Tropical Oceanographic
Research Frontiers

Research Article
Volume 1(2), 2026, 74−88
https://doi.org/10.53623/torf.v1i2.1013

Abundance and Characterization of Microplastics in Marketed Edible Salt from a Coastal Region of South Sumatra, Indonesia

Anna Ida Sunaryo Purwiyanto*, Rizky Herman Saputra, Wike Ayu Eka Putri, Rozirwan, Melki,

[1]Marine Science Department, Faculty of Mathematics and Natural Science, Sriwijaya University, Palembang, South Sumatera 3066, Indonesia

*Correspondence: anna_is_purwiyanto@unsri.ac.id

SUBMITTED: 26 January 2026; REVISED: 10 June 2026; ACCEPTED: 19 June 2026

ABSTRACT: Microplastic contamination in food products has become an increasing environmental concern due to its widespread occurrence in marine and coastal ecosystems. Edible salt, a commonly consumed marine-derived product, has been recognized as a potential pathway of human exposure to microplastics. This study investigated the occurrence, abundance, and physical characteristics of microplastics in commercial table salt marketed in Sungsang Village, Banyuasin Regency, South Sumatra, Indonesia. Two locally marketed salt brands were analyzed using density separation, vacuum filtration, and microscopic examination. Microplastic particles were characterized according to their shape and size distribution. Microplastics were detected in all samples, with abundances ranging from 513 to 587 particles/kg. Fragments were the predominant particle type. Most particles were within the 50–300 µm size range, indicating that small-sized microplastics constituted a substantial proportion of the contamination. Based on average salt consumption rates, consumers may have been continuously exposed to microplastics through their daily consumption of salt. The presence of microplastics in all analyzed samples indicated that contamination could have occurred throughout the production and distribution chain of commercial salt. These findings contributed to the growing body of evidence regarding microplastic contamination in edible salt and highlighted the importance of routine monitoring and improved plastic waste management in coastal environments to reduce contamination of food products.

KEYWORDS: Microplastics; table salt; fine salt; coarse salt; sungsang village

1. Introduction

Plastic pollution has become one of the most pervasive environmental issues worldwide. Global plastic production has exceeded 400 million tonnes in recent years and is expected to continue increasing due to expanding industrial and consumer demand [1, 2]. Inadequate waste management, particularly in rapidly developing coastal regions, facilitates the release of large quantities of plastic debris into aquatic environments. Once introduced into the environment, larger plastic materials undergo fragmentation through physical, chemical, and biological weathering processes, producing microplastics, generally defined as plastic particles smaller than 5 mm [3, 4]. These particles are now widely distributed across marine, freshwater, terrestrial, and atmospheric systems [5–13], highlighting the global scale of microplastic contamination [14, 15].

Marine ecosystems are recognised as major sinks and transport pathways for microplastics. Rivers, urban runoff, wastewater discharge, fisheries activities, maritime transportation, and coastal tourism continuously introduce plastic debris into coastal waters [5, 16]. Following their entry into marine environments, microplastics are transported by ocean currents, tides, and wind-driven circulation, while processes such as biofouling and sedimentation influence their environmental fate and distribution [17]. Consequently, microplastics have been detected in seawater, sediments, mangrove ecosystems, coral reefs, and a wide range of marine organisms, including fish, molluscs, crustaceans, and plankton [18–20]. Their widespread occurrence throughout marine food webs has raised concerns regarding ecological impacts and potential human exposure through seafood consumption.

In recent years, attention has increasingly shifted from aquatic organisms to marine-derived food products that are consumed directly by humans. Among these products, edible salt has emerged as an important indicator of microplastic contamination because it is produced from seawater and consumed regularly across all demographic groups. During the evaporation and crystallisation process, suspended particles present in seawater, including microplastics, may become trapped within salt crystals and remain in the final product [21]. Unlike seafood, which may undergo extensive processing and exhibit variable consumption patterns, salt is a daily dietary component, making it a potentially continuous source of microplastic exposure.

Microplastic contamination in commercial salt has been reported globally, including in countries across Asia, Europe, North America, and South America. Previous studies have reported concentrations ranging from a few particles to several thousand particles per kilogram, reflecting differences in environmental conditions, production methods, analytical protocols, and contamination sources [22–28]. Fragments and fibres are generally the predominant particle morphologies [26, 28–31], although films, foams, and pellets have also been reported in some studies [24, 32]. Variations in particle morphology and size distribution can provide valuable information regarding pollution sources, environmental weathering processes, and transport pathways, making characterisation studies essential for understanding contamination dynamics.

The occurrence of microplastics in food products has prompted growing interest in their potential implications for human health. Current evidence suggests that microplastics may interact with biological systems through physical and chemical mechanisms, including the induction of oxidative stress, inflammatory responses, and disruption of cellular functions under experimental conditions [33, 34]. Furthermore, microplastics can adsorb and transport environmental contaminants, such as persistent organic pollutants, trace metals, and microbial communities, potentially influencing their bioavailability [35, 36]. Although the health consequences associated with long-term dietary exposure remain insufficiently understood, the continuous detection of microplastics in commonly consumed foods highlights the need for further assessment of exposure pathways and contamination sources.

Indonesia is particularly relevant in the context of marine plastic pollution due to its extensive coastline, large coastal population, and dependence on marine resources. Previous studies have identified substantial microplastic contamination in Indonesian coastal waters, estuaries, sediments, fish, shellfish, and other seafood commodities [6–8, 10, 37]. Nevertheless, information regarding microplastic contamination in edible salt remains limited and geographically fragmented. Existing investigations have primarily focused on a small number of production centres, leaving many coastal regions unexplored despite their ecological and economic significance.

One such region is Sungsang Village, located in Banyuasin Regency, South Sumatra. The area represents an important coastal hub characterised by intensive fisheries activities, maritime transportation, estuarine influences from the Musi River system, and increasing anthropogenic pressures. These factors may contribute to the introduction and accumulation of plastic debris in surrounding coastal waters, potentially affecting locally produced and marketed marine-derived products. However, data concerning the occurrence and characteristics of microplastics in edible salt marketed in this region are currently unavailable.

Therefore, this study aimed to quantify the abundance of microplastics in commercially marketed edible salt from the coastal region of South Sumatra, Indonesia, and to characterise the particles based on their morphology and size distribution. By addressing an important geographical knowledge gap, this study provides baseline information for evaluating contamination patterns in marine-derived food products and contributes to ongoing efforts to understand potential dietary exposure to microplastics in Indonesian coastal communities.

2. Materials and Methods

2.1. Study area.

This study was conducted in Sungsang Village, Banyuasin Regency, South Sumatra, Indonesia, a coastal settlement located within the estuarine system of the Musi River. The area is characterised by intensive fisheries activities, dense coastal settlements, and maritime transportation, all of which may contribute to plastic inputs into the surrounding aquatic environment. Estuarine systems are recognised as important accumulation zones for microplastics due to continuous riverine inputs and complex hydrodynamic processes that facilitate particle retention and transport [38, 39]. Therefore, Sungsang Village represents a suitable location for investigating microplastic contamination in marine-derived food products, including edible salt. Sampling was conducted in August 2024.

2.2. Materials.

Two commercially available edible salt brands commonly consumed in Sungsang Village were selected for analysis. Salt samples were purchased from local retailers and included both fine-grain and coarse-grain products. Laboratory analyses were conducted using ultrapure water, glass beakers, erlenmeyer flasks, vacuum filtration equipment, nylon sieves, cellulose nitrate membrane filters (0.45 µm pore size), aluminium foil, and sterile glass petri dishes. Microplastic observation and characterization were performed using an stereomicroscope (Olympus SZ61). To minimise contamination, laboratory personnel wore cotton laboratory coats, nitrile gloves, and face masks throughout all analytical procedures. All glassware and equipment were thoroughly rinsed with ultrapure water before use.

2.3. Sampling procedure.

2.3.1. Field sampling.

Two commercial salt brands frequently purchased by local residents were selected based on preliminary interviews with consumers and retailers. For each brand, ten packages (250 g per package) were obtained from different retail outlets to ensure representative sampling. All samples were individually wrapped in aluminium foil, labelled, and transported to the laboratory in sealed containers to minimise contamination during handling and storage.

2.3.2. Microplastic extraction and identification.

Microplastic extraction was performed using a modified dissolution and vacuum filtration method adapted from previous studies on edible salt contamination [40–42]. For each replicate, 50 g of salt was dissolved in 200 mL of ultrapure water following modified procedures reported for microplastic extraction from edible salt. The suspension was gently heated (50°C) and stirred (300 rpm) for 30 min to ensure complete dissolution of salt crystals and facilitate the release of entrapped particles. The solution was subsequently allowed to settle at room temperature for 24 h prior to vacuum filtration. The supernatant was subsequently filtered under vacuum through a series of nylon sieves and cellulose nitrate membrane filters corresponding to particle-size fractions of 50–100 μm, 101–300 μm, 301–500 μm, 500-1000 μm, 1001–2000 μm, and > 1000 μm. After filtration, the membranes were transferred to covered glass petri dishes and air-dried prior to microscopic examination. Potential microplastic particles were identified under an optical microscope based on commonly accepted visual criteria, including particle shape, homogeneity, absence of cellular structures, and resistance to fragmentation when manipulated [42]. Particles were classified into four morphological categories: fragments, fibres, films, and pellets. To improve identification reliability, a hot needle test was performed on microplastic particles larger than approximately 50 μm, as these particles could be reliably isolated and handled under the stereomicroscope. A heated stainless-steel needle was gently touched to the particle surface, and any visible melting, curling, or deformation was considered evidence of plastic material [43, 44].

2.3.3. Quality assurance and quality control (QA/QC).

QA/QC procedures were implemented throughout the study following established guidelines for microplastic analysis [9, 10]. Sample preparation and filtration were carried out in a clean laboratory, and work surfaces, equipment, and glassware were cleaned and covered with aluminium foil when not in use. The use of plastic materials was minimized whenever possible. Procedural blanks consisting of sterile filter paper were processed alongside the samples to monitor contamination during laboratory procedures. Additional sterile filter paper was exposed during sample preparation and microscopic examination to assess airborne contamination. No suspected microplastic particles were detected in any blank samples, resulting in a mean blank value of 0 particles per blank.

2.4 Data analysis.

Microplastic abundance was expressed as particles per kilogram of salt (particles/kg) [27, 28]:

$$Microplastic\ abundance = \frac{N}{m}$$

where N represents the total number of microplastic particles detected and m is the mass of salt analysed (kg).

Microplastics were further characterised according to morphology and size distribution. Morphological categories included fragments, fibres, films, and pellets. Particle size was classified into 50–100 µm, 101–300 µm, 301–500 µm, 500-1000 µm, 1001–2000 µm, and > 1000 µm. The proportion of each category was expressed as a percentage of the total number of particles detected. Potential dietary exposure was estimated using the Estimated Daily Intake (EDI) equation [45]:

$$EDI = \frac{C\ x\ IR}{BW}$$

where C is the microplastic concentration in salt (particles kg^{-1}), IR is the daily salt intake rate (5 g day^{-1} for adults and 10 g day^{-1} for children), and BW is body weight (58,8 kg for adults and 15 kg for children).

Descriptive statistics were used to summarise microplastic abundance, morphology, and size distribution. Results are presented as mean ± standard deviation, and graphical visualisations were generated to illustrate distribution patterns among particle categories. Statistical comparisons were performed to evaluate differences in microplastic abundance between salt brands and grain sizes (fine-grain and coarse-grain). Prior to analysis, data normality and homogeneity of variance were assessed using the Shapiro–Wilk and Levene's tests, respectively. Depending on data distribution, differences among groups were analysed using an independent samples t-test or the non-parametric Mann–Whitney U test. Statistical significance was determined at $p < 0.05$. All statistical analyses were conducted using appropriate statistical software.

3. Results and Discussion

3.1. Result.

3.1.1. Microplastic abundance in commercial salt.

Microplastics were detected in all salt samples analysed, indicating widespread contamination in commercially marketed edible salt from Sungsang Village. As shown in Figure 2, microplastic abundance varied among salt types and brands. Coarse salt from Brand A exhibited the highest median abundance (246.67 ± 40 particles/kg), whereas coarse salt from Brand B showed the lowest median abundance (171.11 ± 92 articles/kg) Fine salt samples from both brands displayed comparable microplastic abundances, ranging from approximately 193.33 to 246.67 articles/kg. In addition, variability in microplastic abundance differed among sample groups, although the overall distribution patterns remained broadly comparable between the two brands.

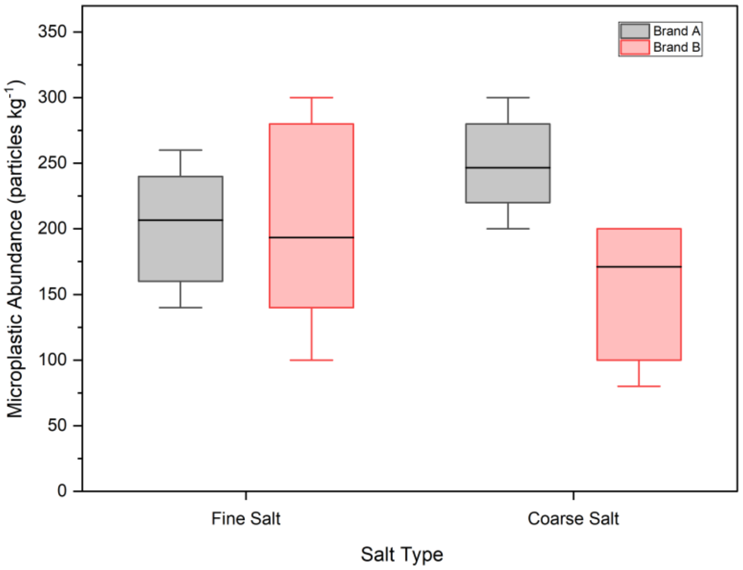

Figure 2. Microplastic abundance (particles/kg) in fine and coarse salt sold at Sungsang Village, South Sumatra, Indonesia.

3.1.2. Morphological characteristics of microplastics.

The morphological composition of microplastics was similar between the two salt brands (Figure 3). Fragments were the dominant particle typein both brand, accounting for 82.1% of total microplastics in fine salt and 83.6% in coarse salt. Fibres represented the second most abundant category, and films and pellets occurred at lower proportions, respectively. The predominance of fragments suggests that secondary microplastics derived from the degradation of larger plastic items are the main source of contamination in the analysed salt samples. The relatively low proportions of fibres, films, and pellets indicate that multiple contamination pathways may be involved, although their contribution was substantially lower than that of fragmented particles.

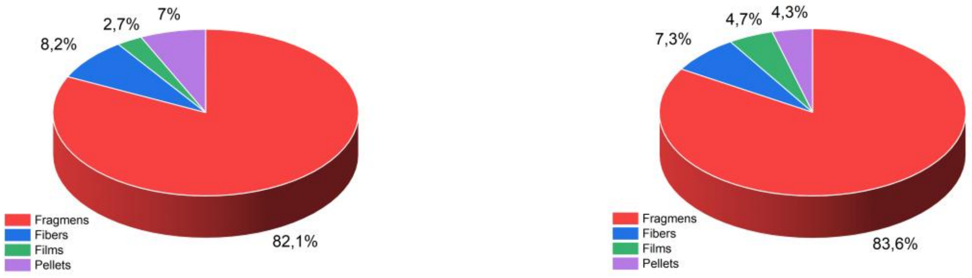

Figure 3. Shape composition (%) of microplastics detected in fine salt (left) and coarse salt (right) marketed in Sungsang Village, South Sumatra, Indonesia

3.1.3. Size distribution of microplastic particles.

The size distribution of microplastics varied among salt types and brands; however, particles within the 50–100 µm size class were consistently the most abundant across all samples (Figure 4). This fraction showed the highest median abundance in both fine and coarse salts, particularly in coarse salt from Brand A. In contrast, the abundance of larger particles generally decreased with increasing size, with particles >1000 µm representing the least abundant size class in most samples. Intermediate size classes (101–300 µm and 301–500 µm) were present at moderate levels, whereas particles between 501 and 1000 µm occurred less frequently.

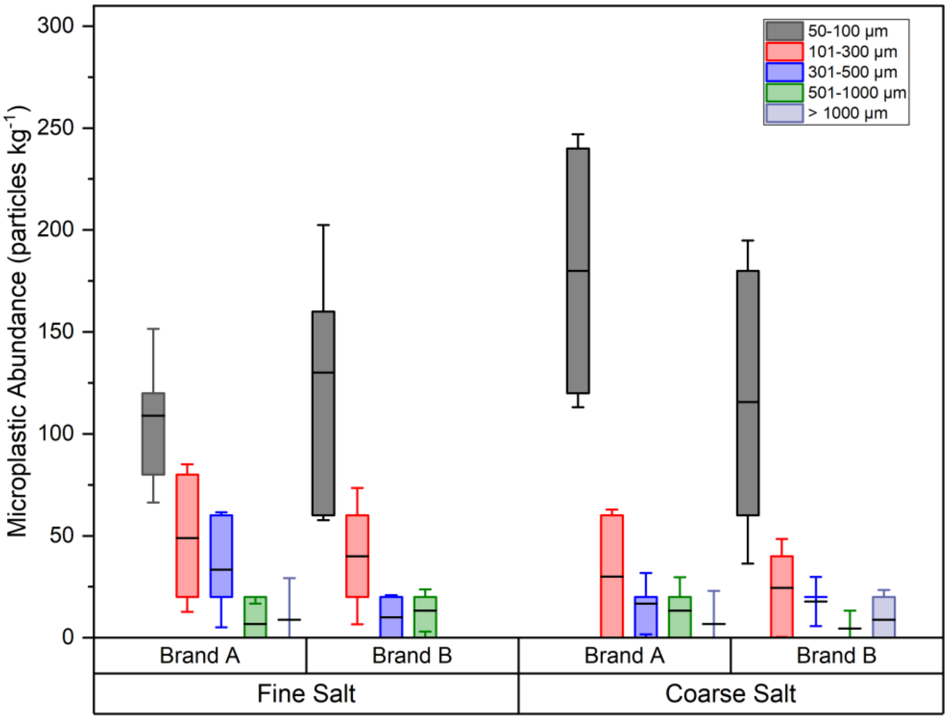

Figure 4. The percentage of microplastic range sizes in salt products selling in Sungsang Village, South Sumatra, Indonesia.

The predominance of smaller microplastics suggests extensive fragmentation of larger plastic debris before incorporation into the salt production system. The lower abundance of larger particles may reflect ongoing weathering and fragmentation processes that progressively generate smaller plastic particles. The normality test indicated that the abundance of microplastic based on size data were normally distributed ($p = 0.17$), allowing further analysis using one-way ANOVA. The ANOVA results showed no significant differences in microplastic size distribution between the two salt brands ($p = 0.37$). This finding suggests that the size composition of microplastics was relatively similar across the analysed products, despite differences in their overall abundance.

3.1.4. Polymer verification.

The hot needle test confirmed the plastic nature of all suspected particles larger than 100 µm. In contrast, only 13% of particles within the 50–100 µm size class could be verified because particles in this size range were too small for reliable hot needle testing. Consequently, identification of most particles in this size class relied on established morphological criteria.

These findings highlight the practical limitations of the hot needle test for small microplastics and indicate that verification reliability generally decreases as particle size becomes smaller. Nevertheless, the method provided useful confirmation for larger particles and supported the visual identification process.

3.1.5. Estimated dietary intake of microplastics.

The estimated dietary intake (EDI) of microplastics through salt consumption was higher in children than in adults across all salt types and brands (Figure 5). In addition, Brand A showed consistently higher EDI values than Brand B, reflecting the higher microplastic abundance detected in its salt products. Similar trends were observed for both fine and coarse salts. The higher EDI in children is primarily associated with their lower body weight, resulting in greater exposure relative to body mass. These findings suggest that children may be more vulnerable to microplastic intake through dietary salt consumption, particularly when consuming products with higher contamination levels.

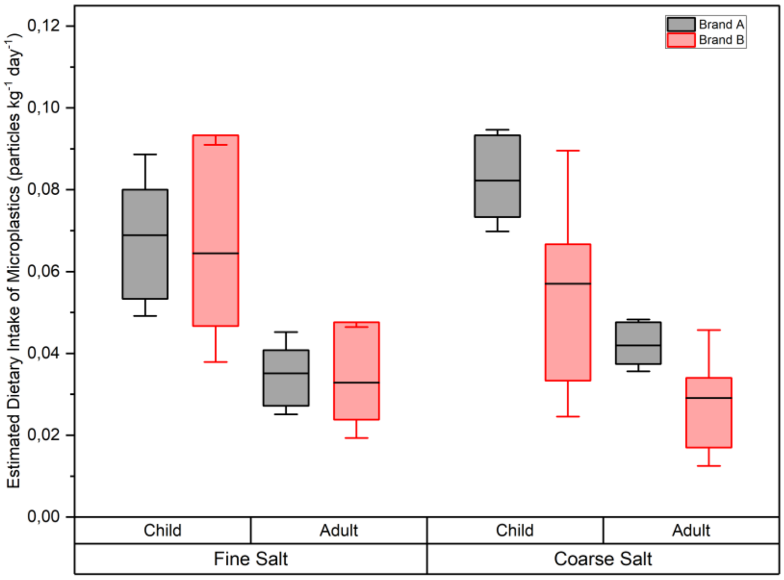

Figure 5. Estimated dietary intake of microplastics (pareticles/kg/day) in salt samples from Sungsang Village, South Sumatra, Indonesia.

3.2. Discussion.

Microplastics were detected in all analysed salt samples, indicating that contamination is consistently present in commercially marketed edible salt available in Sungsang Village. The observed abundances are within the range reported for commercial sea salts accros Indonesia [27], like West Nusa Tenggara, Bali, South Sulawesi, and Java [26, 28, 46]. Also similar within report in the worldwide, where concentrations typically vary from tens to several hundred particles per kilogram depending on environmental conditions, salt sources, and analytical methods [22, 25, 40, 47]. The relatively similar contamination levels among brands suggest that microplastic occurrence may be associated with common production pathways rather than brand-specific factors. The salt brands examined in this study are nationally distributed products that originate from the same production systems and are packaged at the factory before distribution. Therefore, contamination introduced during transportation, storage, or retail handling is likely limited. This suggests that a substantial proportion of the detected microplastics may have originated during earlier stages of production, particularly from the seawater used as raw material and the salt crystallisation process. Previous studies have demonstrated that microplastics present in seawater can persist through evaporation and become incorporated into salt crystals during production [21, 22, 48]. Similarly, [49] reported microplastic contamination throughout the salt production chain in Indonesia, from intake waters and evaporation ponds to final salt products.

Although the analysed products were not produced in Sungsang Village, local environmental conditions provide an important context for understanding potential contamination pathways in Indonesian coastal environments. Sungsang is located within the estuarine region of the Musi River, which receives inputs from urban areas, industrial activities, ports, fisheries, agriculture, and densely populated settlements. Estuaries are recognised as effective accumulation zones for microplastics because river-borne particles are retained and redistributed through tidal mixing, sedimentation, and resuspension processes [39]. Similar environmental pressures are present in many Indonesian coastal regions where commercial sea salt is produced, suggesting that contamination of source waters remains a plausible explanation for the widespread occurrence of microplastics in marketed salt products.

Differences between fine and coarse salts were relatively small, although coarse salt tended to contain slightly higher microplastic abundances, particularly in Brand A. This pattern may be related to differences in processing intensity. Fine salt typically undergoes additional processing steps, including grinding, drying, sieving, and packaging, which may increase opportunities for contamination from processing equipment, packaging materials, and airborne microplastics. Atmospheric deposition has also been recognised as an important source of microplastic contamination during post-production handling and storage. Consequently, differences in processing intensity may contribute to variations in microplastic abundance between salt products. These factors may partially explain the slightly higher microplastic abundance observed in fine salt, although differences in source-water quality and production practices are also likely to influence contamination levels.

Morphological analysis further elucidates the sources and environmental pathways of contamination. Fragment-shaped particles overwhelmingly dominated the microplastic assemblage, accounting for approximately 83% of all detected particles. This dominance is consistent with global observations and reflects the secondary fragmentation of macroplastics driven by prolonged exposure to ultraviolet radiation, thermal stress, and mechanical abrasion in coastal and estuarine environments. Domestic waste, food packaging materials, and degraded fishing gear likely represent major contributors to this fragment-dominated profile, particularly in densely populated and fisheries-intensive coastal regions such as Sungsang Village. In contrast, fibrous microplastics, which comprised approximately 8% of total particles, are commonly associated with textile-derived emissions, fishing nets, ropes, and atmospheric fallout [9, 50, 51]. Recent studies have demonstrated that atmospheric microplastics significantly contribute to contamination in both marine waters and open salt evaporation ponds, especially in areas subject to strong winds and intensive anthropogenic activities [52]. The detection of pellets and films, although less abundant, further suggests contributions from industrial plastic resin loss, cosmetic microbeads, and degraded plastic packaging, indicating a complex mixture of pollution sources influencing salt contamination pathways.

In addition to morphology, microplastic particles exhibited a broad size distribution, with a pronounced dominance of particles in the 50–100 µm range, consistent with previous investigations of edible salt and marine environmental matrices [40,52]. Fine-sized microplastics are capable of penetrating biological membranes, accumulating in tissues, and translocating to secondary organs, where they may induce oxidative stress, inflammatory responses, and endocrine disruption [53, 54]. Moreover, their elevated surface-area-to-volume ratios facilitate the adsorption of hazardous contaminants, including heavy metals, persistent organic pollutants, and pathogenic microorganisms, thereby amplifying their toxicological significance [36]. Consequently, the dominance of fine microplastics in edible salt underscores the potential long-term health implications associated with chronic dietary exposure, particularly among vulnerable populations.

Polymer verification using the hot needle test confirmed plastic characteristics, reinforcing the reliability of morphological identification while minimizing false-positive classification. Although spectroscopic techniques such as FTIR or Raman spectroscopy provide higher analytical resolution, the hot needle test remains a widely accepted rapid screening approach for microplastic verification, particularly in resource-limited settings. Previous studies have demonstrated strong concordance between hot needle testing and spectroscopic methods for common consumer polymers, including polyethylene (PE), polypropylene (PP), and polyethylene terephthalate (PET), which dominate both plastic production and marine debris profiles [55, 56]. The conservative verification strategy adopted in this study therefore enhances analytical robustness and ensures that reported concentrations accurately reflect true polymeric contamination. However, that polymer identification was not confirmed using spectroscopic techniques such as FTIR or Raman spectroscopy become a limitation of this study, due to funding and analytical constraints. Future studies should incorporate spectroscopic analyses to confirm polymer composition and improve the accuracy of microplastic characterization.

The Estimated Dietary Intake (EDI) of microplastics was consistently higher in children than in adults across all salt types and brands. Dietary and inhalation exposure to nano- and microplastic particles and potential implications for human health. In addition, Brand A showed higher EDI values than Brand B, reflecting the higher microplastic abundance detected in the corresponding salt samples. Although EDI values varied among products, the differences generally followed the contamination levels observed in the salt samples, indicating that microplastic concentration is a key factor influencing dietary exposure. The relatively similar EDI values between fine and coarse salts further suggest that both products can contribute to microplastic intake when contamination is present. These findings are consistent with previous studies identifying edible salt as a continuous, although relatively minor, pathway of human exposure to microplastics compared with other dietary sources

4. Conclusions

Microplastics were detected in all analysed salt samples, indicating widespread contamination in commercially marketed edible salt from Sungsang Village. Fragments were the dominant particle type, accounting for more than 80% of total particles, while the 50–100 µm size class was the most abundant across all samples. Microplastic abundance and size distribution were generally similar between salt brands and grain types. Estimated dietary intake (EDI) was higher in children than in adults and reflected the microplastic concentrations detected in the salt products. These findings indicate that edible salt represents a continuous pathway of microplastic exposure and highlight the importance of monitoring marine-derived food products and improving plastic waste management in coastal environments.

Acknowledgments

The authors gratefully acknowledge Jeni Meiyerani for her valuable assistance throughout the research process. We also extend our sincere thanks to Nazarudin, Ali, Rasyid, and Reza for their technical support and contributions during field sampling and laboratory analyses. Additionally, we sincerely appreciate the constructive comments and insightful suggestions provided by the reviewers, which significantly improved the quality and clarity of this manuscript.

Author Contribution

Anna Ida Sunaryo Purwiyanto: Conceptualization, Methodology, Data Collection, Data Analysis, Writing – original draft, Writing – review & editing, Supervision, Funding. Rizky Herman Saputra: Data Collection, Data Analysis, Writing – original draft, Writing – review & editing. Wike Ayu Eka Putri: Data Collection, Data Analysis, Writing – original draft, Supervision. Rozirwan: Data Analysis, Writing – review & editing. Melki: Data Collection, Writing – review & editing.

Competing Interest

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

References

[1] OECD (Organisation for Economic Co-operation and Development). (2022). Global Plastics Outlook; OECD Publishing: Paris, France. https://doi.org/10.1787/de747aef-en.

[2] Geyer, R.; Jambeck, J.R.; Law, K.L. (2017). Production, Use, and Fate of All Plastics Ever Made. *Science Advances*, *3*, e1700782. https://doi.org/10.1126/sciadv.1700782.

[3] Hartmann, N.B.; Hüffer, T.; Thompson, R.C.; Hassellöv, M.; Verschoor, A.; Daugaard, A.E.; et al. (2019). Are We Speaking the Same Language? Recommendations for a Definition and Categorization Framework for Plastic Debris. *Environmental Science & Technology*, *53*, 1039–1047. https://doi.org/10.1021/acs.est.8b05297.

[4] UNEP (United Nations Environment Programme). (2021). From Pollution to Solution: A Global Assessment of Marine Litter and Plastic Pollution; United Nations Environment Programme: Nairobi, Kenya.

[5] Suteja, Y.; Purwiyanto, A.I.S. (2022). The Role of Rivers in Microplastics Spread and Pollution. In: Microplastics Pollution in Aquatic Media; Environmental Footprints and Eco-Design of Products and Processes; Springer: Singapore, Singapore; pp. 65–88. https://doi.org/10.1007/978-981-16-8440-1_4.

[6] Cordova, M.R.; Purwiyanto, A.I.S.; Suteja, Y. (2019). Abundance and Characteristics of Microplastics in the Northern Coastal Waters of Surabaya, Indonesia. *Marine Pollution Bulletin*, *142*, 183–188. https://doi.org/10.1016/j.marpolbul.2019.03.040.

[7] Takarina, N.D.; Purwiyanto, A.I.S.; Rasud, A.A.; Arifin, A.A.; Suteja, Y. (2022). Microplastic Abundance and Distribution in Surface Water and Sediment Collected from the Coastal Area.

Global Journal of Environmental Science and Management, *8*, 183–196. https://doi.org/10.22034/gjesm.2022.02.03.

[8] Purwiyanto, A.I.S.; Putri, W.A.E.; Melki, M.; Barus, B.S.; Suteja, Y. (2025). Persebaran Mikroplastik di Lintas Ekosistem Sumatera Selatan. *Buletin Oseanografi Marina*, *14*.

[9] Purwiyanto, A.I.S.; Prartono, T.; Riani, E.; Naulita, Y.; Cordova, M.R.; Koropitan, A.F. (2022). The Deposition of Atmospheric Microplastics in Jakarta, Indonesia: The Coastal Urban Area. *Marine Pollution Bulletin*, *174*, 113195. https://doi.org/10.1016/j.marpolbul.2021.113195.

[10] Purwiyanto, A.I.S.; Prartono, T.; Riani, E.; Koropitan, A.F.; Naulita, Y.; Takarina, N.D.; et al. (2022). The Contribution of Estuaries to the Abundance of Microplastics in Jakarta Bay, Indonesia. *Marine Pollution Bulletin*, *184*, 114117. https://doi.org/10.1016/j.marpolbul.2022.114117.

[11] Liss, P.S. (2020). Microplastics: All Up in the Air? *Marine Pollution Bulletin*, *153*, 110952. https://doi.org/10.1016/j.marpolbul.2020.110952.

[12] Zhang, Y.; Kang, S.; Allen, S.; Allen, D.; Gao, T.; Sillanpää, M. (2020). Atmospheric Microplastics: A Review on Current Status and Perspectives. *Earth-Science Reviews*, *203*, 103118. https://doi.org/10.1016/j.earscirev.2020.103118.

[13] Allen, S.; Allen, D.; Phoenix, V.R.; Le Roux, G.; Jiménez, P.D.; Simonneau, A.; et al. (2019). Atmospheric Transport and Deposition of Microplastics in a Remote Mountain Catchment. *Nature Geoscience*, *12*, 339–344. https://doi.org/10.1038/s41561-019-0335-5.

[14] Borrelle, S.B.; Ringma, J.; Law, K.L.; Monnahan, C.C.; Lebreton, L.; McGivern, A.; et al. (2020). Predicted Growth in Plastic Waste Exceeds Efforts to Mitigate Plastic Pollution. *Science*, *369*, 1515–1518. https://doi.org/10.1126/SCIENCE.ABA3656.

[15] Hoellein, T.J.; Rochman, C.M. (2021). The Plastic Cycle: A Watershed-Scale Model of Plastic Pools and Fluxes. *Frontiers in Ecology and the Environment*, *19*, 176–183. https://doi.org/10.1002/fee.2294.

[16] Meijer, L.J.J.; van Emmerik, T.; van der Ent, R.; Schmidt, C.; Lebreton, L. (2021). More Than 1000 Rivers Account for 80% of Global Riverine Plastic Emissions into the Ocean. *Science Advances*, *7*, eaaz5803. https://doi.org/10.1126/sciadv.aaz5803.

[17] Kane, I.A.; Clare, M.A. (2019). Dispersion, Accumulation, and the Ultimate Fate of Microplastics in Deep-Marine Environments: A Review and Future Directions. *Frontiers in Earth Science*, *7*, 80. https://doi.org/10.3389/feart.2019.00080.

[18] Alberghini, L.; Truant, A.; Santonicola, S.; Colavita, G.; Giaccone, V. (2023). Microplastics in Fish and Fishery Products and Risks for Human Health: A Review. *International Journal of Environmental Research and Public Health*, *20*, 789. https://doi.org/10.3390/ijerph20010789.

[19] Cañón-Bastidas, J.; Molina, A.; Duque, G. (2025). Impact of Microplastic Ingestion on Commercial Fish: A Trophic-Level Analysis. *International Journal of Environment Research*, *19*. https://doi.org/10.1007/s41742-025-00798-4.

[20] Bonanno, G. (2022). Fate, Transport, and Impact of Microplastics on Planktonic Organisms. In: Bonanno, G.; Orlando-Bonaca, M. (Eds.), Plastic Pollution and Marine Conservation; Academic Press: London, UK; pp. 75–94. https://doi.org/10.1016/B978-0-12-822471-7.00009-2.

[21] Cledera-Castro, M.M.; Hueso-Kortekaas, K.; Sanchez-Mata, C.; Morales-Polo, C.; Calzada-Funes, J.; Delgado-Mellado, N.; et al. (2024). An Exploratory Study of Fibre Microplastics Pollution in Different Process Stages of Salt Production by Solar Evaporation in Spain. *Heliyon*, *10*, e31609. https://doi.org/10.1016/j.heliyon.2024.e31609.

[22] Vidyasakar, A.; Krishnakumar, S.; Kumar, K.S.; Neelavannan, K.; Anbalagan, S.; Kasilingam, K.; et al. (2021). Microplastic Contamination in Edible Sea Salt from the Largest Salt-Producing States of India. *Marine Pollution Bulletin*, *171*, 112728. https://doi.org/10.1016/j.marpolbul.2021.112728.

[23] Kapukotuwa, R.W.M.G.K.; Jayasena, N.; Weerakoon, K.C.; Abayasekara, C.L.; Rajakaruna, R.S. (2022). High Levels of Microplastics in Commercial Salt and Industrial Salterns in Sri Lanka. *Marine Pollution Bulletin*, *174*, 113239. https://doi.org/10.1016/j.marpolbul.2021.113239.

[24] Soares, A.S.; Pinheiro, C.; Oliveira, U.; Natividade Vieira, M. (2021). Microplastic Pollution in Portuguese Saltworks. In: Inland Waters – Dynamics and Ecology. https://doi.org/10.5772/intechopen.91476.

[25] Özçifçi, Z.; Basaran, B.; Akçay, H.T. (2023). Microplastic Contamination and Risk Assessment in Table Salts: Turkey. *Food and Chemical Toxicology*, *175*, 113698. https://doi.org/10.1016/j.fct.2023.113698.

[26] Amqam, H.; Natsir, M.F.; Yusriani, Z.F. (2024). Microplastic Contamination in Indonesian Consumable Salts. *Journal of Sea Research*, *198*, 102475. https://doi.org/10.1016/j.seares.2024.102475.

[27] Suteja, Y.; Purnama, S.G.; Suhaemi.; Hartati, R.; Toruan, L.N.L.; Widianingsih, W.; et al. (2026). Microplastics Footprint in Indonesian Edible Salt: A Comparative Study Across Western, Central, and Eastern Regions. *Science of the Total Environment*, *1030*, 181783. https://doi.org/10.1016/J.SCITOTENV.2026.181783.

[28] Suteja, Y.; Dirgayusa, I.G.N.P.; Purnama, S.G.; Purwiyanto, A.I.S. (2025). From Sea to Table: Assessing Microplastic Contamination in Local and Non-Local Salt in Bali, Indonesia. *Chemosphere*, *374*, 144192. https://doi.org/10.1016/j.chemosphere.2025.144192.

[29] Fadare, O.O.; Okoffo, E.D.; Olasehinde, E.F. (2021). Microparticles and Microplastics Contamination in African Table Salts. *Marine Pollution Bulletin*, *164*, 112006. https://doi.org/10.1016/j.marpolbul.2021.112006.

[30] Karami, A.; Golieskardi, A.; Keong Choo, C.; Larat, V.; Galloway, T.S.; Salamatinia, B. (2017). The Presence of Microplastics in Commercial Salts from Different Countries. *Scientific Reports*, *7*, 46173. https://doi.org/10.1038/srep46173.

[31] Kosuth, M.; Mason, S.A.; Wattenberg, E.V. (2018). Anthropogenic Contamination of Tap Water, Beer, and Sea Salt. *PLoS ONE*, *13*, e0194970. https://doi.org/10.1371/journal.pone.0194970.

[32] Dang, T. (2021). Microplastic Contamination in Commercial Sea Salt of Vietnam. *Vietnam Journal of Science and Technology*, *59*, 333–347. https://doi.org/10.15625/2525-2518/59/3/15718.

[33] Panizzolo, M.; Martins, V.H.; Ghelli, F.; Squillacioti, G.; Bellisario, V.; Garzaro, G.; et al. (2023). Biomarkers of Oxidative Stress, Inflammation, and Genotoxicity to Assess Exposure to Micro- and Nanoplastics: A Literature Review. *Ecotoxicology and Environmental Safety*, *267*, 115645. https://doi.org/10.1016/j.ecoenv.2023.115645.

[34] Hu, M.; Palić, D. (2020). Micro- and Nano-Plastics Activation of Oxidative and Inflammatory Adverse Outcome Pathways. *Redox Biology*, *37*, 101620. https://doi.org/10.1016/j.redox.2020.101620.

[35] Tumwesigye, E.; Felicitas Nnadozie, C.; Akamagwuna, F.C.; Siwe Noundou, X.; William Nyakairu, G.; Odume, O.N. (2023). Microplastics as Vectors of Chemical Contaminants and Biological Agents in Freshwater Ecosystems: Current Knowledge Status and Future Perspectives. *Environmental Pollution*, *330*, 121829. https://doi.org/10.1016/j.envpol.2023.121829.

[36] Purwiyanto, A.I.S.; Suteja, Y.; Trisno.; Ningrum, P.S.; Putri, W.A.E.; Rozirwan.; et al. (2020). Concentration and Adsorption of Pb and Cu in Microplastics: Case Study in Aquatic Environment. *Marine Pollution Bulletin*, *158*, 111380. https://doi.org/10.1016/j.marpolbul.2020.111380.

[37] Suteja, Y.; Atmadipoera, A.S.; Riani, E.; Nurjaya, I.W.; Nugroho, D.; Cordova, M.R. (2021). Spatial and Temporal Distribution of Microplastic in Surface Water of Tropical Estuary: Case Study in Benoa Bay, Bali, Indonesia. *Marine Pollution Bulletin*, *163*, 111979. https://doi.org/10.1016/j.marpolbul.2021.111979.

[38] Wang, T.; Zhao, S.; Zhu, L.; McWilliams, J.C.; Galgani, L.; Amin, R.M.; et al. (2022). Accumulation, Transformation and Transport of Microplastics in Estuarine Fronts. *Nature Reviews Earth & Environment*, *3*, 842–859. https://doi.org/10.1038/s43017-022-00349-x.

[39] Malli, A.; Corella-Puertas, E.; Hajjar, C.; Boulay, A.M. (2022). Transport Mechanisms and Fate of Microplastics in Estuarine Compartments: A Review. *Marine Pollution Bulletin*, *177*, 113553. https://doi.org/10.1016/j.marpolbul.2022.113553.

[40] Kim, J.S.; Lee, H.J.; Kim, S.K.; Kim, H.J. (2018). Global Pattern of Microplastics (MPs) in Commercial Food-Grade Salts: Sea Salt as an Indicator of Seawater MP Pollution. *Environmental Science & Technology*, *52*, 12819–12828. https://doi.org/10.1021/acs.est.8b04180.

[41] Seth, C.K.; Shriwastav, A. (2018). Contamination of Indian Sea Salts with Microplastics and a Potential Prevention Strategy. *Environmental Science and Pollution Research*, *25*, 30122–30131. https://doi.org/10.1007/s11356-018-3028-5.

[42] Hidalgo-Ruz, V.; Gutow, L.; Thompson, R.C.; Thiel, M. (2012). Microplastics in the Marine Environment: A Review of the Methods Used for Identification and Quantification. *Environmental Science & Technology*, *46*, 3060–3075. https://doi.org/10.1021/es2031505.

[43] De Witte, B.; Devriese, L.; Bekaert, K.; Hoffman, S.; Vandermeersch, G.; Cooreman, K.; et al. (2014). Quality Assessment of the Blue Mussel (Mytilus edulis): Comparison Between Commercial and Wild Types. *Marine Pollution Bulletin*, *85*, 146–155. https://doi.org/10.1016/j.marpolbul.2014.06.006.

[44] Löder, M.G.J.; Gerdts, G. (2015). Methodology Used for the Detection and Identification of Microplastics—A Critical Appraisal. In: Bergmann, M.; Gutow, L.; Klages, M. (Eds.), Marine Anthropogenic Litter; Springer: Cham, Switzerland; pp. 201–227. https://doi.org/10.1007/978-3-319-16510-3_8.

[45] Kwon, J.H.; Kim, J.W.; Pham, T.D.; Tarafdar, A.; Hong, S.; Chun, S.H.; et al. (2020). Microplastics in Food: A Review on Analytical Methods and Challenges. *International Journal of Environmental Research and Public Health*, *17*, 6710. https://doi.org/10.3390/ijerph17186710.

[46] Syamsu, D.A.; Deswati, D.; Syafrizayanti, S.; Putra, A.; Suteja, Y. (2024). Presence of Microplastics Contamination in Table Salt and Estimated Exposure in Humans. *Global Journal of Environmental Science and Management*, *10*, 1–14. https://doi.org/10.22034/gjesm.2024.01.14.

[47] Yang, D.; Shi, H.; Li, L.; Li, J.; Jabeen, K.; Kolandhasamy, P. (2015). Microplastic Pollution in Table Salts from China. *Environmental Science & Technology*, *49*, 13622–13627. https://doi.org/10.1021/acs.est.5b03163.

[48] Tahir, A.; Taba, P.; Samawi, M.F.; Werorilangi, S. (2019). Microplastics in Water, Sediment and Salts from Traditional Salt-Producing Ponds. *Global Journal of Environmental Science and Management*, *5*, 431–440. https://doi.org/10.22034/gjesm.2019.04.03.

[49] Efendy, M.; Amir, N.; Nuzula, N.I.; Syaifullah, M.; Efendi, M.Y.; Gozan, M. (2025). Microplastic Contamination Along the Salt Production System: Insights from Water, Sediment, and Salt Samples. *International Journal of Environmental Science and Technology*, *22*, 1–15. https://doi.org/10.1007/s13762-025-06449-7.

[50] Andrady, A.L. (2011). Microplastics in the Marine Environment. *Marine Pollution Bulletin*, *62*, 1596–1605. https://doi.org/10.1016/j.marpolbul.2011.05.030.

[51] Dris, R.; Gasperi, J.; Saad, M.; Mirande, C.; Tassin, B. (2016). Synthetic Fibers in Atmospheric Fallout: A Source of Microplastics in the Environment? *Marine Pollution Bulletin*, *104*, 290–293. https://doi.org/10.1016/j.marpolbul.2016.01.006.

[52] Khuyen, V.T.K.; Le, D.V.; Anh, L.H.; Fischer, A.R.; Dornack, C. (2021). Investigating the Correlation of Microplastic Pollution Between Seawater and Marine Salt Using Micro-Raman Spectroscopy. *Frontiers in Marine Science*, *8*, 735975. https://doi.org/10.3389/fmars.2021.735975.

[53] Hernández, A.F.; Lacasaña, M.; Tsatsakis, A.M.; Docea, A.O. (2025). Cellular and Molecular Mechanisms of Micro- and Nanoplastics Driving Adverse Human Health Effects. *Toxics*, *13*, 921. https://doi.org/10.3390/toxics13110921.

[54] Khan, A.; Jia, Z. (2023). Recent Insights into Uptake, Toxicity, and Molecular Targets of Microplastics and Nanoplastics Relevant to Human Health Impacts. *iScience*, *26*, 106061. https://doi.org/10.1016/j.isci.2023.106061.

[55] Beckingham, B.; Apintiloaiei, A.; Moore, C.; Brandes, J. (2023). Hot or Not: Systematic Review and Laboratory Evaluation of the Hot Needle Test for Microplastic Identification. *Microplastics and Nanoplastics*, *3*, 56. https://doi.org/10.1186/s43591-023-00056-4.

[56] Imhof, H.K.; Schmid, J.; Niessner, R.; Ivleva, N.P.; Laforsch, C. (2012). A Novel, Highly Efficient Method for the Separation and Quantification of Plastic Particles in Sediments of Aquatic Environments. *Limnology and Oceanography: Methods*, *10*, 524–537. https://doi.org/10.4319/lom.2012.10.524.