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Environmental Co-existence of Microplastics and Perfluorochemicals: A Review of Their Interactions

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Abstract: The co-existence of microplastics and perfluorochemicals in the environment has raised concern about their potential interactions, which could complicate their ecotoxicity. This article aims to review the interactions between microplastics and perfluorochemicals in the environment, particularly the mechanisms of interactions and the factors affecting the interactions. It reviewed more than 40 scholarly articles published in the past five years. Thematic analysis was performed on the articles to extract the related information. The review highlights that owing to the structures of perfluorochemicals consisting of hydrophobic moieties and charged functional groups, as well as the surface chemistry of microplastics, the main mechanisms governing the interactions are hydrophobic interactions, hydrogen bonding and electrostatic interactions, with some pore-filling. The interactions are primarily sorption, with adsorption being predominant. Adsorption of perfluorochemicals onto microplastics is generally positively correlated with the carbon chain lengths of perfluorochemicals. However, it is also affected by the functional groups of perfluorochemicals, the types and sizes of microplastics, as well as environmental factors comprising pH, ionic strength, concentrations of organic matter, and the presence of other contaminants. This review provides crucial insight into the interactions between the two pervasive pollutants to permit better characterization of their risk and ecotoxicity in different environments.

Keywords: ecotoxicity; electrostatic interactions; hydrophobic; ionic strength; microplastics; perfluorochemicals.

1. Introduction

Microplastics (MPs) and perfluorochemicals (PFCs) are two emerging pollutants that have received much attention. They are both persistent and widespread. The permeation of MPs into different environmental compartments has been reported in multiple studies due to the increasing use of plastic products [1, 2]. Voluminous macroplastics and MPs have been generated due to the mismanagement of plastic waste. On a global scale, India was the largest generator of mismanaged plastic waste in 2019, contributing 21.04% of the global total. This was followed closely by China at 19.87% and the Philippines at a significantly lower share of 6.52% [3]. The mismanaged plastic waste composes largely of inadequately disposed or littered macroplastics, which could subsequently undergo aging and degradation in the environment, forming secondary MPs [4]. Due to their small sizes, including primary MPs in the calculation of mismanaged plastic waste volume is challenging. Primary MPs can come from numerous sources, such as microbeads in personal care and cosmetic products, microfibers from synthetic textiles, and plastic pellets and additives. Both primary and secondary MPs form the pool of MPs in the environment, and they could be subjected to further degradation, forming nanoplastics that add complexity to the existing plastic pollution [5].

Like MPs, PFCs are found in many consumer products. They are synthetic organic compounds with strong carbon-fluorine bonds that give them hydrophobic and oleophobic properties [2]. These properties confer PFCs a wide array of applications in electrical wiring, clothing, as well as household, cosmetic, and automotive products [6]. They are frequently used as friction-resistant, water-repelling, and oil-repelling materials, such as non-stick coatings. PFCs have also found their use in manufacturing oil- and moisture-resisting paper coatings, albeit in small quantities. This gives rise to the concern of human exposure to PFCs through ingestion of PFCs transferred from these coatings to food [7]. In addition, PFCs are widely used in fire-fighting foam, resulting in their prevalence on fire-fighting training sites [8]. PFCs comprise diverse fluorinated organic compounds often derived from hydrocarbons with fully substituted hydrogen. Like hydrocarbons, they can have different carbon chain lengths and functional groups attached and are, therefore, named according to the carbon chain lengths and the functional groups. Perfluorocarboxylic acids (PFCAs) and perfluoro sulfonic acids (PFSAs) are the two most common PFCs with a carboxyl group and sulfonate group attached, respectively. Perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS) are two typical examples of PFCAs and PFSAs, respectively, bearing eight carbons in the carbon chain [9].

PFCs are highly persistent and tend to accumulate in the environment. Landfill leachate and garbage dumps were found to contain different PFCs at varying concentrations, and they are important sources of PFCs in the environment [10, 11], causing soil pollution with PFCs detected to a depth of 15 m below the soil surface [12]. The presence of PFCs in a multitude of items due to their versatility has resulted in a complex mixture of PFCs in landfill and dumpsite leachates [13]. Aqueous film-forming foams are another important source of PFCs, and they are frequently used in foam-type fire extinguishers to blanket hydrocarbon fuel surfaces and cut off the oxygen supply for combustion. Fluorotelomer in the foams breaks down under heat, forming PFOA, which subsequently enters the soil and migrates into groundwater [12]. In addition, PFCs enter the environment through the effluents of wastewater treatment plants which are either discharged into waterways or recycled for agricultural irrigation [14]. PFCs are also entrapped in sludge during wastewater treatment, and the application of biosolids derived from wastewater treatment sludge causes PFCs to enter soil [15]. Nonetheless, it was reported that concentrations of PFCs in soil treated with biosolids were low [16]. Despite the efforts to phase out PFCs, it is likely that PFCs will stay in the environment due to their recalcitrant nature. The elimination or substitution of PFCs in consumer products and industrial applications is bound to be challenging due to their unique properties that confer their versatility.

Similar to PFCs, MPs have permeated all environmental phases and are persistent. MPs have been detected in landfill leachate, especially untreated landfill leachate. They are found in sludge dewatering liquor from leachate treatment [17]. Wastewater treatment plants are also known as an important source of MPs. While they receive MPs in inflowing wastewater streams from different sources, the wastewater treatment process traps and concentrates most of the MPs in sludge [18]. A sludge-to-influent MPs ratio as high as 3.4 has been reported, probably due to the recycling of activated sludge resulting in the accumulation of MPs before treatment and disposal. The commonly reported sludge to influent MPs ratios ranges from 0.02

to 0.77, indicating sludge is a significant sink of MPs in wastewater treatment [19]. Wastewater treatment sludge is usually recycled as biosolids for agricultural application, and once applied as fertilizer, these biosolids return MPs to the environment [20]. It was found that agricultural soil fortified with biosolids contained significantly more MPs than that without [21]. MPs have been detected in soil and surface water at widely varying concentrations, which to a certain extent, depending on population density and intensity of anthropogenic activities [22]. The presence of MPs could also be tracked to remote areas such as the Scilly Islands of the United Kingdom [23].

MPs and PFCs share the major commonalities that both are recalcitrant to degradation and are found in all environmental media, even those of remote regions. It is highly likely that MPs and PFCs coexist in certain media, particularly in soil, sludge, water treatment plant effluents, and surface water, leading to their interactions. However, papers examining such interactions are limited, let alone reviews. The existing papers in this area are mostly research papers investigating the adsorption of PFCs on different types of MPs such as polyamide (PA) [24], polyethylene (PE), polystyrene (PS) [25, 26], as well as aged microplastics in the environment [27]. Reviews on interactions of MPs with other organic pollutants and heavy metals encompassing their adsorption behaviors [28, 29] and effects [30] are available, but they are not specific to PFCs. Because of a lack of reviews to systematically and critically present the interactions between the two important emerging pollutants, this review aims to examine the interactions between MPs and PFCs to evaluate the influences of such interactions on their fates and transport in the environment. It has the novelty of delving into the in-depth of these interactions to explain the underlying mechanisms and the factors influencing them, through which the risks and ecotoxicity can be better understood.

2. Materials and Methods

Articles related to the interactions between MPs and PFCs were first retrieved from major scientific journal databases comprising ScienceDirect, Scopus, and Web of Science [31]. The main keywords used in the search were microplastics, perfluorochemicals, perfluoroalkyl substances, interactions, sorption, and adsorption. Combinations of keywords, such as interactions/ reactions between microplastics and perfluorochemicals/ perfluoroalkyl substances, were entered to refine the search. The articles retrieved were further screened with the following inclusion criteria: 1) They must be peer-reviewed; 2) They must have been published within the last 10 years; 3) They must be about the interactions of microplastics and perfluorochemicals, not other types of chemicals; and 4) They must be about microplastics and not nanoplastics. 105 papers were retrieved from the databases, but only 51 passed through the screening and were included in this review. Thematic analysis was performed to extract the relevant information.

3. Results and Discussion

MPs provide ideal surfaces for the adsorption of PFCs due to their small sizes, hence large surface area. As such, MPs are potential carriers of PFCs into various receptors upon exposure, especially through ingestion and inhalation [5]. As PFCs contain hydrophobic moieties and MPs are usually hydrophobic, interactions between the two substances are likely. Other than PFOS and PFOA, the PFCs commonly encountered in environmental samples are perfluorobutanoic acid (PFBA), perfluoropentanoic acid (PFPeA), perfluorohexanoic acid

(PFHxA) and perfluoroheptanoic (PFHpA) acid [12, 22]. PFCs have been revealed to disrupt the respiratory, reproductive, endocrine, and immunological systems [33]. The coexisting MPs in the environment could concentrate PFCs and increase their ecotoxicity. In fact, Alvarez-Ruiz *et al*. underscored that the bioaccumulation of four PFCs in Mediterranean mussels (*Mytilus galloprovincialis*) could be facilitated by PE MPs, which acted as a vector of the PFCs, and MPs seemed to impede the expulsion of the PFCs from the mussels [34]. MPs of polyvinylchloride (PVC) in soil caused higher bioaccumulation of PFOA and PFOS (>200% higher) in earthworms, implying the potential of MPs to concentrate the chemicals leading to their increased uptake. This aggravated the decline in their reproduction [35]. As such, understanding the interactions between MPs and PFCs and the factors governing them becomes crucial.

3.1. Sorption mechanisms of PFCs on MPs.

Sorption generally refers to absorption and adsorption, where a substance is attached to another physically or chemically. It is frequently used interchangeably with adsorption, and in most instances, the former indicates the partitioning of a dissolved chemical to a surface in a non-specific way. In this paper, where sorption appears, it mainly implies adsorption. A study was conducted to examine the adsorption of six PFCs on PA MPs, and it revealed that PFOS adsorbed to PA MPs to the largest degree (0.873 mg/g), followed by PFOA (0.235 mg/g), PFHpA (0.231 mg/g), PFHxA (0.201 mg/g), PFPeA (0.192 mg/g) and PFBA (0.188 mg/g) isothermally at pH 5.88. This shows a clear trend of decreasing adsorption with decreasing carbon chain lengths, leading to a decline in hydrophobicity [24]. It was further shown that hydrophobic interaction, pore filling, and hydrogen bonds played an important role in the sorption of PFCs to MPs (Figure 1). Generally, PFOS portrayed a greater inclination to sorb onto PA MPs in comparison to PFCAs [24]. Another study demonstrated the greater affinity of PFOS and perfluoro-sulfonamides on MPs, particularly PS and polystyrene carboxylate (PS-COOH), confirming the higher tendency of PFOS to sorb onto MPs [25]. More PFCs were found to sorb onto PS and PS-COOH than HDPE, owing probably to the limiting rate of PFCs diffusion into the pores of granular HDPE MPs [36]. Du *et al*. had previously reported higher adsorption of PFCs on powdered sorbents with a high surface area than on granular sorbents [37]. The sorption of PFCs on MPs tested in the study followed the Freundlich Isotherm [25].

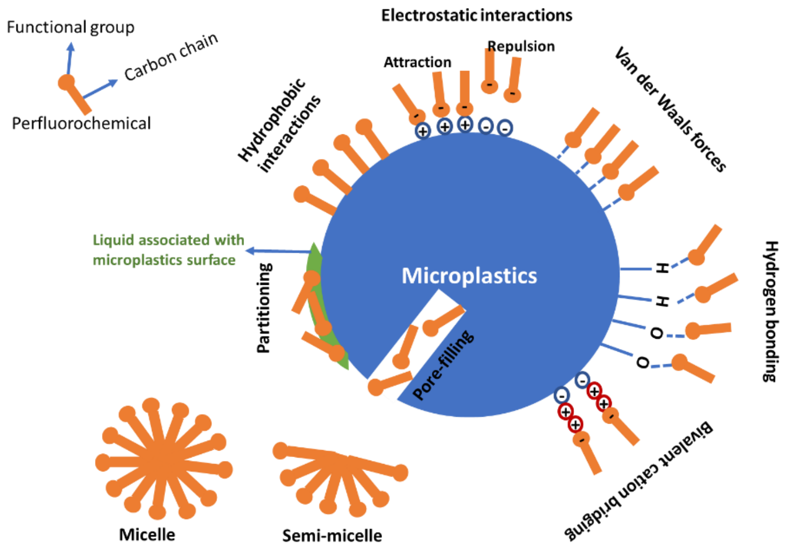

Figure 1. Mechanisms of PFCs sorption onto the surface of MPs.

While it is generally established that PFCAs of longer carbon chains have higher sorption coefficients in an aqueous environment due to greater hydrophobic interactions, some very long-chain PFCAs such as perfluorohexadecanoic acid (PFHxDA) and perfluorooctadecanoic acid (PFODA) do not seem to follow the trend [38]. The reason could be due to their formation of semi-micelles or higher affinity to dissolved organic carbon in water (Figure 1) [39]. Besides, certain exceptional behaviors of PFCs, such as the lack of influence of ionic strength on the adsorption of perfluorooctanesulfonamide (FOSA) on PE and PS MPs, imply predominating hydrophobic interactions, whereas a rise in the adsorption of PFOS as ionic strength increases points to the influence of electrostatic interactions on ionizable PFCs (Figure 1) [40]. A study on the mechanisms of PFCAs adsorption on PS MPs through linear solvation energy relationship revealed that polarizability and hydrophobicity promote adsorption. Dipolar interactions were identified as the most important adsorption mechanism between MPs and PFCAs, followed by bulk water's polarization induction effect and hydrophobic repulsion or non-specific van der Waals attraction (Figure 1) [26]. Higher polarization induction of water decreases adsorption, while greater hydrophobic repulsion of PFCAs in water or van der Waals attraction between PFCAs and MPs increases adsorption. Nonetheless, the study was constrained in its ability to differentiate the effects of hydrophobic repulsion and van der Waals attraction [26].

A study investigating the sorption of PFOA on PVC and PE MPs in simulated seawater revealed low affinity of PFOA to spherical PVC ($K_d = 7 \pm 2$ L kg^{-1}) and PE ($K_d = 496 \pm 358$ L kg^{-1}) sized 200 – 250 µm [41]. This implies that the sorption of PFCs on MPs is affected by multiple factors, such as the ionic strength of the aqueous environment and the types of MPs. The study shows the adsorption followed linear isotherm instead of Freundlich isotherm, as reported in the study of Llorca *et al*., suggesting the prevalence of partition effect [27, 34]. However, in the study of Ateia *et al*., hydrophobic and van der Waals interactions were identified to be the major mechanisms of the sorption of PFCs on MPs. The study also showed MPs adsorb PFCs more readily than the constituent polymers due to surface roughness and additives consisting of dyes, stabilizers, plasticizers, etc. [42]. This again unveils a wide range of factors affecting interactions between MPs and PFCs, which is further discussed in subsequent sections. Besides, partition-domain interaction has been identified to govern the sorption of PFOS and FOSA on MPs [40].

3.2. Factors affecting sorption of PFCs on MPs.

Sorption of PFCs on MPs is influenced by numerous factors, consisting of MPs types which determine their polarity and crystallinity, MPs sizes and extents of aging, physicochemical properties, particularly the pK_a and K_{ow} of PFCs which determine their behaviors in different pH and their hydrophobicity, as well as the environmental conditions ranging from ionic strength, temperature, and pH to dissolved organic matter (Figure 2). Conventionally, MPs of PE, PS, and polypropylene (PP) types are widely studied for their sorption of PFCs. Two main sorption mechanisms, namely hydrophobic and electrostatic interactions, have been proposed (Figure 1). Besides, it is likely that other mechanisms, such as pore filling, partitioning, and hydrogen bonds, might be involved. The diverse arrays of MPs and PFCs mean that different types of interactions could be involved for different MP-PFC pairs, and these interactions are subjected to many influencing factors. These factors could be largely classified into the properties of MPs, the properties of PFCs, and environmental factors.

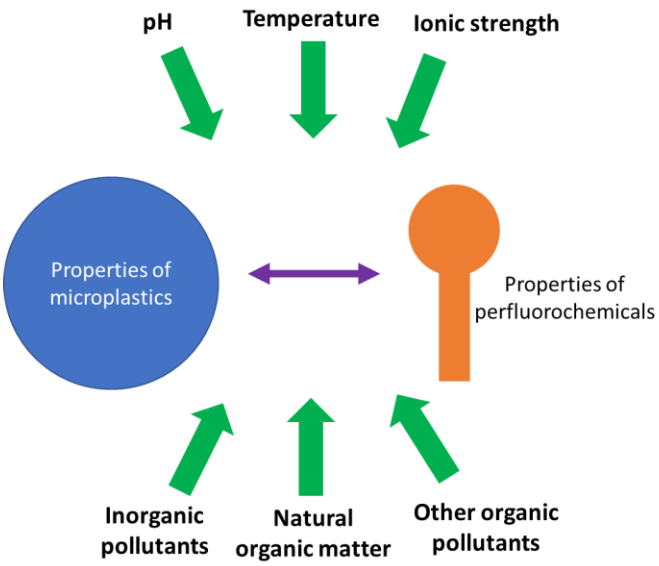

Figure 2. Factors affecting the interactions between MPs and PFCs.

3.2.1. Properties of MPs.

MPs differ in crystallinity due to how the carbon polymers are packed in the MPs, and this, in turn, affects their hardness, density, rigidity, and thermal properties. MPs with higher crystallinity have more orderly arranged polymeric chains resulting in larger crystalline regions [43]. MPs with higher crystallinity, such as PE and PP, are generally called semi-crystalline MPs, while those of lower crystallinity, such as PS and PVC, are called amorphous [43]. Adsorption of organic compounds on MPs tends to decrease as their crystallinity increases. However, crystallinity does not seem to be a major player in the sorption of PFCs on MPs, as portrayed in the study of Wang *et al*., which suggests the molecular structure and polarity of MPs have a greater effect on PFCAs sorption [40].

PFCs sorption is also influenced by MPs size and shape. HDPE MPs have been reported to adsorb PFCs to a low extent because their granular shape hampers intraparticle diffusion. This resulted in slower adsorption rates of PFCs onto HDPE [25]. In the same study by Llorca *et al*., PFCs seemed to adsorb onto PS at a higher rate than HDPE due to the smaller particle size of PS. PS-COOH exhibited a PFCs adsorption behavior similar to PS though adsorption occurred to a lower extent [25]. Furthermore, the adsorption of PFCs onto PA MPs was also size-dependent, with those sized < 50 µm adsorbing more PFCs than those sized < 3 mm owing to the larger surface area of the former. The effect of MPs size is shown in the adsorption of perfluorobutanoic acid (PFBuA) by PA MPs where PA MPs of 50 µm, 55 µm, and 3 mm adsorbed 99%, 55%, and 2% of PFBuA, respectively [24].

An inverse correlation between MPs particle size and sorption was observed, with sorption increasing as particle size decreased due to the increase in surface area. This correlation was not affected by MPs polymer type [27, 32]. However, factors such as natural organic matter and weathering might have greater influences on the sorption of PFCs on MPs [42].

3.2.2. Properties of PFCs.

PFCs with different functional groups have been found to differ in their capability to adsorb onto MPs. It was generally observed that PFCs with sulfonamide groups exhibit greater sorption onto PS MPs than those with sulfonate groups, which in turn, have greater sorption onto PS MPs than those with carboxylic groups [25]. The opposite was observed for sorption onto HDPE MPs, indicating that the influence of PFCs functional groups on their sorption behaviors might differ for different MPs [25]. As for PA MPs, they have a higher tendency to sorb PFOS than PFCAs, and when the sorption of PFCAs of different carbon chain lengths onto PA MPs was tested at pH 5.88, 0% salinity, and 0% dissolved organic matter, it was revealed that adsorption capacity increased with the carbon chain lengths of PFCAs [24]. In parallel, PFCs with longer carbon chains (13 to 16 carbons) seem to exhibit higher adsorption onto HDPE in freshwater, which is attributed to a predominant hydrophobic interaction, especially with HDPE as a hydrophobic sorbent [37]. In such instances, the sorption efficiency of PFCs to MPs tends to be positively correlated with their degree of hydrophobicity, and PFCs' hydrophobicity often increases with their carbon chain lengths [37]. Sorption of PFCs on MPs can be affected by the presence of other substances in the environment, such as natural organic matter and other organic contaminants, which can compete for the sorption sites on MPs resulting in the discrepancy of PFCs sorption on MPs in seawater and freshwater. This is discussed in Section 3.2.3.

PFCs having the same carbon chain lengths but different functional groups exhibit different sorption behaviors toward the same MPs. Mejias *et al*. found PFOS and PFOA of the same chain length to have different sorption capacities for PA MPs, with PFOS showing greater sorption capacity than PFOA [24]. The different behaviors could be explained by complex hydrogen bonding between the functional groups of PFCs as proton acceptors and the amide group of PA as a proton donor. The authors also speculated that the porous structure of PA MPs might have a role to play in the differential sorption capacities, and this accentuates the intricate interactions between the properties of PFCs and those of MPs to influence sorption behaviors [24].

Notably, certain PFCAs begin to gradually desorb from HDPE MPs after reaching maximum adsorption in seawater, and the desorption has been found to be higher for PFCs with longer carbon chains and with sulfonate functional groups. Seawater was thought to favor the amphoteric behavior of longer-chain PFCs, thus implying the influence of environmental factors on the properties of PFCs [44]. Furthermore, the adsorption behaviors of PFCs onto MPs vary with time in relation to their carbon chain lengths. It was reported that PFCAs of 11 to 14 carbons showed greater adsorption onto PS MPs after 50 days, but this trend was not maintained for longer PFCAs of 16 and 18 carbons, owing probably to micelles formation [25] (Figure 1). The critical micelle concentrations (CMCs) of PFCAs generally decrease as their carbon chain lengths increase. With lower CMCs, longer PFCAs are inclined to form micelles, and this reduces their adsorption onto MPs [44]. As for MPs of PS-COOH, they have a lower affinity for PFCs than PS and long-chain acidic PFCs (C11 – C18) tended to adsorb more to PS-COOH MPs than other PFCs due to increased hydrophobicity. Hence hydrophobic interaction as carbon chain lengths increase [25].

3.2.3. Environmental factors.

Section 3.2.2 shows that the sorption of PFCs onto MPs is multifactorial, with sorption behaviors often differing in different environments, such as freshwater and seawater. The environmental factors likely to influence the interactions between MPs and PFCs are ionic strength, pH, natural organic material, as well as the weathering of and biofilm formation on MPs (Figure 2). The influences of pH and ionic strength are more prevalent on short-chain PFCs demonstrating stronger electrostatic interactions with MPs [25]. This was supported by higher adsorption of short-chain PFCAs (<10 carbons) onto HDPE MPs in seawater as compared to freshwater. A feasible reason is that seawater has high ionic strength, which facilitates salting out and cation-bridging resulting in enhanced hydrophobicity of short-chain PFCs and increased sorption on MPs [45]. A similar observation that PE and PS MPs tended to adsorb more PFOS in seawater was reported by Wang *et al*. [40].

Increased pH was found to decrease the sorption of anionic PFCs onto PE, PS, and PS-COOH in freshwater and seawater, indicating the effects of pH on the sorption of PFCs by MPs [25]. This is likely attributed to the development of negative charges on MPs surfaces in an alkaline environment, leading to electrostatic repulsion between anionic PFCs and MPs, thus impeding sorption [42]. In that vein, an acidic environment with low pH promotes the protonation of MPs surfaces which may increase hydrophobic and electrostatic interactions between PFCs and MPs, thus, driving sorption [39]. The negative influence of higher pH on sorption seems to override the bridging effect of bivalent cations in seawater, which promotes sorption [40]. On the other hand, pH affects the dissociation of PFCs since different PFCs have different acid dissociation constants (pK_a). When the environmental pH is higher than the pK_a of a PFC, it promotes dissociation of the PFC to form the anionic conjugate base, which interacts with the charges on the surface of MPs [24].

Hence, ionic strength plays a crucial role in the sorption of PFCs on MPs, particularly ionic PFCs. This was demonstrated through higher adsorption of PFOS on PE and PS MPs after $CaCl_2$ and NaCl were added to the reaction medium, and such an effect was not observed between non-ionic PFCs (i.e., FOSA) and MPs [40]. Bivalent cations usually function to bridge anionic PFCs with negatively charged sites on MPs to enhance adsorption. However, the presence of inorganic anions, such as Cl^- and SO_4^{2-} as well as natural organic material, could increase competition for adsorption sites and lower the sorption of anionic PFCs onto MPs [46]. Natural organic matter such as fulvic acid, humic acid, and amino acids may cause structural changes in MPs, resulting in enhanced or decreased sorption of PFCs onto MPs [47]. The effects of natural organic matter depend on its concentration and properties. For instance, humic acid was reported to decrease the sorption of PFOS and PFOA onto the soil as it competed with PFCs for sorption sites on soil particles [48]. PFCAs with very long carbon chains (16 and 18 carbons), in addition to the tendency to form micelles, could also strongly bind to dissolved organic carbon, leading to lower sorption onto MPs [39].

Furthermore, the weathering of MPs usually leads to their oxidation, forming oxygen-containing groups such as carboxyl and hydroxyl groups [49]. This causes MPs to be more polar and has a lower affinity for hydrophobic PFCs. Forming biofilm on MPs could make adsorption sites unavailable to PFCs, thus reducing their sorption. It is also possible that biofilm formation might alter the aging of MPs by shielding them from environmental aggressors such as UV and oxygen while promoting biodegradation. These changes the properties of MPs and their sorption of PFCs [47].

Like inorganic anions and natural organic matter, the presence of other contaminants in the environment could compete with PFCs for sorption onto MPs. This was shown in the reduced sorption of phenanthrene to PE, PS, and PVC MPs due to the co-existence of pyrene. Still, there is currently a lack of study elucidating the effects of other contaminants on PFCs sorption onto MPs [50]. It is likely that climate change, especially global warming, as well as ocean acidification resulting from the higher dissolution of carbon dioxide, whose atmospheric concentration has increased significantly over the years, will affect the interactions between PFCs and MPs [51]. This is a domain that can be further examined.

4. Conclusions

This review recognizes that PFCs and MPs are two emerging pollutants in the environment that have garnered much attention because they have been detected virtually everywhere. Their co-existence in the environment has resulted in their interactions. These interactions are primarily sorption or, particularly, adsorption. The sorption or adsorption behaviors are dependent on three overarching factors, namely the properties of MPs, the properties of PFCs, and environmental factors demonstrated through the interplay between multiple elements such as pH, ionic strength, organic matter, the presence of other contaminants, etc. A PFC typically consists of a functional group and a hydrophobic part. Hydrophobic interactions, hydrogen bonds therefore govern the interactions between PFCs and MPs due to the functional groups on MPs and PFCs, electrostatic interactions between functional groups of PFCs and charges on the surface of MPs, as well as van der Waals interactions and pore filling. Generally, the hydrophobicity of PFCs increases with their carbon chain lengths causing enhanced sorption onto MPs, but exceptions are demonstrated by very long PFCAs with 16 to 18 carbons owing probably to micelles formation. As different functional groups of PFCs interact differently with MPs and even MPs of the same type, the adsorption capacities of PFCs for MPs differ though the PFCs have the same carbon chain length. PFCs adsorption is generally higher on MPs of smaller sizes due to the larger surface areas. Environmental factors, particularly pH and ionic strength, alter the charges in the surrounding, hence the electrostatic interactions between MPs and PFCs. This may promote salting out and cation-bridging, as well as alter the charges on PFCs and MPs surfaces, thus driving or deterring adsorption. The presence of inorganic anions, organic matter, and other environmental pollutants might lead to competition for the binding sites on MPs surfaces, reducing PFCs adsorption. It is worth noting that MPs are potential carriers of PFCs, which could alter their ecotoxicity. Understanding the interactions is, therefore, instrumental to assessing the ensuing ecotoxicity and risk, especially when co-exposure to MPs and PFCs is likely due to their interactions.

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Conflicts of Interest

The author declares no conflict of interest.

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