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Article

Microplastics in Freshwater Environment in Asia: A Systematic Scientific Review

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Abstract: Microplastics (MPs) are an emerging pollutant in the aquatic environment, and this has gradually been recognized in the Asian region. This systematic review study, using the Scopus database, provides an insightful understanding of the spatial distribution of scientific studies on MPs in freshwater conducted across the Asian region, utilized sampling methods, and a detailed assessment of the effects of MPs on different biotic components in freshwater ecosystems, with special focus on its potential risks on human health. The results of this review indicate that research on microplastics in Asia has gained attention since 2014, with a significant increase in the number of studies in 2018, and the number of scientific studies quadrupled in 2021 compared to 2018. Results indicated that despite a significant amount of research has been conducted in many Asian countries, they were not distributed evenly, as multiple studies selected specific rivers and lakes. Additionally, around two-thirds of all the papers focused their studies in China, followed by India and South Korea. It was also found that most of the studies focused primarily on reporting the occurrence levels of MPs in freshwater systems, such as water and sediments, and aquatic organisms, with a lack of studies investigating the human intake of MPs and their potential risks to human health. Notably, comparing the results is a challenge because diverse sampling, separation, and identification methods were applied to estimate MPs. This review study suggests that further research on the dynamics and transport of microplastics in biota and humans is needed, as Asia is a major consumer of seafood products and contributes significantly to the generation of plastic litter in the marine environment. Moreover, this review study revealed that only a few studies extended their discussions to policies and governance aspects of MPs. This implies the need for further research on policy and governance frameworks to address this emerging water pollutant more holistically.

Keywords: microplastics; freshwater; human health; Asia; systematic review

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1. Introduction

Among various emerging pollutants, plastic is of high concern as its contamination poses a serious threat to different components of the environment as well as human well-being [1]. Although the first commercial synthetic polymer, "phenol-formaldehyde resin," also known as Bakelite, was developed by Leo Baekeland in 1907 [2], the wider use of commercial plastic in all the sectors viz. textile, packaging, personal care products, etc. around the world started in the 1950s [3]. People prefer using plastic products because of their durability, low conductivity, low corroding properties, etc. [4]. It is reported that the global production of plastic for the year 2019 was 368 million metric tons, and only 20% of it was recycled or burned properly, whereas the rest, about 80% of it, ended up either in landfills or was dumped in water bodies [5]. These large untreated pieces of plastic typically go through different decomposition pathways, and over time, small particles are formed with diameters of less than 5 mm, also called microplastic [6]. Because of their very small size, they can travel undetected through different parts of the Earth, for example, from the soil to the water and atmosphere [7]. Additionally, because of their slow degradation rates, microplastics can be present in nature for a long period (ranging between 20 to 500 years) and cause severe environmental pollution [8].

Assessing the detrimental effects of MPs on the ecosystem is quite challenging because they include a variety of physical (size, shape, colors, etc.) and chemical (polymer, adhesives, other chemicals, etc.) compounds, which regulate their fate, transport, and bioaccumulation in different ecosystems [9,10]. For instance, depending on the density, they can either float and interact with pelagic organisms on the top layer of the water surface (low-density MPs) or sink in water bodies and interact with benthic organisms (high-density MPs) [11]. Similarly, it is reported that MPs with strident ends (for instance, fibers) might have more harmful impacts than MPs with blunt edges (such as spherical ones) because they can severely injure the digestive system or other body parts upon digestion [6]. Additionally, regarding the impacts of MPs on different organisms, most studies give a snapshot of the effect of MPs on any particular species for any specific biological functions like accumulation, mortality, reproduction, etc.; however, very few or almost none of the studies discuss how MPs affect different key ecological interactions and functions at different trophic levels [12]. Similarly, very little is known about how directly or indirectly MPs affect or will affect human health [13,14].

In 2015, the United Nations and its associated members univocally recognized the different actions needed to achieve Sustainable Development Goals (SDGs). Among these, one goal is to assess emerging environmental pollutants such as plastic pollution, their environmental impacts, and different management options both in terms of adaptation and mitigation. Addressing plastic pollution will help to expedite our efforts to achieve various SDG goals, namely SDG 12 (Responsible Consumption and Production), SDG 14 (Life Below Water), SDG 15 (Life On Land), etc. Therefore, both the scientific community and policymakers are confronting this issue on an urgent basis, and many efforts are being directed to address this critical issue.

A past study found that Asian countries, particularly China, Indonesia, the Philippines, Thailand, and Vietnam, contributed to about half of the world's marine litter generation [15]. There have been a few review studies conducted in the Asian region, but they have focused on individual countries. Unfortunately, a comprehensive and comparative study focusing on several countries in this region has not been found. Considering the general pathways of plastic wastes to the ocean, the freshwater system is a critical part of the entire plastic problem because of its close connection to human life. Therefore, our review study emphasizes MPs in the freshwater system in Asia. Furthermore, few systematic review studies have investigated the human health impacts of MPs; therefore, our research also explored what studies have been carried out on MPs and their effects on human health.

With basic background information obtained through this exercise, a detailed analysis of research articles was carried out to achieve the following objectives: (a) to examine the spatial distribution of scientific studies on MPs in freshwater in Asia; (b) to identify the sampling methods of MPs for laboratory analyses (different size, color, shapes, their associated materials such as adhesives/heavy metals, etc.) in soils/sediment/water, for source identification; (c) to evaluate the effects of MPs on different organisms in the freshwater ecosystem and their ultimate impacts on human health as an end-user; (d) to understand the needs for policy improvements at institutional and governance levels in order to tackle this emerging environmental pollutant in a more holistic manner. In the methodology section, we provide information on how the literature database was constructed for this review, and the first part of the results section presents the summary of these reviewed articles. The results of the systematic review analysis are presented in the second half of the section. Here, the following items are analyzed and presented: spatio-temporal variation of research works on MPs, their target journals, various samples from the freshwater environmental system being analyzed, morphological and chemical features, aquatic organisms being analyzed, and methodological techniques being employed for the analysis of MPs, to report key findings related to MPs in the freshwater environment in Asia. Then, we discuss the gaps in the current research related to MPs in riverine systems and the way forward for future research activities to understand the consequences of MP pollution and ameliorate the situation.

2. Methodology

A systematic literature review was conducted using the Scopus database (http://www.scopus.com/ Accessed on 18 October 2021) to collect existing literature related to microplastic pollution in the freshwater environment. This means that our search was limited to references published before 18 October 2021. A few articles published in 2022 were included in our literature database because they became available online before we retrieved the data from SCOPUS. For this study, freshwater bodies included rivers, ponds, reservoirs, and wetlands. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were followed to document the literature review process [16]. As the search query, the Boolean string was used: TITLE-ABS-KEY (Microplastic) AND (TITLE-ABS-KEY (River) OR TITLE-ABS-KEY (Riverine) OR TITLE-ABS-KEY (Freshwater). The search did not limit the language; however, non-English articles were omitted at the review stage later. With the above search query, a total of 1335 research articles were retrieved. Next, the full texts of "article" and "review" retrieved from this search were downloaded and manually screened for peer-reviewed articles, and the screened number of articles was reduced to 1093. Again, the second round of screening was performed for the following purposes: (i) screening of review papers dealing with microplastics (MPs) in freshwater around the globe to get an overall idea about the scientific progress made and remaining gaps in this area, (ii) screening of research articles dealing with MPs in freshwater in Asian regions. As a result, the number of review papers and research articles retrieved is 83 and 166, respectively (see Tables S1 and S2 in the Supplementary File). Supplementary Table S1 is giving the information about 83 review papers being assesses in this manuscript to gather the basic information about the MPs in freshwater system around the world and the knowledge gap especially in Asia. Table S2 mainly depicts the list of 166 research papers being analyzed and their assessment result presented in this manuscript. The methodology adopted for this work is shown in the flowchart in Figure 1.

First, we analyzed above mentioned 83 accessible review articles to investigate the important research highlights or updates on microplastics and knowledge gaps around the world. The result showed that all 83 review studies were published between 2015 and 2022, and 59 were published between 2020 and 2021, showing a sharp spike in the last few years. Among them, 63 articles reviewed studies without spatial consideration, while 4 articles focused on Europe, 3 articles on Africa, and 4 articles on Latin and North America. There were nine articles that reviewed studies in Asia, out of which four focused on China, two on India, and one each on Indonesia, Iran, and Malaysia. All these review studies had different objectives and perspectives. Looking at the target water environment, 35 articles reviewed articles on MPs in all types of water such as marine, lake, reservoir, and river; 25 articles reviewed articles focusing on the freshwater system, such as a lake, reservoir, and river; and 3 articles focused on the marine system. The other 21 articles emphasized the removal of MPs from wastewater treatment plants, groundwater, and laboratory analysis, rather than looking at MP problems in specific water environments. Many of the studies analyzed MPs in water, sediment, and aquatic organisms and examined their effects on ecosystems. However, there were 6 papers that reviewed MP studies from the perspective of human health and 36 papers that reviewed MP studies from the perspective of their effects on ecosystems. Morphological analysis was one of the major objectives in the MP studies, which is well supported by 44 review articles. Overall, it was found that a review work presenting a holistic approach to depict the current status quo of MPs, particularly in the freshwater environment and its impact on different ecosystems, is still lacking. With the aforementioned gap, this review work was carried out to achieve our aforementioned objectives.

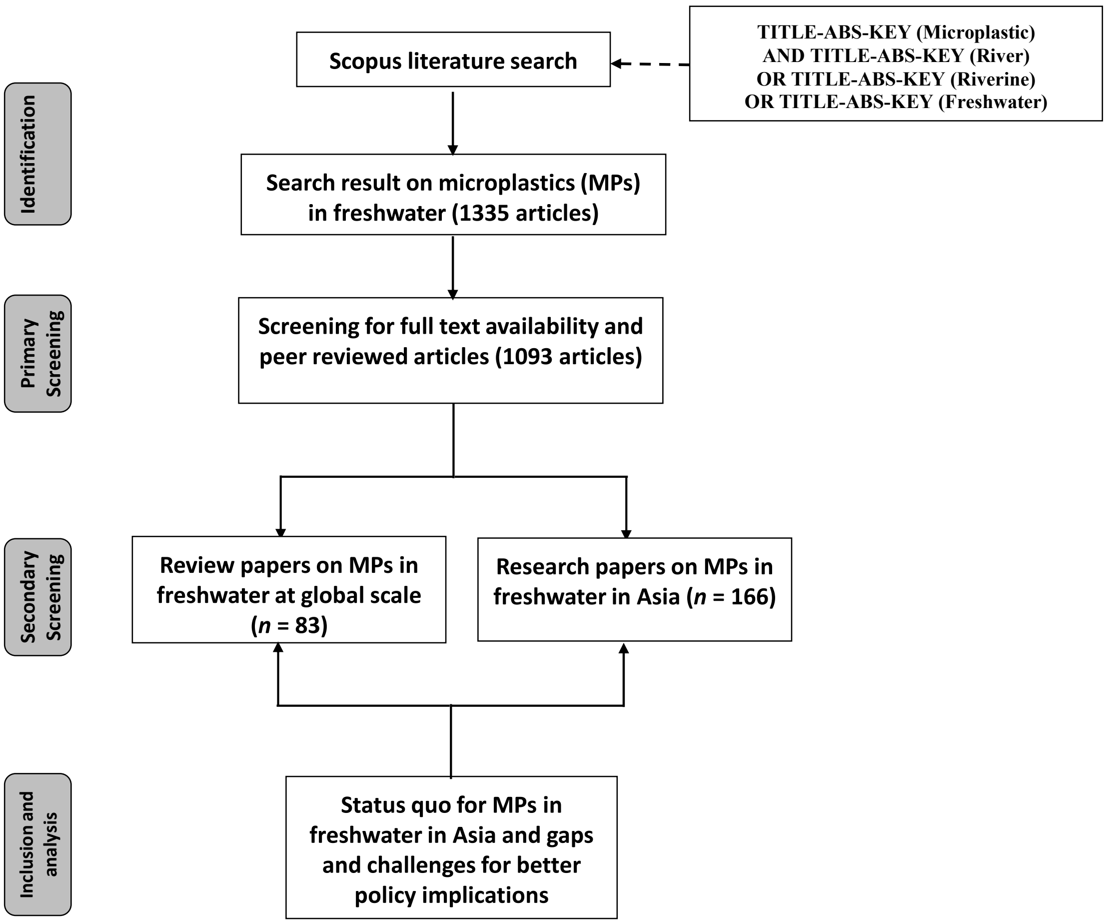

Figure 1. PRISMA flowchart of literature review work.

Moreover, these review articles bring out different lines of information based on the objectives mentioned. For example, Wang et al. [17] reviewed MP studies conducted in different parts of the world; they compared the sampling, processing, and identification methods, presented characteristics of MPs such as concentration and morphologies, and explored the sources, paths, and impacts in 53 articles. Xu et al. [18] also reviewed MP studies focusing on the source and morphologies. Similarly, Koutnik et al. [19] conducted a systematic review of 196 studies, and their review extended to finding the MP transport modeling frameworks in the literature. Gao et al. [20] reviewed 32 studies and summarized MPs found in freshwater and marine algae. Bellasi et al. [21] provided an overview of MP pollution as well as ecotoxicology. The review studies define the ongoing research and highlight crucial aspects and gaps. Many review studies reviewed laboratory analysis and the characteristics of MPs and discussed the impacts of MPs in introductions or discussions. Fewer studies extended their reviews to the impacts on ecosystems, and a few studies extended their reviews to the human health impacts.

Based on this mentioned exercise, the knowledge or information gap was identified about microplastics in the freshwater system, especially in the Asian region. Thereafter, a review of 166 research articles was conducted, and the findings are presented in the next sections, i.e., Results and Discussions.

3. Results

3.1. Spatio-Temporal Distribution of Scientific Literature

The temporal distribution of research articles is shown in Figure 2. Among all retrieved articles on MPs in the freshwater environment, the oldest one was from 2014, while the latest one is from 2022. The number of publications per year suddenly increased by many folds from 2018. This trend continues moving upwards, clearly showing that it is one of the emerging environmental pollutants. In 2021 alone, 54 articles focused their investigation on MPs in the freshwater environment.

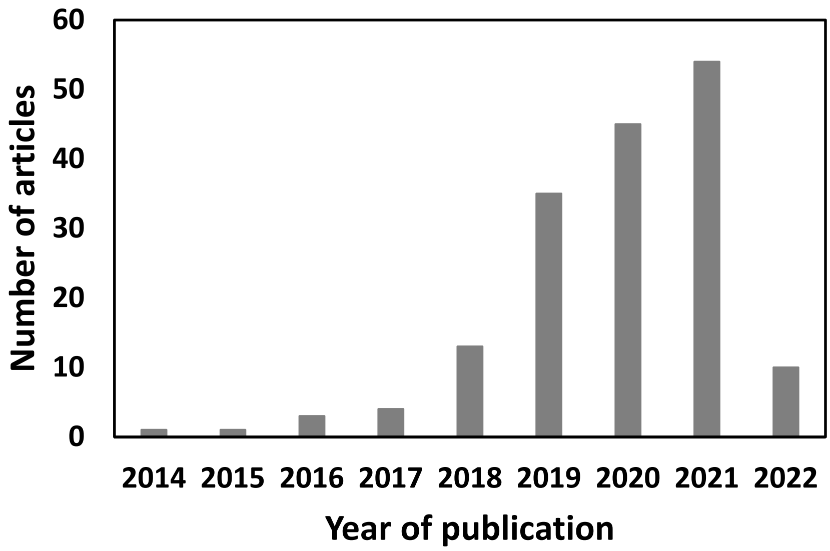

Figure 2. Yearly distribution of research articles on MPs in freshwater environments.

The spatial distribution of research work on MPs in freshwater at the country level is shown in Figures 3 and 4. The reviewed studies generally select a water system and collect samples from multiple locations in the same system. The points in Figure 3 do not indicate all sampling points, but they indicate the centers of sampling points in each study. Thus, one point represents one study. The detailed information for the GPS locations of all sampling sites is provided in Table S3 as a Supplementary File. In other words, Table S3 give the detailed information about various geographical locations from where samples being collected in total 166 research papers considered for the analysis in this manuscript. The light blue points indicate the studies that assessed MPs in multiple water systems such as rivers and lakes. Since MPs have been recognized as an emerging pollutant affecting the water environment, the MP studies were conducted in various countries, from Turkey in the west to Japan in the east of Asia. Indeed, out of 166 papers, research work was spatially distributed among 18 different countries. Also, two articles focus on two countries, for example, China and Nepal [22] and India and Bangladesh [23]. While the objective of many articles was a field-based assessment of the water environment, there were a few studies that conducted experiments in the laboratory, mainly in China but also in Bangladesh and Indonesia. It was found that 68.1% of the reviewed works are focused on China, followed by India and South Korea with 5.4% and 4.2%, respectively. There is a huge gap between China and the rest of the countries in Asia regarding the research findings on MPs in freshwater. Overlapping points in Figure 3 imply that some water bodies attract more scientific attention, such as the Pearl River, Yangtze River, etc., in China.

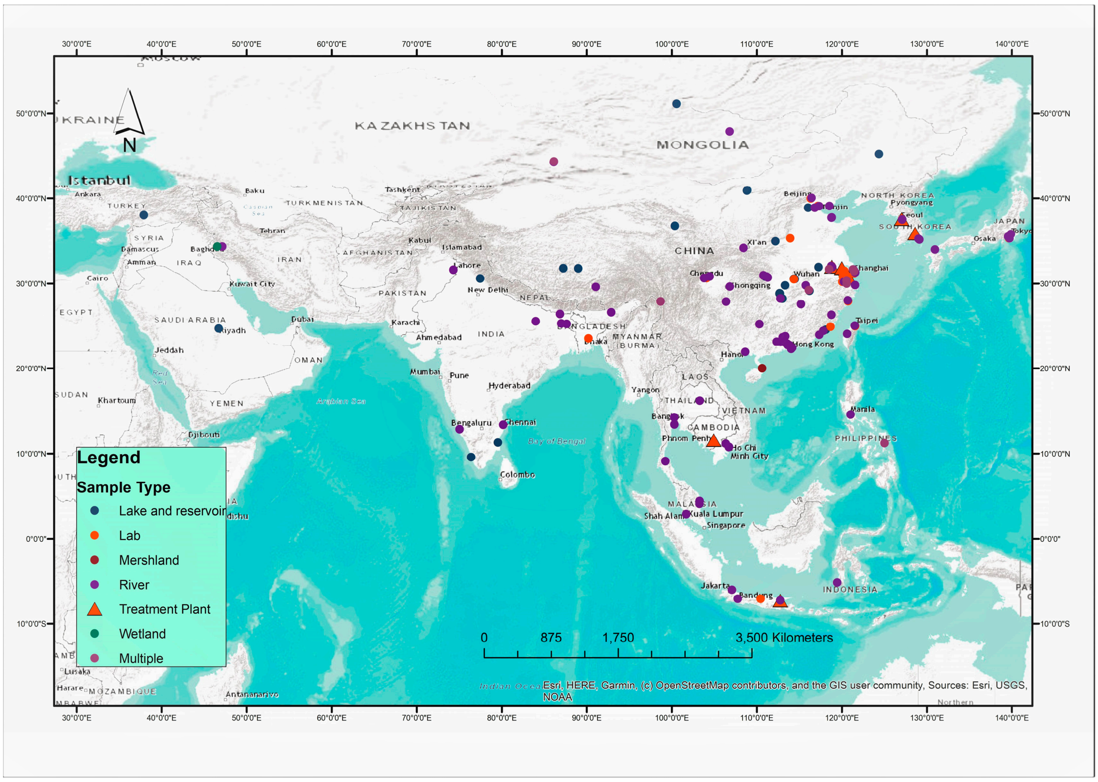

Figure 3. Map of study locations of reviewed articles.

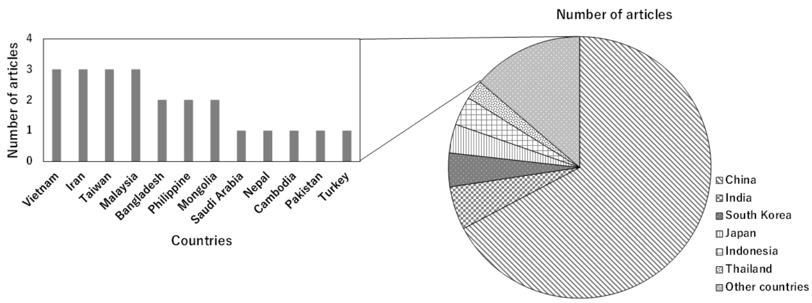

Figure 4. Spatial distribution of research articles on MPs.

Extensive scientific investigation has been performed on some key rivers/lakes, such as the Yangtze River (15 papers), Pearl River (21 papers), Haihe River (8 papers), and Taihu Lake (7 papers). For India, 9 research papers were found that focused on rivers or lakes in the high-altitude areas of Brahmaputra (2 papers), Ganga (2 papers), and Renuka Lake (1 paper). Other papers focused on rivers/lakes from coastal Southern India in areas such as the Netravathi River, Vembanada Lake, and Veeranam Lake, with one case study from each. For South Korea, seven papers were found that focused on urban rivers, such as the Han River and Nakdong River. Additionally, some papers focused on the role of wastewater treatment plants in the fate and transport of MPs in urban water bodies. For Japan, a total of six papers were found that focused on the Awano, Tsurumi, and Ayaragi Rivers, with one case each. For Indonesia, the target rivers were the Tallo River, Surabaya River, and Ciwalengke River, with one paper each. For Thailand, the main river bodies explored were the Tapi-Phumduang River system (one paper), Chi River (two papers), and Chao Phraya River (one paper).

3.2. Target Journals and Objectives of Research Papers

Academic journals publish diversified research articles taking a transdisciplinary approach, and the 166 articles on freshwater MP were published in 34 different journals. Figure 5 shows the major discipline of the journals where the 166 papers were published. Although environmental pollution could be considered part of environmental science, it is shown separately in the graph because a significant number of articles found in the journals were mainly concerned with environmental pollution. We found that two-thirds of the articles were published in journals that are strongly linked to environmental science. Furthermore, this shows that research works about microplastics are getting attention from across disciplines such as chemistry, biology, environment, sustainable resource management, disaster risk reduction, climate change, etc. Hence, there is a high demand for up-to-date information on the status of microplastics in the environment on a regional or local basis. Such need/demand makes this review work even more crucial at the present time. We further classified all the research articles based on the broad categories of the objective for the research work on MPs, and the result is shown in Figure 6. A total of seven broad categories were found. It was found that more than half, 52.4%, of the research works were carried out with the objective of reporting the concentration of MPs in freshwater (river, lake, reservoir, pond, etc.). The reason behind this is very clear. Because this is a very new research topic, no past studies and data are available, so in most cases, these are a kind of baseline study reporting the concentration of MPs for the first time. The second largest group contained 23.5% of articles that assessed the exposure of MPs in freshwater in different aquatic animals like fish, mollusks, clams, planktons, crustaceans, bacteria, amphibians, etc. In the third major category, with 10.2% articles, the objective was to assess the concentration of MPs in the sediment/soil/sludge in the freshwater environment. In addition, 5% of articles reported assessments of MPs in both water and sediment, and 4% of articles focused on the interaction of MPs with other chemicals and associates. Next were papers focusing on the removal efficiency of various treatment plants (domestic treatment plants, wastewater treatment plants) for MPs and their impact on the freshwater environment. The number of papers focused on exposure analysis to aquatic plants and human health was less than 2% of articles. This indicates that scientific information on how MPs impact human health is still in the incipient stage, especially in the Asian region. Both of these papers first reported the exposure to aquatic animals and then extended their evaluation to human beings. Hence, to prepare a robust management plan, more efforts are needed to obtain scientific evidence on MPs' status, their fate, and transport in different environments or ecosystems.

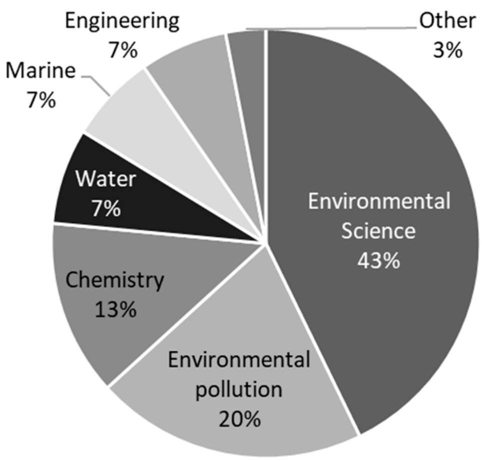

Figure 5. Main discipline of journals in which selected papers were found.

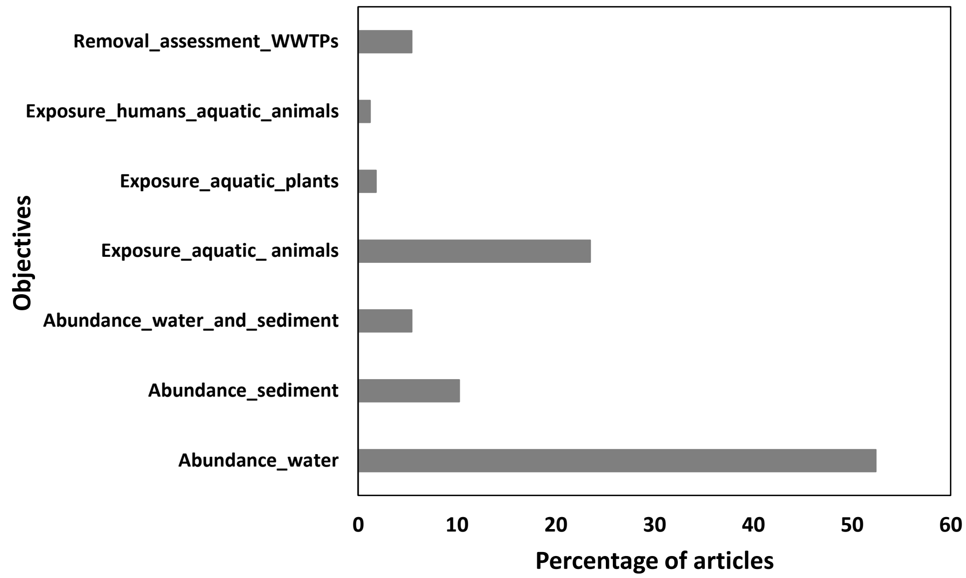

Figure 6. Classification of research articles based on the broad categories of the objective for the research work on MPs.

For this review study, we retrieved articles on MPs in the freshwater environment. Of these, 83% of selected articles assessed MPs in rivers, lakes, and reservoirs, or both water systems. The studies assessing MPs provided detailed pictures of MP pollution in the study area by estimating the concentration and analyzing the morphology. In Asia, MPs in the freshwater system are intensively studied in China, as supported by Figures 3 and 4, and MPs in lakes and reservoirs gained more attention there than in other countries. Figure 7 shows that 72% of studies analyzing lakes and reservoirs came from China. While the major focus was on the assessment of MPs in the natural environment, 13% of the reviewed articles performed exposure analysis, carried out experiments in the laboratory to understand the mechanisms of MP absorption by organisms, or explored MP removal mechanisms by aquatic organisms [24,25].

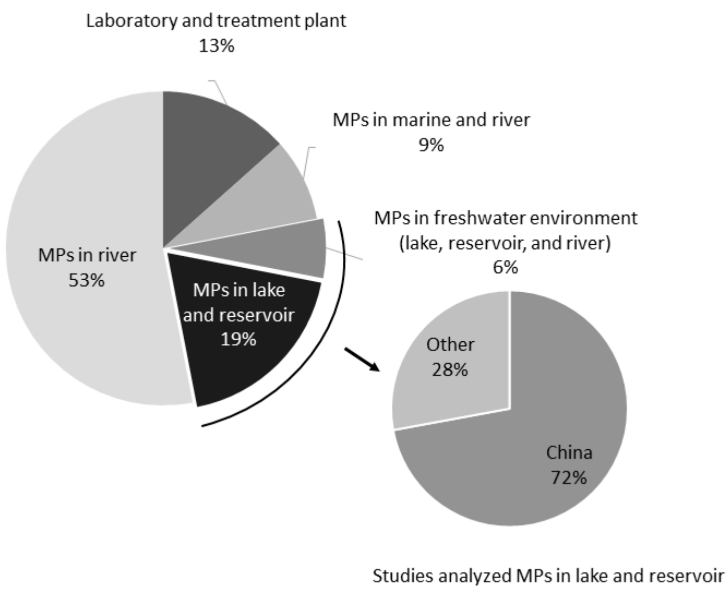

Figure 7. Water systems focused on by the selected studies.

The reviewed articles had diversified objectives; hence, different types of analyses were conducted. The studies assessing MPs in the freshwater system generally sampled water, sediment, and sometimes organisms and analyzed the presence of MPs in the samples.

Among 166 articles, half aimed to assess the abundance of MPs, as Figure 6 shows, and 70% of them analyzed MPs in either water, sediment, or both, as seen in Figure 8. In addition to sampling water for the assessment, some studies collected water to use in a laboratory experiment [26–28]. Studies focusing on MPs in sediment investigated if the received water played a role as a pathway to other waterbodies or a final destination, such as the sink [29], as well as if the protected area would make any differences in MP occurrence [30,31]. Additionally, 19% of the studies extended the assessment to aquatic organisms by sampling plants, fishes, and other species. A few reviewed articles did not take any samples from the natural environment because they conducted experiments by purchasing what was needed for the experiment and artificially creating the environment in the laboratory [32–34].

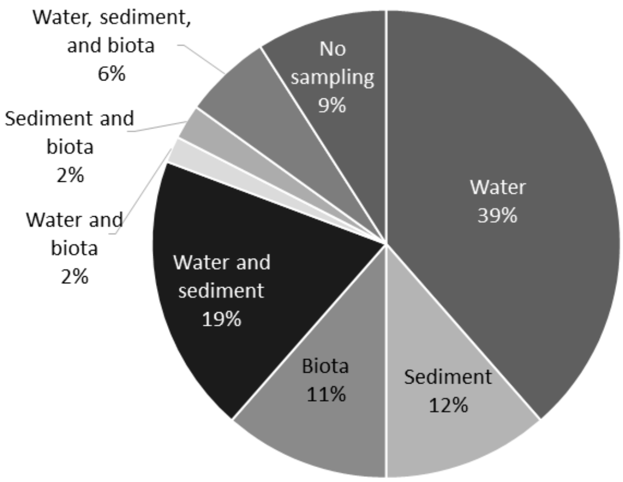

Figure 8. Sample categories investigated in the studies.

3.3. *Different Key Features of the Reviewed Papers*

3.3.1. MP Shapes, Polymer Types, and Color

The articles that assessed MPs conducted morphology analysis and identified shape, color, and polymer types. Figure 9 shows the shapes of MPs found in the studies. Fiber was found the most in the studies, as 95% of assessment studies found it, followed by fragments (86%) and film (74%). While the dominant shape was fiber in some studies [35–38], other shapes were dominant in a few studies [39–41]. The major sources of fiber were found to be the textile industry, households, and wastewater treatment plants [ibid.]. Polypropylene, polyethylene, and polystyrene were identified in many studies and were dominant in some studies [42–45].

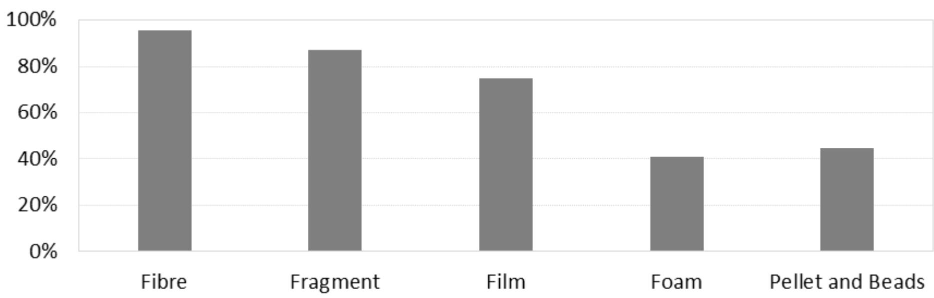

Figure 9. Shape of MP identified in studies.

The other important attribute when assessing the occurrence of MPs in any environment is their variety of colors. Color is often identified in the morphology analysis. More than half (84 of 166 articles) of the studies analyzed the color of the MPs found in their analyzed samples, and 48% of them differentiated 6 colors or more, as shown in Figure 10.

Typical colors identified were transparent, white, red, black, blue, green, and yellow. Some studies identified brown, grey, pink, purple, or violet [46–50]. Dominant colors differed from study to study, such as white and transparent [24,51] or black [36], depending on the location of the study conducted.

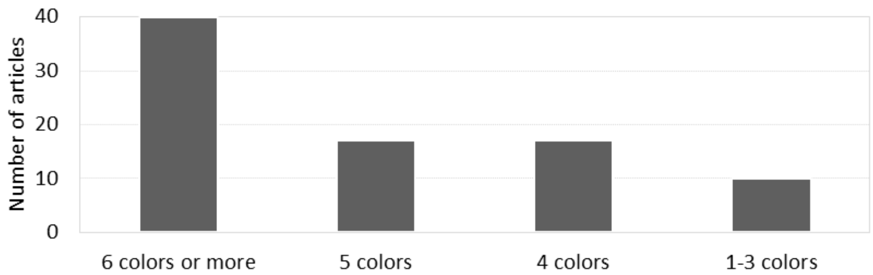

Figure 10. MP colors identified in the analysis.

3.3.2. Target Organisms

Further, target organisms in the reviewed papers were explored, and the summary is presented in Figure 11. It was found that some studies assessed the impacts of MPs on aquatic organisms by capturing them in the field for the MP assessment, and others assessed the impacts by exposing them to MPs in the laboratory environment. China conducted a significant number of studies on the impacts of MP on biota; 66% of 47 studies that analyzed the impacts on biota were found, followed by South Korea at 6%, Bangladesh, Indonesia, Iran, Taiwan, and Thailand at 4%. Of these, 88% of the studies analyzing biota investigated the impacts on fauna, and 6% flora and bacteria. Freshwater fishes were the most investigated organisms, followed by amphibians. The impacts on flora were all investigated in China [52–57], and the impacts on bacteria were investigated in China and Indonesia [33,45,58].

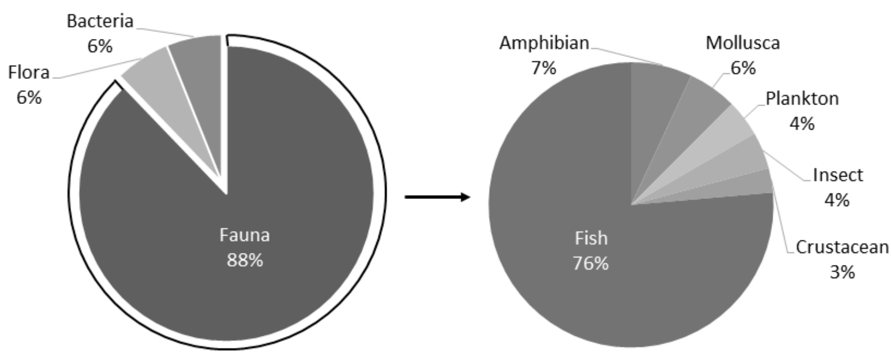

Figure 11. Aquatic organisms analyzed in the studies.

3.3.3. Methodological Techniques

To understand how the literature investigates MPs differently, we compared the following four steps and items: (a) sample collection, (b) density separation, (c) organic matter digestion, and (d) identification. The findings are shown in Figure 12a–d, respectively. Here, both organic matter digestion and density separation can also be understood as extraction steps. The first step for the MPs' investigation/study of the environmental components is sample collection, and the result is shown in Figure 12a. All the processes for sample collection are divided into four categories, and the order for them is grab > net > pump > hand. Out of 108 papers that reported sample collection techniques, 55 opted for the grab sampling methodology. This is followed by net, pump, and hand, represented in 32, 20, and 1 paper, respectively. Figure 12b shows the result for the summary of chemical treatments authors have used for density separation to obtain MPs of different shapes/ sizes. It was found that low-density treatment using salts such as NaCl is a very common practice, as shown in 49 out of a total 94 articles which mentioned it. This is followed by high-density treatment using salts such as $ZnCl_2$ to separate different MPs species, as found in 29 out of 94 articles. Figure 12c shows the methodology to remove organic matter from the sample being collected. The most common method is to treat the sample using H_2O_2, as found in 93 out of 111 papers that mentioned it. This was followed by other methods such as using H_2O_2 plus Iron (Fe) salts and using other chemicals.

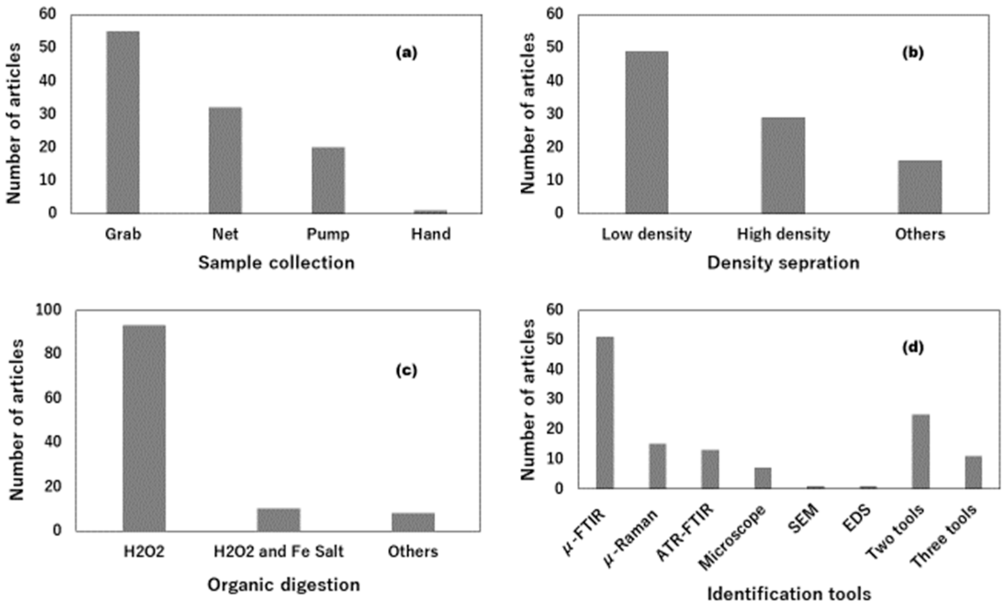

Figure 12. Summary for different steps of methodology (**a**) Sample collection, (**b**) Density separation, (**c**) Digestion of organic matter, and (**d**) Identification tools used to study MPs in the reviewed research articles.

Figure 12d describes different technologies or tools used to identify MPs in the reviewed research work, as shown in Figure 10. A total of 124 articles out of 166 were identified where authors mentioned any type of tools used to identify MPs in their studies. The results show that six different standalone technologies, namely Micro Fourier transform infrared (μ-FTIR) spectroscopy, Attenuated Total Reflection-Fourier transform infrared (ATR-FTIR) spectroscopy, μ-Raman imaging microscope, Microscope, Energy-dispersive X-ray spectroscopy (EDS), and Scanning electron microscope (SEM), were used to identify the MPs in the reviewed research works. In addition, many articles used multiple (two or three) technologies to identify MPs. The most common technology used was μ-FTIR spectrophotometer, with 51 articles. The order of frequency for different technologies employed in the reviewed research works were in the order of μ-FTIR > Two tools > μ-Raman > ATR-FTIR > Three tools > Microscope > SEM > EDS. Among two tools, different combinations were used, such as μ-FTIR and SEM, μ-Raman and stereomicroscope, chromatography and stereomicroscope, fluorescence microscopy and SEM, etc. On the other hand, among the three tools, the most common combinations used were stereo microscope, μ-FTIR, and EDS; stereo microscope, ATR-FTIR spectrophotometer, and SEM; and stereo microscope, μ-Raman, and SEM, etc.

4. Discussions

For measuring the concentration of MPs, several units were adopted by the scientific communities. First, this study analyzed the trend in the number of studies per year and found that since the year 2018, the numbers increased by almost four times by 2021. Regarding spatial distribution, it was found that about two-thirds of the total publications are focused on China, followed by India and South Korea. Furthermore, the gap between percentage shares of papers between China and India was around 61% of total papers, meaning China is leading the scientific investigation on MPs in freshwater systems in

Asia. However, on the other hand, the number of scientific publications may not provide a true picture of the available data within a country. For example, 2 freshwater MPs-related publications cover more than 150 sampling locations in Japan, with wide spatial distribution over the whole country [59,60]. Based on the objectives of the papers analyzed, it was found that estimating the concentration of MPs in freshwater environments, whether in water or sediment, is the primary focus, followed by exposure analysis on different organisms. This shows that baseline studies on MPs in freshwater systems are still lacking in most countries. Regarding units of measurement, the most common units for water, sediment, and biota found were items/L [61], items/Kg dw [62], and items/individuals [63], respectively. Looking at the objectives of these reviewed articles, it was found that most of the articles were reporting for the first time about concentration and accumulation in the freshwater environment (water, soil/sediment) and biota, respectively. Furthermore, looking at the exposure analysis, a few articles presented the effect of MPs pollution and its impact on biota [52,64,65]. According to the Food and Agriculture Organization of the United Nations, per capita consumption of fish in Asia is the second highest, 24.1 kg/year, following the Oceania region, 24.2 kg/year [66]. Many articles indeed studied the impacts of MPs on freshwater fishes but did not represent the real picture for the whole aquatic ecosystem. Carbery et al. [67] reviewed articles to investigate trophic transfers in the marine food web and found eight articles that presented MP ingestion by the transfer. Furthermore, Hasegawa and Nakaoka [68] investigated how MPs were ingested by trophic transfer, and they found that aquatic organisms ingest more MPs through it than from the water. Considering the high consumption of fish and the trophic transfer, exposure analysis of the first trophic level as well as multiple levels is important in this region, although more attention is currently paid to aquatic organisms at the single and higher trophic level in the reviewed articles. Assessing MPs in multiple trophic levels and understanding trophic transfer in organisms is important in considering MP transfer to humans and its impacts on health in this region. When referring to the exposure to human health, only two papers focused on the effect of MP pollution on human health [69,70]. Li et al. [69] investigated the joint cytotoxicity of two different MPs co-exposed with diverse ionic pollutants in two cell lines from the human digestive system: human gastric epithelium (GES-1) and colorectal mucosa (FHC) cell lines. Also, their finding indicated that the cytotoxicity of cationic pollutants was alleviated by MPs more significantly than that of anionic pollutants in both culture medium and river water. Additionally, the electrostatic attraction between negatively charged MPs and cations was a key factor in determining the ultimate joint toxicity. On the other hand, Ajay et al. [70] investigated MPs and phthalic acid esters in the aquatic system. However, they mentioned that PAEs end up accumulating in the human body and cause various health effects, including a hormonal imbalance in adults and changing levels of urinary thyroid hormones in children. This shows that the scientific works in this domain or direction are still in the early days, and it will take some time to further develop a clear understanding of the fate and transmission mechanism through which MPs in the ambient environment could impact human health. Color was analyzed in about half of the studies as it plays an important role in identifying the source and the original plastic before decomposition into microplastic. There were 40 studies that identified more than 6 colors. However, Xu et al. [50] mentioned the possibility of discoloration at the digestion of organic matter by hydrogen peroxide solution and found fading fibers from blue to transparent and fragments from green to light blue. UV light decomposes plastic into microplastic as well as changes the color. Therefore, it may be difficult to rule out that the colors identified in the analysis are the original color. Further studies and discussions are needed to understand the discoloration of MP and usage of the information.

It was found that three main types of sampling methodology were opted for in most of the articles, i.e., grab, net, and pump sampling. Here, both pump and net sampling can be kept together in a category called on-site filtration [29]. Grab sampling is mainly used to collect sediment samples or large volumes of water [50,70], whereas on-site filtration is used for water bodies where a net or pump is used to pass the water through the net and collect the filtrate for MPs analysis [42,71]. After collection, samples go through an extraction process to remove undesirable materials. Here, the extraction step again comprised two steps, i.e., density separation and organic matter degradation (especially for sediment and sludge samples). For density separation, the majority of research papers opted for low-density separation using saturated NaCl solutions [65]. As the name suggests, this method is especially effective for removing debris with low-density polymers. However, to separate high-density polymers like Polyethylene Terephthalate (PET), Poly Vinyl Chlorate (PVC), etc., $ZnCl_2$ or KI solutions are used [35]. The reason for fewer occurrences of the high-density separation method is because both $ZnCl_2$ and KI solutions are comparatively more expensive than NaCl, and they need special disposal measures, which constrain their common use [38]. Steps for organic materials decomposition are used when samples have too many biofilms, such as in the case of sediment and sludge. The most commonly used chemical for this purpose is H_2O_2 [72,73], as shown in about 90% of the reviewed articles; however, Iron (Fe) salts are added to H_2O_2 if there is a high amount of clay present in the sample [74]. For the identification phase, the main objective is to classify different MPs on the basis of their physico-chemical properties. Here physical properties refer to their shape, color and mass, whereas chemical properties refer to polymer types. Obtained results show that the most common tools used in the reviewed articles were μ-FTIR followed by the use of two tools > μ-Raman > ATR-FTIR > Three tools > Microscope > SEM > EDS. However, when we looked closely at the single instrument used for the identification, it was found that μ-FTIR was followed by μ-Raman, because of their ability to identify various polymers from MPs [75,76]. On the other hand, microscopes were also used in a significant number of studies, and their usage is often associated with the application of fluorescence dye to identify different MP polymers as well as their relatively low price [77]. The use of SEM was quite low, maybe because of the high price and low affordability [78].

There were no publications concerning the policy aspects of MP pollution in the Asian region. However, there were few studies that extended the discussion on MP pollution, but their geographical focus was either on the EU region or global in general [79–81]. Considering this policy gap, one of the important aspects for future studies is to discuss possible options to mitigate MP pollution.

While the issue of the marine plastic problem has been well studied and management policies are well established, there is a huge knowledge gap in terms of MPs in the freshwater environment. The number of research works on MPs in the freshwater environment is also on the rise, but addressing this problem is still in the incipient stage. This systematic review revealed spatial unevenness and differences in field sampling methods as well as laboratory analyses in the scientific studies; they are some of the key challenges for designing robust management strategies for MPs in freshwater environments [82,83]. Hence, to address the knowledge and information gap mentioned above, further engagement from all the relevant stakeholders, such as scientific communities, policymakers, local communities, industries, etc., need to work together to co-design and co-deliver holistic management options for MPs from cradle to grave. Although this is an exclusive study showing up-to-date scientific information on MPs in freshwater environments presented through research papers from Asia, there might be a possibility that it missed some vital information covered in the grey literature, which can be considered as the limitation of this study. This also calls for a more integrated and holistic approach to designing future scientific studies to investigate this pressing issue.

5. Conclusions

The increase in the number of freshwater MP studies indicates a high level of interest in this emerging issue, which is increasingly recognized in Asia, although there is a regional bias in that many studies have been conducted in China. The finding of this study indicates that most of the papers are primarily focused on reporting the level of occurrence of MPs in the freshwater system, whether in water or sediment (majority of the reviewed papers) and aquatic organisms (relatively fewer papers). While the assessment of MPs reveals pollution in the water environment, it does not reach to understand the amount of ingestion and the impact on human health in the region. Considering the various methods used to assess MPs in freshwater, diversified samples, and different approaches and presentations in the morphologic analysis in the reviewed articles, establishing a standard method for the examination of MPs would help to manage the MP pollution in the region. The establishment of sample collection and separation methods are particularly important because different methods lead to different results. MPs in the freshwater environment are greatly influenced by solid waste management on the ground; hence, the pollution level is expected to be high in countries where waste management is not properly performed. The ability to identify various polymers as well as smaller sizes depends on lab technologies, but countries that do not have proper waste management are often developing countries and have difficulties procuring expensive equipment and materials. As MP pollution has become ubiquitous, further studies are needed in various locations, but at the same time, the issues found in this review study also need to be discussed. Results from this study also revealed that only a few studies extended their discussions to policies and governance aspects of MPs. Based on the remaining gaps in scientific understanding, the following points should be considered for future studies:

- To have a better understanding of the relationships between MP pollution and its potential risks to human health, it is vital to build a robust inventory (big data both on the temporal and spatial scale) on MP pollution and transport in the agroecosystem.
- Because MPs have huge, diverse morphological characteristics, understanding their physio-chemical dynamics and evolution in different ecosystems is of utmost importance. Most of the existing studies are focused on the ecotoxicity of a particular target organism; hence it is very important to understand the comprehensive effects of mixtures of MPs (mimicking the natural condition) on different trophic levels.
- Because the life cycle of MPs is very long, it is imperative to conduct field-based experiments to understand the interaction of different MPs with various environmental components.
- Further research to address policy and governance aspects of MPs for effective management and control of this emerging pollutant is also needed.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/w14111737/s1, Table S1: List of review papers on MPs in freshwater; Table S2: List of research articles on MPs in Asia; Table S3: Detailed information for the GPS locations of all sampling sites collected from reviewed papers.

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