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Microplastics in Table Salts: Sources, Abundance, Types, and Consumption– A Review

Fatima Kanwal* and Zafar Iqbal Shams

[1]Department of Environmental Sciences, Federal Urdu University of Arts, Sciences, & Technology, Karachi, Pakistan.

[2]Institute of Environmental Studies, The University of Karachi, Karachi, Pakistan.

*Corresponding author Email: fatima.kanwal@fuuast.edu.pk

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Abstract

Microplastics (MPs) exist everywhere, from the bottom of the ocean to the peak of mountains, and pose a significant threat to species and habitats. These tiny plastic particles have polluted all components of the biosphere, including both biotic and abiotic components of the Earth. There is a global concern regarding this problem and studying MPs in various compartments of Earth is mandatory. This paper reviews the research articles published worldwide on microplastic particles' prevalence, composition, abundance, color, and structure using methodologies like filtration, spectroscopy, and chemical analysis in all table salts, including sea, rock, and lake salts. This review paper analyzes and compares the Atlantic Ocean as the most polluted with per capita plastic waste disposal compared to the Arctic and Pacific oceans. Microplastic contamination is higher in Asia. The most contaminated salt type is sea salts followed by lake and rock salts. Morphologically, fibers are more abundant than fragments or films of plastics. The consumption of table salts is higher in some countries, indicating the varying microplastic consumption in humans.

Keywords: Microplastics, Sea salt, Table salt, Health impacts, Global plastic pollution.

Introduction

The extensive consumption of plastic has been altering the globe and its inhabitants. The increasing population, demand, and production of plastics lead to more damaging environmental consequences [1]. Kaza et al. reported the production of 238 million tons of plastics in 2011 (Fig. 1) and its continuous escalation till 2024 which doesn't seem to stop projecting up to 2050 [2]. Plastic often ends up in oceans and seas when waste is improperly handled and disposed of. Studies show that each year, marine debris containing 80 to 85% of plastic waste goes to these water bodies, accounting for thousands of tons of plastic trash [3,4].

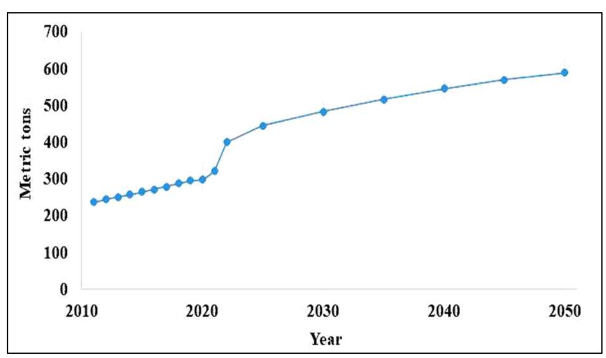

Figure 1. **Global plastic production (metric tons) from 2011 to 2022 and projections up to 2050 [2]**

Hannah et al. [5] reported that Asian countries account for 81% of the world's total mismanaged plastic disposal in the marine environment (Fig. 2). Few countries, particularly in Asia are mainly responsible for the mismanaged plastic. Fig. 3 illustrates the per capita plastic waste disposal in oceans among the top 20 contributing countries, showcasing the extent of this environmental issue.

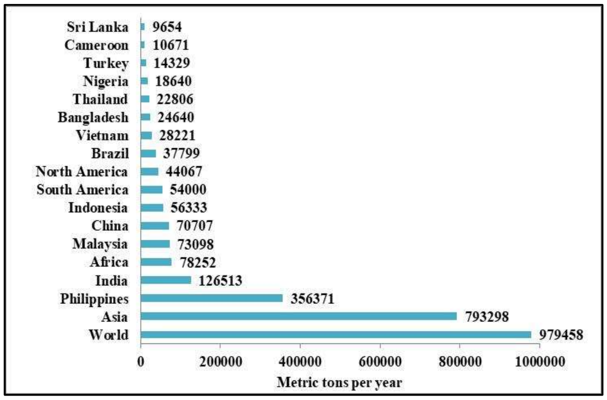

Figure 2. **Mismanaged plastic waste annually entered the ocean from different countries in 2019 [5]**

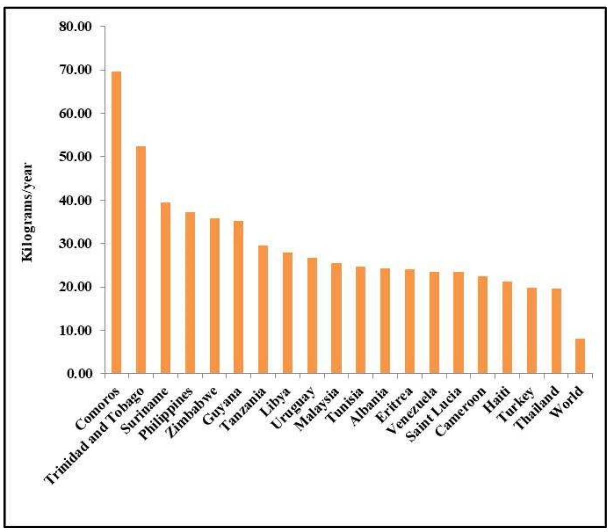

Figure 3. **Per capita plastic waste disposal in oceans among the top 20 countries [5]**

Plastics are widely used in various products, including clothing, cosmetics, household items, personal care items, and food [6]. They are manufactured through the process of polymerization using synthetic polymers. Plastics are classified into several categories, based on their size, including mega-plastics (more than 1 meter), macroplastics, and mesoplastics (>5 mm), larger plastics disintegrate into smaller particles called MPs, ranging in size from 0.1 µm to 5 mm, and nanoplastics (< 1 µm) [6,7]. These microplastic fibers have become a significant environmental concern and are emerging contaminants [8, 9].

Types of Plastics

MPs are of many sizes, specific densities, chemical compositions, and shapes. Nylons, polyvinyl chloride, and polyethylene terephthalate are dense and the most frequent plastics, which sink in water. Polypropylene, polyethylene, and polystyrene are lighter in density and float on the water. Polyamide and polyvinyl alcohol are other types of MPs [10].

Plastics can be classified into seven major types depending on physical and chemical properties, such as melting temperatures, shape, solubility, chemical composition, specific density, and tensile strength. The types of plastics are polypropylene (PP), low-density polyethylene (LDPE), high-density polyethylene (HDPE), polyvinyl chloride (PVC), polyethylene terephthalate (PET), polycarbonate (PC), polystyrene (PS), acrylonitrile butadiene styrene, and acrylonitrile styrene [11, 4]. Detailed information about plastic types is described as follows:

i. Polyethylene terephthalate has a density of 1.38 gcm^{-3} and was initially manufactured from ethylene monomers in the early 1900s. It is transparent, inflexible, and heat-resistant and makes potable water bottles, beverages, beer, carpets, and textile fibers.
ii. High-density polyethylene has a density of 0.97 gcm^{-3} and manufactured since 1957. It is hard, has a tensile strength of 5000 to 6000 psi, and is resistant to chemicals

below 60 °C. Its melting point ranges from 130 to 137 °C and is used to make detergent bottles, retail bags, crates, compost bins, milk containers, and cereal bag liners.

iii. Polyvinyl chloride has a density of 1.40 g cm^{-3} and was manufactured for the first time in 1933 and extensively manufactured in Europe by a mass polymerization and suspension procedure. It is malleable and can be flexible and rigid. Its strength stretches from 1500 - 3500 pounds $inch^{-2}$ (flexible) and 6000 - 7500 pounds $inch^{-2}$ (inflexible). Its melting temperature ranges from 75 - 105 °C and is partially soluble in acetone, toluene, and cyclohexanol. It is resistant to chemicals, grease, and oil. It makes plumbing pipes, construction pipes, toys, shampoo bottles, construction flooring, and fittings.

iv. Low-density polyethylene has a density of 0.92 gcm^{-3} and was manufactured initially in 1939. It is soft, flexible, and has a malleable strength of 600 to 2300 psi. Its melting point ranges from 98 to 115 °C, and resistant to solvents at temperatures below 60 °C. It is used to manufacture products such as bin bags, frozen food bags, trash bins, squeezable bottles, and plastic grocery bags.

v. Polypropylene has a density of 0.90 gcm^{-3} and was made initially in 1955 through the addition reaction of propylene gas and titanium chloride. It has a malleable strength of 4500 – 5500 psi. It is flexible, versatile, and rigid. It melts at 175 °C and resists heat, oil, grease, and solvents below 80 °C. It is used to produce margarine and yogurt containers, ketchup, syrup, and tablet bottles.

vi. Polystyrene has a density of 1.05 gcm^{-3} and was manufactured initially in 1851 by passing ethylene and benzene through a red hot tube. Its tensile strength ranges from 5000 – 7200 psi. It is rigid, versatile, brittle, lightweight, and transparent. It melts at 100 °C and is soluble in toluene, acetone, benzene, and methylene dichloride. It manufactures plastic cutlery, meat trays, disposable cups, compact disc cases, packaging egg cartons and foams.

vii. Other plastics include resins, polycarbonate, acrylonitrile styrene, and acrylonitrile butadiene styrene. They produce automobile parts and baby bottles.

Classification of Microplastics

Microplastic particles are classified as primary and secondary, based on the manufacturing method (Fig. 4).

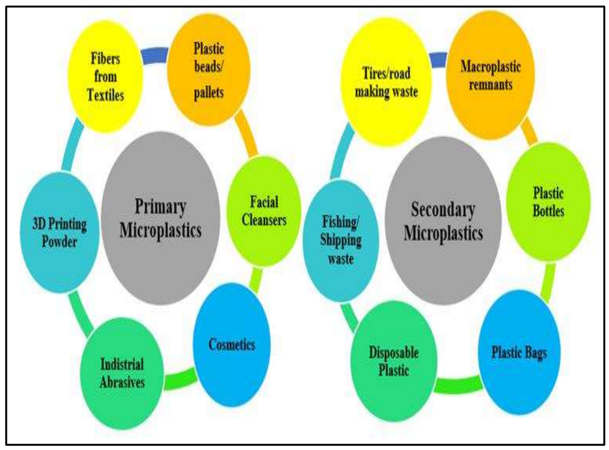

Figure 4. **Examples of primary and secondary microplastics**

Primary and secondary Microplastic Particles

Primary MPs are produced purposely on a large scale for products such as toothpaste, cosmetics, exfoliating facial scrubs, foot and hand cleansers, abrasives, and resin pellets [12,4].

Secondary MPs are derived from the breakdown, abrasion, wear, and tear of larger plastics and are not manufactured [13,4]. Once they reach the oceans and seas, plastics are degraded quickly due to the low temperatures. Low temperatures and ultraviolet light can break large plastics into microparticles, making them even more hazardous to the living planet. Their decomposition can take thousands of years [14, 3].

Sources of Microplastic Contaminants

Domestic Sources: Micro-beads used in personal health care items like exfoliating creams, scrubbers, toothpaste, face cleansers, hand cleaners, shaving foams, pharmaceuticals, and cosmetics, found in waste streams are the primary cause of microplastic particles in marine habitats. These micro-beads eventually enter the river, sea, ocean, and other aquatic environments [15].

Industrial sources: Other sources are transport and industries. Accidental spills during plastic manufacturing and plastic items transport can lead to the incidental discharge of plastic particles into the environment. Development projects, such as construction activities, contribute to raising environmental MPs. The textile industry also releases plastic particles in the effluent.

Environmental Sources: Both natural and anthropogenic processes produce plastic garbage. Plastics from municipal garbage also find their way into the marine environment. MPs in coastal environments are caused by the direct discharge of plastics at seashores during recreational activities, such as throwing away plastic bottles, utensils, and chip containers [16]. The microplastic contaminants in aquatic habitats are increased as macroplastic waste items break down into tiny particles over time.

Direct and Indirect Runoff

MPs are also classified based on direct and indirect runoff through which they enter the water bodies. MPs used in consumer goods like toothpaste, cosmetics, skin cleansers, and industrial solvents or generated in shipbreaking processes are direct runoff particles. The MPs produced in water bodies due to the disintegration of large plastics are indirect runoff MPs [17-19].

Plastic Decomposition in the Marine Environment

Plastic decomposition is slow in marine ecosystems, typically taking thousands of years. However, partial decomposition can occur in the sea and ocean depending on the type and size of plastics and processes like mechanical degradation, thermo-oxidation, thermal-degradation, biodegradation, and photolysis or photodegradation. The textbook definition of these terms is as follows [20-22].

Larger plastics can be broken into smaller particles due to some physical agents such as ocean waves, wind, and friction from sand or other debris, particularly in coastal and marine environments called mechanical degradation.

When sunlight breaks down the polymer chains in plastics, causing them to deteriorate. Fragmentation results from this process, which weakens the material and causes fissures. Plastics that float on the ocean's surface and are exposed to sunlight are especially prone to this process, which is called photodegradation.

The degradation of plastic polymers is accelerated by temperature changes, particularly at higher temperatures. Plastics break down more quickly in tropical or warmer waters because of the higher thermal energy. Over time, the cycles of heating and cooling cause the plastic to become more brittle, which aids in fragmentation. The process is called Thermal Degradation.

Plastics can be further broken down by chemical processes like oxidation that occur in water. The polymer chains in plastics can be broken down into smaller molecules by oxidative processes when they are exposed to oxygen, either in the air or dissolved in water. In a similar vein, seawater's salt and other substances aid in the decomposition and erosion of plastics. This is chemical degradation.

Under the correct circumstances, some bacteria and fungi can gradually break down plastic, even though of most common polymers are resistant to microbial degradation. MPs are frequently left behind as a result of partial biodegradation, nevertheless, as this process is usually sluggish and insufficient. This process is called Biodegradation.

Impacts on Human Health

MPs are hazardous to humans, marine organisms, and the biosphere and can cause various diseases and other health issues. MPs can carry pathogenic bacteria and other pollutants like pesticides and other organic contaminants since they provide an adsorption surface. They may affect immunity, damage the reproductive system, and cause cancer and other ailments in humans or animals. They can get into humans indirectly through the food chain [23-25].

Effects of Microplastics on Human Safety and Protection

Conclusive research about the health impacts of MPs on human beings is still in its early stages but some studies depict that there are thousands of chemicals that make plastic and many of them may be associated with hazards and risks. Some studies identify that MPs may cause oxidative stress, DNA damage, inflammation, endocrine disruption, cancer, dermatitis, defective reproductive system, immune system, digestive, and nervous system damage including asthma, cancer, and gut microbiome disturbances [23-25]. Given these impacts, the review emphasizes the importance of further research into cellular toxicity and its long-term effects on human health [26-28]. MPs also serve as a carrier and provide a platform for some other toxic pollutants like pathogens, and chemicals to adhere to MPs polypropylene and polyethylene are not known to cause direct harm. Polycarbonate contains a monomer called bisphenol A (BPA), which is hazardous to humans. Polystyrene makes Styrofoam [29, 30]. Styrene and BPA are considered endocrine disruptors and can damage the reproduction system. The presence of BPA in breast milk, urine, and blood of affected persons demonstrates reproductive abnormalities [31]. BPA and styrene can enter the human or animal body through dermal contact, ingestion, and inhalation. Other plastic constituents, such as phthalates, like di-n-octyl phthalate and di (2-Ethylhexyl) phthalate, can cause dysfunction in the human body, including developmental abnormalities, damage to respiratory organs, and the reproductive system of males and females. Polybrominated diphenyl ethers and Tetrabromobisphenol A are plastic additives that may be hazardous. They may disturb thyroid hormone homeostasis and anti-androgen action [32, 33].

Microplastics in Various Components of the Environment

MPs are a ubiquitous problem in the environment and are found in a variety of biotic and abiotic components such as freshwater, seawater, terrestrial and marine organisms, sediments, and shorelines worldwide [34-37]. Studies demonstrate the microplastic presence in these components, including in biotic sea products consumed by humans, such as fish, mussels, lobster, crabs, and sea plants, and abiotic sea products, such as sea salts. Fig. 5 shows MPs in the surface water of the Atlantic, Arctic, and Pacific oceans during 2015 – 2018 [38, 39].

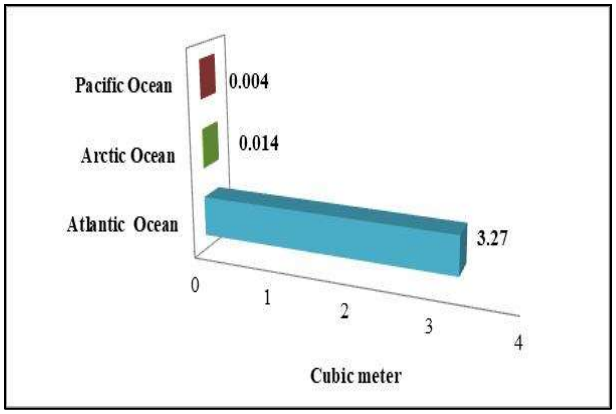

Figure 5. **Microplastics in the Atlantic, Arctic, and Pacific Oceans during 2015 – 2018 [39]**

Microplastics in table salts

Table salt is a daily essential for human consumption, providing elements such as sodium to maintain the body's homeostasis [40, 41]. Table salt is extracted from many sources, including lakes, wells, seas, and rocks, and is named accordingly, such as lake salt, well salt, sea salt, and rock salt [42-44]. The World Health Organization (WHO) advises that humans should consume around 5g of salt per day per person, with varying recommendations and consumption levels worldwide [44-46]. In this study, the focus is on rock, lake, and sea salts. Rock salts, produced from a mineral called halite, occur in rocks, while sea salt is extracted through the evaporation and crystallization of seawater with the help of wind and sunlight [47]. The raw salt is gathered and transported for processing or packaging. The present investigation aims to review the published papers written worldwide on the prevalence and abundance of microplastic particles in salts, such as sea, lake, and rock salts. The current paper also reviews the morphology, color, and composition of microplastic particles in table salt and compares and analyzes the presence and abundance of MPs.

Various Studies on the Microplastics

Plastics are synthetic organic products manufactured from natural polymers like resin and synthetic polymers of elongated chains. They are inexpensive, lightweight, transparent, easy to use and handle, durable, bio-inert, and inflexible, and possess oxygen/moisture barrier characteristics and long-lasting capacity. Due to the increased manufacturing and consumption, plastics have affected the entire biosphere, particularly the marine environment. Plastics have become a threat to the living planet.

Plastic disposal in the seas and oceans was first reported as a problem in the 1970s but did not receive enough attention until studies appeared on the entanglement of aquatic mammals, cetaceans, and other aquatic organisms. Various investigations reported plastic ingestion by birds and turtles, with 44% of bird species found to have ingested plastic particles directly or indirectly [48, 49].

These studies report that 1.15 – 2.41 million tons of plastic are dumped worldwide in the ocean annually. Asia is the top plastic waste contributor to the marine habitat, with the 20 highest polluted rivers. The top 20 most plastic-producing countries are located in the Asian region. Asia contributes 70% of global plastic pollution, and China alone is 26% of the total plastic production contributor worldwide [50, 51]. Due to the great plastic producers, Asia is at high risk for the declining health of humans, and aquatic and marine organisms.

According to Vries [52] a significant proportion of marine trash comprises plastics, with estimates ranging from 60-80% and an annual deposition of 4.8-12.7 million tons . Eriksen et al. [53] also noted a significant presence of plastic debris floating in the oceans, estimated at 250,000 tons . Reisser et al. [54] revealed that The National Academy of Sciences (USA) in 1997 estimated that 6.4 million tons of garbage annually moved into the marine environment globally, which is currently about 8 million tons annually.

Microplastic Abundance in Table Salts

Table 1. **Number of microplastics found in table salts worldwide.**

Location	Number of Samples	Microplastics per kg	Ref.
8 Countries*	N/A	1 - 10	[7]
Turkey	3	16 - 102	[41]
China	15	46	[43]
Spain	21	50 - 280	[47]
India	N/A	35 - 72	[55]
Africa	N/A	38.42	[56]
India	8	56 - 104	[57]
Pakistan	19	35	[58]
Portugal	14	595 - 5090	[59]
Taiwan	N/A	9.77	[60]

*= Australia, France, Iran, Japan, Malaysia, New Zealand, Portugal, and South Africa

All the above investigations highlighted that table salts are polluted worldwide with MPs (Table 1). The contamination levels vary widely, with some countries having higher levels of MPs in their salts than others. The variability in microplastic measurements among countries might be attributed to several reasons. Countries with large-scale plastic production, less stringent waste management systems, improper waste disposal and recycling, or differences in environmental regulations, stronger policies on plastic waste, such as bans on single-use plastics or stricter enforcement of waste management, tend to influence the microplastic contamination levels. These factors might collectively influence the observed differences in microplastic abundance across countries. However, MPs are present in many table salts, with sea salts being the most contaminated due to their proximity to highly polluted oceans (Fig. 6). It is believed that MPs come from the natural breakdown and disintegration of larger plastic debris. The packaging and processing may also contribute to MPs' presence in table salts. For example, Iñiguez et al. [47] reported that packaging items do not predominantly contribute to raising MPs in salts.

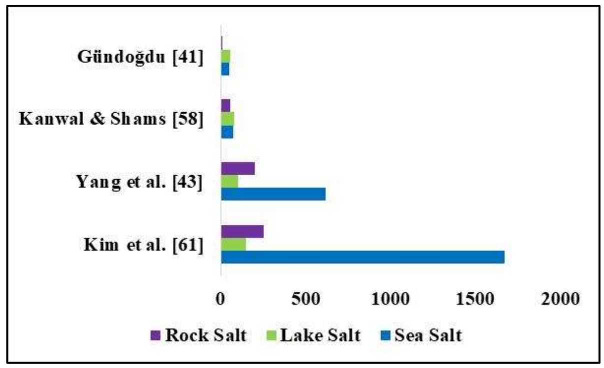

Figure 6. **Number of microplastics in one kilogram of different types of salts**

Microplastic Morphology in Table Salts

The breakdown and the natural disintegration of larger plastics in marine habitats are the main contributors to microplastic particles and fibers in sea salts. The disposal of colored plastics such as toys, dishes, and cosmetics can lead to the presence of colored microplastic particles in the environment. Microplastic particles of various structures and colors enter the aquatic environment through textile product washing. Other sources, such as domestic effluent, laundry, commercial fisheries, and industrial processes contribute to the microplastic particles of various colors and structures in the table salts [55].

The studies on microplastic particles in table salts reveal that the proportion of fibers and fragments of the particles varies depending on the location and method used for sampling (Fig. 7). For instance, Sathish et al. [55] revealed that 83% of the MPs in their samples were fibers, while 17% were fragments. Fadare et al. [56] found that 93.83% of the MPs in their salt samples were fibers, and 6.17% were fragments. In another study, Seth and Shriwastav [57] found that 63% of their salt samples possessed fragmented microplastic particles, and 37% had fiber particles. Suaria et al.[62] and Henry et al. [63] stated that the most common microplastic particles are textile fibers in marine habitats. Kosuth et al. [64] reported a high abundance of microplastic fiber in salts. The variation in the percentage of fragments and fibers may be due to the different sampling methods and locations used in these studies.

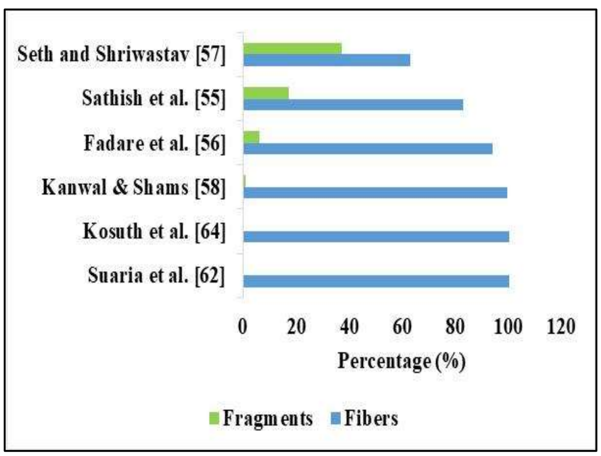

Figure 7. **Proportion of fibers and fragments of microplastics in table salts**

It is difficult to review the color attributes of microplastic particles worldwide since the color composition of microplastic particles has been scarcely reported elsewhere. However, some investigations state the color composition of microplastic particles and found that black particles are typically polystyrene, white particles are polyethylene, and transparent particles are polypropylene [65, 66].

Microplastic Polymers in Table Salts

Studies reveal that polypropylene and polyethylene are the most widespread MPs found in table salts. Polyethylene terephthalate is another type of microplastic found in table salts. It is a rigid and flexible polymer generally used in packaging, bottle manufacturing, and textile industry. For that reason, these fibers occur everywhere in terrestrial and aquatic environments. However, Seth and Shriwasta [57] found only 7% of polyethylene terephthalate fibers that make a smaller proportion of MPs in Indian sea salts.

The proportion of different microplastic polymers in table salt and other products.

a. Karami et al. [7] found that 40% of MPs in table salt were polypropylene, and 33.3% were polyethylene.

b. Gündoğdu [41] reported that 22.9% of fibers in Turkish table salt were polyethylene, and 19.2% were polypropylene.

c. Iñiguez et al. [47] found that the most common type of fiber in Spanish table salt was polyethylene terephthalate, followed by polypropylene and polyethylene.

d. Seth and Shriwasta [57] discovered that 61% of MPs in Indian sea salt were polyesters, with polyethylene making up 22%, polyamide 16%, polyethylene terephthalate 7%, and polystyrene 1% .

e. Kedzierski et al. [67] found that polyethylene is the most frequent microplastic particle in the surface waters of the Mediterranean Sea, followed by polypropylene, polystyrene, and polyethylene terephthalate.

f. Zhang et al. [68] reported that polypropylene is the most common microplastic in the sediments of three rivers in China, followed by polyethylene, polyethylene terephthalate, and polystyrene.

g. Eerkes-Medrano et al. [69] revealed that polypropylene and polyethylene are the most common MPs in mussels of the North Sea, followed by polyethylene terephthalate, polystyrene, and nylon.

Microplastics Human Consumption through Table Salts

The WHO suggests a maximum annual intake of 1825g and a daily intake of 5g of table salt per capita [44]. However, in Pakistan, the table salt intake is 3066g per capita per annum which exceeds the WHO guidelines. A similar study disclosed that men consume more table salt and therefore take more microplastic particles through salt intake than women [70]. The microplastic intake from salt may be small compared to other sea-based products like mussels, which can contain 178 MPs per mussel [71]. Daily salt consumption means daily microplastic ingestion. Salt consumption patterns vary from country to country. Many countries consume twice the recommended WHO guidelines and some even take more than double the recommended limits (Fig. 8) [46, 72, 73]. The average annual global salt consumption is 3,833g per capita, suggesting an intake of 270 MPs per person annually if we take an average of all MPs found in table salts [46]. In Bangladesh, the annual salt intake is 6,205g per capita, indicating an estimated 436 microplastic intake per person per annum [74]. Turkey also has a high annual salt intake of 5,990g per person, resulting in an estimated 421 MPs per person being taken annually [46]. China, India, Taiwan, and Europe also have high annual salt intake, with an estimated 303, 282, 258, and 244 MPs per capita [75]. MP levels in food must be regulated locally and globally. Several studies are here to address levels of MPs in consumable products and yet legislation and regulation of MPs as contaminants in different foods is still absent due to unsettled or lack of agreement about a standardized quantifying method and a lack of integrated nomenclature. According to Shopova et al. [76] there is no legislation for MPs and nanoplastics as contaminants in food.

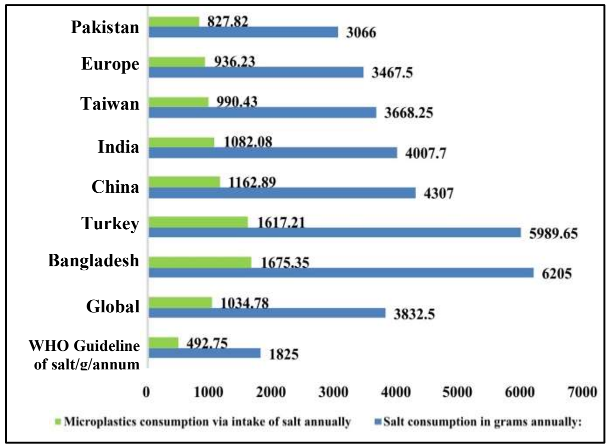

Figure 8. **Global probable microplastic intake (number) via table salt (g) per capita per annum**

Conclusion

This study examines the abundance, composition, color, and structure of microplastic contamination in all table salt types globally, including sea, rock, and lake salts. The review provides an up-to-date assessment of microplastic particles in table salts and highlights the potential risk to human health from consuming table salts contaminated with MPs. Conclusively, table salts, extracted from oceans, rocks, and lakes are consumed daily worldwide as a food product and are contaminated with MPs in several countries. The plastic disposal in water bodies is increasing continuously. Sea salts are more contaminated than lake, and rock salt. Structurally, fibers are more abundant than fragments or films of plastics. The consumption of table salts is higher in some countries which depicts the varying Microplastic consumption in humans. The study shows that the Atlantic Ocean is the most polluted with per capita plastics waste disposal than the Arctic and Pacific oceans. Microplastic contamination is higher in Asia. Various studies emphasize that the continuous use of plastics by humans has led to the contamination of biotic and abiotic components of the environment. Even if plastics are degraded, microplastic remnants are even more dangerous for life and the environment. All marine environment biotic and abiotic products are loaded with MPs. However, the diseases associated with these are still undocumented and studies are required on the direct health impacts of MPs. For instance, toxicological studies should be conducted to understand the physiological impacts of MPs on various demographics, including the most vulnerable populations such as children and pregnant women. Epidemiological research can be designed to expose the potential correlations between microplastic consumption and specific health outcomes or investigating the interactions between MPs in salt and other food sources will help clarify their overall impact on human health. Such research efforts are crucial for developing a comprehensive understanding of the risks posed by MPs in our food supply. Regulation of MPs in food products should be set on a priority basis meanwhile consumers can take proactive steps to mitigate the risk of microplastic contamination in food by staying informed about potential sources, particularly in seafood and table salt, also reducing usage of single-use plastics can be proven in favor of reusable and biodegradable options. Promoting transparency from food producers regarding the presence of MPs is also helpful. On the other hand, food producers should adopt sustainable sourcing and packaging practices, invest in research to understand contamination sources, and support emerging regulations to establish effective policies that protect consumer health and the environment. Together, these actions can significantly address the challenges posed by MPs in our food supply.

Conflict of Interest

The authors declare that they have no conflict.

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