Review

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How Natural Phenomena and Disasters Together with the Weathering Conditions Affect Microplastics and Nanoplastics in Agricultural Soils and in Farmlands

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Review

How Natural Phenomena and Disasters Together with the Weathering Conditions Affect Microplastics and Their Transport from Aquatic Systems to Agricultural Soils and Farmlands

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Abstract: Concern over microplastics (MPs) in the environment is rising. Microplastics are generally known to exist in aquatic settings, but less is known about their occurrence in soil ecosystems. When plastic waste builds up in agricultural areas, it can have a negative impact on the environment and food sources, as well as have an indirect effect on all trophic levels of the food chain. This paper addresses the relationship between microplastics and the management of plastic waste, which contributes to their accumulation, and it describes the sources and primarily the movement processes of microplastics in agricultural soils as a result of natural events. Evaluating the impact of weather on coastal microplastic contamination is critical, as extreme weather events have become more frequent in recent years. This study sheds light on how weather patterns affect the dispersion of plastic waste in terrestrial habitats, including the impacts of seasonality and extreme weather. According to the results of this review, typhoons, monsoons, rainfall, and floods all contribute significantly more microplastics to the surface sediment through surface runoff and wind transport, particle redistribution caused by agitated waves, and fragmentation under intense abrasion forces. Severe weather conditions have the potential to disperse larger and more varied kinds of microplastics.

Keywords: Microplastics; aquatic environments; agricultural soil; farmlands; microplastic transport

Introduction

The maritime environment is said to be the sink for the improperly handled garbage. A prominent illustration of this occurred during the floods in several regions of India, as land-based plastic waste that had been transported to marine waters by runoff found its way back onto the beaches[1]. To put it another way, according to a study by Belioka et al., 2024[2], by the end of 2060, all plastic waste produced worldwide will either be recycled, disposed of in landfills, burned, or, in the worst case, completely mismanaged. To reduce the consequences of pollution in the future, plastic trash must be properly addressed [2]. Plastics should be recycled wherever possible, and if that isn't practicable, they should either be burned with energy recovery or landfilled in an environmentally friendly manner. This lessens the quantity of inappropriately handled garbage and leaves only hard-to-treat leakage sources, including microplastics (MPs) and uncollected litter. As a result, rates of incorrect trash disposal will decrease and rates of recycling will rise globally[3].

Microplastics are a type of pollution that is becoming more and more of a worry since the plastic waste that is dumped in the marine environment breaks down into tiny fragments for a variety of reasons [4,5]. All additional microplastics—aside from the basic microplastics—are created by breakdown from bigger plastics. In the marine environment, the conversion of macroplastics into microplastics is contingent upon their duration of residence in the ecosystem; a longer residence period leads to a greater degree of degradation[5]. While MPs in aquatic systems have been researched in great detail, little is known about their existence and ultimate fate in agricultural systems. Weather conditions are one of the factors that direct MPs to agricultural soils. The use of

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compost and biosolids, irrigation with wastewater, mulching film, polymer-based fertilizers and pesticides, and atmospheric deposition are the main contributors to MPs contamination in agricultural soils. The properties of the soil, agricultural techniques, and soil biota variety are the primary factors influencing the fate and dispersal of MPs in the soil environment. Despite the fact that MP contamination in the soil environment is on the rise, there are currently no established methods for detection and measurement. Because of this, emphasis is placed on understanding the causes that drive microplastic transport from aquatic environments and steaming to farmland and agricultural soils[6].

Agricultural soil systems are the primary sources of microplastics; they are exposed to them in a variety of ways, and a range of environmental and weathering conditions may have an impact on how the microplastics behave. The primary sources include air deposition, agricultural operations, and input from irrigation and fertilizer. Microplastics are broken down and broken down in agricultural soils by mechanical abrasion and photo-oxidation, with UV irradiation playing a major role in the early phases of the microplastic degradation process. Additionally, depending on the features of the soil environment, agricultural practices, and the qualities of the microplastics themselves, microplastics may move through soil systems in both physical and biological ways. By directly ingesting or accumulating in organisms, microplastics have a variety of effects on agricultural soils. They can also indirectly change the microbial population or soil's qualities[7]. Extreme weather is being impacted globally by Earth's changing climate. There is an increasing frequency and intensity of extreme weather events like as heat waves that shatter records both on land and in the water, torrential rains, major floods, prolonged droughts, intense wildfires, and extensive flooding during storms. It is anticipated that some extreme weather event types may become more frequent, intense, and damaging due to climate change[8].

Dry and wet atmospheric fallouts are the means by which airborne microplastics reach the aquatic and terrestrial habitats. Concerns about airborne microplastics have grown, as has the number of places investigated since proof of their existence in atmospheric fallouts was discovered[9]. Research is concentrating on various environmental kinds. Only a portion of the destiny of microplastics in the atmosphere is known[10]. Microplastics were discovered in the dry and wet atmosphere in alpine regions, metropolitan areas, and maritime habitats. They showed patterns in relation to the quantity of precipitation, whether it be in the form of rain or snow, as well as the direction and intensity of the wind [11,12].

In higher altitude ecosystems, precipitation—snow and rain—is thought to be the main factor causing MP deposition. Due of their low density, MPs are carried by wind into the upper atmosphere where they settle as a result of precipitation or snowfall. This presents serious environmental problems [13]. Airborne MPs settle at various altitudes thanks to the transport, dispersion, and deposition processes in the atmosphere brought on by downward air movement, local turbulence, and wind flow. Additionally, it has been observed that smaller MPs and smaller relative densities have been detected at greater elevations than larger MPs. Hence, MPs' abundance and dispersion at faraway locations may be facilitated by air movement[14].

It is well accepted that microplastics can act as carriers to encourage microbial colonization and biofilm development, and eventually turn into a pelagic habitat for microorganisms because of their extended half-life and hydrophobic surface[15]. Microplastics also increase the possibility of potentially harmful bacteria spreading over long distances, which has an ecological impact on the original environment. According to some research, tropical cyclones—also known as tropical storms and typhoons—and other catastrophic storm occurrences can have a major impact on coastal ecosystems[16].

Recent studies have highlighted surface runoff as a major source of microplastic contamination, suggesting that it contributes more to the problem than point sources do. Furthermore, a few recent researches have looked at the temporal dynamics of microplastics' abundances and properties. Significant fluxes in microplastic abundances in freshwater and marine ecosystems have been documented following rainfall events, storms, floods, and typhoons, with regards to the impacts of runoff on the receiving water bodies[17]. Most of the studies calculated that the wet or monsoon season contributed more to the yearly emissions of microplastics than did the dry season. Furthermore, relationships based on regression analysis have been shown between microplastic abundances and rainfall features[18]. A characteristic example is the waste from masks during COVID-19 period and how weathering conditions contributed to their transportation. After the soil weathered, a significant amount of fibers on the mask's surface were released into the surrounding area and were entangled on the broad soil surface. The combination of soil microorganisms and hydraulic erosion during wet weather also contributed to the release of microplastics. Significant amounts of microfiber were released by microplastics from mask waste; the sequence of release ability, from greatest to smallest, is soil > ocean > river > air > new mask[19].

Information on the potential origins and routes of microplastics in the marine environment may be gleaned from the distribution of microplastics in relation to the geographic characteristics of the region. Furthermore, it is anticipated that the temporal variations in the distribution of microplastics will shed light on how natural events like floods and oceanographic characteristics like wave height affect the microplastic contamination of the maritime environment. Microplastics are predicted to be transported in large quantities from the terrestrial to the marine environments during floods. However, there isn't much information in the academic literature about how flooding affects microplastic pollution[1]. The majority of research done to date has been carried out in industrialized nations with temperate climates, where precipitation may occur year-round, and where plastic waste management is generally effective. Developing nations with high GDP are known for their poor handling of plastic trash, which causes significant environmental plastic pollution and it can have serious consequences after a natural disaster for example[11,20].

Here, our goal is to create a mini-review that investigates how the distribution of MPs in farmlands and agricultural soils is affected by changes in seasonality and harsh weather. This brief overview offers information on three key topics related to microplastic distribution: (1) seasonality and its consequences; (2) the effects of typhoons, rainstorms of varying intensities, and other meteorological phenomena; and (3) a link with inappropriate plastic waste management. Additionally, a statistical study has been conducted to categorize the impact of the most severe natural disasters. We note that increased microplastic abundances are detected during (1) the wet season with higher precipitation and during (2) extreme weather events with heavy precipitation, strong wind, and storm surge. These findings are supported by earlier research on the impacts of seasonality.

Research Methodology

This mini-review compiles findings from researches about natural phenomena and natural disasters together with weathering conditions that affect the transport and accumulation of Microplastics in agricultural soils and farmlands. The number of publications on such topics is limited and the number of relevant articles is small. The reason is that research studies focus mainly in aquatic environments, oceans, rivers, lakes and coastal areas instead of agricultural soils and farmlands. Therefore our review has a small data base with a total of 80 papers.

The terms "microplastics" and "transport" were combined with the following keywords to extract literature from the databases of Google Scholar, Scopus, and Web of Science: "natural disaster," "natural phenomena," "weather," "weathering conditions," "climate," "climate change," "farmlands," and "agricultural soils." The studies that were retrieved were categorized according to the monitoring technology they covered. Every article that was found was released between 2004 and 2024. Moreover, research conducted in aquatic environments—such as lakes, rivers, and oceans—was also included because they describe the mechanisms of MPs transportation.

After conducting the necessary searches in the relevant databases, we came to an end when we discovered many pages of results lacking any relevant publications from Scopus, Google Scholar, or Web of Science. Conference papers, postgraduate and doctoral theses, and articles written in languages other than English were all disregarded since the search was limited to locating publications that included literature reviews. As a consequence, relevant publications were added to our collection after published papers were sifted using the previously mentioned criteria (title,

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keywords, and abstract). Each article's content was examined, with particular attention paid to the abstract and conclusion sections. This review paper's research methodology followed the optimal reference criteria for systematic reviews and meta-analyses established by Moher et al. approach as you can see from Figure 1[21].

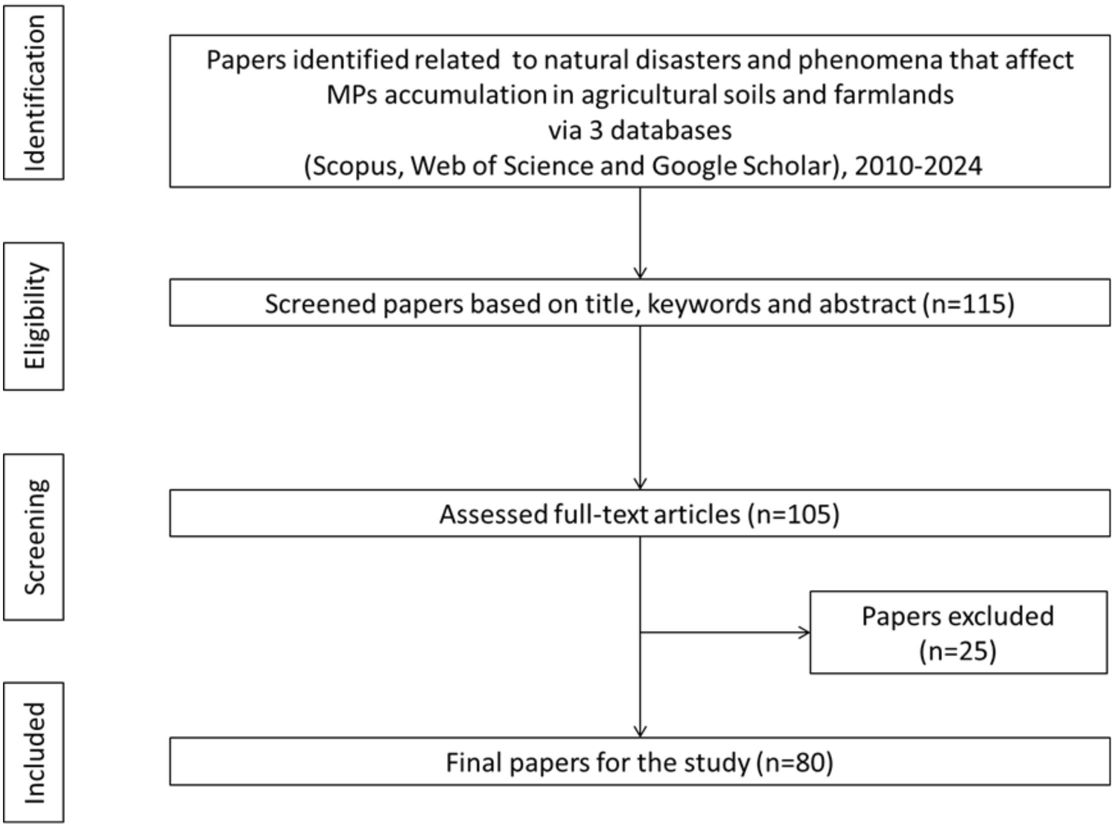

Figure 1. Comprehensive workflow of the research project.

Results and Discussion

The ecology is seriously threatened by microplastic contamination, which can be impacted by a variety of meteorological conditions. Evaluating the impact of weather on coastal microplastic contamination is critical, as extreme weather events have become more frequent in recent years[22].

One of the biggest problems nowadays is the pollution of freshwaters, seas, and soils by microplastics (MP). Large amounts of MP are carried from the land to the sea via river systems, where they end up in floodplains and river sediments that damage agricultural soils and farmlands. Floodplains and the soils inside them are recognized for their ability to act as sinks for pollutants, nutrients, and sediments as a component of the river system[23]. Still unanswered are the following: How much of this deposition happens in soils in floodplains? Which is the geographical distribution of MP accumulations that may be caused by various environmental drivers? The attempt is made here to compile information and carefully look at each of the variables (natural phenomena and disasters) that influence the buildup of MPs in farmlands and agricultural soils.

Microplastics (MP) enter wastewater treatment facilities through three different channels: stormwater, household wastewater, and industrial wastewater.

The pace at which MP enters wastewater treatment plants can be changed by extreme weather circumstances, such as increased temperatures and excessive rains brought on by climate change. The distribution and destiny of MPs can be impacted by natural catastrophes or events, as demonstrated by seasonal changes and a thorough investigation of MP dispersion in various phases of wastewater treatment plants[24]. Additionally, a significant positive association was discovered between the MP concentration and the quantity of precipitation. A large amount of MPs from our daily lives end up in wastewater and are used in agriculture as sewage sludge. Thus, a closed loop is produced.

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Enhancing my writing skills requires a deeper comprehension of the movement and final destination of microplastics in wastewater treatment facilities[25].

Microplastics are mostly stored in soil[26]. Large amounts of microplastic fibers or debris have been discovered in compost fertilizers and sewage sludge by several research [27,28]. These sludges are frequently utilized in agricultural activities[29,30]. Researchers have found various microplastics in soil ecosystems, which may have originated from applying organic fertilizers or sewage sludge to farmlands, from atmospheric deposition, from flooding or polluted waters, from littering, from the weathering and disintegration of plastic films on farmlands, from the fragmentation of plastic waste and items in landfills, and from littering[31,32]. Furthermore, some industrial, agricultural, marine, urban, suburban, and even floodplain soils have been shown to contain microplastics[33]. Below there is a classification of the different weathering conditions, natural phenomena that affect the transport of MPs in soils and farmlands.

Figure 2 shows the classification of the most often natural phenomena that contribute to the MPs transport in agricultural soils and farmlands after a comprehensive statistical analysis of the studies presented in this mini-review. The most dominant phenomena are floods and storms together with winds and tidal having together a percentage very close to 50%, almost the half. Typhoons and monsoons occupied together the second position with a perecentage close to 36%, which means that together with the first category the 86% of the accumulation of MPs is due to natural and meteorological phenomena. The rest belongs to phenomena of minor importance such as snow and precipitation, meteorological parameters at high altitude areas and drought together with dust storms. It is important to highlight that there is almost a 2% contribution to MPs transportation due to the salinity of the water. Figure 3 shows the literature review’s results that refer to the frequency of case studies produced in each country on this topic and it is worth noting that the first two places are occupied by China and India, followed by Japan and Australia, then a few European countries, even fewer African and South American countries and no North American countries.

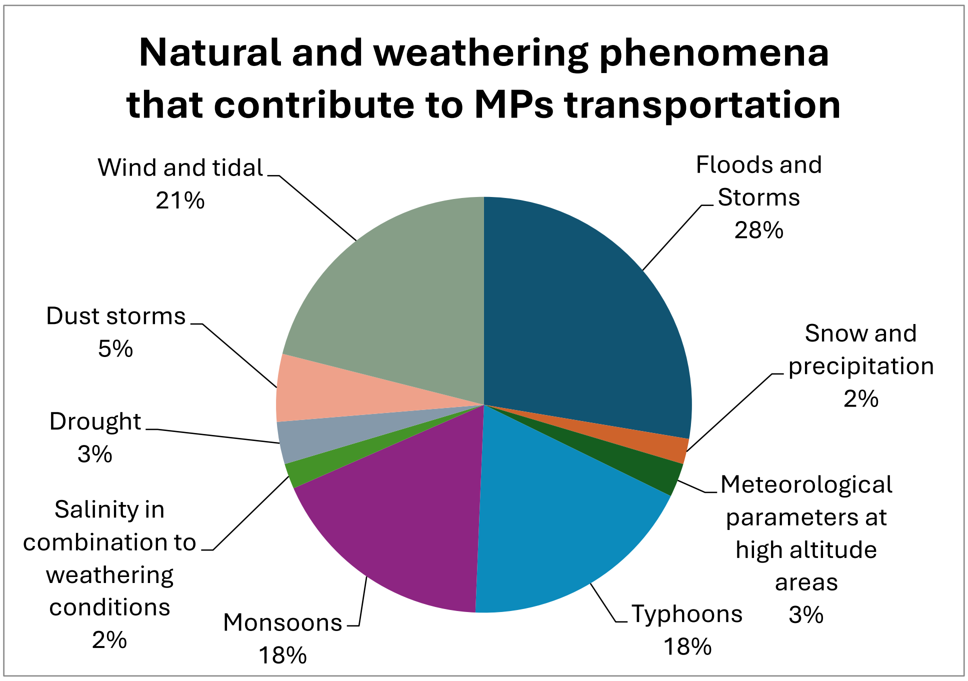

Figure 2. Natural and weathering phenomena that contribute to MPs transportation.

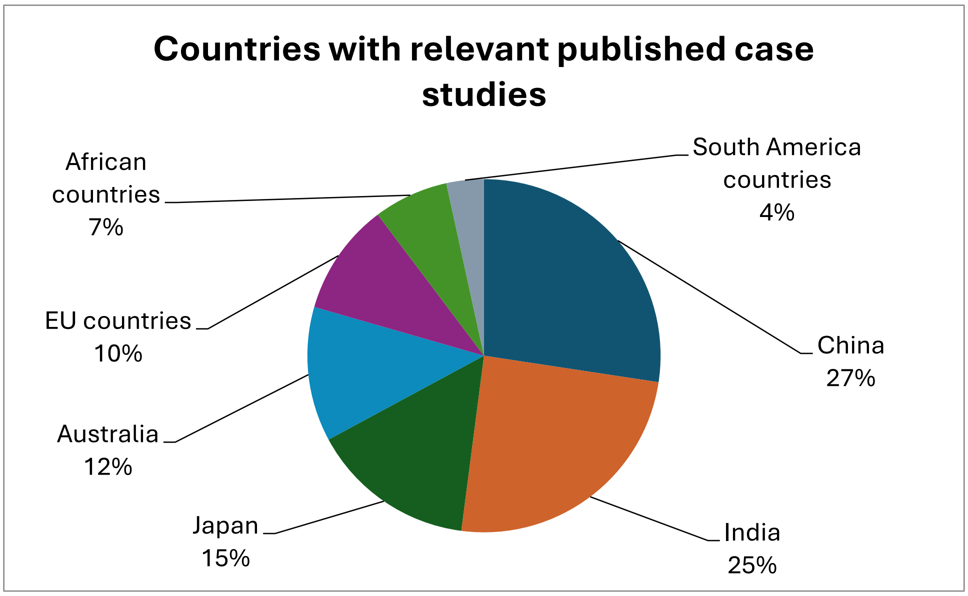

Figure 3. Countries with relevant published case studies.

Floods and Storms

The ecology is seriously threatened by microplastic contamination, which can be impacted by a variety of meteorological conditions. Evaluating the impact of weather on coastal microplastic contamination is critical, as extreme weather events have become more frequent in recent years. Cheung et al. (2023) carried out follow-up studies following typhoon and rainy events in addition to a year-long baseline survey on surface seawater and beach sediment in Hong Kong. According to our research, the quantity of microplastics was five times more in the rainy season than in the dry season. However, the seasonal fluctuation was negligible when the baseline condition was taken into account, indicating that extreme weather events are the primary cause of the seasonal variation in the distribution of microplastics. Larger amounts of microplastic in beach sand and a higher percentage of hard pieces after severe weather point to a greater mobility of heavier plastic debris from a wider source. Positive correlations were found between plastic levels and various weather variables, such as rainfall, wind, and tide[22]. These findings raise the possibility of microplastics entering the Earth through surface runoff and wind transport, as well as the possibility of microplastics being redistributed from deep sediment to surface sediment by wave agitation. Additionally, they found a highly positive correlation between the abundance of macro- and microplastics in beach sediment, indicating the possibility of plastic fragmentation under high wave abrasion. This could exacerbate the pollution of farmlands nearby by coastal microplastics[22].

Cheung et al. (2019) investigated the relationship between the dynamics of microplastics in rivers and the degrees of pollution they cause, by measuring the quantity and characteristics of microplastics at the surface of an urban river during a rainy event in Hong Kong. Following a three-day rainstorm event, plastic samples were gathered at the river's surface, and the microplastic abundance was almost twice as high as that of the coastal sea surface in the same region. The discovery of a ten-fold reduction in microplastic abundances in a span of two hours indicates a very dynamic temporal distribution of river microplastics following rainfall[34].

Water contamination is mostly shaped by urban surface runoff (USR) and drainage system overflows during rainy weather (WWF). In particular, it is uncertain how much contamination from microplastics affects metropolitan water bodies. In six primary urban drainage systems along Suzhou Creek in the Chinese megacity of Shanghai, Sun et al. carried out an in-field analysis. They determined the effects of land use and storm conditions on the real-time dynamic changes in microplastic abundance and features in USR and WWF. In both USR and WWF, they discovered statistical evidence of the broad relationships between microplastic abundance and storm variables (accumulated storm depth and WWF flow). Both USR and WWF have the first flush phenomena of

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microplastic dynamics. The properties of microplastics also varied dynamically with storm duration. Polypropylene and small-sized (<1 mm) microplastics in USR occurrences rose and then declined with significant storm components[35].

In order to evaluate the quantity and make-up of microplastic pellets (MPPs) along the Chennai coast prior to and following the 2015 flood, Veerasingam et al. (2016) examined the effects of the flood on the distribution of MPPs on Chennai beaches, along with potential sources and controlling factors, and identified the types of polymers present in the soils[36].

A significant amount of new MPs swept down the Cooum and Adyar rivers from land during the storm, as evidenced by the three-fold increase in MP abundance in November 2015 compared to March 2015. The movement and deposition of MPs from the sea to beaches in November was mostly driven by winds and surface currents[36].

Due to its unusual geographic location, Kerala, which borders the western coast of peninsular India and lies to the west of the Western Ghats mountain ranges, receives abundant monsoon rains. A study made by Kumar et al., (2021) demonstrated that the 2018 and 2019 Southwest monsoon was terrible since it brought about river flooding. The extremely heavy rainfall raised the water load in nearly every reservoir's catchment region, pushing the water levels above critical limits. The need to quickly activate reservoir flood gates contributed to the intensity of the floods. Waste from the land, such as plastic, construction, and biological debris, may be carried by floods caused by overflowing canals, rivers, and dams. Surprisingly, the quantity of microplastics in the samples gathered during the flood continued to be high. In both of the flood period samples, there was a significant concentration of microplastics in soils. Furthermore, more industrial pellets were found during the flood months than at any other time throughout the test period. One potential cause might be the flood overflow from the surrounding plastic manufacturing sector[1].

Wind and rainfall have been shown to have an impact on the fluxes of microplastic deposition in air fallouts from temperate regions, as well as from both urban and distant locations. Surface runoff, urban drainage (stormwater drainage), and interflow (from the near-surface unsaturated zone) are some of the mechanisms that provide direct runoff, which is the quick delivery of water to the stream.

Farmlands are expected to have a large amount of direct runoff contributing to the overall MP load of the water and soil. According to Moses et al.'s 2023 assessment, every headwater source is located in the lower mountain range, near to agricultural soils and farmlands[37]. Balthazar Silva et al. verified and emphasized that local-scale variability is dependent on tides, beach hydrodynamics, and distance from source, whereas regional scale variation is driven by rainfall and source distance[38].

In another study carried out in 2024 by Imbulana et al., microplastics mobility may also be influenced by rainfall intensity and event length. The research has indicated that microplastic mobilization happens when rainfall intensity surpasses 2.5 mm/h for a period more than two hours. Despite the fact that microplastic discharge characteristics can vary greatly between catchments and rainfall events, our data from the lowest rainfall event suggested that two hours at an intensity of 1.5 mm/h would be enough to introduce over two billion MPs into the river. Furthermore, the findings demonstrate that, in order to fully capture the range of variability in MP emissions, consideration should be given to the effective time during which a rainfall event may impact river flow, rather than the duration of the rainfall.

The primary routes via which land-sourced microplastics enter the world's seas are urban waterways. While the concentrations of MPs were correlated with the number of preceding dry days, the inter-event total loads of MPs correlated strongly with the total rainfall. At lesser rainfall intensities, MPs above 2000 μm are released immediately after the peak rainfall intensity, whereas smaller MPs (10–40 μm) are mobilized quickly. Furthermore, <70 μm MPs show a surge that occurs after periods of intense rainfall because of turbulent flow conditions that put the deposited MPs back into suspension[18].

Xia et al., 2020 also looked at the connection between surface water microplastic content and rainfall. During the summer, the experiment was carried out at China's largest urban lake, Lake Donghu. The findings showed a substantial relationship between microplastic content and rainfall.

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Therefore, in order to effectively assess microplastic contamination and its effects, high frequency sampling and rainfall data are required[39].

Hitchcock (2020) investigated the changes in microplastic concentrations during a storm event in an urban estuary. Rain and storm events are accountable for the mobilization and transport of various contaminants in aquatic systems. High-frequency sampling was carried out before to, during, and following a storm event that resulted in flooding in Australia's Cooks River estuary. The quantity of microplastics rose from 400 particles per cubic meter prior to the storm event to as high as 17,383 particles per cubic meter following two days of intense rain. The five-day average antecedent rainfall was positively correlated with variations in microplastic abundance. The findings emphasize how crucial rain and storm-related events are for the pollution of aquatic systems with microplastics. The findings have implications for estimating the maximum amount of microplastics to which aquatic life may be exposed and for managing stormwater to reduce the amount of microplastics entering aquatic environments[17].

Since deposition plays a significant role in microplastic migration and transport in the atmosphere and urban areas are the most severely affected by microplastic pollution, Jia et al. (2022) looked into the characteristics of atmospheric microplastic deposition in megacities in order to shed light on the contributions of anthropogenic and meteorological factors as well as to identify the sources of atmospheric microplastics. Microplastic characteristics were correlated and variance-analyzed with meteorological and anthropogenic factors (land-use, atmospheric pollutants, and urban indicators). The results indicated that wind and precipitation had an impact on deposition flux, size, and shape, and that these effects were more pronounced at small scales (individual cities), while the population was the primary microplastic influence at large scales. Shanghai's atmospheric microplastics may be mostly produced by external sources due to a combination of the microplastics' properties, wind, and backward trajectories. The destiny of urban air microplastics was also disclosed by this study, and it has consequences for the contaminating of agricultural areas and farmlands[40].

One important route for the transfer of microplastics to land from aquatic habitats is thought to be stormwater runoff. Rainfall-splashed particles and MPs block soil pores, sealing off the soil's surface and preventing adequate water penetration. Rainwater will gather and flow downslope in sheet or rill erosion rather than seeping into the soil.

Microplastics found in stormwater runoff from residential and industrial regions were examined by Cho et al. in 2023. When there were more antecedent dry days (ADDs), the concentration of microplastics in stormwater was greater. During a rainfall event, the concentration of microplastics often peaked in the early stages of runoff and fluctuated depending on the severity of the rainfall. The overall rainfall depth had a significant impact on the microplastic load and contamination level. The majority of microplastics were carried by early runoff to agricultural soils, while the percentage of bigger, heavier particles increased throughout the runoff's final stages. It is likely that stormwater runoff is the primary means of introducing microplastics into aquatic habitats since the amount of microplastics released by stormwater runoff was much larger than the amount released through wastewater treatment plant effluent in the same location[41].

Pollutant levels in marine habitats are significantly increased by floods brought on by heavy rain. Gündogdu et al. (2018) assessed the impact of many floods that took place in Turkey's northeastern Mediterranean area between December 2016 and January 2017 on the amount of microplastic pollution in Mersin Bay in another research. The current structure and the spatial and temporal distributions of microplastics were hinted at by sampling from four different stations both before and after the flood period, along with a hydrodynamic modeling study. The results showed that severe rains and floods can significantly raise the levels of microplastics in various environments, such as the sea or the mainland[42].

Due to the paucity of research on the quantity and distribution of microplastic in rivers, as well as how they are distributed in farmlands and agricultural soils, Wong et al. (2020) looked at the contamination of the Tamsui River and its tributaries in northern Taiwan with microplastics. Each sample had varied levels of microplastics, which suggests that the Tamsui River and its tributaries are heavily polluted. Precipitation and the quantity of microplastic particles detected in the rivers have been determined to positively correlate, according to the data. Furthermore, a significant geographical and temporal fluctuation in the quantity of microplastic in the left, center, and right parts of each river was noted[43].

Yadav et al. (2022) also highlighted that microplastics (MPs) exist in water bodies, and in certain places, runoff, floods, and irrigation bring these aquatic MPs onto the agricultural fields and farmlands[44]. Crop fields that are close to water resources are more likely to experience this, and soil contamination also results from irrigation from rivers, lakes, and groundwater that already contain microplastics. Another significant factor is flooding, which has the power to carry enormous volumes of trash and waste from water bodies and even landfills onto agricultural land[45].

Another study confirms that precipitation and atmospheric deposition might potentially be sources of MP contamination in agricultural soils. Due to intense rains, the Luo Yongming study group discovered MP levels in China's coastal towns' air environments for the first time. These MPs that have been deposited in the sky have the potential to directly contaminate agricultural nonpoint sources with MPs by penetrating the topsoil of suburban agriculture[46]. Furthermore, there exists a linear negative correlation between the average particle size of microplastics and soil depth. Smaller particle size microplastics are more easily migrated via soil pores when water is applied following intense rainfall and fertilizer application[47].

In their 2020 study, Gorman et al. attempted to provide an explanation and understanding of the ways in which fluvial processes—the materials that rivers and streams carry into coastal waters—cause microplastic particles to travel and concentrate in estuarine coastal waters and agricultural soils near rivers. According to model results, the debris field is most likely to be in the near- and offshore locations (between 34 and 40 km2), intermediate at the river mouth (mean 34 km2), and modest within the estuary (between 3.6 and 8.1 km2). The study found that the spatiotemporal dynamics of microplastic debris movement and accumulation within dynamic coastal habitats are significantly influenced by the fluvial forcing (rainfall and estuary flushing)[48].

Osinski et al. (2020), selected Baltic sea in their case study to examine how natural phenomena and disasters affect the transport of microplastics. The selection of a storm event was made because severe wave heights lead to significant sediment erosion to generally unaffected depths; hence, these occurrences are essential for identifying the accumulation zones. The determination of metocean characteristics in such harsh weather events demonstrates that storm events dictate the movement of settled MP, and it has been discovered that atmospheric circumstances significantly influence the amount of material that is deposited and degraded[49].

Rainfall increases surface water runoffs, which transfer microplastics from land-based soils into the aquatic ecosystem[50]. The concentration of microplastic in the river surface water was double that of the coastal saltwater in Hong Kong after a three-day rainstorm event[34]. According to Xia et al., surface water microplastic content rose four times during a period of intense rainfall[39]. Because they become trapped in the raindrops, atmospheric microplastics can be carried into the aquatic environment via precipitation[51].Furthermore, rainfall may have an inverse link between suspended microplastics and sediment by altering the hydrodynamics of water flow and resuspending the microplastics in the sediments[52]. Acid rain has the potential to bleach coral reefs and enhance the discharge of microplastics that have been stored, which will cause a redistribution of microplastics[53,54].

A baseline study conducted by Cheung et al. (2023), on Hong Kong's beaches and surface waters for a full year, with follow-up studies conducted following typhoons and rainstorms. The research shows that the quantity of microplastics was five times more in the rainy season than in the dry season. However, the seasonal fluctuation was negligible when the baseline condition was taken into account, indicating that extreme weather events are the primary cause of the seasonal variation in the distribution of microplastics. Rainstorms and typhoons increased the amount of microplastics in sediments by 11.7 and 36.4 times, respectively. Larger amounts of microplastic in beach sand and a higher percentage of hard pieces after severe weather point to a greater mobility of heavier plastic debris from a wider source[22,34]. The results of this study showed that there are positive correlations between plastic levels and a number of meteorological variables, such as rainfall, wind, and tide.

These findings raise the possibility that microplastics may be transported from deep sediment to the surface by waves, or that they may be introduced onto land through surface runoff and wind transport. Additionally, a highly positive association was found between the concentration of macro- and microplastics in beach sand, indicating the possibility of plastic fragmentation under high wave abrasion, which might exacerbate the microplastic pollution along the coast[22].

Snow and Precipitation

In a paper written by Padha et al., 2022, when glaciers melt, they are discharged, polluting marine systems and freshwater lakes. The majority of supraglacial debris is rich in microplastics (MPs), which are deposited by snow or air. As these glaciers move down the valley, they carry the imbedded MPs and other pollutants, which build up downstream in rivers or lakes and have an impact on farming and agricultural soils. Freshwater lakes and marine ecosystems are contaminated by the melted glaciers. Microplastics (MPs) are mostly found in supraglacial debris and are deposited by snow or air. These glaciers transport embedded MPs and other pollutants down the valley, where they accumulate in rivers or lakes and affect farming and agricultural soils[14].

Following a period of continuous snowfall, samples of new snow were gathered from various sites in both urban and rural areas of northern Iran from a study made by Abbasi et al. (2022). The thawed contents were then analyzed using standard procedures to look for microplastics (MPs). MP concentrations were high, and neither the kind of sample location nor the depth of snow (or time of deposition) collected at different sites showed a statistically significant variation in MP concentration. The recorded mean and median concentrations of MPs in rains that were gathered at an elevated site in southwest Iran were not significantly different from the MPs' mean and median concentrations in the snow samples. However, in contrast to rainfall, MPs in snow tend to be bigger, more varied in form, and include rubber particles. This might be due to the fact that snowflakes have lower terminal velocity than raindrops, despite their larger size. More research is necessary since snowfall is an important way that MPs are taken up from the atmosphere and end up in surface waters and soil[55].

Meteorological Parameters at High Altitude Areas

Microplastics (MPs) are a class of new pollutants that are widely present in the environment. However, little is known about MPs in high-altitude, isolated, terrestrial environments with few populations and difficult-to-access traffic. Feng et al. (2023), studied the effects of land use type, altitude, meteorological parameters, and distance from the road edge on MP distribution. Fifty-four soil samples were collected from various land use patterns (bare land, grassland, greenhouse, and ordinary farmland) in the western area of the Tibetan Plateau. Because there are less human activities (particularly agricultural ones) in high-altitude regions, the concentration of MPs was somewhat inversely linked with altitude. According to the random forest (RF) models, the primary driving factor influencing the MP distribution was height. Higher elevations showed a greater abundance of small-sized MPs than lower ones, and the unique natural environment of these regions—which includes strong winds, UV radiation, and sparse vegetation—may encourage the breakdown of MPs in surface soils. The unique source of microplastics (MPs) in non-agricultural soils was linked to traffic patterns, namely the parking and resting of vehicles next to high-altitude roadways. This activity accounted for a significant portion of MPs in the plateau region[56,57].

Typhoons

It is not well known how frequent extreme weather events, such typhoons, affect atmospheric MPs. Li et al. (2022) thus gathered rainfall samples and suspended atmospheric MPs (SAMPs) in the South China Sea during Typhoon Sinlaku (2020) in order to examine this problem. The typhoon considerably altered the pathway of MP transport in the atmosphere, including its direction and distance, according to the trajectory source-receptor map[58].

The impacts of Typhoon Wipha on MPs quantity and composition in surface water and sediment-crossed coastal regions of Shenzhen were examined in a published case study by Chen et al., 2021. They discovered a notable rise in the quantity of microplastics in surface water brought on by typhoons. Typhoons may have brought in an inflow of microplastics despite the fact that agitation clearly carried the particles from sediment to surface water, as indicated by the significant amount of unknown force assigned to the source tracking study. Moreover, over the course of the 190 km coastal line, the typhoon skillfully unified the plastisphere population in the sediment. Following the storm, a notable rise in nitrogen fixers was seen everywhere, which might change the nitrogen cycle and worsen the eutrophic state of the coastal biological system[16].

Wang et al.'s work from 2024 improved our understanding of how typhoons affect the redistribution of pollutants, particularly microplastics, and provided crucial empirical data and theoretical underpinnings for pollution control. The microplastic abundance and morphological characteristics of microplastics in sediments were found to be enhanced by typhoons. This was demonstrated by a change in the predominant microplastic shape from fibers to fragments and a decrease in size that was accompanied by an increase in abundance within the 100 μm–1 mm fraction. Typhoon-induced wave intensity amplification may be responsible for the change in microplastic shape[59].

There were a number of noteworthy meteorological phenomena that occurred during the Cai et al. (2017) research period that would have had an impact on the material available for air fallout, including strong typhoons, cold fronts, and easterly winds. Severe typhoons in the China Sea cause significant wave motion along the shoreline and entice a lot of biological material and sea salt into the sky. The necessity to take into account potential MP atmospheric transport and source scenarios outside microclimate urban MP creation is suggested by these noteworthy maritime weather circumstances. One possibility is that MP particles were entrained and moved from the beach to city sites, agricultural soils, and farmlands near the city by high winds and wave activity along the shoreline caused by the typhoons[60].

The ecological risks posed by plastics and the growing severity of microplastic contamination in coastal regions have garnered international attention. Typhoon frequency and severity have risen as a result of global warming, which has a significant impact on the distribution and makeup of microplastics in coastal ecosystems. Jian et al. (2022), examined the microplastic flow, variety, abundance, and composition in three estuaries and one sewage outlet located in Zhanjiang Bay. Following the storm, the average abundance of microplastics from land-based sources rose.Furthermore, following the storm, the percentage of fiber and big microplastics also rose. It has been shown that Typhoon Kompasu had an impact on microplastics from land-based sources in ZJB coastal waters, and it has also supplied essential information for future research on the subject[61].

Monsoons

Numerous elements, like as winds, currents, waves, longshore drift, and the morphodynamic condition of beaches, influence the quantity of MPs on a beach. The distinctive feature of seasonal reversal of wind systems that takes place during south-west (SW) and north-east (NE) monsoon seasons is what essentially drives the dynamics of the Indian Ocean as studied by. The plastic garbage that is carried to the coast is caused by seasonal winds and currents. The study region's wind statistics are from the months of January and June 2015, which correspond to the NE and SW monsoon seasons, respectively. Veerasingam et al. (2016) found that winds' speed and direction, as well as ocean surface currents during the monsoon seasons, are important factors in the geographical distribution of floating debris[36].

Similar research was done by Warrier et al. to look at the seasonal distribution and presence of microplastics in Lake Manipal's surface water samples in southwest India. Compared to the post-monsoon period (0.117 particles/L), the concentration of MPs was found to be greater during the monsoon season (0.423 particles/L). The increased amount is ascribed to surface runoff during times of heavy rainfall as well as the intake from storm-water drains that are linked to the lake[62].

One of the primary factor facilitating the long-distance movement of Microplastics during monsoons is surface current. Large volumes of plastic trash are accumulated in the global ocean circulation due to wind and thermohaline processes, which has raised serious ecological concerns.

Similar foci of aggregation in the gyres produced by wind-driven transport and geostrophic circulation have been independently predicted by numerical modeling studies. It has long been known that one of the main routes for terrestrial debris, including microplastics, to enter open waters is through boundary currents (such as the Gulf Stream and Kuroshio) that run along the continental shelves. Boundary currents can carry floating microplastics quite quickly. The capacity of coastal currents to carry microplastics from the shore to the continental shelf is more variable over time, and it may be impacted by weather disturbances, vertical stratification, and seasonal fluctuations in upwelling and downwelling[63]. Wind may directly influence the direction and velocity of plastic floating on the ocean surface in addition to causing wind-induced circulation. Plastic particles may travel in different directions and at different speeds than those of the surface current alone due to the influence of leeway drift or windage[64].

The East Asian summer monsoon (EASM) has a large seasonal impact on air mass movement over the South China Sea. A recent study found that the monsoon system has a major influence in the worldwide movement of persistent organic pollutants and microplastics. Strong anticyclonic circulation may carry the MPs after air parcels are convected to the high troposphere, where they will then gradually climb into the lower stratosphere. Therefore, the horizontal and vertical distributions of atmospheric MPs may be exceedingly irregular and diverse. Furthermore, modeling research and observation have demonstrated that the summer monsoon affects East Asian aerosol concentration seasonal and interannual fluctuation[65,66].

Salinity in Combination to Weathering Conditions

Because of the stratification and mixing that occur at the interface between salty saltwater intrusion and fresh riverine flows, salinity should be taken into consideration while tracking the geographic distribution of MPs in river estuaries. The aforementioned interaction causes the salinity in the estuary and may thus affect the buoyancy of MPs, despite the fact that several studies showed no relationship between MP abundance and salinity. Estuaries are divided into three categories based on their salinity structure: thoroughly mixed, somewhat mixed, and salt wedge estuaries.

Restricted tidal fluctuation is a characteristic of salt wedge estuaries. The contact between a surface freshwater outflow and a bottom seawater input is where the salt wedge forms. Salinity is often lower at the estuary's head than it is at the mouth. Furthermore, the lack of high winds that would exacerbate turbulence in the estuary is necessary for the creation of a salt wedge. It works better to blend fresh and salt water in estuaries with a large tidal range. An estuary that is partially or well mixed depends on the degree of mixing. The salinity front in salt wedge estuaries creates a barrier that prevents MPs from moving from upstream to downstream and vice versa. Because of the salt wedge's poor circulation, MPs and other particles sediment at high rates. The movement of buoyant microplastics (MPs) in freshwater flow into the ocean and the sedimentation of negatively buoyant MPs are facilitated by the circulation in a salt wedge estuary. Nevertheless, MPs acquire a negative charge that encourages settling when they come into touch with the salt water at the incursion.

The saline front's limit, which is determined by tidal and climatic factors, is known as the estuarine turbidity maximum (ETM). The center of the estuary is where salt intrusion originates during the dry season, having the lowest concentration there. Salinity drops during the rainy season, and salt wedge estuaries serve as makeshift sources and sinks during the wet season[67]. By monitoring the shift in the chemicals' partition coefficient with salinity, one may assess the effect of salt on the adsorption of compounds by MPs. The adsorption caused by hydrophobic contact may not be impacted by salt, while salinity does alter the adsorption caused by electrostatic interaction[68]. In their 2014 study, Bakir et al. examined the movement of POPs (persistent organic pollutants) by MPs in estuaries and discovered that while salinity had no influence on POP adsorption and desorption rates by PE and PVC, for example, it did cause a drop in overall adsorption as salinity increased[69].

Abrasion and photo-oxidation are the most practical microplastic weathering processes. The weathering process modifies the adsorption behavior and performance of MPs. Even though most

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synthetic polymers are made to be robust, they can break down through photo-oxidative reactions that are triggered by solar UV radiation. This can result in the creation of secondary microplastics and the release of chain scission products into the nearby aquatic environment[70]. According to certain viewpoints, physical factors including UV irradiation, mechanical abrasion, and temperature variations may cause microplastics in soil to physically decompose and be transfered[71].

Drought

The upward mobility of the microplastic is confirmed by a laboratory investigation that mimics rainy-dry seasons using a sandy wet-dry cycle in a soil column[72]. The study also demonstrates a linear relationship between the number of wet-dry cycles and the soil depth. However, to validate the lab results, a field-scale investigation is needed[73]. In a study, it was shown that microplastics have beneficial impacts on plant communities in drought-stricken soil systems. Another element that affects the destiny of microplastics is the water content of the soil. In the event of a significant downpour, microplastics may find their way into the groundwater or wash up on the surface. Microplastics would remain in the soil pores and accumulate in the event of a drought[54,74,75].

Dust Storms

Even the most distant areas of the planet are affected by the pervasive microplastic contamination. Nonetheless, there aren't much observational data on the deposition of microplastics in deserts, which make about 21% of the world's surface area[76].In dry and semi-arid areas, dust storms are frequent occurrences that have a variety of effects on the environment and public health. In a case study published in 2022, Abbasi et al. examined the presence, characteristics, and possible origins of microplastics (MPs) in these kinds of incidents by examining MPs that were deposited with dust particles in the city of Shiraz, southwest Iran, during a severe dust storm in May 2018. Scanning electron microscopy analysis of a few chosen MPs showed that the samples varied in terms of weathering and contamination from exogenous geogenic particles. They concluded that between 0.1 and 5% of the MPs deposited by the dust storm are obtained from local sources within the city, with the remaining MPs originating from more distant sources, using reported concentrations of MPs in urban dusts and distant, desert soils. They also employed documented geochemical markers of local dust particles, satellite imaging, and HYSPLIT modeling to show that Saudi Arabia's deserts are the main distal and transboundary source. In dry and semi-arid regions, dust storms may be a major mode of MP transportation and redistribution, as well as a major source of MPs entering the ocean[77]. A similar study has been made to close the information gap about the distribution of microplastics in Asian deserts. China's second-largest desert is the Badain-Jaran Desert in Central Asia. Wang et al., 2021 demonstrated long-distance atmospheric movement and deposition in deserts, with the majority of the microplastics coming from the urbanized regions southeast of the desert[76].

Wind and Tidal

Wind speed enhances the transportation of microplastics from terrestrial zones to their eventual sinks, as well as to urban regions in the western United States and along European shorelines. The atmosphere provides a channel for the microplastic to travel over tens of kilometers to distant places. Typhoons in China, for instance, raised the amount of microplastics in the aquatic environment nearby[78]. Microplastics were thought to be an airborne pollution that traveled to far-off places up to the Antarctic snow top. The wind carried the microplastics to the Antarctic ice sink[79]. Microplastics in the air are known to cause localized warming or cooling of the atmosphere and to have direct radiative effects. Their ability to absorb light allows the local air temperature to rise even higher[80]. Airborne microplastics in the polar areas would cause the cryosphere to melt, releasing the microplastics contained in the ice. According to Dong et al.'s estimation, microplastics may have traveled by air to the isolated lake basin in the Tibetan Plateau (an ecosystem of alpine lakes)[81]. The movement of microplastics, their concentration in surface water, and wind speed are all positively correlated[10]. After reaching isolated areas, storms and precipitation would carry atmospheric microplastics into surrounding rivers and snow beds, or they would migrate to other cities[54].

Seasonal variations in the wind and currents can cause microplastic abundance in different places. When items are floating on the sea surface, wind can be a useful propellant. Given that a flood tidal current may carry microplastics, the direction in which the tidal current flows may also be a driving factor in the spread of marine debris[82].

Depending on the characteristics of the microplastic and the surrounding circumstances, the aquatic habitat may act as the main sink in the environmental matrix, where microplastics can float in the water column, sink to the bedrock, and collect in sediments. Global warming would increase wind and rainfall, which would improve water circulation and make it easier for microplastics to get to far-off aquatic zones. Microplastics are carried by the atmosphere to glacier environments at higher wind speeds. The melting of ice caps results in the release of accumulated microplastics when temperatures rise. The destiny of terrestrial soil microplastics is determined by floods and droughts. Flooding causes the microplastics to migrate between the terrestrial soils and the marine ecosystem, while dryness causes them to stay stuck in the soil[54].

Paris is in a very different climate and is around 150 kilometers from the coast. There are no typhoons or monsoonal lows in Paris. It does, however, mostly receive onshore winds from the Atlantic Ocean and North Sea, which are particularly powerful during the winter[83]. Dris et al. (2016) found that there was often higher deposition throughout the winter. Wintertime reduces the possibility of dust or plastic becoming atmospherically entrained since the ground is moist or covered with snow. The bulk of the recorded fallout is likely to have originated from local or regional land, and the unique urban radiative microclimate makes comparison difficult at this early stage of research, impacting the region's farmlands and agricultural soils[84].

The primary factors influencing the movement of microplastics in the marine environment are water currents, wind, and tides[85]. These factors cause the microparticles to sink slowly and migrate along the seashore (Bagaev et al., 2017). Denser polymers, like PVC, may still be carried by underlying currents, but buoyant polymer particles, like PE and PP, are often carried on the sea surface. According to Bagaev et al. (2017), microfibers are either resuspended by bottom currents or trapped by increased turbulence in the benthic boundary layer for a specific amount of time once they reach the bottom[86].

Gaps and Future Research on the Potential Transfer of Microplastics in Agricultural Soils and Farmlands

In accordance with the description previously mentioned, there are significant re-search gaps in the areas of microplastic toxicity, quantitative study of the many pathways by which microplastics can be transferred. Different natural phenomena and disasters, and the processes by which microplastics can be transfered to different environments contribute their accumulation in waters and soils, and this is a big threat as they can be harmful when consumed by humans or other animals.[87]. Thus, more thorough research on this topic is needed. The discussion above indicates how little is known currently about the behavior, destiny, and decomposition of microplastics in terrestrial ecosystems. Furthermore, the ability to directly compare many of these studies has been hampered by the use of diverse techniques for sample collection and microplastic identification across multiple environmental compartments in earlier research. We propose the following directions for further investigation:

- Examine the spatial and temporal concentrations of microplastics in various environmental compartments worldwide to gain a better understanding of their global distribution;
- investigate the sources of environmental microplastics and the factors influencing their fate and distribution;
- identify and quantify environmental pollutants adsorbed onto microplastics and derive quantitative relationships between microplastics and these contaminants;
- research the ecotoxicological effects of microplastics on typical organisms in various compartments;

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- comprehend the mechanism of microplastics degradation under natural conditions and its impact on the fate of microplastics in the environment.More research should be done on the dispersion of plastic in more varied environmental compartments, , where dynamic microplastic transfer may occur in response to stronger weather conditions.
- In the meanwhile, waste management systems' security should be strengthened to prevent plastic trash from entering the land during severe weather, since this would help reduce coastal plastic pollution. Create mathematical models that connect processes unique to microplastics to a spatially explicit fate model. These models should be relevant to the migration, transformation, and fate of microplastics in all types of environments, and software should be established to support them.Standardize the expression method of microplastics concentration/content; create high-efficiency microplastics collection devices appropriate for various environmental compartments; and set standards for uniform microplastic sample collection, classification, separation, and identification.

Conclusions

In this review the natural and weathering phenomena that contribute to MPs transportation in different systems and especially in farmlands and agricultural soils have been studied. All review articles have been classified in categories according to the natural phenomena that are presented in them.

From a statistical classification of the physical factors associated with microplastic transport and presented in Figure 2, it appears that typhoons, monsoons, winds together with tidal and floods together with storms are the most dominant and predominant factors that contribute the most to microplastic transport and concentration among the physical phenomena that have been presented and discussed above at length.

This might be due to a variety of factors, including particle redistribution to the surface sediment by wave agitation, fragmentation under severe abrasion pressures, and terrestrial inputs via surface runoff and wind transport. Severe weather conditions have the potential to transfer heavier and more varied kinds of microplastics from the land to the ocean. The results of the review papers show that the seasonal fluctuation may have been caused by extreme weather events that mostly happened during wet seasons, contrary to earlier research that primarily linked seasonal variability in microplastic level to higher rainfall in rainy seasons.

It is critical to continue evaluating the effects of various extreme weather conditions on the dispersal of plastic debris since climate change has led to an increase in the number of extreme weather events worldwide as well as their intensification. A characteristic gap in the resulting research is that there are not enough case studies related to natural disasters and phenomena from developed countries. As shown in Figure 3, the US is missing from the countries with relevant publications, while Europe, Asia and Africa together account for less than half of the total. Dominant countries in this are Asian as China, India and Japan due to the natural phenomena they face have more studies related to this.

Farmland may become more contaminated by plastic as a result of the growing use of plastics in agriculture. Global MP pollution is getting worse, and agricultural soil dangers require care.

All the experimental findings, extracted from MPs measurements, from the reviewed papers indicate a changing environmental issue. The climate crisis brings to the surface a new serious factor in the transport and dispersion of microplastics, that of natural disasters and extreme weather events.

Further study on MPs is necessary in light of scientific knowledge, particularly to develop a standard procedure for isolating, quantifying, and characterizing MPs from the soil environment

There is connection between mechanisms causing MP buildup in various ecosystems and poorly managed plastic waste. Despite the recent growth in study on MPs found in rivers, lakes, and oceans, more has to be discovered about the outside forces affecting MP transit and dispersion in farmlands and agricultural soils. The distribution and quantity of microplastics (MPs) in different environmental systems are expected to increase dramatically in the upcoming decades due to the rising amount of plastic entering the environment. Incorrect waste management together with

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extreme weathering phenomena due to climate change would result in an increase in plastic garbage, severely harming agricultural soils and farmlands unless immediate worldwide action is taken.

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