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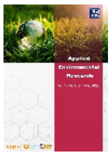

Research Article

Microplastic Contamination in Table Salt: A Study of Consumer Behavior in Cox's Bazar, Bangladesh

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Abstract

Plastic particles resulting from the breakdown of bigger plastics may be introduced directly as micro- and nano-sized particles polluting the marine ecosystem, including ocean-extracted table salt. This study investigated the presence of microplastic (MP)-like particles in table salt from Bangladesh, focusing on both locally refined and commercially branded varieties. Local salt samples from Sadar and Moheshkhali Sub-district of Cox's Bazar contained an average of 23.4 and 12 particles kg^{-1}, respectively. In contrast, no particles were detected in commercial brands, likely due to their complex refining processes. The study also explored factors influencing local salt consumption, finding it influenced by the economy, availability, education level, occupation, income level, and misperceptions about local salt's health benefits compared to commercial brands. Interestingly, the study found that 71% of local salt consumers believed it to be more beneficial than branded salt, while education level influenced salt preference, with 83% of graduate and 53% of primary-educated individuals opting for commercial brands. These findings provide a valuable foundation for further research on MP exposure in different consumer groups, highlighting the need to investigate potential health risks and inform policy decisions regarding MP contamination in table salt in Bangladesh.

ARTICLE HISTORY

Received: 10 Jun. 2024
Accepted: 14 Oct. 2024
Published: 13 Nov. 2024

KEYWORDS

Microplastic pollution;
Table salt contamination;
Consumer behavior;
Health risk

Introduction

Marine environments are increasingly threatened by microplastic (MP) pollution, originating from various sources including plastic wastes and industrial processes [1–2]. According to Plastics Europe, global plastic production reached 270 million tonnes in 2010 and surged to an estimated 460 million tonnes in 2023, marking a 70% rise in just 13 years [3]. Rising plastic production, fueled by population growth and consumer needs, is compounded by ineffective waste management, leading to environmental pollution [4–5]. A vast array of products, from medical equipment to fishing gear, are manufactured from plastic. Improper waste disposal has led to plastic debris entering the environment, where it degrades into tiny fragments known as MP that persist for centuries and contaminate the food chain [6–9]. Microplastics are generally less than 5 millimeters in diameter and they have been found in various marine products, including table salt, raising concerns about potential human exposure [10]. Improper disposal of plastic wastes on land eventually finds its way into waterways through wind, rain, and other natural processes [11–12]. Industrial processes can also release MP directly into the environment through wastewater discharge [13]. Microplastics can be ingested by marine organisms, causing physical harm, hindering growth, and potentially bioaccumulating in the food chain [14]. While research is ongoing, there are growing concerns about potential human health risks associated with MP ingestion through contaminated food, water, and salt [15].

Microplastics can absorb harmful pollutants and contribute to the spread of invasive species, disrupting natural ecosystems [16]. As they are not biodegradable, they don't break down readily in the environment [17]. They can enter the food chain through various pathways like direct ingestion, bioaccumulation, and contamination of food sources [18–20]. As larger predators consume smaller organisms, MP accumulate in the bodies of higher trophic levels. This process can concentrate the plastic particles, potentially increasing their harmful effects, and can adhere to or contaminate food sources like fish, shellfish, and table salt leading to their indirect consumption by humans [20]. A study found micro-plastics in most analyzed salt brands globally, ranging from 1 to 10 MP per kilogram [21]. However, a recent study on Bangladeshi sea salt suggests that sea salt production processes might not effectively remove MP, revealing higher levels than other regions (2,676 MP per kilogram ranging from 0.1 to 5 millimeter) [22]. These studies indicate that MP can be present in table salt extracted from the ocean but the amount of MP potentially ingested through table salt is likely minimal compared to other sources [23–24]. In addition, a broader study encompassing eight countries, including several European nations, found MP in most analyzed salt brands, albeit at lower concentrations compared to Asia (1–10 particles per kilogram), and this suggests possible regional variations in contamination levels [25]. Further research is necessary to gain a comprehensive understanding of the global picture. Building on this limited knowledge, this study aims to investigate the abundance of MP in both local and branded salts in Bangladesh, to develop and validate a cost-effective way for isolating MP from table salt samples, and to analyze the impact of socio-economic factors such as education level, occupation, and family income on salt consumption patterns. By quantifying MP levels, we hope to gain insights into potential human exposure through salt consumption in this region, while also understanding how socio-economic factors influence these risks.

Materials and methods:

1) Study area

This study was conducted along the southeastern coast of Bangladesh in the Cox's Bazar District for a period of 18 months, from June 2022 to November 2023. Local salt samples were collected from two groups of locations: Cox's Bazar Sadar Sub-district, and Moheshkhali Sub-district. These selected sites of sampling represent areas where branded or local salts are collected for further refining.

2) Sample collection

Each location was visited five times over 18 months for separate sample collections. (Figure 1). To investigate the local and branded table salt consumption patterns, a questionnaire survey was conducted among 2,400 households over eight sub-districts of Cox’s Bazar (Chakaria, Cox's Bazar Sadar, Kutubdia, Moheshkhali, Pekua, Ramu, Teknaf, and Ukhia), with 300 households surveyed in each sub-district. So, data gathering techniques included observation, structured questionnaires, surveys, and informal dialogue with the respondents.

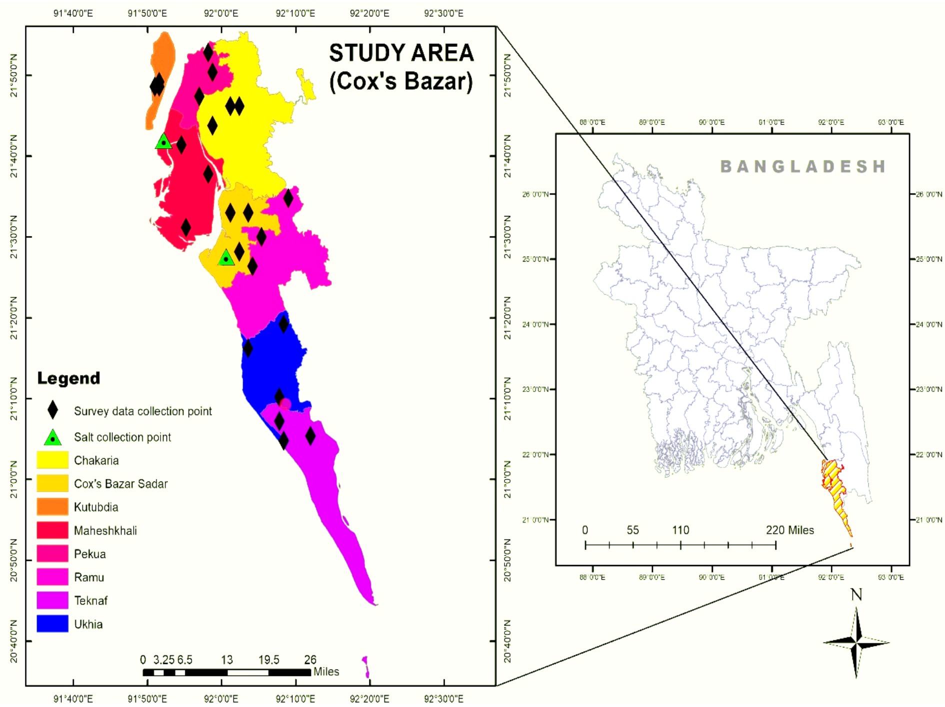

Figure 1 Sampling site and study area covered for data collection.

3) Method

In Bangladesh, salt is extracted from seawater using solar evaporation and lixiviation techniques in the coastal areas of Chittagong, Cox's Bazar, Noakhali, Barishal, Khulna, and the adjacent offshore islands [26]. This study analyzed two types of salt samples collected in Cox's Bazar: local and commercial brand salt. Local salt is sourced from seawater in coastal areas and processed using traditional methods, while brand salt is also sourced from seawater but processed, iodized, and packaged in a standardized manner by established companies. To minimize bias in representing the local salt, twenty composite samples, each weighing between 800-1,000 g, were prepared. These composites were formed by collecting salt from six random locations within the storehouses of local refineries (e.g., top and bottom shelves). In contrast, ten individual samples of commercially branded salt were purchased from a local market. The poor traditional method of refining local salt allows us to investigate whether MP are being possibly introduced or retained in the salt.

3.1) Quality control and extraction of MP

All samples were collected in glass and tin jars to avoid contamination. Before usage, all of the liquid (tap water and H_2O_2) was filtered using filter paper with a 1 micrometer (μm) pore size. The containers and beakers were washed with filtered water three times and 70% ethanol, and all operations were performed under a closed fume hood [27–28]. When the samples were not being used, they were quickly covered, and the experiment was completed as soon as feasible. Each package's 150 g aliquot was weighed, and 500 milliliter jars were filled with it. After that, 50 mL of 30% H_2O_2 was added to oxidize any organic compounds. These glass jars were covered with aluminum foil paper and placed in an oscillation incubator for 24 hours at 65°C and 80 rpm shaking speed. Following that, the samples were left at room temperature for 48 hours. After that, 400 mL of pure water was added to each bottle, and the bottles were stirred with a glass rod until all of the salt had dissolved. After the salt had been completely dissolved, the bottles were allowed to rest at room temperature for 24 hours. The supernatant in the bottles was passed through a 47 mm 0.45 μm cellulose nitrate membrane filter and placed in sterile Petri dishes after the settling process was confirmed. The membrane filter was placed in a 100ml laboratory bottle and was treated with 10–15 mL of 4 M $ZnCl_2$. The bottle was centrifuged to ensure the complete separation of MPs. The supernatant was passed through a 47 mm 0.45 μm cellulose nitrate membrane filter again for final isolation and further optical observation. Material remaining at the bottom of the bottles was also transferred to a 100 mL laboratory bottle and was treated with $ZnCl_2$ (approximate density = 1.6 g mL^{-1}) saved and filtered in the previous process, and the upper portion of the solution went through centrifugation and filtration by 47 mm 0.45 μm cellulose nitrate membrane filter. A blank extraction was tested to measure the procedural contamination of MP in filtered pure water, H_2O_2, and $ZnCl_2$.

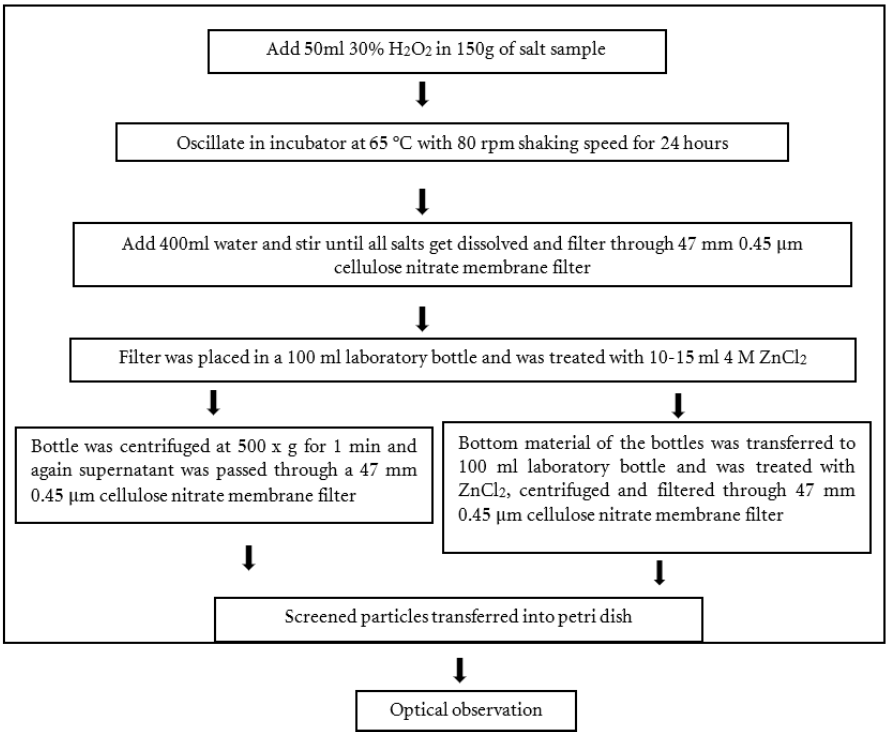

Figure 2 Flow chart of laboratory analysis for MP isolation.

3.2) Weight measure of MP

Sterile Petri dishes were washed three times with pure filtered water dried in an oven and weighed (W_1) in a weight machine. Then screened particle in a 47 mm 0.45 µm cellulose nitrate membrane filter was transferred into a petri dish, and the petri dish was weighed with the screened particle (W_2). The weight of MP (W) can be measured by subtraction of W_2 and W_1.

4) Microplastics identification

4.1) Microscopic examination

Filter papers were examined under an optical microscope with a Canon EOS 450D camera attached at magnification levels 4x. Particles that were thought to be MPs were MP-liked was measured using ImageJ software (Version 1.8.0), and MPs in this study were categorized by color (e.g., white, transparent, blue, black) and shape (e.g., fibers, fragments, films), aiding in the identification and characterization of the particles.

4.2) Prodding pieces and texture

The majority of plastic objects are reasonably flexible and won't shatter when poked. Individual bits can be prodded with tweezers and probes. When prompted, plastic things frequently bounce or spring. A component is not considered plastic if it breaks when touched.

4.3) The hot needle test

This test is practical when we cannot tell the difference between plastic and organic stuff. Plastic components will melt or curl in the presence of a highly hot needle. Biological and other non-plastic materials will not, and when your fragments are spread out, the hot needle test works effectively [29]. However, we found this test challenging to perform when several pieces are close together. We made sure the needle was very hot and held it as close to the object in question as possible when employing this approach (without blocking the view). If the needle is not heated sufficiently, no movement is detected, even if the item is made of plastic. This test is used in conjunction with knowledge of other plastic item qualities, and to ensure and understand clearly, we removed the piece in question and inspected it under a compound microscope.

The identification of MP was based on a microscopic method only, as this study did not use FTIR or µ-FT-IR, or Raman Spectroscopy which is one of the most widely used methods for determining the composition of MP [30] Alternatively, it used the hot needle Test, especially for two particles, as they look like organic particles. Because of its effectiveness, availability, denser than PET (polyethylene terephthalate, 1.38 g cm^{-3}), and non-hazardous properties, $ZnCl_2$ ($ZnCl_2$, 1.6 kg L^{-1}) was used in the present study for floatation and density separation [31–32].

5) Data analysis

Finally, experimental data shown here were gathered from the Cox's Bazar District. The questionnaire aimed to quantify the proportion of the population consuming local or branded salt, and the target population was people living in Cox's Bazar over 18 years. In the analysis of collected data, Microsoft Excel (2013) software is used and visualized. However, the description lacks details on the specific statistical tests employed (descriptive or inferential) for data analysis.

Results and discussion

1) Characterizations of MP-like particles

No particles were found in the procedural blank extraction group without salt. Among the two groups of samples (local salt and brand salt), no MP particles were found in branded salt or commercially available packaged salt, but in 20 samples (10 local salt of Cox's Bazar and 10 local salts of Moheshkhali) of local salt, "0-33" MPs particles were found per kilogram which's size ranges from 0-4,500 µm (Table 1). Salt from Cox's Bazar has a higher concentration of MP-like particles than salt from the Moheshkhali one of the sub-districts of Cox’s Bazar.

2) Colors and shapes of MP

Among all isolated particles, four type-colored particles were identified. The color of MP like particles in sampled salts are transparent, white, black, and blue (Figure 3A). White and transparent particles are quite tough to identify in sea salt by visual identification. The majority of MP detected in table salt samples were transparent in color. This transparency may result from the fragmentation and discoloration of ocean plastics, which can occur after long exposure to sunlight in the natural environment [33]. Furthermore, tourists often discard plastic items such as glasses, bottles, and plates after use, which are primarily white or transparent. These discarded plastics could be a source of transparent MP particles found in salt [22]. The shape of identified MP like particles based on appearance was classified into three different categories like fiber, film, and fragment (Figure 3B). Fibers generally make up the largest proportion of particles found in environmental samples and are defined by their length, which is much greater than their width. Fragments, on the other hand, can have either smooth or angular edges, and may be flat (referred to as films), generally appearing as like they have broken down from larger pieces of debris [34].

Table 1 Number and size of MP like particles found in different samples of salt analyzed

Sample no.	Classification code	MP (particles kg^{-1})	Average MP (particles kg^{-1})	Size range (μm)
1	*LSS- A	33		1,000-2,000
2	LSS- B	27		170-2,850
3	LSS- C	27		1,000-4,500
4	LSS- D	33		500-2,000
5	LSS- E	7	23.4	1,000-1,200
6	LSS- F	20		760-1,200
7	LSS- G	27		1,500-2,100
8	LSS- H	20		1,500-3,500
9	LSS- I	20		1,000-1,500
10	LSS- J	20		500-1,500
11	**LSM- A	20		800-1,500
12	LSM- B	27		800-1,400
13	LSM- C	13		500-1,200
14	LSM- D	13		1,000-2,000
15	LSM- E	7	12	500-1,000
16	LSM- F	13		1,500-3,800
17	LSM- G	0		0
18	LSM- H	7		1,000-1,500
19	LSM- I	20		1,500-2,500
20	LSM- J	0		0

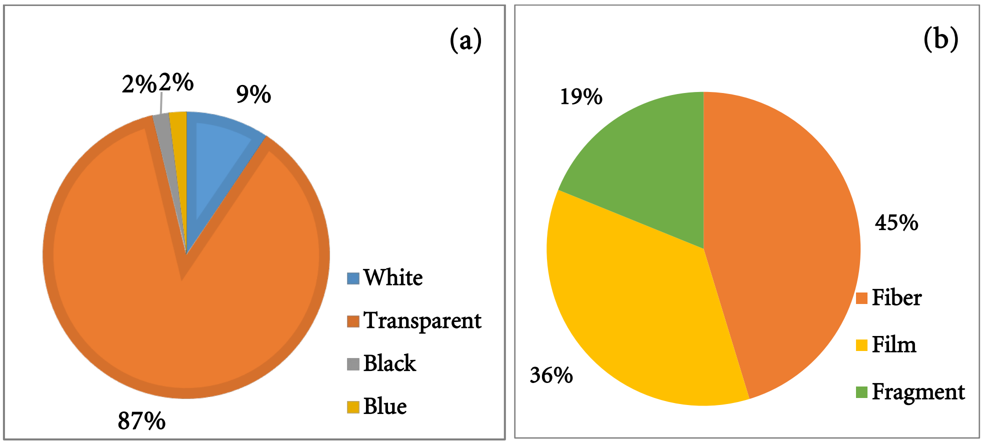

Figure 3 Percentages of (a) colors and (b) shapes in MP like particles.

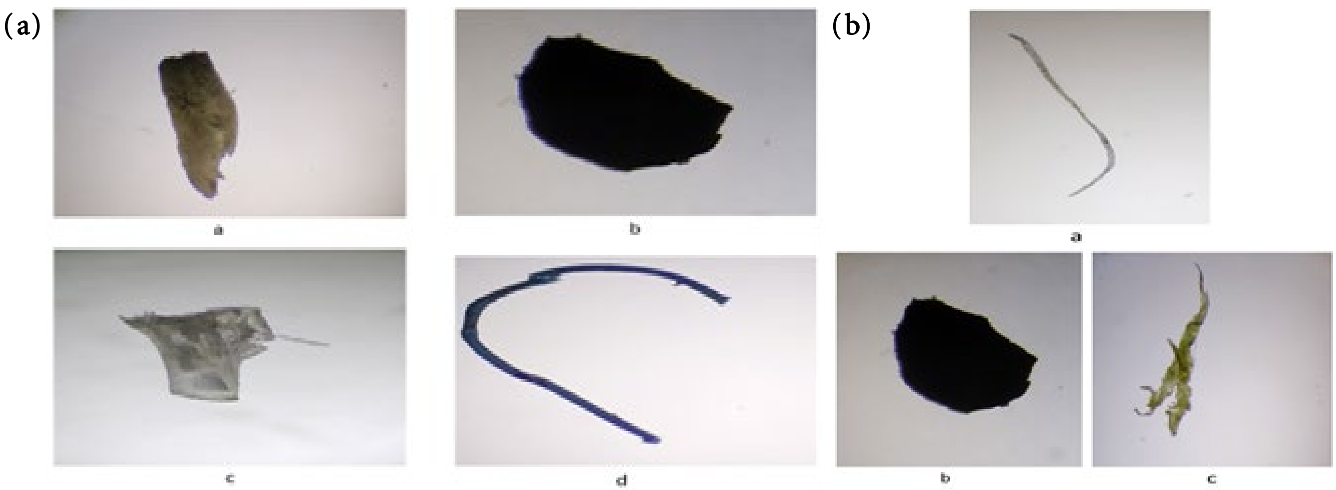

Figure 4 Pictures of (a) color of MP like particles (a= white, b= black, c= transparent and d= blue) And (b) shape of particles (a= fiber, b= fragment, c= filament).

3) Table salt consumption status

Figure 5 provides valuable insights into the impact of education level, occupation, and family income on mean scores. In Bangladesh, the education system begins with primary education, followed by secondary school certificate (SSC), higher secondary certificate (HSC), and then graduation. Figure 5 shows that local salt consumption (LSC) is generally higher among individuals with lower educational levels (primary), while branded salt consumption (BSC) tends to increase with higher education levels. That means those with a higher level of education are more likely to prefer branded salt, possibly due to greater awareness of its perceived quality or health benefits.

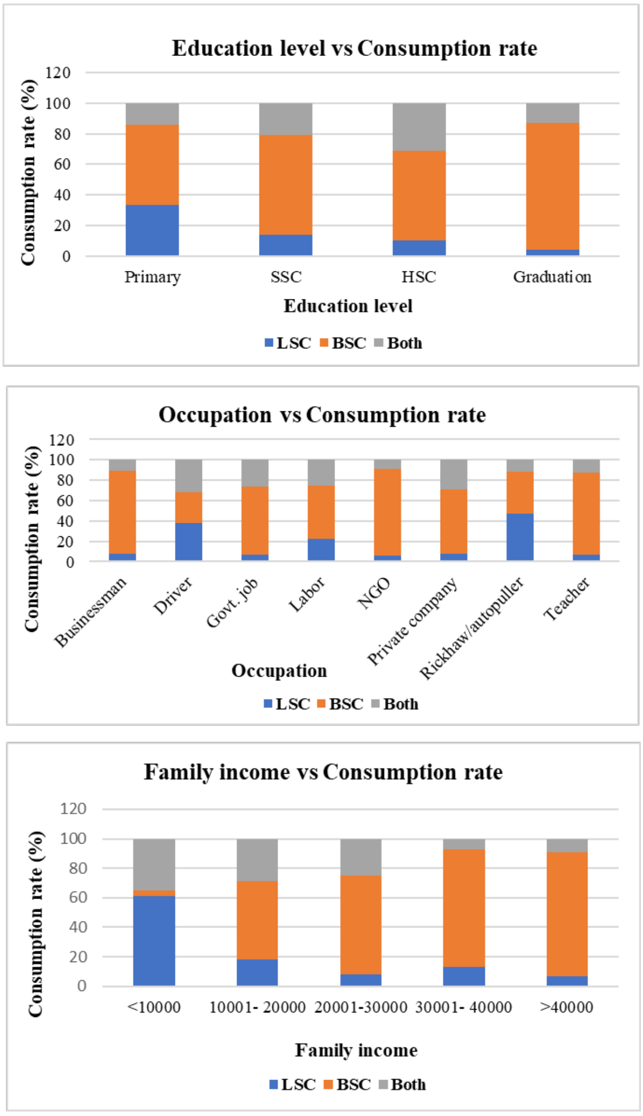

Figure 5 Variation in LSC and BSC across education levels, occupations, and family income.

Considerable variations in both LSC and BSC across various occupations is revealed in Figure 5. Specifically, LSC is significantly higher among drivers and auto-pullers, whereas BSC is more common among businessman, teachers and people working in NGOs. This suggests that occupation is a key factor influencing salt consumption preferences, likely related to differences in income levels, access to information, or occupational habits. Figure 5 illustrates a distinct trend where LSC generally decreases as income increases, while BSC grows with higher family income. Because families with higher incomes are more inclined to choose branded salt, likely because they can afford it and perceive it to have better quality or health benefits compared to local salt.

However, this study isolated (Figure 2) MP-like particles in both local salt and commercial brand salt in Bangladesh. It also created a simple and low-cost protocol for isolating MPs from salt samples. Besides, it is now well understood that the local salts of Bangladesh contain an alarming level of MPs, and commercial brand salt is mostly free of MPs. Sea salt containing the highest number of MP like particles, in the local salt average of 23.4, 12 particles kg^{-1}, originated from Cox's Bazar Sadar and Moheshkhali, respectively. The higher number of particles in the Sadar Sub-district might be an indication of greater economic activities like tourism, fishing, and industrial operations.

Discussion

According to the study of Song et al., 2015, seawater and salts showed significant MP contamination, whereas lake salts and rock/well salts had lower levels of contamination compared to the marine environment [30, 35]. The extent of MP contamination in the local environment is influenced by high population density and economic conditions [36]. Microplastics have been linked to various health impacts, including respiratory issues, neurological effects, gastrointestinal problems, skin irritation, endocrine disruption, and immune system compromise (Table 2). In this study, MP were identified only in local salts, an average of 23.4, 12 particles kg^{-1}, originating from Cox's Bazar Sadar and Moheshkhali while branded salts showed no MP contamination. This suggests that branded salt packaging processes may prevent contamination. At the same time, a study reported 28.53 ± 2.43 to 93.53 ± 4.21 particles per kg in raw salts collected from local producers, quite a similar range to the present study [37]. The characterization of MPs identified four distinct colors: transparent, white, black, and blue, with transparent particles being the most common. This predominance of transparent particles may result from the fragmentation and discoloration of ocean plastics, which can occur after long exposure to sunlight in the natural environment [33]. Furthermore, tourists often discard plastic items such as glasses, bottles, and plates after use, which are primarily white or transparent. These discarded plastics could be a source of transparent MP particles found in salt [22]. The shape of the MP particles identified in this study were fibers, films, and fragments. Fibers, the most common MP shape, are mainly associated with fishing nets and ropes, both of which are prevalent in coastal regions like Cox's Bazar [38]. Fragments and films generally appear as if they have broken down from larger pieces of debris [34].

In Section 3.3, the study showed that local salt consumption was more common among lower-educated and lower-income groups due to its affordability. However, local salts were found to have MP, while branded salts were free of contamination, indicating that local salt production needs improved packaging and processing. The reason for the difference may be the misconception that local salt is more natural which is behind the continued use despite the potential pollution risks. However, this study found that Cox's Bazar Sadar, with a high population density (12,154 people km^{-2}) and popularity as tourist destination, is highly vulnerable to plastic pollution compared to Moheshkhali (5,464 people km^{-2}), which is still under development in economic structures. The higher number of particles in Sadar Sub-district might be an indication of greater economic activities like tourism, fishing and industrial operations. Additionally, this study created a simple and low-cost protocol for isolating MPs from salt samples, revealing that while local salts pose significant contamination risks, branded salts are largely free from MP.

Table 2 Health impacts induced by MP reported by several studies

Affected sites	Health impacts	Reference
Respiratory system	Oxidative stress in airways and lungs resulting in sneezing, cough and shortness of breath, fatigue, dizziness	[39]
Neurological impact	Short time exposure to PS MPs adversely affects embryonic brain development -like tissue while long-term exposure decreases cell viability	[40]
Gastrointestinal tract	IBD, colorectal and pancreatic cancers, metabolic disorders, non-alcoholic fatty liver disease	[41]
Skin	Triggers allergic reaction and dermatitis	[41]
Endocrine system	Disrupts normal endocrine function leading to detrimental health effects	[42]
Immune system	Promotes the generation of ROS and causes endoplasmic reticulum stress	[43]

Conclusion

This study revealed a worrying trend of MP like particles contamination in locally produced sea salt from Bangladesh. While commercially processed salts appeared free of it, local salt samples contained concerning levels, with areas like Cox's Bazar Sadar showing particularly high concentrations. This highlights a potential environmental justice issue, as lower-income populations who rely more on local salt might be disproportionately exposed to MP. The study emphasizes the need for stricter regulations on plastic use and disposal to reduce marine pollution, along with the development of more effective cleaning methods for local salt production. Further research is crucial to understand the long-term health effects of MP ingestion and identify ways to protect vulnerable communities.

Limitations of the study

This study offers valuable insights into MP contamination of salt in Bangladesh, but some limitations restrict its overall scope. Firstly, the reliance solely on visual microscopy for MP identification might underestimate the true variety and quantity of MP present. Secondly, the analysis of branded salt was limited, leaving a gap in understanding the potential difference in MP content between local and commercially processed salts. Finally, the study doesn't delve into the potential health consequences of MP ingestion on humans, leaving a crucial question unanswered. These limitations highlight the need for further research that incorporates advanced identification techniques, expands the analysis to branded salt, and investigates the health risks associated with MP exposure.

Declarations of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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