Microplastic (MP) - An emerging global threat to food and water security: MP contamination of seafood, other foods (*rice, vegetable, salt, sugar, honey*), drinks (*drinking water, tea, milk, soft drink*) and environmental waters (*surface water, sediment*)

By

Golam Kibria, Dayanthi Nugegoda and A. K. Yousuf Haroon

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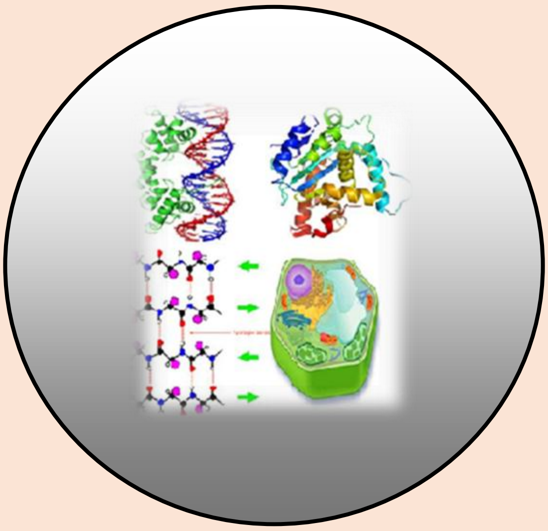

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Dr. Golam Kibria

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RESEARCH PAPER

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Microplastic (MP) - An emerging global threat to food and water security: MP contamination of seafood, other foods (*rice, vegetable, salt, sugar, honey*), drinks (*drinking water, tea, milk, soft drink*) and environmental waters (*surface water, sediment*)

Golam Kibria, Dayanthi Nugegoda and *A. K. Yousuf Haroon
School of Science, RMIT University, Australia
*Bangladesh Fisheries Research Institute, Bangladesh

ABSTRACT

This short article collected, collated, analysed, synthesised, reviewed, interpreted, and documented microplastic (MP) contamination of seafood, other foods, drinks, and environmental waters across the globe. It identified the possible routes of MP contamination. Fishes, as well as, surface waters and sediments were found contaminated with MP across the globe. There has been very limited research on other foods and drinks with reference to MP contamination. Based on those limited research, rice brands (Australia, India, Pakistan, and Thailand), vegetable samples (Mexico), salt samples (Australia, China, France, Iran, Japan, Malaysia, New Zealand, Portugal, South Africa, Spain, the USA), sugar samples (Germany), and Honey samples (Germany, France, Italy, Spain, and Mexico) have been contaminated with MPs. Among the drinks, bottled water samples (Germany), tap water samples (Cuba, Ecuador, England, France, Germany, India, Indonesia, Ireland, Italy, Lebanon, Slovakia, Switzerland, Uganda, and the USA), beer samples (Germany, Mexico, the USA), soft drink samples (Mexico), energy drink samples (Mexico), cold tea and tea infusions samples (Mexico, Canada), and milk samples (Mexico) were also contaminated with MPs. In a number of food and drink samples, MP contaminant levels were 100% (beer, bottled water, carrot, cold tea, dried fish, fruit, fresh fish, honey, milk, mussel, rice, salt, sediment, surface water, and sugar). Fibres were the dominant MPs detected. MP as well high-risk chemicals/pollutants adsorbed in MPs can be transferred to humans via the consumption of contaminated food and drinks. This article confirmed that MP is an emerging global threat to food and water security.

Apart from the risk posed on seafood, other foods, drinks, and environmental waters, MP can threaten the global climate by increasing greenhouse gas emissions (CO_2, CH_4) from plastic waste and may undermine achieving the UN sustainable development goals. Therefore, attempts should be made to curb the proliferation of plastic pollution by phasing out its use in consumer goods.
Keywords: Microplastic, contamination, seafood, rice, vegetable, sugar, salt, water, drinks and environmental waters.

INTRODUCTION

Plastic waste/pollution is ubiquitous and is reported from the Arctic to the Antarctic, from the surface to sediments (Kibria, 2017). They are most commonly derived from petrochemicals (natural gas, oil, or coal). Plastic waste does not readily biodegrade but persists in the aquatic environment for a long period (for example, plastic fishing lines and nets can last up to 600 years (Kibria et al., 2021). Plastic breaks into smaller pieces such as microplastics (MP) (<5 mm in size).

MP can be found across the globe, including the deepest area of the ocean (Lusher et al., 2015) and marine sediments (Peng et al., 2017). It has been detected in fishes (Jabeen et al., 2017; Karami et al., 2017a), sharks (Parton et al., 2020), molluscs (Mathalon and Hill, 2014; Rochman et al., 2015), crustaceans (Murray and Cowie, 2011; Devriese et al., 2015) and seaweed (Li et al., 2020). MP contamination has also been reported in various other foods and drinks including rice (Dessi et al., 2021), vegetables (Conti et al., 2020), salt (Yang et al., 2015; Karami et al., 2017b; Iñiguez et al., 2017; Gündoğdu 2018; Kosuth et al., 2018), sugar (Liebezeit and Liebezeit, 2013), honey (Liebezeit and Liebezeit, 2013), bottled waters (Oßmann et al., 2018; Schymanski et al., 2018), tap water (Kosuth et al., 2018), beer (Liebezeit and Liebezeit, 2014; Lachenmeier et al., 2015; Kosuth et al., 2018), soft drinks (Shruti et al., 2020), energy drinks (Shruti et al., 2020), tea (Hernandez et al., 2019; Shruti et al., 2020) and milk (Kutralam-Muniasamy et al., 2020). One of the main risks of MP particles as a contaminant is that they can transfer to humans via food and water. The objectives of this article are to:

- Collect, collate, analyse, synthesise, review, interpret, and document MP contamination of seafood, other foods, drinks, and environmental waters across the globe; and
- Identify possible routes of contamination of seafood, other foods, drinks, and environmental waters

MATERIAL AND METHODS

Data and information relating to MP contamination of seafood, other foods, drinks, and environmental waters were obtained using the following search engines: Google Search, Science Direct, Research Gate online, Scopus, PubMed, SpringerLink, Web of Science, Wiley Online Library, Springer Nature, and RMIT University Library database. We have used the following keywords in our search: **(i)** *microplastics +seafood/fish/sharks/ shrimps/mussels/oysters/ seaweed;* **(ii)** *microplastics + rice/ vegetable/salt/sugar/honey;* (**iii)** *microplastics + drinking water/tap water/bottled water/soft drinks/energy drinks/milk/tea*; and (**iv)** *microplastics + surface water/lake/oceans/coast/river sediment.*

RESULTS AND DISCUSSION

MP contamination of seafood, other foods, drinks, and environmental waters

Seafood

MP contaminated a wide range of seafood organisms including fishes, sharks, oysters, mussels, shrimps, lobsters, and seaweeds. For example, fishes have been found contaminated across the Arctic Ocean, the Atlantic Ocean, Australia, the Baltic Sea, Bangladesh, Belgium, Brazil, Canada, Chile, China, Fiji, France, the Gulf of Mexico, India, Indonesia, Iran, Italy, Japan, Malaysia, The Mediterranean Sea, the Netherlands, North Pacific Central Gyre, North Pacific Subtropical Gyre, North Sea, Norway, Portugal, Saudi Arabia, Scotland, South Pacific Subtropical Gyre, Spain, Tanzania, Thailand, Turkey, the United Kingdom, the United States of America and Vanuatu (Kibria et al., 2021).

MP was found in 100 % of fishes from the East China Sea (Jabeen et al., 2017), in 67 % of sharks from the UK (Parton et al., 2020), 63 % in brown shrimps from Belgium (Devriese et al., 2015), 83 % in Lobsters from Norway (Murray and Cowie, 2011), 100 % in blue mussels from Canada (Mathalon and Hill, 2014), 33 % in the Pacific oysters from Canada (Rochman et al., 2015), 95.8 % in nori seaweeds from China (Li et al., 2020), 20 % in canned fishes from Australian and Malaysian markets (Karami et al., 2018) and 100 % in dried fishes from Malaysia (Karami et al., 2017a). MPs may have been ingested by pelagic fishes, demersal fishes, and demersal prawns /shrimps 'mistakenly/ or confusing' it as 'preys or food' while searching for food. MPs can also be accidentally ingested by filter-feeding organisms such as mussels and oysters during their normal filter feeding processes. The presence of MPs in the fish may reflect MPs occurrence in the environment where the fishes live.

Moreover, the ingested MP can result in a number of sub-lethal or lethal effects on seafood organisms, such as (a) gut blockage, false satiety sensation, physical injury in exposed fish (Browne et al., 2008; Wright et al., 2013); (b) hepatic stress due to bioaccumulation of chemical pollutants in plastics (Rochman, 2013) and (c) effect on reproduction and growth (Watts et al., 2015). As a consequence of MP contamination of seafood, there is a strong likelihood of human exposure to MPs as well as high risks pollutants adsorbed in MPs via the food chain (Kibria, 2018; Kibria et al., 2021a) (see also Table 1, Figure 1). Seafood contamination with MPs is a significant threat to seafood security. Seafood is a source of protein, vitamins (B6, B12), omega-3 fatty acids, income (employment), export (foreign exchange earnings), and support livelihoods of people across the globe. It is an important source of animal protein to more than one billion poorest people in the world and in some tropical countries like Bangladesh, the Pacific islands, and the Maldives, fish provides more than 60 % of the animal protein supply (Kibria et al., 2021b).

Other Foods

Rice

A total of 52 rice samples from *Australia* (Jasmine white, Japanese white sushi, brown, arborio), *India* (white, white basmati); *Pakistan* (brown, basmati, white basmati), and *Thailand* (brown, Jasmine and white) were found 100% contaminated with MPs (Dessì et al., 2021). Polymer types detected in rice samples were polyethylene/PE (95%), polypropylene/PP (4%) and Polyethylene terephthalate/PET (1 %). The study (Dessi et al., 2021) reported that plastic concentrations in rice samples differed by the type of rice (instant rice Vs uncooked rice; the washed Vs unwashed rice). Washing the rice significantly reduced the amount of plastic contamination in rice samples.

Rice contamination with MPs is a significant threat to food security since rice is the staple food for more than half of the global population. In particular, in the case of Bangladesh and Cambodia rice constitute about 70% of the daily dietary energy intake (Calpe, 2006) (see also Table 1, Figure 1).

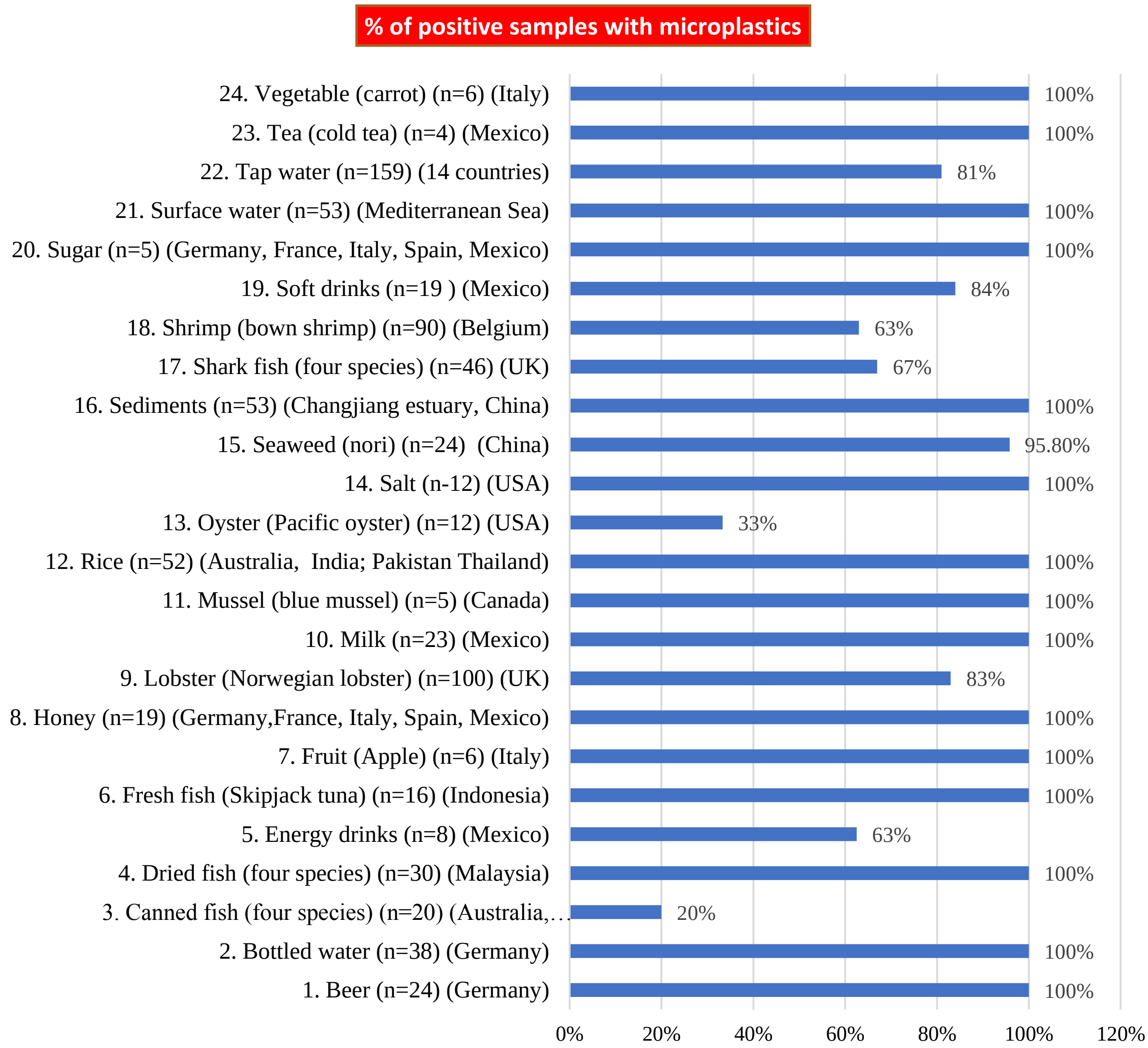

Figure 1. Frequency of occurrence of microplastics (% of MPs detected) in seafood, other foods, drinks, and environmental waters [MP=microplastics; n = number of samples examined; 1-24 on the y axis are references. 1. Liebezeit and Liebezeit, 2014; 2. Schymanski et al., 2018; 3. Karami et al., 2018; 4. Karami et al., 2017a; 5. Shruti et al., 2020; 6. Lessy and Sabar, 2021; 7. Conti et al., 2020; 8. Liebezeit and Liebezeit, 2013; 9. Murray and Cowie, 2011; 10. Kutralam-Muniasamy et al., 2020; 11. Mathalon and Hill, 2014; 12. Dessi et al., 2021; 13. Rochman et al., 2015; 14. Kosuth et al., 2018; 15. Li et al., 2020; 16. Peng et al., 2017; 17. Parton et al., 2020; 18. Devriese et al. 2015; 19. Shruti et al., 2020; 20. Liebezeit and Liebezeit, 2013; 21. Schmidt et al., 2018; 22. Kosuth et al., 2018; 23. Shruti et al., 2020; 24. Conti et al., 2020].

Table 1. Selected examples of seafood (*fish, shrimp, lobster, mussel, oyster, seaweed*), other foods (*rice, vegetable, honey, sugar, salt),* drinks *(bottled water, tap water, soft drinks, beer, energy drinks)*, and environmental waters *(surface water, sediment)* contaminated with microplastics [*ABS= acrylonitrile-butadiene-styrene; dw = dry weight; MPs = microplastics; na= data is not available; PA = polyamide; PAA= polyacrylamides; PE = polyethylene; PEA = Poly(ester-amide); PET = polyethylene terephthalate; PEST =polyester; PES = Polyethersulfone; PP = polypropylene; PS = polystyrene; PSU = polysulfone*]

Items and country	Positive samples/ Total samples	Polymer shapes detected	Polymer types detected	Remarks/ main research findings	References
Beer Mexico	23/26 (88 %)	Fibres (93.42%), fragments (6.52%)	PA, PEA, ABS	152 MP particles/L; water source and packaging materials (PET, which breaks down overtime) are possible sources for MPs.	Shruti et al., 2020
Bottled water Germany	22/22 (100 %)	na	PET (84%), PP (7%)	Returnable bottles had higher MPs (118 MP /L) compared to single-use plastic bottles (14 MP/L) (bottles are made of PET).	Schymanski et al., 2018
Energy drinks Mexico	5/8 (62.5 %)	Fibres (100%)	PA	14 MP particles/L; water source and packaging materials are possible sources for MPs.	Shruti et al., 2020
Fish (dry) (four species) Malaysia	12/12 (100 %)	Fragments (85.7%), films (10%),	PP, PE, PS, PA	(i) MP contamination in eviscerated fish: mullet> croaker> mackerel> anchovy. (ii) MPs contaminated during handling or salting or drying processes.	Karami et al., 2017a
Fish (marine) China	21/21 (100 %)	Fibres (61.4%), fragments (15.4%)	Cellophane (49%), PET (10.6%), PEST (7.9%)	(i) All pelagic, benthopelagic, demersal fish ingested MPs. (ii) The ingestion of plastics in fish was closely related to the habitat.	Jabeen et al., 2017
Fish (canned) (Australian, Malaysian markets)	4/20 (20 %)	Fragments (46.6%), films (26.6%)	PP (33.3%), PET (33.3%), PE (16.6%)	Sardines and sprats can be contaminated via translocation of MPs into the edible tissues, improper gutting, or canneries.	Karami et al., 2018

Fruit (02 species) Italy	12/12 (100%)	na	na	Apples were most contaminated with MPs: apple> pear.	Conti et al., 2020
Honey Germany, France, Italy, Spain, Mexico	19/19 (100%)	Fibres (95%), fragments (5%)	na	87 MP (fibres)/g honey; Possible MPs contamination (airborne, by bees into the hive or introduced during honey collection/ processing).	Liebezeit and Liebezeit, 2013
Lobster (Norwegian lobster) UK	100/120 (83%)	Filaments	PP	Filaments ingested can block different organs of the lobster and provide false satiation (no desire to eat) effects.	Murray and Cowie, 2011
Milk Mexico	23/23 (100%)	Fibres (97.5%), fragments	PES, PUS	6.5 MP particles/L: Sulfone polymers (PES, PSU) originating from membrane filters used in dairy processes.	Kutralam-Muniasamy et al., 2020
Mussel (wild) (blue mussel) Canada	5/5 (100%)	Fibres	PP	Microfibers (as MP) in farmed mussels (126.5 fibres/mussels) were higher than in the wild mussels (75 fibres/mussels); farmed mussels grown on PP lines released MPs fibres and caused contamination.	Mathalon and Hill, 2014
Oyster (Pacific oyster), Canada	4/12 (33.3%)	Fibres (80%)	na	Consumption of MPs contaminated oyster can be a health risk to humans	Rochman et al., 2015
Rice Australia, India, Pakistan, Thailand	52/52 (100%)	na	PE, PP, PET	(i) MP concentrations in rice differed between washed vs non washed type. (ii) Washing the rice reduced the amount of MPs contamination.	Dessi et al., 2021
Salt (USA)	12/12 (100%)	Fibres (99.3%)	na	Contamination means: 212 MP particles/kg (range: 46.7 to 806 particles/kg)	Kosuth et al., 2018

Seaweed (nori) China	23/24 (95.8%)	Fibres (85.2%)	PEST (18.9%), rayon (6.6%), PP (4%)	The fibres may come from plastic lines used for the attachment of seaweed seedlings.	Li et al., 2020
Sediment (Changjiang estuary) China	100%	Fibres (93%)	Rayon (63.1%), PEST (18.5%)	121 MP particles/ kg dw (mean); synthetic fibres (rayon, polyester) in the estuary may come from washing clothes.	Peng et al., 2017
Shark fish (four species) UK	31/46 (67%)	Fibres (95%)	Cellulose, PP, PAA, PEST	MP contamination: starry smooth-hound> bull huss> small-spotted catshark> spiny dogfish	Parton et al., 2020
Shrimp (brown shrimp) Belgium	57/90 (63%)	Fibres (95.6%)	na	Brown shrimp ingested MPs either accidentally or as a colour preference as 43% of fibres ingested were purple-blue.	Devriese et al., 2015
Soft drinks Mexico	16/19 (84%)	Fibres (100%)	PA, PET, ABS;	40 MP particles/L.	Shruti et al., 2020
Sugar Germany, France, Italy, Spain, Mexico	5/5 (100%)	Fibres, fragments	na	Fibres (mean 217/kg of sugar) and fragments (32/kg of sugar) were found in refined sugars.	Liebezeit and Liebezeit, 2013
Surface water Arctic Ocean Norway	20/21 (95%)	Fibres (95%), fragments (4.9%)	Rayon (30%), PES (15%), PA (15%), PE (5%)	28,000 MP particles/km^2; MPs (fibres) may be a breakdown of larger items, local fishing vessel activity, input of sewage and wastewater from coastal areas.	Lusher et al., 2015
Tap water (14 countries)*	129/159 (81%)	Fibres (98.3%)	na	Contamination means: 5. 45 MP particles/L.; USA had the highest MPs in tap water (9.24 MPs/L).	Kosuth et al., 2018
Tea (cold tea) Mexico	4/4 (100%)	Fibres (100%)	PA	11 MP particles/L; clothes, water used during production and the plastic container could be the sources of MPs (fibres)	Shruti et al., 2020
Vegetable (four species), Italy	24/24 (100%)	na	na	Carrots were most contaminated with MPs: carrot> broccoli> potato> lettuce	Conti et al., 2020

*14 countries include Cuba, Ecuador, England, France, Germany, India, Indonesia, Ireland, Italy, Lebanon, Slovakia, Switzerland, Uganda, and the USA.

Vegetable

Research carried out in Mexico reveals that 100 % of common vegetables including carrot, broccoli, potato, and lettuce were contaminated with MPs (Conti et al., 2020). Carrots were most contaminated with MPs in the following orders: carrot> broccoli> potato> lettuce. The research demonstrated that MPs are capable to penetrate the seed, root, and leaves of vegetable plants (Dietz and Hertz, 2011). As a consequence of MP contamination, the growth and taste of vegetables can be modified (see also Table 1, Figure 1).

Salt

100% of salt was found contaminated with MPs in several countries. For example, salt from Australia, France, Iran, Japan, Malaysia, New Zealand, Portugal, and South Africa (Karami et al., 2017b), salt from China (Yang et al., 2015), salt from Spain Iñiguez et al., 2017), salt from Turkey (Gündoğdu, 2018) and Salt from the USA (Kosuth et al., 2018). The possible contamination routes are atmospheric deposition of MPs and local contamination of coastal water. Sea salt contamination may demonstrate the extent of MPs pollution in the environment (see also Table 1, Figure 1).

Sugar

Five commercial sugar brands analysed from Germany were found contaminated with MP fibres and fragments. Transparent and coloured fibres (mean 217/kg of sugar) and fragments (32/kg of sugar) were found in refined sugars. In contrast, unrefined cane sugar had higher fibres and fragments (560 number fibres/kg and 540 number of fragments/kg) (Liebezeit and Liebezeit, 2013). The possible routes of MP contamination of sugar are environmental sources as well as material used during sugar processing (see also Table 1, Figure 1).

Honey

Honey from Germany, France, Italy, Spain, and Mexico was found 100 % contaminated with plastic fibres and fragments (Liebezeit and Liebezeit, 2013). Possible MPs contamination of honey is **(a)** airborne MPs, (**b)** transportation of MPs by bees into the hive or **(c)** introduction of MPs during honey collection/ processing (see also Table 1, Figure 1).

Drinks

Bottled Water

A total of 32 bottle water samples from Germany were found contaminated with MPs. MP concentrations were higher with reusable PET bottles (4,889 MPs/L) and less with single-use PET bottles (2,649 MPs /L). The polymers detected in water bottles were PE, PP, or styrene-butadiene-copolymer (Oßmann et al., 2018). In another study, Schymanski et al., (2018) also reported contamination of 22 bottled water samples (also from Germany) with MPs. The returnable water bottles (118 MP particles/L) had an average of eight times higher of plastic particles than in water from single-use plastic bottles (14 MP particles/L). Polymers detected in returnable water bottles were also higher [PET – 78 %; PP – 7 %; PE – 5 %] compared to single-use plastic bottles [PET – 57 %; PE – 9 %; PP -1 %] (Schymanski et al., 2018).

The Possible MP contamination sources in water bottles are the bottle cap, the washing machinery, or the other steps during bottle filling process. The returnable bottles are made of PET and the caps are made of PP, which may have resulted in higher PET and PP in returnable bottles (see also Table 1, Figure 1).

Tap Water

Nearly 81% of global tap water samples (159 samples tested) from 14 countries were found contaminated with plastic fibres (mean: 5. 45 MP particles/L) (Kosuth et al., 2018). These 14 countries include Cuba (7.17 MPs/L), Ecuador (4.02 MPs/L), England (7.73 MPs/L), France (1.82 MPs/L), Germany (0.91 MPs/L), India (6.24 MPs/L), Indonesia (3.23 MPs/L), Ireland (1.83 MPs/L), Italy (0 MPs/L), Lebanon (6.64 MPs/L), Slovakia (3.83 MPs/L), Switzerland (2.74 MPs/L), Uganda (3.93 MPs/L), and the USA (9.24 MPs/L). Among all the countries, the USA had the highest MPs in tap water (9.24 MPs/L). Water source (well, surface, snowmelt), regional human population density, and water filtering methods may have caused in differences in MP particles in different countries (see also Table 1, Figure 1).

Beer

100% of beer samples from Germany (Liebezeit and Liebezeit, 2014; Lachenmeier et al., 2015), the USA (Liebezeit and Liebezeit, 2014) and Mexico (Shruti et al., 2020) were reported to be contaminated with MPs. Fibres and fragments were the major polymers by shapes in beers. The contaminant level in beer samples from Mexico was 152 MP particles/L, where 93.42% MPs were fibres (Shruti et al., 2020). The possible contamination routes of MPs in beer are atmospheric deposition, clothing worn by workers and materials used in the beer production process (see also Table 1, Figure 1).

Soft Drinks

About 84 % of soft drink samples (n= 19) were found contaminated with MPs in Mexico (40 MP particles/L) (Shruti et al., 2020). The major polymers in soft drinks by shapes were fibres (100 %) and by types were PA, PET and ABS (acrylonitrile-butadiene-styrene) (see also Table 1, Figure 1).

Energy Drinks

About 62.5% of energy drink samples (n=8) were found contaminated with MPs in Mexico (14 MP particles/L) (Shruti et al., 2020). The major polymers in energy drinks by shapes were fibres (100%) and by types were PA. The water source and packaging materials are possible sources for MPs in energy drinks (see also Table 1, Figure 1).

Tea

Both cold teas from Mexico (Shruti et al., 2020) and tea infusions from Canada were found contaminated with MPs (Hernandez et al., 2019). Polymers detected were PA (Shruti et al., 2020) and nylon and PET (Hernandez et al., 2019). Research results reveal that steeping (soaking) a plastic tea bag at a brewing temperature of 95°C released around 11.6 billion micro-plastics and 3.1 billion nano plastics into a single cup of beverage (Hernandez et al., 2019) (see also Table 1, Figure 1).

Milk
A total of 23 milk samples (22 for adults and 1 for kid) from Mexico were found contaminated with MPs (6.5 MP particles/L) (Kutralam-Muniasamy et al., 2020). Polymers detected by shapes were fibres (97.5 %). Thermoplastic sulfone polymers (polyethersulfone and polysulfone) were common types of MPs detected in milk samples. It is likely that sulfone polymers (PES, PSU) may have originated from membrane filters used in dairy processes (see also Table 1, Figure 1).

Environmental Waters
Surface waters
Plastics can enter or be transported to the aquatic environment through many pathways including the open dumping, urban and stormwater run-off, wastewater treatment discharges, landfill wastes, the release of microfibers during washing of synthetic clothes, discharge of micro-beads from the use of personal care products, and from fishing nets and lines. MP pollutants are widespread and occur in all types of surface waters including creeks, lakes, channels, rivers, estuaries, coasts, oceans, and gyres. Around 80% of plastic pollution in the marine environment originates from land-based sources, while the remainder comes from ocean-based sources (fishing nets, fishing ropes). The increased abundance of MPs was reported in waterways close to larger cities, cities with higher population density and lakes adjacent to horticultural, agricultural, fishing and tourism activities. MP pollutants have reached even the remotest and pristine parts of the world such as in the Arctic Ocean, the Antarctic Ocean, and the Atlantic Ocean. Surface water have been contaminated across the globe including the Arctic, the Antarctica, Australia, Austria, The Bay of Bengal, Canada, China, European coasts, Germany, Great Pacific Garbage Patch (GPGB), Hong Kong, India, Japan, Kenya, Mediterranean Sea, Mongolia, New Zealand, North Atlantic Subtropical Gyre, North Pacific Central Gyre, North Western Pacific, Oceania, Papua New Guinea (PNG), Russia, Qatar, Sri Lanka, South Korea, South Pacific Ocean, Sub-Antarctic, Switzerland, Tibet, the USA, and Vanuatu. There have been more plastics than fish or plankton in various waterways (e.g., the Danube River, Austria; Portuguese coastal waters; and the North Pacific central gyre). Several MP accumulations zones have been identified worldwide, for example, the semi-enclosed basin in the Mediterranean sea and the Great Pacific Garbage Patch (Kibria et al., 2021) (see also Table 1, Figure 1). Plastic debris can affect marine organisms through entanglement, ingestion, suffocation (Gall and Thompson, 2015). Further, MP can not only harm aquatic biota (fish) and but can even cause death. Microplastics are mistaken as food and ingested by various marine organisms including invertebrates (Murray and Cowie, 2011), fishes (Carpenter and Smith, 1972; Davison and Asch, 2011), sea turtles (Lazar and Gracan, 2011), seabirds (Spear et al., 1995) and whales (Tarpley and Marwitz, 1993). In fact, the low-density MP particles (that floats) on the surface (such as PE) can be ingested by pelagic/benthopelagic organisms (Brandao et al., 2011; Wright et al., 2013), whereas high-density MP particles (PVC, PA) that sink in the sediments of the sea can be ingested by demersal/benthic organisms (Brandao et al., 2011; Wright et al., 2013).

Sediments
MP pollutants are widespread and detected in sediments of deep seas, and aquatic habitats adjacent to harbours, high population areas, industries, lagoons, mangroves, tourism areas, shellfish farms, and ship-breaking yards.

Sediments have been contaminated with MPs across the globe including the Arctic Ocean, Bangladesh, Belgium, Black sea, Brazil, Canada, China, Fiji, Germany, Ghana, India, Indian Ocean, Indonesia, Iran, Italy, Japan, Maldives, Netherlands, Norway, Pakistan, Qatar, Russia, Singapore, Slovenia, Solomon Islands, South Africa, Tunisia, UK, Vanuatu, and Vietnam. At some places, MP abundance in sediments reached 64% to 100% of the samples sampled (Kibria et al., 2021). Fish species have been exposed to MPs inadvertently during feeding at the bottom sediments while searching for food. For example, the higher MP concentration was found in demersal fish (bartail flathead, *Platycephalus indicus)* which search their food in the sediment (Abbasi et al., 2018). Sediments are known as major sinks for MPs, where most of the denser and heavier MPs stay. Nonetheless, the high-density MP particles (such as PET) that sink in the sediments of the sea can be ingested by demersal/benthic organisms (Brandao et al. 2011; Wright et al. 2013) (see also Table 1, Figure 1).

CONCLUSION

This article collected, collated, analysed, synthesised, reviewed, interpreted, and documented microplastic contamination of seafood (fish, shrimp, lobster, mussel, oyster, seaweed), other foods (rice, vegetable, honey, sugar, salt), drinks (bottled water, tap water, soft drinks, beer, energy drinks), and environmental waters (surface water, sediment) across the globe (Table 2). It identified the possible routes of MP contamination of seafood, other foods, drinks, and environmental waters.

Table 2. Locations or countries where food, drinks and environmental waters have been contaminated with microplastics.

Items	Locations or countries where microplastic contaminated food, drinks, and environmental waters found	References
Beer	Germany, the USA, and Mexico	Liebezeit and Liebezeit, 2014; Lachenmeier et al., 2015; Shruti et al., 2020
Bottled water	Germany	Oßmann et al., 2018; Schymanski et al., 2018
Energy drinks	Mexico	Shruti et al., 2020
Fishes	Across the globe including the Arctic Ocean, Atlantic Ocean, Australia, the Baltic Sea, Bangladesh, Belgium, Brazil, Canada, Chile, China, Fiji, France, the Gulf of Mexico, India, Indonesia, Iran, Italy, Japan, Malaysia, the Mediterranean Sea, the Netherlands, North Pacific Central Gyre, North Pacific Sub-tropical Gyre, North Sea, Norway, Portugal, Saudi Arabia, Scotland, South Pacific Sub-tropical Gyre, Spain, Tanzania, Thailand, Turkey, the United Kingdom, the United States of America and Vanuatu	Kibria et al., 2021

Honey	Germany, France, Italy, Spain, and Mexico	Liebezeit and Liebezeit, 2013
Milk	Mexico	Kutralam-Muniasamy et al., 2020).
Rice	Australia, India, Pakistan, and Thailand	Dessì et al., 2021
Salt	Australia, China, France, Iran, Japan, Malaysia, New Zealand Portugal, South Africa, and Turkey	Yang et al., 2015; Iñiguez et al., 2017; Karami et al., 2017b, Gündoğdu, 2018; Kosuth et al., 2018
Sediments	Across the globe including the Arctic ocean, Bangladesh, Belgium, Black sea, Brazil, Canada, China, Fiji, Germany, Ghana, India, Indian ocean, Indonesia, Iran, Italy, Japan, Maldives, Netherlands, Norway, Pakistan, Qatar, Russia, Singapore, Slovenia, Solomon Islands, South Africa, Tunisia, UK, Vanuatu, and Vietnam	Kibria et al., 2021
Soft drinks	Mexico	Shruti et al., 2020
Sugar	Germany	Liebezeit and Liebezeit, 2013
Surface waters	Across the globe including the Arctic, Antarctica, Australia, Austria, The Bay of Bengal, Canada, China, European coasts, Germany, Great Pacific Garbage Patch (GPGB), Hong Kong, India, Japan, Kenya, Mediterranean Sea, Mongolia, New Zealand, North Atlantic Subtropical Gyre, North Pacific Central Gyre, North Western Pacific, Oceania, Papua New Guinea (PNG), Russia, Qatar, Sri Lanka, South Korea, South Pacific Ocean, Sub-Antarctic, Switzerland, Tibet, the USA, and Vanuatu	Kibria et al., 2021
Tap water	Cuba, Ecuador, England, France, Germany, India, Indonesia, Ireland, Italy, Lebanon, Slovakia, Switzerland, Uganda, and the USA	Kosuth et al., 2018
Tea	Mexico and Canada	Hernandez et al., 2019; Shruti et al., 2020
Vegetables	Mexico	Conti et al., 2020

Seafood

Fishes (both pelagic, demersal) have been found contaminated with MPs across the globe (Table 2). In addition, canned and dry fish, as well as shrimps, lobsters, mussels, oysters, seaweeds were also found contaminated with MPs. As a consequence of MP ingestion by seafood organisms (mistakenly/ or confusing' MP as 'preys or food'), it can result in injury, poor growth, and reproduction. There is a likelihood of human exposure to MPs as well as high risks pollutants adsorbed in MPs via the food chain (eating contaminated seafood).

Other foods

Rice samples from Australia, India, Pakistan, and Thailand was found contaminated with MPs. MP Concentrations in rice samples differed by the type of rice (instant rice Vs uncooked rice; or the washed Vs unwashed rice). Rice contamination with MPs is a significant threat to food security since rice is the staple food for more than half of the global population. Research carried out in Mexico reveals that 100% of common **vegetables** including carrot, broccoli, potato, and lettuce were contaminated with MPs in the following orders: carrot> broccoli> potato> lettuce. As a consequence of MP contamination, the growth and taste of vegetables may be modified. **Salt** was found contaminated with MPs in several countries including Australia, China, France, Iran, Japan, Malaysia, New Zealand Portugal, South Africa, and Turkey. The possible salt contamination routes are atmospheric deposition of MPs and local contamination of coastal water. Commercial **sugar** from Germany was found contaminated with MP fibres and fragments. The possible sources of MP contamination of sugar are environmental sources as well as the material used during sugar processing. **Honey** from Germany, France, Italy, Spain, and Mexico was found 100% contaminated with plastic fibres and fragments. Possible MPs contamination of honey is a. airborne MPs, transportation of MPs by bees into the hive and introduction of MPs during honey collection/ processing.

Drinks

Drinking bottled water samples from Germany were found contaminated with MPs. MP Concentrations were higher with reusable PET bottles and less with single-use PET bottles. The Possible MP contamination sources in water bottles themselves (which is made of polymer PET), the bottle cap (made of polymer PP), the washing machinery, or the other steps during the bottle filling process. Global **tap water** samples from 14 countries were found contaminated with plastic fibres. These 14 countries are Cuba, Ecuador, England, France, Germany, India, Indonesia, Ireland, Italy, Lebanon, Slovakia, Switzerland, Uganda, and the USA. Among all the countries, the USA had the highest MPs in tap water (9.24 MPs/L). Water source (well, surface, snowmelt), regional human population density, and water filtering methods may have caused in differences in MP particles in different countries. **Beer** samples from Germany, the USA and Mexico were reported to be contaminated with MPs. The possible contamination routes of beer are atmospheric deposition, clothing worn by workers, materials used in the beer production process. **Soft drink** samples were found contaminated with MPs in Mexico. **Energy drink** samples were also found contaminated with MPs in Mexico. The water source and packaging materials are possible sources for MPs in energy drinks. Both cold **teas** from Mexico and tea infusions from Canada were found contaminated with MPs. **Milk** samples from Mexico were found contaminated with MPs. It is likely that sulfone polymers (PES, PSU) found may have originated from membrane filters used in dairy processes.

Environmental Waters

MP pollutants are widespread (Table 2) and occur in all types of **surface waters** including creeks, lakes, channels, rivers, estuaries, coasts, oceans, and gyres.

Plastic debris can affect aquatic organisms through entanglement, ingestion, suffocation, harm and even death. Micro-plastics are mistaken as food and ingested by various marine organisms including invertebrates, fishes, sea turtles, seabirds, and whales. MP pollutants are also widespread (Table 2) and detected in **sediments** of deep seas, and aquatic habitats adjacent to harbours, high population areas, industries, lagoons, mangroves, tourism areas, shellfish farms, and ship-breaking yards. Fish species have been exposed to MPs inadvertently during feeding at the bottom sediments while searching for food.

Overall

MP contaminant levels varied from 20 % in canned fish to 100 % in a number of food and drink samples (including beer, bottled water, carrot, cold tea, dried fish, fruit, fresh fish, honey, milk, mussel, rice, salt, sediment, surface water, and sugar) (Figure 1). In most food, drinks and environmental waters, fibres were the dominant MPs detected (Table 1). This article confirmed that MP is an emerging global threat to food and water security. Apart from the threat and risk posed on seafood, other foods, drinks, and environmental waters, MP can threaten the global climate by increasing greenhouse gas emissions (CO_2, CH_4) from plastic waste (see Kibria 2021a) and undermine achieving the UN sustainable development goals (Kibria, 2021b). Therefore, attempts should be made to curb the proliferation of plastic pollution by phasing out its use in consumer goods.

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REFERENCES

Abbasi, S., Soltani, N., Keshavarzi, B., et al. (2018). Micro-plastics in different tissues of fish and prawn from the Musa Estuary, Persian Gulf. *Chemosphere*. 205, 80–87. https://doi.org/10.1016/j. chemosphere.2018.04.076

Brandao, M.L., Braga, K.M. and Lunque, J.L. (2011). Marine debris ingestion by Magellanic penguins, *Spheniscus magellanicus* (Aves: Sphenisciformes), from the Brazilian coastal zone. *Mar. Poll. Bull.* 62, 2246-2249.

Browne, M.A., Dissanayake, A., Galloway, T.S., et al. (2008). Ingested microscopic plastic translocates to the circulatory system of the mussel, *Mytilus edulis*. *Environ. Sci. Techn*. 42 (13), 5026–5031. http://dx.doi.org/10.1021/es800249a

Calpe (2006). Rice International Commodity Profile. FAO, Markets and Trade Division. (http://www.fao.org/economic/est/publications/rice-publications/en/).

Carpenter, E. and Smith, K. (1972). Plastics on the Sargasso Sea surface. Science 175, 1240−1241.

Conti, O.G., Ferrante, M., Banni, M., Favara, C. et al. (2020). Micro- and nano-plastics in edible fruit and vegetables. The first diet risks assessment for the general population. *Environ. Res.* 187, 109677 https://doi.org/10.1016/j.envres.2020.109677.

Davison, P. and Asch, R. (2011). Plastic ingestion by mesopelagic fishes in the North Pacific Subtropical, *Gyre. Mar. Ecol. Prog. Ser.* 432, 173−180.

Dessì, C., Okoffo, E.D., O'Brien, J.W. et al. (2021). Plastics contamination of store-bought rice. *J. Haz. Mat*. 416, 125778. doi: 10.1016/j.jhazmat.2021.125778. Epub, 3.

Devriese, L.I., Van de Meulen, M.D., Maes, T. et al. (2015). Micro-plastic contamination in brown shrimp (*Crangon crangon*, Linnaeus 1758) from coastal waters of the southern North Sea and channel area. *Mar. Poll. Bull.* 98 179–187.

Dietz, K.J. and Herth, S. (2011). Plant nanotoxicology. *Trends Plant Sci.* 16 (11), 582–589. https://doi.org/10.1016/j.tplants.2011.08.003. 2011.

Gall, S.C. and Thompson, R.C. (2015). The impact of debris on marine life. *Mar. Poll. Bull.* 92, 170–179.

Gundoğdu, S. and Cevik, C. (2017). Micro- and meso-plastics in Northeast Levantine coast of Turkey: The preliminary results from surface samples. *Mar. Poll. Bull.* 118, 341–347.

Hernandez, L.M., Xu, E.G., Larsson, H.C.E., Tahara, R., Maisuria, V.B. and Tufenkji, N. (2019). Plastic teabags release billions of micro-particles and nanoparticles into tea. *Environ. Sci. Technol.* 53 (21), 12300–12310. https://doi.org/10.1021/acs.est.9b02540

Iñiguez, M.E., Conesa, J.A. and Fullana, A. (2017). Micro-plastics in Spanish table salt. *Sci. Rep.* 7, 8620.

Jabeen, K., Su, L., Li, J. et al. (2017). Micro-plastics and meso-plastics in fish from coastal and fresh waters of China. *Enviro. Poll.* 221, 141–149.

Karami, A., Golieskardi, A., Ho, Y.B. et al (2017a). Micro-plastics in eviscerated flesh and excised organs of dried fish. *Sci. Rep.* 7 5473. doi: 10.1038/s41598-017-05828-6.

Karami, A., Golieskardi, A., Choo C.K. et al. (2017b). The presence of micro-plastics in commercial salts from different countries. *Sci. Rep.* 7, 46173.

Karami, A., Golieskard, A., Choo, C.K., et al. (2018). Micro-plastic and meso-plastic contamination in canned sardines and sprats. *Sci. Total Environ.* 612, 1380-1386.

Kibria, G. (2017). Plastic waste and plastic pollution - A Threat to All Nations. DOI: 13140/RG.2.2.11169.51048 https://www.researchgate.net/publication/319391174_Plastic_Waste_Plastic_Pollution,A_Threat_to_All_Nations#:~:text=Plastic%20pollution%20threatens%20the%20global,an%20increase%20in%20global%20temperature.

Kibria, G. (2018). Plastic pollution- sources, global production, global "hotspots", Impacts on biodiversity & seafood; Adsorption of organic & inorganic chemicals, and mitigation. DOI: 10.13140/RG.2.2.35028.24967/3 https://www.researchgate.net/publication/327230697_Presentation_Plastic_Pollution,Sources_Global_Production_Global_Hotspots_Impacts_on_Biodiversity_Seafood_Adsorption_of_Organic_Inorganic_Chemicals_and_Mitigation

Kibria, G. (2021a). The connection between plastic pollution and climate change. DOI: 10.13140/RG.2.2.15502.48966/4 https://www.researchgate.net/publication/355493472_The_connection_between_plastic_pollution_and_climate_change

Kibria, G. (2021b). Plastic pollution undermines achieving the UN sustainable development goals. DOI: 10.13140/RG.2.2.16162.76485/3

Kibria, G., Haroon, A.K.Y., Rose, G., Hossain, M.M. and Nugegoda, D. (2021a). Pollution risks, impacts and management. Social, economic, and environmental perspectives. 833 pages. Scientific Publishers. ISBN: 978-93-89184-96-9. DOI: 10.13140/RG.2.2.35056.79362 https://www.researchgate.net/publication/349669182_Book_Pollution_Risks_Impacts_Management_Social_Economic_and_Environmental_Perspectives_833_pages

Kibria, G., Nugegoda, D., Rose, G. and Haroon, A.K.Y. (2021b). Climate change impacts on pollutants mobilization and interactive effects of climate change and pollutants on toxicity and bioaccumulation of pollutants in estuarine and marine biota and linkage to seafood security. *Mar. Poll. Bull.* 167, 112364.

Kosuth, M., Mason, S.A. and Wattenburg, E.V. (2018). Anthropogenic contamination of tap water, beer, and sea salt. *PLoS One* 13 (4), e0194970. https://doi.org/10.1371/journal.pone.0194970.

Kutralam-Muniasamy, G., Pèrez-Guevara, F., Elizalde-Martìnez, I. and Shruti, V.C. (2020). Branded milks–are they immune from micro-plastics contamination? *Sci. Total Environ.* 714, 136823.

Lachenmeier, D.W., Kocareva, J., Noack, D. and Kuballa, T. (2015). Micro-plastic identification in German beer-an artefact of laboratory contamination? *Deutsche Lebensmittel-Rundschau* 111 (10), 437–4.

Lazar, B. and Gracan, R. (2011). Ingestion of marine debris by loggerhead sea turtles, *Caretta caretta*, in the Adriatic Sea. *Mar. Poll. Bull.* 62, 43−47.

Lessy, M.R. and Sabar, M. (2021). Micro-plastics ingestion by Skipjack tuna (Katsuwonus pelamis) in Ternate, North Maluku – Indonesia. IOP Conf. Series: *Materials Sci. Engineering.* 1125, 012085.

Liebezeit, G. and Liebezeit, E. (2013). Non-pollen particulates in honey and sugar. Food Additives and Contaminants Part A Chem. *Anal. Control Expo. Risk Assess* 30(12), 2136–2140.

Liebezeit, G. and Liebezeit, E. (2014). Synthetic particles as contaminants in German beers. *Food Addit. Contam.* Part A Chem. *Anal. Control Expo. Risk Assess.* 31 (9), 1574–1578.

Li, Q., Feng, Z., Zhang, T. et al. (2020). Micro-plastics in the commercial seaweed nori. J. Haz. Mat. 388, 122060.

Lusher, A., Tirelli, V., O'Connor, L. and Officer, R. (2015). Micro-plastics in Arctic polar waters: the first reported values of particles in surface and sub-surface samples. Scientific Reports 5: 14947; doi: 10.1038/srep14947.

Mathalon, A. and Hill, P. (2014). Microplastic fibers in the intertidal ecosystem surrounding Halifax Harbor, *Nova Scotia. Mar. Poll. Bull.* 81, 69−79.

Murray, F. and Cowie, P.R. (2011). Plastic contamination in the decapod crustacean, *Nephrops norvegicus* (Linnaeus, 1758). *Mar. Poll. Bull.* 62 (6), 1207-1217.

Oßmann, B.E., Sarau, G., Holtmannspötter, H., Pischetsrieder, M., Christiansen, S.H. and Dicke, W. (2018). Small-sized microplastics and pigmented particles in bottled mineral water. *Water Res.* 14 (1), 307–316.

Parton, K.J., Godley, B.J. and Santillo, D. (2020). Investigating the presence of micro-plastics in demersal sharks of the North-East Atlantic. *Sci. Rep.* 10, 12204. https://doi.org/10.1038/s41598-020-68680-1

Peng, G., Zhu, B., Yang, D. et al. (2017). Micro-plastics in sediments of the Chingjiang Estuary, China. *Environ. Poll.* 225, 283–290.

Rochman, C.M. (2013). Plastics and priority pollutants: a multiple stressor in aquatic habitats. *Environ. Sci. Tech.* 47, 2439–2440.

Rochman, C.M., Tahir, A., Williams, S.L. et al. (2015). Anthropogenic debris in seafood: plastic debris and fibres from textiles in fish and bivalves sold for human consumption. *Sci. Rep.* 5, 14340.

Schmidt, N., Thibault, D., Galgani, F. et al. (2018). Occurrence of micro-plastics in surface waters of the Gulf of Lion (NW Mediterranean Sea). *Progr. Oceano.* 163, 214–220.

Schymanski, D., Goldbeck, C., Humpf, H.U. and Fürst, P. (2018). Analysis of microplastics in water by micro-Raman spectroscopy: release of plastic particles from different packaging into mineral water. *Water Res.* 129, 154–162.

Shruti, V.C., P´erez-Guevara, Fermín, Elizalde-Martínez, I., Kutralam-Muniasamy and Gurusamy (2020). First study of its kind on the micro-plastic contamination of soft drinks, cold tea and energy drinks - future research and environmental considerations. *Sci. Total Environ.* 726, 138580 https://doi.org/10.1016/j.scitotenv.2020.138580.

Spear, L.B., Ainley, D.G. and Ribic, C.A. (1995). Incidence of plastic in seabirds from the tropical pacific, 1984−91 - Relation with distribution of species, sex, age, season, year and body-weight. *Ma. Environ. Res.* 40, 123−146.

Tarpley, R.J. and Marwitz, S. (1993). Plastic debris ingestion by cetaceans along the Texas coast: Two case reports. Aquatic Mammals 19, 93−98.

Watts, A.J.R., Urbina, M.A, Corr, S. et al. (2015). Ingestion of plastic microfibers by the crab, *Carcinus maenas* and its effect on food consumption and energy balance. *Environ. Sci. Technol.* 49 (24), 14597–14604.

Wright, S.L., Thompson, R.C. and Galloway, T.S. (2013). The physical impacts of microplastics on marine organisms: a review. *Environ. Poll.* 178, 483–492.

Yang D., Shi, H., Li, L. et al. (2015). Micro-plastic pollution in table salts from China. *Environ. Sci. Techn.* 49(22), 13622−13627.

Corresponding author: Dr. Golam Kibria, School of Science, RMIT University, Australia
Email: kibriagolam0@gmail.com