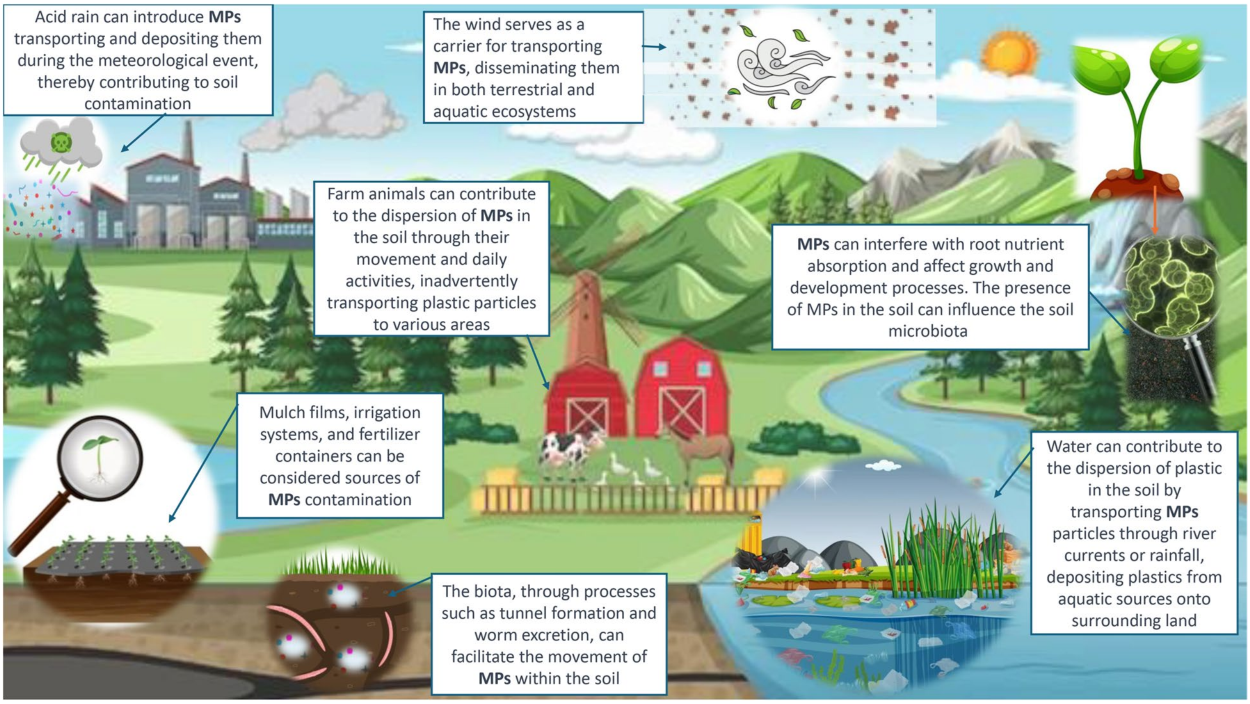


Fig. 3 Dispersion of MPs in the environment

Table 2 Concentrations of MPs in the soil of several countries

Location	type	MPs concentration	Polymer types	Reference
Tibetan Plateau	soil	5–340 items/kg	PVC, PE, PP, and PS	[39]
China	agricultural soils	4.94252.70 items/kg	PP	[40]
Chile	croplands	306 ± 360 particles/kg	PA	[41]
	Pasture	184 ± 266 particles/kg	PA	
China	soil	7100 to 42,960 particles kg^{-1}	Plastic fibers	[42]

enhance crop yields. Notably, the direct application of sewage sludge introduces a substantial volume of MPs into European agricultural land annually, with continued accumulation further elevating their concentration [44].

The introduction of MPs into soils induces modifications in biogeochemical cycles, including the nitrogen cycle, given the nitrogen content in the chemical structure of MPs. These alterations, however, extend beyond the direct realm, impacting microbiota/enzymes catalyzing nitrogen cycle reactions, soil fauna responsible for organic matter decomposition, and physicochemical soil parameters such as evapotranspiration, electrical conductivity, and macroaggregates proportions [39, 45, 46]. Direct consequences of these effects manifest in fruits and vegetables from terrestrial ecosystems. Studies indicate the presence of both MPs and nanoplastics (NPs) in these crops, with roots absorbing NPs that accumulate in them, and to a lesser extent, migrate to leaves and fruits. Vegetables such as salad or cabbage exhibit relatively lower concentrations, while carrots, turnips, radishes, and tubers tend to accumulate more (Fig. 3) [47, 48].

MPs perturb ionic homeostasis and the concentrations of essential elements such as Ca, N, P, and K in the roots and shoots of rice (*Oryza sativa*), making them of "hazardous" for these characteristics. Their presence induces oxidative stress, as evidenced by increased malondialdehyde (MDA) and H_2O_2 levels, coupled with elevated superoxide dismutase (SOD) and catalase (CAT) activities [49]. Consequently, MPs pose hazards not only through their translocation in plant roots but also due to tissue-specific retention of variously sized MPs in crops, influencing food quality and safety. Terrestrial plants exhibit the capacity to fix MPs, underscoring their ecological impact on agricultural ecosystems. Moreover, a critical aspect of this issue is linked to the release of greenhouse gases from soil containing MPs. The anaerobic decomposition of MPs, favored by specific soil conditions, can generate methane. Therefore, understanding and mitigating the impact of MPs on the soil becomes essential not only for the health of terrestrial ecosystems but also for addressing emerging challenges associated with climate change [50, 51].

MPs in water ecosystems

Plastic waste and MPs in oceanic environments constitute a secondary drivers of climate change, following direct atmospheric emissions of greenhouse gases. The escalating influx of plastics into oceans globally is a critical concern and is exacerbated by the finite assimilative capacity of the near-surface ocean layer. This finite space intensifies the impact of plastics on the water column temperature, wherein plastics influence the scattering and attenuation of incoming solar radiation. This, in turn, directly contributes to oceanic warming, thereby influencing climate change dynamics and the occurrence of meteorological disasters. In fact, when MPs are present in water and absorb sunlight, they increase the temperature of the water itself. Although this temperature increase may seem to be a localized phenomenon, it can have effects that extend well beyond individual areas. One of the most significant influences is on ocean currents [52]. If a specific area of the ocean warms, it can alter the water density, modifying ocean currents and circulation patterns. These changes can have lasting impacts on the climate of coastal regions and may even influence the global climate [53]. Plastics have the potential to instigate climate feedback cycles by affecting physical processes at the ocean surface, as delineated in studies such as that by VishnuRadhan et al. (2019) [54]. The pivotal role of algae in groundwater and oceanic primary production, which are vital for global CO_2 fixation and climate modulation, renders them susceptible to the dual threats of ongoing global warming and increasing MP pollution. While the heightened temperatures associated with global warming adversely impact cell viability in algae, certain taxa, such as diatoms, exhibit synergistic responses to the combined effects of MPs and warming. Notably, these algae exhibit substantial increases in growth rates and nitrogen uptake rates. The interactive influences of MPs and elevated temperatures extend to the promotion of essential metabolic pathways, including fatty acid metabolism, the urea cycle, glutamine and glutamate production, and the tricarboxylic acid cycle. Thus, the effects of MPs and elevated temperatures on algal carbon and nitrogen cycles in aquatic environments have emerged as non-negligible considerations, as expounded in the research by Sun et al. (2023) [55].

Furthermore, various studies have investigated the presence of MPs in drinking water [56]. One of the main entry points is linked to the improper disposal of plastic waste, or plastic waste can also originate from industrial sources, where manufacturing processes or industrial activities release plastic fragments into the environment [57]. Additionally, synthetic fabrics, common in many modern garments, release plastic microfibers during washing machines, which can then end up in the water system [58] (Table 3).

The impact of these MPs on drinking water is the subject of ongoing study and debate. The presence of such particles in water resources raises questions about safety and the need for effective strategies to reduce plastic production and responsibly manage waste. Addressing this challenge requires a One Health approach, involving legislators, industries, and consumers in transitioning towards more sustainable practices and promoting eco-friendly alternatives [63].

Effects of MPs on human health

MPs have become widespread contaminants in both the environment and the food chain. On average, people now ingest approximately 5 g of MPs per week [64]. However, the way MPs behave in the human body and their effects on human health are still not well understood.

Research from both laboratory and animal studies suggests that ingested MPs can pass through the intestinal barrier, enter the bloodstream, and affect various organs such as the liver, kidneys, and intestines. This can lead to oxidative stress, metabolic problems, inflammation, and harm to the immune and nervous systems [65]. Oliveri Conti et al. (2020) [47] reported that absorption into a plant system follows an inversely proportional pattern to the size of the nanoparticles. This phenomenon could have a significant impact on the growth of plants and fruits. Larger particles encounter difficulty in entering plant cells, while nanomaterials can be absorbed through the roots, penetrate seeds, and subsequently translocate to shoots and aerial parts. These evidences underscore the importance of furthering our understanding of the impacts of MPs in the context of food production and food safety [47].

Table 3 Different water sources and their respective concentrations of MPs

Location	Type	MPs concentration	Reference
14 countries World-wide	Tap water	4.23 particles per L	[59]
Groundwater	raw water and drinking water	0 7 particles s per m^3	[60]
Ergene River	surface water	4.65 ± 2.06 to 6.90 ± 5.16 (particles L^{-1})	[61]
Qiantang River	surface water	1183 ± 269 particles/m^3	[62]

Food consumption is considered one of the primary and most significant pathways of human exposure to MPs. Concerns may arise not only from the exposure to the plastic polymer itself, which, although generally considered biologically inert, may still contain some reactive monomers in its structure, but also from associated chemicals or contaminants.

Many researchers have reported oxidative stress and immunotoxicity as the main consequences of exposure to virgin micro and nanoplastic particles, with the latter having a longer retention time within the organism. Additionally, numerous studies have provided information on the individual toxicity of many plastic additives and components (e.g., flame retardants, plasticizers, monomers), as well as the potential adverse effects caused by environmental pollutants sorbed to MPs [7].

Studies using human placental cell models and experiments with placental tissues have shown that PS—MPs can cross the placental barrier [65, 66]. Ragusa et al. detected MPs in human placenta samples. However, our understanding of how these MPs interact with the placenta is still limited [67–69] (Table 4).

Gathering more information about these processes is crucial for a better grasp of the potential risks to placental development and function and how these might impact fetal health (Table 4) [69].

The effects of MPs on biodiversity and animal health

Plastic in the environment harms both terretrial and aquatic ecosystems, causing significant concerns [70]. For instance, marine life is particularly affected by the ingestion of various plastic waste items, such as nets, balloons, bags, and bottles. Bags, in particular, can strangle or suffocate birds and marine creatures. If these creatures swallow plastic bags, they can damage their digestive systems or even cause starvation by blocking their stomachs. Birds searching for food along the shore also risk being caught in plastic debris [71].

Research by Zhai and others revealed that 16 out of 17 landbird species had MPs in their digestive tracts [72]. Additional studies have revealed that some plants, such as turnips, contain MPs [73, 74]. An example of the harmful impact of plastics can be seen in the case of the California Condor, a critically endangered species. These

Table 4 MPs on placentas

Sample type	Size	Effects	Reference
carboxylated polystyrene spheres (PS25C)	25 nm	Nanoscale PS magnetic nanoparticles (MNPs) have the ability to penetrate the intestinal barrier, allowing them to subsequently traverse the maternal-fetal barrier of the placenta. This enables access to the fetal circulation and all fetal tissues	[68]
MPs PP	rom 5 to 10 μm	MPs were found in 4 of 6 placentas	[67]
PS nanoparticles	80 nm	the protein corona formed by human albumin significantly induced the transfer of MPPSs across the placenta	[66]
COOH-modified PS	50 nm - 0.5 μm	Intestinal and placental cellular uptake and intracellular accumulation of MNPs and MPs of PS	[65]

birds ingest plastic from landfills, which is believed to be a significant factor in their nesting failure [75].

Exposure to MPs, which results from this problematic feeding behavior, increases the risk for these species. This type of diet, consisting of organic waste and synthetic materials, can lead to intestinal blockages, nutritional issues, infections, and metabolic changes [76]. Cary et al., in a rat study, proposed that very small MPs could move through the intestinal lining, enter the bloodstream, cross the placental barrier, and reach fetal tissues [68].

On land, the increasing accumulation of MPs in soils poses a threat to microclimates and soil biodiversity. Earthworms play a crucial role in ecosystem processes and are often considered ecosystem engineers. They are widely used to evaluate the toxicity of pollutants. Studies have shown that exposure to soil contaminated with MPs affects the health of earthworms, causing damage to their reproductive organs, increased oxidative stress, higher mortality, and DNA damage [77, 78]. The decreasing numbers of these invertebrates signal a significant issue for soil health. Earthworms help maintain soil moisture and aeration by digging tunnels, and they are essential for breaking down organic matter in the soil, releasing important nutrients such as nitrogen and phosphorus [79].

Interestingly, recent research has shown that the microbiomes of certain insects can break down plastic. The main organisms involved in this process are *Zophobas morio* and *Tenebrio molitor* [80]. These insects use their oral appendages to mechanically break down and ingest plastic particles, which are then further broken down by the microbial community in their digestive tracts. The enzymes present in these insects are capable of degrading materials such as PS and styrene. Expert estimates suggest that PS takes more than 100 years to breakdown naturally, but with the help of *Zophobas morio* and *Tenebrio molitor*, this process could occur in just a few days [81].

From a climate change perspective, the widespread presence of plastic has significant consequences for biodiversity, contributing to the loss of variety in various life forms [82].

The negative consequences of plastic on biodiversity are evident in both land and sea, where marine species and birds risk entanglement, suffocation, and damage to their digestive systems due to the accidental ingestion of plastic waste. The loss of biodiversity in these communities raises a range of concerns, with cascading impacts throughout the food chain.

Plastic, as a pervasive pollutant, contributes to the degradation of ecosystems, creating a vicious cycle where biodiversity loss and climate change mutually influence each other [83].

Conclusion

Platisphere is an important environmental reservoir of MPs in all ecosystems. Compared to aquatic environments, soils accumulate more MPs, which adversely affects the health of terrestrial biota.

The Paris Agreement of the UN Framework Convention on climate change provides an opportunity for achieving decarbonization, representing the first tool to minimize global warming, also thanks to the energy transition. However, currently, no indications are available to limit the emission of MP by-products and plastic wastes except for EU regulations (2019/904). Another important tool to minimize climate change is to achieve complete management of plastic waste increasing the prevention of MPs dispersion, to protect planetary health, especially human health and to address plastic pollution by preventing virgin plastic production. It is important to highlight the lack of proper regulations, so we need a worldwide policy setting that could regulate the green production of plastics and the recovery of plastic waste from the environment.

We hope that our proposal of a "One Health" point of view of the problem could be used to promote effective measures for a wider application of One Health approaches in shaping real-world policies and practices in the relationships between plastics and environmental health.

In summary, the widespread presence of plastic in the environment and its impact on humans are issues of growing concern. Plastic has become an integral part of our modern world, but its constant presence and large-scale production have led to significant environmental and health consequences. The accumulation of plastic waste in our oceans, air, and soil, along with potential implications for human health, calls for concrete actions to address this issue. It is essential to reduce plastic production, promote recycling, and develop sustainable alternatives to mitigate the negative effects on human health and the global ecosystem.

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Authors' contributions
G.O.C.: Conceptualization, Methodology, Software, Writing- Reviewing and Editing; P.R.: Data curation, Formal analysis, original draft preparation, Writing- Reviewing and Editing; M.F.: Visualization, Investigation, Supervision, Validation, Reviewing and Editing. All authors read and approved the final manuscript.

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