Global J. Environ. Sci. Manage. 10(1): 205-224, Winter 2024, Serial #37

Global Journal of Environmental Science and Management
(GJESM)

Homepage: https://www.gjesm.net/

Podcasts

ORIGINAL RESEARCH PAPER

Presence of microplastics contamination in table salt and estimated exposure in humans

D.A. Syamsu[1,2], D. Deswati[3,*], S. Syafrizayanti[3], A. Putra[4], Y. Suteja[5]

[1] *Department of Chemistry, Faculty of Mathematics and Natural Sciences, Andalas University, Padang, Indonesia*

[2] *Indonesian Food and Drug Authority, Jambi, Indonesia*

[3] *Department of Chemistry, Faculty of Mathematics and Natural Sciences, Andalas University, Padang, Indonesia*

[4] *Department of Medical Laboratory Technology, Syedza Saintika College of Health Sciences, Padang, Indonesia*

[5] *Department of Marine Science, Faculty of Marine Science and Fisheries, Udayana University, Bali, Indonesia*

ARTICLE INFO

Article History:
Received 21 September 2023
Revised 13 August 2023
Accepted 08 June 2023

Keywords:
Contaminants
Marine debris
Marine litter
Plastics
Table salt

DOI: 10.22034/gjesm.2024.01.14

ABSTRACT

BACKGROUND AND OBJECTIVES: Microplastics are plastic fragments measuring less than 5 millimeters which are formed from degraded plastic materials and have the potential to pollute the environment. Due to their widespread presence in the marine environment, microplastics have become a significant global threat. The presence of microplastics is often considered as causing pollution in various environments, especially aquatic ecosystems such as rivers and oceans. Microplastics contamination can even be found in consumed salt, thus raising concerns about its impact on human health. However, information on the presence of microplastics in salt is still very limited. This study aims to determine the abundance and characteristics of microplastics as contaminants in salt and assess the human exposure to microplastics in Indonesia.

METHODS: A total of 21 samples of salt products were taken from various brands available in Padang City and Jambi City, Indonesia for analysis. Microplastics extraction was carried out by removing the organic materials contained in the salt samples using 30 percent hydrogen peroxide and then filtering them with a 0.45 micrometer pore filter. A stereomicroscope was used to detect the abundance, shape, size, and color of microplastics, while the Attenuated Total Reflection-Fourier Transform Infrared Spectroscopy was utilized to identify the polymer type of the microplastics. Furthermore, human exposure to microplastics can be predicted by calculating the estimated dietary intake and taking into account the daily salt intake.

FINDINGS: Microplastics were detected in significant amounts ($p<0.05$) in all salt samples, ranging from 33 to 313 particles/kilogram. The types of microplastics most commonly found in the samples were fragments (67.49 percent), fibers (23.82 percent), films (6.08 percent), and pellets (2.61 percent). The types of polymer identified include polyethylene, polypropylene, polyethylene terephthalate, and polyester. The dominant microplastics were 100-300 micrometers in size (47.3 percent) and black in color (52.88 percent). It is estimated that adults in Indonesia will be exposed to 60.225-571.225 microplastics/year if they consume 5 grams of salt/day or 120.45-1142.45 microplastics/year if they consume 10 grams of salt/day.

CONCLUSION: Of the 21 salt samples analyzed, all were detected to contain microplastics. Inadequate and unhygienic salt production and contaminated seawater used as raw material contribute to microplastics contamination of salt, thus posing a risk to human health. By calculating of daily salt intake of the Indonesian population, it is possible to estimate their daily and annual exposure to microplastics. The results of this study contain useful information for the efforts to prevent microplastics contamination by relevant stakeholders and the provision of education and socialization about the proper salt production process in accordance with food safety standards as to reduce or even eliminate microplastics in salt. In addition, this study can provide valuable data on human exposure to microplastics in salt products that can assist policymakers in making standard references for microplastics.

This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
79	7	3

*Corresponding Author:
Email: *deswati@sci.unand.ac.id*
Phone: +6285 2639 09573
ORCID: 0000-0002-8655-9838

Note: Discussion period for this manuscript open until April 1, 2024 on GJESM website at the "Show Article".

INTRODUCTION

Owing to their convenient manufacturing and utilization properties, the demand for plastics has experienced a substantial surge across various sectors, which ultimately leads to a notable escalation in the quantity of plastic waste. Plastic waste is estimated to account for 60-80 percent (%) of all marine debris and even reaches 90-95% in some regions (Moore, 2008; Qiu *et al*., 2016; Wang *et al*., 2016). Every year, 9-23 million tons of plastics are dumped into rivers, lakes, and oceans throughout the world (Borrelle *et al.,* 2020). This number is expected to increase to 155-265 million tons by 2060 (Lebreton and Andrady, 2019). Plastic waste entering the oceans has become a global concern because of its negative impact on marine and coastal ecosystems (Sabilillah *et al*., 2023). Shorelines, seafloors, and surface waterways have all been contaminated by decades of plastic waste dumping into seas and rivers (Selvam *et al*., 2020). Plastic waste contains microplastics (MPs), plastic particles of less than 5 millimeters (mm) that are considered global environmental pollutants. With their small size, microplastics are persistent in the environment, thus having the potential to produce harmful effects if they enter animal cells (Barboza *et al*., 2018; Cole *et al*., 2014). Microplastics enter the environment in two different ways. Primary microplastics are tiny particles produced during industrial processes and then utilized in a wide variety of consumer goods, including face cleansers and cosmetics containing microbeads (Napper *et al*., 2015). Meanwhile, secondary microplastics are formed when larger pieces of plastics degrade in the environment (by means of biological, photo, or mechanical degradation) (Andrady, 2011). The ability of microplastics to permeate the food chain and accumulate at elevated trophic levels is attributed to their hydrophobic properties, which facilitate the efficient absorption of persistent organic pollutants (POPs) and inorganic substances onto their surfaces (Buwono *et al*., 2022; Jung *et al*., 2022; Mamun *et al*., 2023). According to Jambeck *et al*. (2015) and Tibbetts (2015), Indonesia is the second largest contributor of plastic waste in the world after China, with annual production of 3.22 million tons. The combination of heightened plastic production and suboptimal recycling rates leads to the substantial disposal of plastics into river systems, subsequently contributing to the influx of plastic materials into the ocean (Sutherland *et al*., 2022). This phenomenon exacerbates the accumulation of plastics within the marine ecosystems. Microplastics have been identified as novel food contaminants that may threaten human health and safety (Barboza *et al*., 2018; Rainieri and Barranco, 2019; Zhang *et al*., 2020). The presence of microplastics in food products, which then enter the human body, can bring various health problems. Once ingested, microplastics can migrate to organs such as the kidneys and liver and cause adverse effects at the cellular level. Human embryonic kidney cells (HEK 293) and human hepatocellular liver cells (Hep G2) are commonly used to test the potential toxicological effects of 1 micrometer (µm) polystyrene microplastics (PS-MPs). Exposure to PS-MPs causes a major reduction in cell proliferation. Kidney and liver cells exposed to polystyrene microplastics result in an increase in reactive oxygen species (ROS) (Goodman *et al*., 2022). In addition, polystyrene microplastics cause hepatotoxicity and lipotoxicity. These microplastics can also increase production of the hepatocyte nuclear factor-4 alpha (HNF4A) and cytochrome P450 family 2 subfamily e member 1 (CYP2E1) genes in the liver, subsequently increasing the risk of steatosis, fibrosis, and cancer (Cheng *et al*., 2022). Several studies have evaluated the presence of microplastics in fish, shellfish, bivalves, honey, sugar, lager, and salt (Barboza *et al*., 2018; Possatto *et al*., 2011; Rainieri and Barranco, 2019). Microplastics contamination in commercial salt has also been monitored and reported in numerous prior studies conducted in various countries around the world, such as Lebanon (Nakat *et al*., 2023), Spain (Iñiguez *et al*., 2017), Turkey (Gündoğdu, 2018), India (Selvam *et al*., 2020; Seth and Shriwastav, 2018; Vidyasakar *et al*., 2021), Iran (Makhdoumi *et al*., 2023), Italy (Renzi and Blašković, 2018), China (Yang *et al*., 2015), Sri Lanka (Kapukotuwa *et al*., 2022), South Korea (Lee *et al*., 2021), Vietnam (Ha, 2021), Australia, France, Japan, Malaysia, New Zealand, Portugal, and South Africa (Karami, *et al*., 2017). Salt can be contaminated by water taken from the sea to make the salt, which may contain microplastics, organic matters, and sand particles, as well as during its manufacture (Gündoğdu, 2018; Yang *et al*., 2015). The abundance and characteristics of microplastics in several Indonesian waters have been reported in previous studies (Cordova *et al*., 2019; Purwiyanto *et*

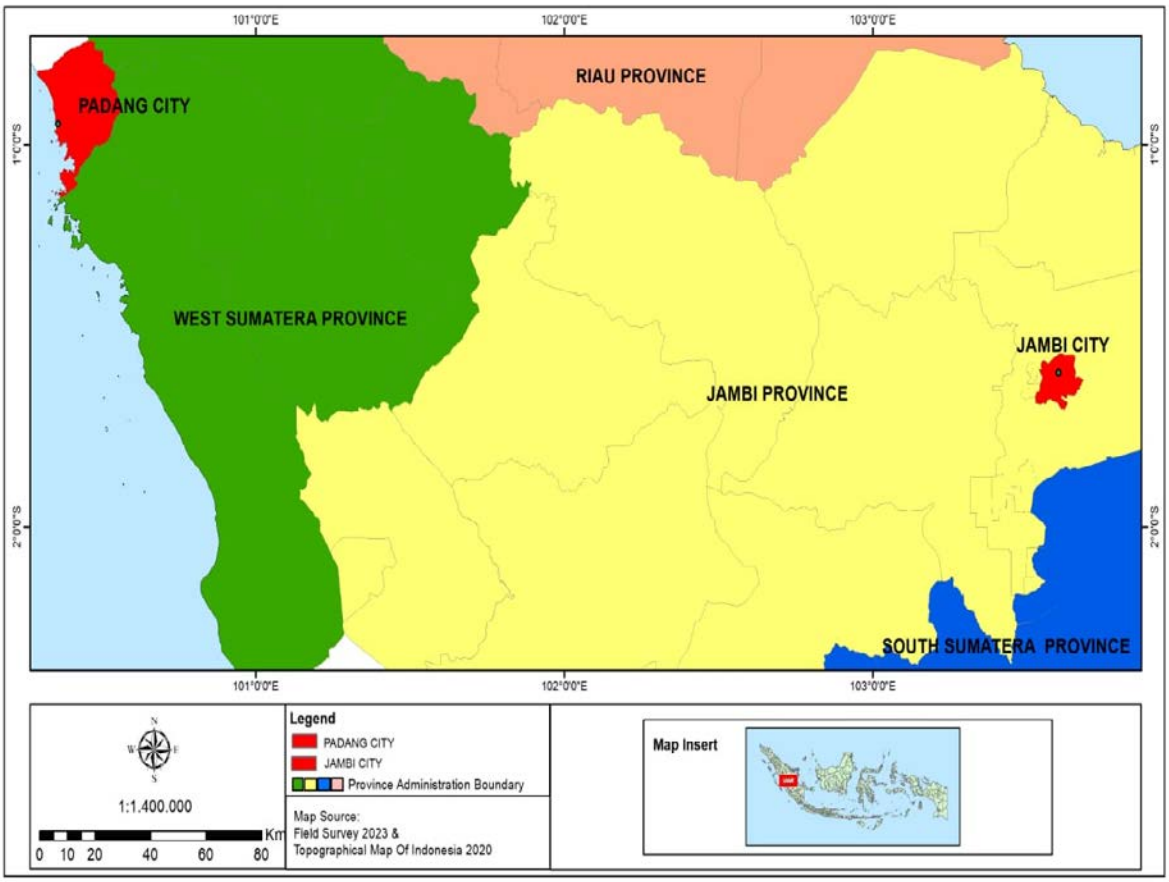


Fig 1: Geographic location of salt sampling areas in Padang and Jambi, Indonesia

al., 2022; Takarina *et al*., 2022; Suteja *et al*., 2021). Microplastics contamination in marine waters can also be present in the salt taken from these waters using traditional method of extraction and collection in evaporation ponds. The heat of the sun and the wind help the evaporation process, leaving behind concentrated saltwater which then crystallizes into salt; all the solids remain when the water is drained, and the salt is then extracted (Nilawati *et al*., 2020; Yang *et al*., 2015). Based on the literature review, no research has been conducted on microplastics contamination in table salt available in Padang City and Jambi City, Indonesia. This study identifies and describes microplastic particles found in salt, and compares the level of MPs contamination in Indonesian salt with those produced in other countries worldwide. Furthermore, this study also estimates the exposure of Indonesian adults to microplastics from their annual salt consumption. This study was carried out in these two cities in 2022 with the aims of determining the abundance and characteristics of microplastics in salt and assessing their exposure in the Indonesian population.

MATERIALS AND METHODS

Sample collection

Sampling was carried out in August 2022. Twenty-one salt samples from different brands weighting 250 to 500 grams were collected from various traditional markets and supermarkets in Padang and Jambi, consisting of 10 brands from Padang and 11 brands from Jambi. Of the 21 brands, 19 were fine salt and the remaining two were coarse salt. Five packages were randomly selected to represent each brand. Information about the brands of salt purchased cannot be disclosed to maintain privacy.

Quality assurance and quality control

Water was used as a control blank. To test for possible water contamination, the (Milli-Q) water used to prepare the sample solution was filtered through a Millipore membrane filter with a diameter of 47 mm and a pore size of 0.45 µm. All laboratory equipment was washed three times with filtered (Milli-Q) water and dried under a fume hood (ESCO) to remove possible contaminants. When not in use, all equipment was immediately covered with aluminum foil (Lusher *et al*., 2015). During each extraction phase, cotton lab coats and nitrile gloves were consistently worn (Di Fiore *et al*., 2023). No plastic utensils were used. Before and after each procedure, ethanol (70%) was used to clean all work surfaces and instruments. Before the end of the vacuum pump process, the inside of the vacuum tube was washed with filtered water to prevent loss of plastic particles. Experimental blank tests were also carried out using only 20 milliliters (mL) of filtered 30% hydrogen peroxide (H_2O_2) in a glass-lidded Erlenmeyer flask, and then all extraction steps were followed. The entire extraction procedure was performed as quickly as possible to avoid contamination during the experiment (Karami, *et al*., 2017). The results of the blank experiment found no contamination.

Microplastics extraction

Microplastics extraction was carried out using a modified reference (Seth and Shriwastav, 2018). For each brand, extraction was done in three replicates, each from a different package. Salt samples from each brand were weighed 50 grams and put into a 300 mL glass-lidded Erlenmyer flask, and then 20 mL of 30% H_2O_2 (Merck Millipore) was added to remove organic impurities. The Erlenmeyer flask was placed on a digital hot plate stirrer (Heidolph) with 300 revolutions per minute (rpm) at 65 degrees Celsius (°C) for 30 minutes. After being stored at room temperature and allowed to cool, 200 mL of (Milli-Q) water was added to the solution, stirred using a glass stirring rod, and continued with a stirring speed of 300 rpm for another 30 minutes. After the salt was completely dissolved, the Erlenmeyer flask was left at room temperature for 24 hours. After ensuring that the precipitation process was complete, the supernatant was filtered through a Millipore cellulose nitrate membrane filter with a diameter of 47 mm and a pore size of 0.45 µm using a vacuum pump. The membrane filter was air-dried at room temperature in a sealed petri dish for further analysis of microplastic particles.

Microplastics characterization

Visual identification

Olympus SZ61 stereo microscope (Olympus KK, Japan) was utilized to visually identify as well as quantitatively and qualitatively detect the microplastics. Microplastic particles on the membrane filter were counted microscopically, and each particle was photographed. Microplastic particles were analyzed based on their shape, size, and color. In this study, microplastics (MPs) were classified into four categories based on their shape, i.e., fragments, films, fibers, and pellets, and five categories based on their size, namely <100 µm, ≥100-300 µm, >300-500 µm, >500-1000 µm, and >1000 µm (Desforges *et al*., 2014; Seth and Shriwastav, 2018). Several representative particles were selected as microplastic particles characterized using Attenuated Total Reflectance-Fourier Transform Infrared (ATR-FTIR) spectroscopy. Nicolet iS10 (Thermo Fisher Scientific) in absorbance mode was utilized to identify the polymeric form of microplastics with a spectral range of 4000–650/cm, spectral resolution of 4/cm, and 16 scans per analysis. Meanwhile, Micro-forceps were used to transfer visible particles onto Attenuated Total Reflectance (ATR) diamonds. Then, the polymer type of the selected particles was identified by comparing their spectra with a polymer database (Agilent Polymer Handheld Library). Identification was based on a match index score greater than or equal to 70% (Song *et al*., 2014; Yang *et al*., 2015). Characterization was also carried out to compare the characteristic peaks of each particle assessed with a reference database (Nakat *et al*., 2023; Deswati *et al*., 2023). Each wave peak was then analyzed to determine its functional group. Afterwards, the observed functional groups were examined to determine the chemical formula and molecular structure of the plastic monomers being tested (M. R. Jung *et al*., 2018; Noda *et al*., 2007).

Assessment of the estimated human exposure to microplastics in salt

There are no regulations in Indonesia or other countries governing the assessment of human exposure to microplastic particles in food, and it is

not clear whether microplastic particles should be classified as chemical, physical, or microorganism contaminants. The World Health Organization or WHO (WHO, 2012) and the Regulation of the Minister of Health of the Republic of Indonesia Number 30 of 2013 have recommended a daily salt intake limit of 5 grams. However, according to a previous study conducted by Atmarita *et al*. (2017) in Indonesia, 18.9% of Indonesian adults consume more than 10 grams of salt per day. Therefore, to better assess exposure of Indonesian adults to microplastics in salt, the results of this present study were calculated in two categories of daily salt intake, namely 5 grams/day and 10 grams/day. The estimated dietary intake (EDI) of microplastic particles was calculated using Eq. 1 below (Rubio-Armendáriz *et al*., 2022).

$$EDI = Microplastics\ in\ salt \times daily\ salt\ intake\ per\ person \times 365 \quad (1)$$

Statistical analysis

Differences in the average abundance of microplastics in particles per kilogram (particles/kg) among salt samples taken from each brand were tested using Analysis of Variance (ANOVA), followed by Tukey's honest significant difference (HSD) test. The significance level of difference ($p<0.05$) (Samimi *et al.,* 2023) was analyzed using SPSS software (SPSS version 27, IBM Inc).

RESULTS AND DISCUSSION

Quantification of microplastics

All salt samples of 21 different brands were found to contain microplastics (Fig. 2), with the abundance of microplastics in the samples ranging from 33 ± 9 to 313 ± 57 particles/kg. The two samples with the highest abundance were S1 and S6 (both were coarse salt), which had an abundance of 313 ± 57 and 313 ± 81 particles/kg, respectively (Table 1). The ANOVA followed by Tukey's HSD test on the abundance of microplastics in each salt sample showed significant differences ($p<0.05$).

This study discovered lower amounts of microplastics than those reported in previous studies on salt conducted in Italy (Renzi and Blašković, 2018), China (Yang *et al*., 2015), South Korea (Lee *et al*., 2021), and Vietnam (Ha, 2021). Meanwhile, another prior study by Kim *et al*. (2018) found microplastics of 12,326-14,932 particles/kg in sea salt in Indonesia (n = 1). Coarse salt has a high abundance of microplastics compared to fine salt. This is because coarse salt is produced by evaporating seawater under direct sunlight in open fields and is highly dependent

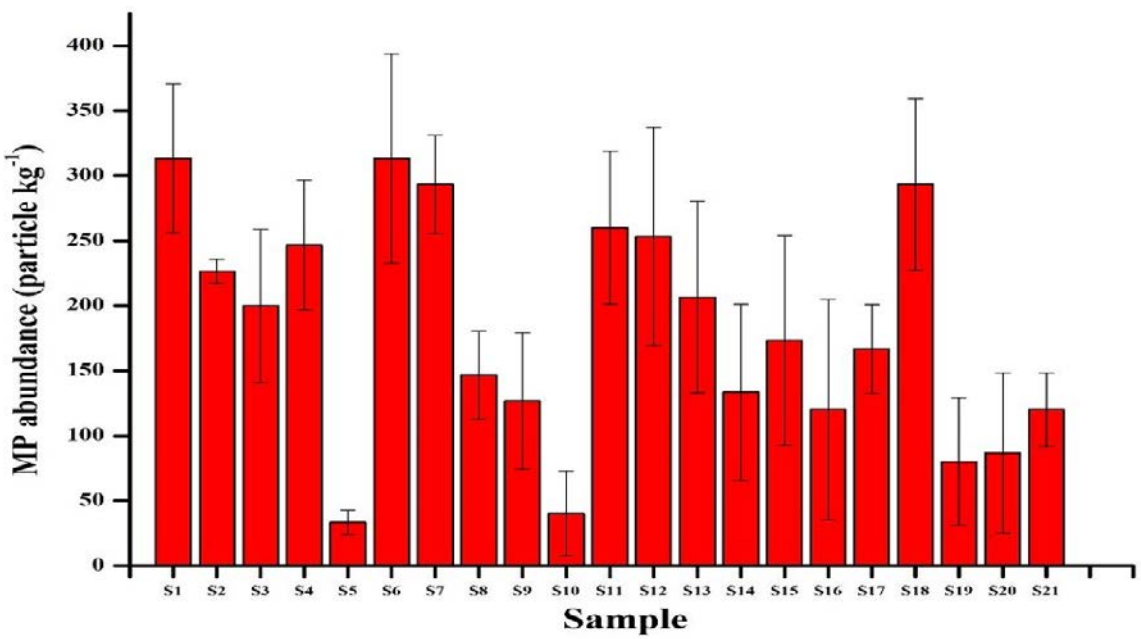


Fig. 2: Histogram of MPs counts in different salt samples

Table 1: The abundance of microplastics in various salt samples in Indonesia

Sample code	Salt type	Average (± SD) of MPs abundance (Particle/kg)[a]
S1	coarse	313 ± 57
S2	fine	227 ± 9
S3	fine	200 ± 59
S4	fine	247 ± 50
S5	fine	33 ± 9
S6	coarse	313 ± 81
S7	fine	293 ± 38
S8	fine	147 ± 34
S9	fine	127 ± 52
S10	fine	40 ± 33
S11	fine	260 ± 59
S12	fine	253 ± 84
S13	fine	207 ± 74
S14	fine	133 ± 68
S15	fine	173 ± 81
S16	fine	120 ± 85
S17	fine	167 ± 34
S18	fine	293 ± 66
S19	fine	80 ± 49
S20	fine	87 ± 62
S21	fine	120 ± 28

[a] Average abundance of microplastics per brand was calculated using the particles detected in each filter of the triplicate samples.

on climate and weather conditions. Airborne microplastics can also contaminate salt production facilities located in open fields. In addition, unlike that of fine salt, there is no further refining stage in the manufacture of coarse salt. The production of fine salt involves three phases of washing: (1) initial washing to remove debris such as grass; (2) washing with brine; and (3) final washing with fresh water. The washed salt solution is then compressed, filtered, and crystallized using the pure-dried vacuum technique. Table 2 lists relevant prior studies on sea salt conducted in several countries.

Despite being contaminated with microplastics, seawater is a major source of salt manufacture, thus having a high potential to produce salt that contains microplastics. Several previous studies have examined the presence of microplastics contamination in Indonesian waters and oceans. The estuary in Benoa Bay, Bali, for example, has a MPs abundance of 1.41-1.88 particles per cubic meter (particles/m^3) (Suteja *et al.,* 2021). Another study by Syakti *et al*. (2017) found 16.8-41.6 microplastic particles per square meter (particles/m^2) in coastal waters in Cilacap, Central Java. The abundance of microplastics in the northern coastal waters of Surabaya, East Java ranges from 0.38 to 0.61 particles/L, with an average of 0.49 particles/L (Cordova *et al*., 2019). The brands of salt examined in previous studies predominantly come from regions other than Jambi and Padang, such as Jakarta, West Java, Central Java, and East Java. Based on data, the four largest salt-producing regions in Indonesia are East Java, Central Java, East Nusa Tenggara, and West Java (KKP, 2021). Salt production in Padang and Jambi also involves the utilization of raw materials obtained from two salt-producing regions, namely West Java and East Java. The abundance of microplastics in salt samples taken from salt production area in East Java was found to be 303 particles/kg, whereas the abundance of microplastics in seawater used for salt production was 9667 particles/m^3. The sea itself can be described as the convergence point of various river estuaries. On the other hand, Cordova *et al*. (2022) conducted a study to monitor marine debris (specifically macro debris) and microplastics in Citarum River located in West Java and revealed that plastics account for 85% of the total waste present in the river, amounting to approximately 5369±2320 items or 0.92±0.40 tons per day. Furthermore, the study also estimated that around 6043±567 items or 1.01±0.19 tons of macro debris are released into the

Table 2: Abundance, shape, color, size, polymer type, and annual human intake of microplastics

Country	Particles/kg	MPs shape	MPs color	MPs size	Polymer type	EDI (Particles /year)	Sources
Lebanon	0-635,2	Fiber	Transparent, white, yellow, blue, black	NA	PE, Plasticized Rubber, PP, BBP, PES, TPE, Plasticizer	0-2372.5	Nakat *et al*., 2023
Italy	1653	Fiber, fragment, sphere	Blue, red, black, white	0-500 µm	PP, PA, PE	NA	Di Fiore *et al*., 2023
Bangladesh	560-1253,33	Fiber, fragment, foam, line, film, pellet	Black, transparent, yellow, red, gray, blue, green	300-5000 µm	PP, PE, PET, PS	1021.74 – 2286.76	Siddique *et al*., 2023
India	56-103	Fiber, fragment	Black, red, brown, blue, purple	500-2000 µm	PES, PET, PA, PE, PS	NA	Seth and Shriwastav, 2018
India	T/A	Fragment, fiber, sheet	White, blue, green, colorless	<2mm	PE, PP, cellulose, nylon	NA	Selvam *et al.*, 2020
Iran	55,2–151,3	Fragment, fiber	White, black, red, blue, green, colorless	1000-5000 µm	PE, PP	15.540	Makhdoumi *et al*., 2023
Spanish	50-280	Fiber	Black, red, blue, white, transparent	30-3500 µm	PET, PP, PE	510	Iñiguez *et al*., 2017
China	550-681	Fragment, fiber	Black, red, white, blue	<200 µm	PET, PE, cellophane	NA	Yang *et al.*, 2015
Türkiye	16-84	Fiber, film, fragment	NA	>1000 µm	PU, PP, PET, PE, PA, PVC	249-302	Gündoğdu, 2018
Italy	1570-8230	Fragment, fiber, film, foam, granule	Black, grey, blue, orange, brown, green, pink, yellow, purple	4-2100 µm	NA	40.6–1085.2	Renzi and Blašković, 2018
Croatia	27,13-31,68	Fiber, film, fragment, granule	Blue, black, white, yellow	15-4628 µm	PP	NA	Renzi and Blašković, 2018
Sri Lanka	11-193	Fiber, fragment	Transparent, red, blue, white, black	65-2500 µm	LDPE, resin dispersion, HDPE	158	Kapukotuwa *et al.*, 2022
Korea	2395	Fragment, fiber	NA	63-100 µm	PP, PE, PS, PET, PVC	12.000	Lee *et al*., 2021
Vietnam	340-878	Fiber, fragment	Blue, grey, black, yellow, white, red	100-700 µm	PE, PP, PS	637-1270	Ha, 2021
Indonesia	33–313	Fragment, fiber, film, pellet	Black, blue, yellow, red, transparent	≥100-300 µm	PE, PP, PET, PES	60.225-571.225	Current study

Polyethylene (PE), polypropylene (PP), polyester (PES), polyethylene terephthalate (PET), polyamide (PA), polyvinyl chloride (PVC), benzyl butyl phthalate (BBP), thermoplastic elastomers (TPE), low-density polyethylene (LDPE), high-density polyethylene (HDPE). Not Available (NA)

river every day. The concentration of microplastics in Citarum River was found to be reach 3.35±0.54 particles/m^3, indicating their presence in the river and their potential transport to the sea. The presence of microplastics was also detected in Brantas River located in East Java, with particle concentrations

ranging from 133 to 5467 particles/m^3, as reported by Buwono *et al*. (2021). The water in this river flows into Madura Strait. The Indonesian marine waters located to the north of Java Island and around Madura Island are wide-ranging bodies of water utilized for the production of salt.

*Shape, size, and color of microplastics*This study successfully identified four different forms of microplastics contained in all 21 salt samples, of which fragments are the most common (67.49%), followed by fibers (23.82%), films (6.08%), and pellets (2.61%) as secondary components. The morphologies of microplastics show variations across different brands of salt. However, fragments and fibers have a higher prevalence than films and pellets which only constitute less than 7% of the overall quantity of microplastics detected (Fig. 3a). This is in line with prior studies that have documented that fragments and fibers are the types of microplastics most commonly found in salt samples taken from various countries (Karami *et al*., 2017; Makhdoumi *et al*., 2023). Similar results were also obtained in a study conducted by Yang *et al*., (2015), where the prevailing forms of microplastics discovered in sea salt in China are fragments and fibers, while other forms such as pellets and films constitute a smaller proportion (less than 6%). In another previous study carried out by Seth and Shriwastav (2018) in India, the commonly identified types of microplastics are fragments, which accounts for 63% of all microplastics, and fibers, which comprises 37% of all microplastics. The fate and influence of MPs on the health of living organisms are determined by their form. The physicochemical characteristics of microplastics, specifically their shape and size, have the potential to impact the transit of microplastic particles within the digestive organs. Gray and Weinstein (2017) revealed that the morphology of microplastic particles had a statistically significant impact on the quantity of particles consumed by shrimp ($p<0.001$). The experiment involved exposing shrimp to microplastic particles of different shapes, including pellets, fibers, and fragments. In the study, Gray and Weinstein (2017) found that the mortality rate of crustaceans varied between 5% and 40% when exposed to pellets and fragments larger than 50 µm. Makhdoumi *et al*. (2021) documented the presence of microplastics in the muscle cells of fish, showing that only 4% of these particles were in the form of fibers, while the other 96% were fragments. As indicated by Qiao *et al*. (2019), the influence of the shape of microplastics on their impacts and

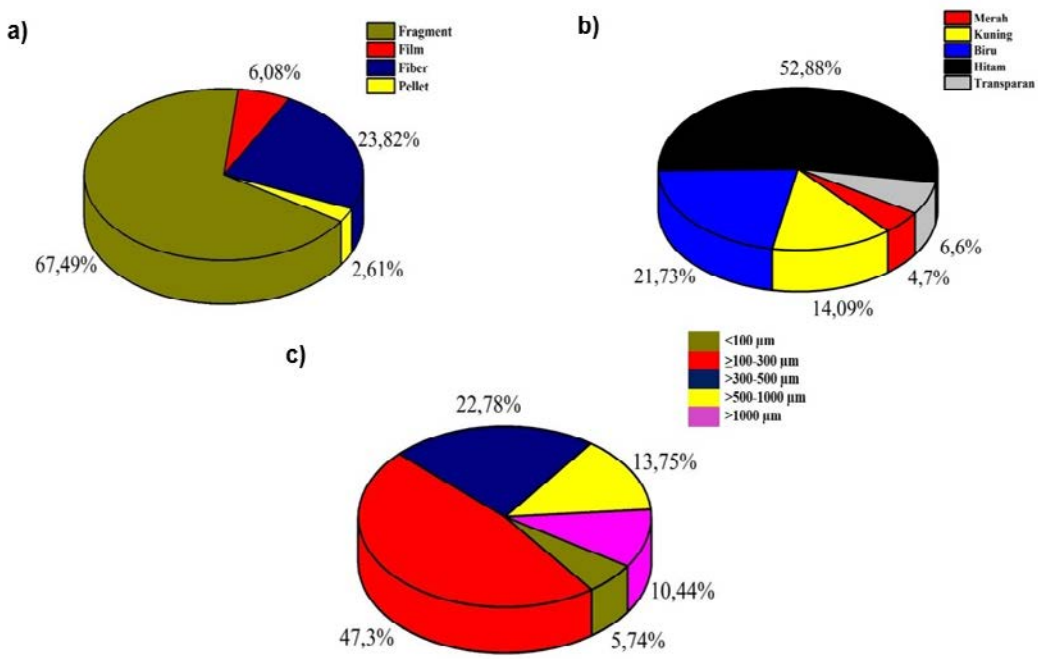


Fig. 3: Composition of microplastics found in salt in Indonesia: (a) shape, (b) color, and (c) size

significance for consideration in the assessment of their health impacts should not be disregarded. In their study, the presence of microplastics in the gastrointestinal tract of zebrafish was also found to be able lead to a range of detrimental consequences, such as damage to the mucosal lining, inflammation, and disruptions of metabolic processes. Notably, the fibrous form of microplastics was observed to have a more pronounced negative impact compared to fragments and pellets.

As presented in Fig. 3c, microplastic particles with sizes ranging from 100-300 µm were the most prevalent, reaching 47.3% of all salt samples. The percentages of microplastics within the size range of >300-500 µm, >500-1000 µm, and >1000 µm were 22.78%, 13.75%, and 10.4%, respectively. Meanwhile, microplastics which are smaller than 100 µm only constituted 5.74% of all samples. The study conducted by Yang *et al*. (2015) revealed that the size of microplastic particles in salt samples varied between 45 µm and 4.3 mm. However, the most prevalent particle size was less than 200 µm, which was 55% of the total amount of microplastics in salt ($p<0.05$). In a study conducted by Seth and Shriwastav (2018), it was observed that the majority of fibers and fragments had a size range between 500-2000 µm (80%). Iñiguez *et al*. (2017) observed that the size of fibers in 21 table salt samples in Spain varied between 30 µm and 3.5 mm. Researchers around the world have noted the absence of microplastic particles smaller than 30 µm. As seen in Table 2, smaller microplastics are contained in sea salt from China (Yang *et al*., 2015) and South Korea (Lee *et al*., 2021), while larger microplastics were present in sea salt from Iran (1000-5000 µm), India (500- 2000 µm), Italy (0-500 µm), Croatia (15-4828 µm), Spain (30-3500 µm), Bangladesh (500-1000 µm), and Vietnam 100-700 µm (Makhdoumi *et al*., 2023; Seth and Shriwastav, 2018; Renzi and Blašković, 2018; Iñiguez *et al*., 2017; Siddique *et al*., 2023; Ha, 2021). According to Rakib *et al*. (2021), variations in the size of microplastics across different countries can be associated with changes in weathering processes induced by factors such as wind, precipitation, temperature, salinity, and sea waves. These weathering patterns may also be influenced by the velocity of wind, as suggested by Kukulka *et al*. (2012).

The areas with the highest concentrations of plastics were observed to be located at a considerable distance from land, and within the initial kilometers adjacent to the coastline. This pattern may be attributed to the proximity of coastal areas to human populations, with hundreds of thousands of plastic pieces typically found per square kilometer in coastal regions in close proximity to human settlements. This is in line with a study conducted by Pedrotti *et al*. (2016), which found that smaller fragments, measuring less than 2 mm, were more prevalent in areas within 1 kilometer (km) of coastal waters, indicating that high levels of fragmentation occur near the coastline. In this regard, Nilawati *et al*. (2020) stated the establishment of salt ponds by farmers is contingent upon the availability of seawater around the coastal areas. This practice, however, raises concerns regarding the potential for plastic pollutants to enter seawater. According to Yuan *et al*., (2022), microplastics have the capacity to induce acute toxicity, subchronic toxicity, carcinogenesis, and genotoxicity. As particles ranging in size from 0.2 to 150 µm, microplastics have been observed to exhibit the ability of traversing living cells and infiltrating the human lymphatic and circulatory systems, as documented in several previous studies (Hussain *et al*., 2001; Rieux *et al*., 2005; Waring *et al*., 2018). Stock *et al*. (2019) also reported that intestinal cells have the capability to uptake microplastics with sizes smaller than 4 µm. Meanwhile, microorganisms can absorb particles with a diameter of 150 µm or less. These particles can subsequently traverse the gut walls, lymph nodes, and various organs, releasing detrimental compounds that have the potential to trigger diseases, such as cancer.

The salt samples in this study were found to contain microplastics in different colors, namely red, yellow, blue, black, and transparent, as depicted in Fig. 4. The prevalence of black color was observed to be dominant in all salt samples analyzed, reaching 52.88% of the total samples. The distribution of black microplastics was uniform across all samples, as shown in Fig. 3b. Iñiguez *et al*. (2017) reported in their study that the dominant colors observed in salt samples collected in Spain include black, red, blue, white, and transparent. Microplastics with a size greater than 1000 µm can be seen starting from the extraction stage (Fig. 5). The presence of microplastics in Chinese salt has been documented by Yang *et al*. (2015); these microplastics are generally black, red, blue, or white in color. The color of microplastics is attributed to

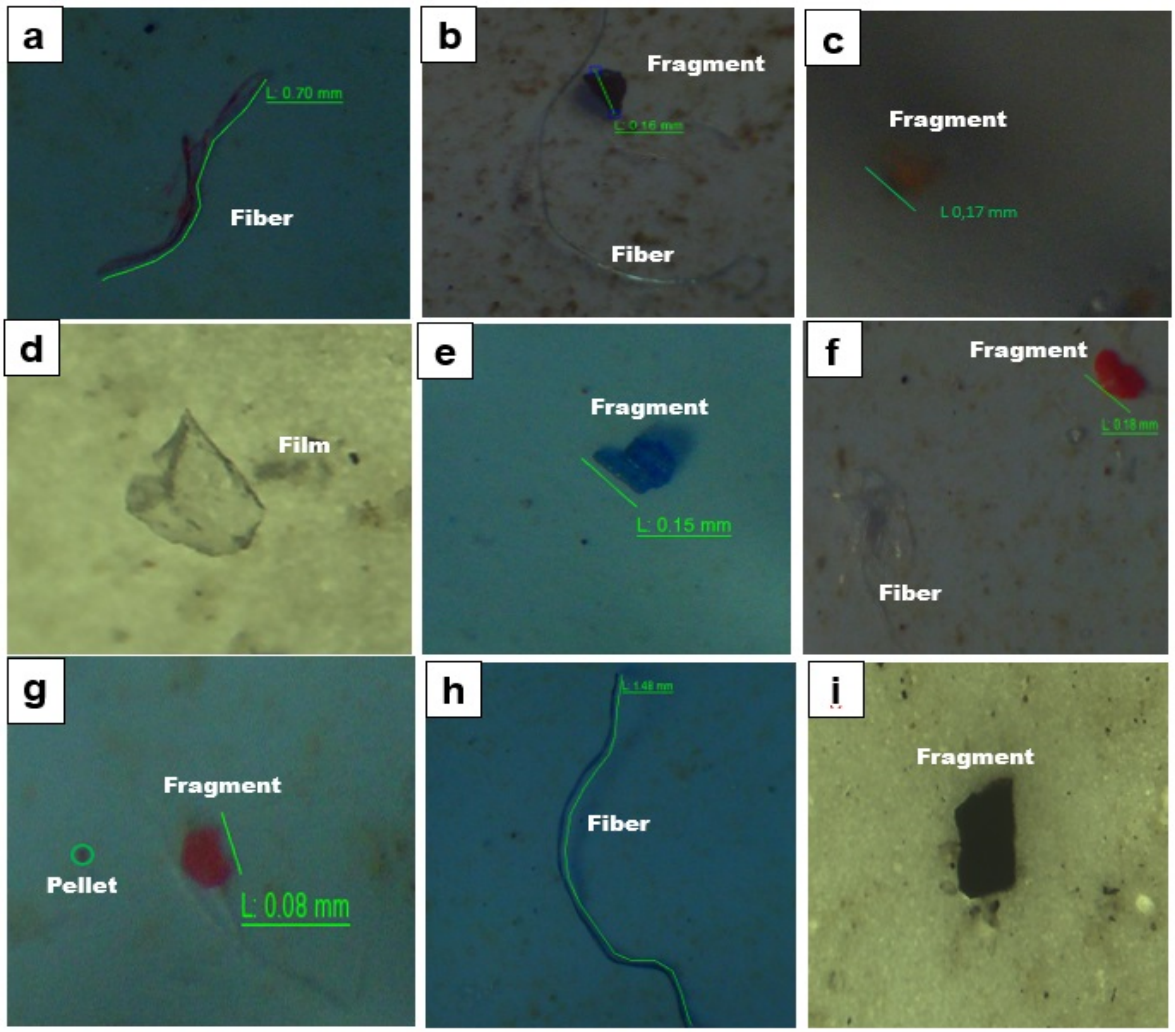


Fig. 4: Microscopic images showing different morphotypes and colors of microplastics obtained from table salt in Indonesia (a) red fiber, (b) black fragment and transparent fiber, (c) yellow fragment, (d) transparent film, (e) blue fragment, (f)-(g) red pellet, (h) red fragment, (h) blue fiber, (i) black fragment

the degradation of black plastic materials. Black plastic is utilized across a diverse range of industries, encompassing food packaging, cookware, trays, toys, household appliances, and automobile components. The escalating prevalence of black plastic waste in the environment caused by a decline in recycling rates has led to the emergence of black microplastics as its potential consequence (Huang and Xu, 2022). Similarly, transparent microplastics can result from the packaging of various products, including disposable plastic bags, containers, and bottles. The presence of pigmented microplastics can be associated with the utilization of packaging materials and various plastic consumer products (K. Zhang *et al*., 2018). Microplastics of various colors, including blue, yellow, and red, can appear as a result of plastic pigmentation and the photoaging process. According to Zhao *et al*. (2022), the phenomenon of photoaging can induce alterations in the coloration of microplastics, thereby offering a way to determine the duration of plastic particle exposure in the surrounding environment.

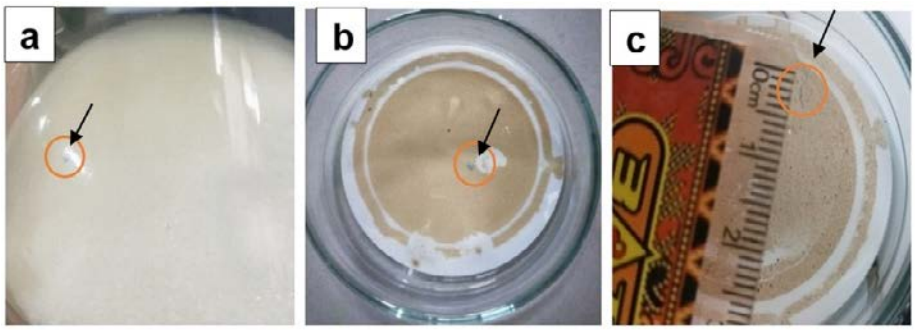


Fig. 5: (a) Microplastics in the form of blue fragments visible at the extraction stage, (b) Microplastics on filter paper, and (c) Microplastics in the form of blue fibers on filter paper.

Types of microplastics

Fourier Transform Infrared (FTIR) spectroscopy is a highly effective technique that enables efficient, rapid, and nondestructive identification of samples (Samimi and Shahriari Moghadam, 2023). By analyzing the infrared absorption bands resulting from vibrations of functional groups (Ehzari *et al*., 2022), FTIR spectroscopy can successfully identify a wide range of plastic polymers. In this study, the ATR-FTIR instrument was utilized to characterize a representative sample of microplastic particles deposited on filter paper, with a total of 26 particles analyzed for their polymer composition. Identification of the polymer type of these particles was achieved through a comparative analysis of their spectra with a polymer database, i.e., the Agilent Polymer Handheld Library. The identification process relied on a match index score that met or exceeded the threshold of 70% (Kim *et al*., 2018; Yang *et al*., 2015). Then, identification of the functional groups was performed manually, wherein the characteristic peaks of each evaluated particle were compared with a specific reference database for each polymer, as outlined by Nakat *et al*. (2023). Various microplastic polymers have been identified based on the results of the FTIR spectrum analysis, namely polyethylene (9 particles), polypropylene (8 particles), polyethylene terephthalate (4 particles), polyester (1 particle), and unidentified (4 particles).

Analysis of the type of microplastic polymer in the blue fragment of sample S2 (Fig. 6a) used the Nicolet iS10 ATR-FTIR Spectrometer (Thermo Fisher Scientific) and showed a polyethylene polymer match score of 89%. Furthermore, the FTIR spectrum indicated the presence of C-H stretching at wave numbers 2915/ cm and 2845/ cm, CH_3 bending at 1377/cm, CH_2 bending at 1467/cm and 1462/cm, and CH_2 rocking at 730/cm and 717/cm. Likewise, analysis of the type of microplastic polymer in the yellow fragment-shaped particles of sample S1 (Fig. 6b) also used the Nicolet iS10 ATR-FTIR Spectrometer and revealed a polypropylene polymer match score of 80%. In the FTIR spectrum, significant absorbance peaks appeared at wave numbers 2950/cm and 2838/cm, indicating C-H stretching and asymmetric vibrations (Fotopoulou and Karapanagioti, 2012; Käppler *et al*., 2015; Löder *et al*., 2015), and at wave number 1455/ cm signifying CH_2 bending vibrations (Kappler *et al*., 2016). CH_3 bending was detected at wave number 1377/cm. Since the area around 1375-1450/cm refers to CH_3 bending, CH_3 rocking was detected at wave numbers 997/cm and 972/cm. meanwhile, CH_2 rocking was detected at wave numbers 840/cm and 880/cm (Fotopoulou and Karapanagioti, 2012; M. R. Jung *et al*., 2018; Löder *et al*., 2015; Syakti *et al*., 2017). Analysis of the type of microplastic polymer in the black fiber-shaped particles of sample S8 (Fig. 6c) with Nicolet iS10 ATR-FTIR Spectrometer showed a polyethylene terephthalate polymer match score of 88%. PET has a characteristic peak at 720/cm, indicating the presence of the CH Aromatic functional group. C-O stretching was detected at wave numbers 1094 and 1241/cm, C=O stretching at wave number 1713/cm, and OH group vibrations at 3608/cm (M. R. Jung *et al*., 2018; Noda *et al*., 2007). The presence of microplastic polyester fibers in the black fiber-shaped particles of sample S5 (Fig. 6c) was analyzed also using Nicolet iS10 ATR-FTIR Spectrometer, indicating a polyester fiber match score of 89%. Polyester is confirmed by the characteristic band of valence

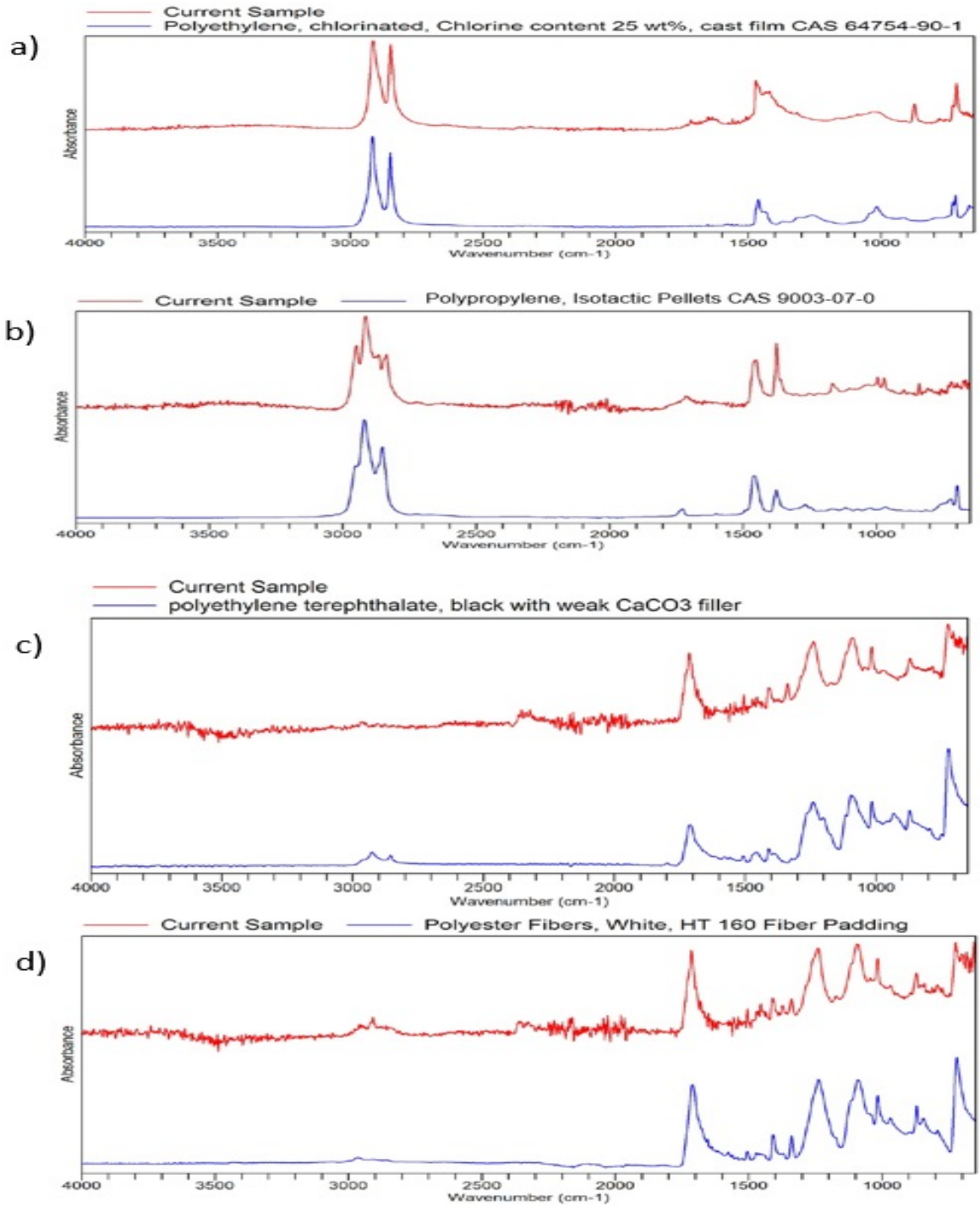


Fig. 6: FTIR spectra of microplastics

vibration of the carbonyl group at 1727/cm. Other special bands were detected at 2819/cm (CH_3 group), with 725/cm corresponding to carboxylic esters and anhydrides and 971/cm indicating C-C bending (Käppler *et al*., 2015; Noda *et al*., 2007).

In this study, four types of microplastics were found (Fig.7), namely PE (34.62%), PP (30.77%), PET (15.38%), and PES (3.85%). Similar results were found in a study by Nakat *et al*. (2023) which identified PE as the dominant polymer type of microplastics in salt available on the market in Lebanon, followed by plasticized rubber and PP. Another study by Selvam *et al*. (2020) also pointed out PE as the most common polymer type, followed by PP, cellulose, and nylon. Meanwhile, a study carried out in India by Seth and Shriwastav (2018) revealed the occurrence of PES, PE, and PA polymer types, with PES being the most prevailing constituent. Sea salts found in African markets mainly contain polyvinyl acetate, PP, and PE (Fadare *et al*., 2021). PE and PP are major contributors to global plastic production, primarily due to their extensive utilization as packaging materials for various applications, such as containers, bottles, and bags (Andrady, 2011; Geyer *et al*., 2017). PE and PP are lightweight polymers; PE has a density of 0.85 grams per milliliter (g/mL), while PP has a density of 0.97 g/mL. Both PE and PP are commonly used in packaging, typically for single-use products with a short shelf life that quickly end up in waste streams and landfills (Pedrotti *et al*., 2016). PE has been identified as the easiest polymer to identify in both freshwater (Koelmans *et al*., 2019) and marine ecosystems (Hidalgo-Ruz *et al*., 2012) due to its lower density compared to water. This property causes PE to float and has the potential to accumulate as residue during the process of sea salt production following water evaporation (UNEP, 2016). The presence of microplastic pollutants in sea salt is initially attributed to the packaging materials used by the community. However, Fadare *et al*. (2021) challenged this hypothesis by demonstrating that packaging materials do not contain any microplastic particles. Instead, Nakat *et al*. (2023) argued that the primary source of microplastics contamination in salt is the seawater itself. PET constitutes a relatively minor fraction of the overall output of non-fiber plastics on a global scale, as indicated by the findings of a study by Lee *et al*. (2021). According to Iñiguez *et al*. (2017), PET is the predominant form of microplastics discovered in salt samples collected in Spain. Previous studies have also reported the presence of PET and polyethylene in salt samples obtained from various countries worldwide (Gündoğdu, 2018; Iñiguez *et al*., 2017; Karami *et al*., 2017; Yang *et al*., 2015).

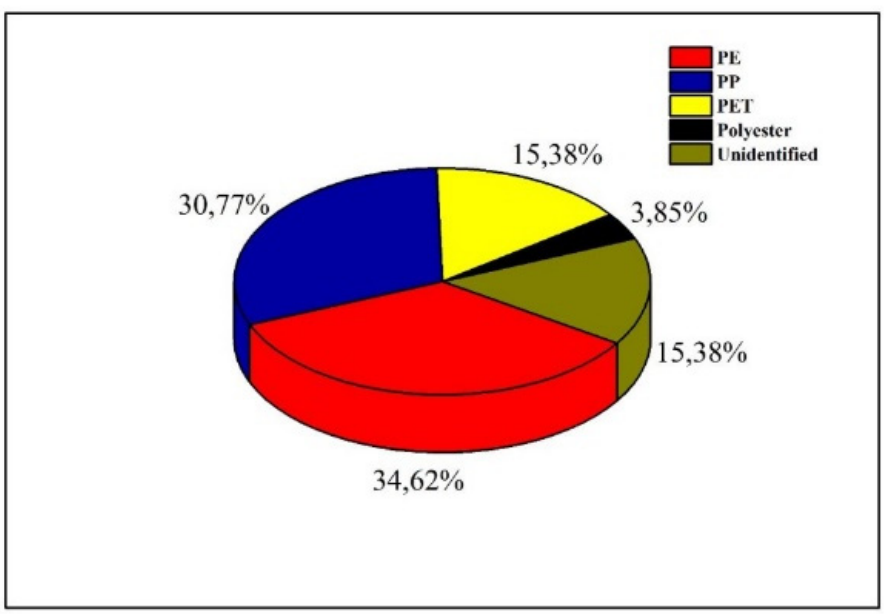


Fig. 7: Polymer types of microplastics in salt samples

Table 3: Estimated dietary intake (EDI)

MPs abundance (Particles/kg)	Level	EDI for adults (microplastics/capita/year)	
		Salt intake of 5 g/day	Salt intake of 10 g/day
33	Lowest	60.225	120.45
183	Median	333.975	667.95
313	Highest	571.225	1142.45

PET, which stands for polyethylene terephthalate, is a type of polyester that is frequently employed as a packaging material in various forms such as flexible films, bottles, and textiles (Iñiguez *et al*., 2017). According to Acharya *et al*. (2021), various other polyesters and polyamides are mostly sourced from textile materials. Similarly, the utilization of polyethylene and polystyrene polymers in packaging is very extensive (Andrady, 2011). Factors affecting the distribution of microplastics are due to the various human activities around marine and river waters. Polluted rivers become a route for disposal of wastewater, both household and industrial, to the sea (Priya *et al*., 2023).

Estimated human intake of microplastics in salt

Salt is one of the food seasonings consumed daily by humans. Therefore, it is extremely important to calculate the estimated contamination with microplastics. The WHO has set a standard for salt intake of 5 grams per day for adults (WHO, 2012). This is in line with the guidelines outlined in the Regulation of the Minister of Health of the Republic of Indonesia Number 30 of 2013 on salt consumption. However, a study conducted by Atmarita *et al*. (2017) revealed that a significant proportion of Indonesian adults, approximately 46.3% of the total population, consumed an average of 5 grams per day, while 18.9% of them consume a higher range of 10-30 grams/day. Based on data on salt consumption in Indonesia, it is absolutely necessary to conduct a careful and precise evaluation of microplastics contamination in salt. This study examines the potential health risks associated with the consumption of microplastics contained in salt available in Padang and Jambi, Indonesia, and calculates the level of contamination based on the estimated daily intake (EDI) of salt by the Indonesian population. For this purpose, the EDI was estimated using microplastic detection techniques and three levels of contamination. The minimum, average, and maximum levels of microplastics abundance were determined. The minimum, average, and maximum annual exposures of Indonesian adults to microplastics were approximately 60.225 particles/year, 333.975 particles/year, and 571.225 particles/year for the recommended salt intake of 5 grams per day (g/day), or approximately 120.45 particles/year, 667.95 particles/year, and 1142.45 particles/year for salt intake of 10 g/day (Table 3).

Microplastics are considered food contaminants that pose potential risks to human health and food safety. However, studies on the effects of these contaminants on human health are still very limited and little is known about the risks associated with human exposure to microplastics (Barboza *et al*., 2018; Rainieri and Barranco, 2019; Rubio-Armendáriz *et al*., 2022). Several studies have evaluated the presence of microplastics in foods, such as fish, shellfish, bivalves, oysters, honey, sugar, and beer (Kasmini *et al*., 2023; Maulana *et al*., 2023; Barboza *et al*., 2018; Rainieri and Barranco, 2019). The exact mechanisms of the damage caused by microplastics to organisms are not yet fully understood. Limited data on this topic suggest that ingestion and accumulation of MPs in animals may cause localized inflammation in the gut and particle toxicity through the induction of immune responses. Besides, MPs enters in various ways into human body, mainly indirectly through the consumption of fish and other seafood (Makhdoumi *et al*., 2023).

Techniques to reduce microplastics contamination in salt

Salt can be contaminated with microplastics mainly from polluted seawater and various stages of salt production, handling, and repackaging. Several methods that can reduce microplastics contamination in salt include the sand filtration technology proposed by Seth and Shriwastav (2018) to remove the amount of microplastics from seawater, with an

efficiency of up to 90%. A method with the use of reverse osmosis membranes is also suggested, where the seawater feed is pretreated with microfiltration membranes to remove unwanted particles and then further concentrated by separating the water on reverse osmosis membranes (Yaranal *et al*., 2020). In addition, coagulation methods using various coagulants such as Aluminum sulfate ($Al_2(SO_4)_3$), Aluminum chloride ($AlCl_3$), and Poly Aluminum Chloride (PAC) can also be employed to remove microplastics, with efficiency exceeding 60% (Ma *et al*., 2018). Coagulation techniques require simple settings, are cost-effective, and have already been widely used by the community. The magnetic carbon nanotube method is considered to be able to remove microplastic particles in water through adsorption, with results showing 100% efficient removal of PE, PET, and PA. These carbon nanomaterials offer the advantages of being economical and environmentally friendly materials that have a large specific surface area and multiple adsorption sites (Tang *et al*., 2021). Further studies are highly necessary to prove the usefulness of the new laboratory-tested methods in salt production and to assess the safety of their application in food production. One example of these new innovations is the nano-based technology, which is an important advancement that can affect the food sector by improving the quality of food products (Pushparaj *et al*., 2022).

CONCLUSIONS

Based on the results of this study, coarse salt and fine salt circulating in Padang City and Jambi City, Indonesia are found to be contaminated with microplastics. Microplastic particles are found more in coarse salt than in fine salt. The abundance of microplastics in the total samples ranges from 33 ± 9 to 313 ± 57 particles/kg. Most of Indonesian people consume salt every day, thus being at risk of being exposed to microplastics contained in salt. Microplastics contamination in salt can be caused by contaminated seawater as the raw material for salt production, as well as inadequate and unhygienic salt production facilities. The most commonly detected form of microplastics is fragment (67.49%), followed by fiber (23.82%), film (6.08%), and pellet (2.61%). In terms of size, microplastics are classified into size range of <100 µm, ≥100-300 µm, >300-500 µm, >500-1000 µm, and >1000 µm, with the most dominant size being ≥100-300 µm (47.3%). Microplastics in salt samples are in 5 different colors: black, blue, yellow, red, and transparent, with black being the dominant color of microplastics (52.88%). Lastly, four types of polymers are also identified, namely: polyethylene (34.62%), polypropylene (30.77%), polyethylene terephthalate (15.38%), and polyester (3.85%). It is estimated that each adult in Indonesia is exposed to 60.225-571.225 microplastic particles/year by consuming 5 grams of salt per day, or 120.45-1142.45 particles/year by consuming 10 grams of salt/day. Due to the adverse effects associated with microplastics, further studies are highly necessary to explore strategies for their removal. The process of evaporating seawater into salt can increase the risk of microplastics contained in salt consumed by humans. Some of the available methods that can be employed to reduce the microplastic content in seawater include the implementation of sand filtration technology with an efficiency of up to 90% in removing microplastics from seawater; this simple technique has been widely applied in small-scale salt production in Indonesia. Aside from this technique, the use of reverse osmosis membranes and the application of coagulation methods using coagulants such as $Al_2(SO_4)_3$, $AlCl_3$, PAC Aluminum sulfate ($Al_2(SO_4)_3$), Aluminum chloride ($AlCl_3$), and Poly Aluminum Chloride (PAC) with efficiencies exceeding 60% are also strongly recommended. Coagulation techniques require simple settings, are cost-effective, and have already been widely used by the community. The magnetic carbon nanotube method has been proven to efficiently remove microplastic particles (PE, PET, and PA) in water by adsorption. However, further studies should be conducted to prove the usefulness of this new laboratory-tested method in salt production and to assess the safety of its application in food production. Furthermore, to prevent potential airborne microplastics contamination from air pollution and waste incineration, coastal salt production areas are suggested to be located in a significant distance from estuaries, landfills, and other possible polluting industries while monitoring areas on land and off land. In addition, salt producers and handlers must follow good manufacturing practices (GMP) and good hygiene practices (GHP) to improve the safety of salt consumption. Tools, supplies, and ponds should also be properly adapted and maintained in accordance

with the tailor-made food safety training programs by the Ministry of Marine Affairs and Fisheries to reduce physical contamination.

AUTHOR CONTRIBUTIONS

D.A. Syamsu conducted literature review, designed and conducted experiments, analyzed and interpreted data, prepared the manuscript, and edited the manuscript. D. Deswati, the corresponding author, supervised co-authors in experiments, analyzed data, interpreted the results, and prepared the manuscript. S. Syafrizayanti conducted data analysis, interpreted the results, prepared the manuscript in the discussion and conclusion sections. A. Putra performed secondary data collection, carried out supporting analysis, linked the findings with existing literature, interpreted data, and arranged the layout of the manuscript. Y. Suteja assisted in drafting, reviewing, and revising the manuscript.

ACKNOWLEDGEMENT

The authors would like to express the deepest grateful to the Indonesian FDA for funding this study [PB.02.03.2.9.08.21.223 2021].

CONFLICT OF INTEREST

The author declares is no conflict of interest regarding the publication of this manuscript. The ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy, have been completely observed by the authors.

OPEN ACCESS

©2024 The author(s). This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution, and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made. The images or other third-party material in this article are included in the article's Creative Commons license unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this license, visit:

http://creativecommons.org/licenses/by/4.0/

PUBLISHER'S NOTE

GJESM Publisher remains neutral with regard to jurisdictional claims with regard to published maps and institutional affiliations.

ABBREVIATIONS	DEFINITION
%	Percent
^0C	Degrees Celsius
µm	Micrometer
$Al_2(SO_4)_3$	Aluminium sulfate
$AlCl_3$	Aluminium chloride
ANOVA	Analysis of variances
ATR	Attenuated total reflectance
ATR-FTIR	Attenuated total reflectance-fourier transform infra-red
BBP	Benzyl butyl phthalate
CYP2E1	Cytochrome P450 family 2 subfamily E member 1
EDI	Estimated human dietary intake
FDA	Food Drug and Authority
FTIR	Fourier transform infra-red
g/day	Gram per day
g/mL	Gram per milliliter
GHP	Good hygiene practice
GMP	Good manufacturing practice
HDPE	High-density polyethylene
HEK 293	Human embryonic kidney cells
HEP G2	Human hepatocellular liver cells
HNF4A	Hepatocyte Nuclear Factor-4 Alpha
HSD	Honest significant difference
H_2O_2	Hydrogen peroxide
km	Kilometer
LDPE	Low-density polyethylene
mL	Milliliter
mm	Millimeter
MPs	Microplastics

NA	Not available
PA	Polyamide
PAC	Poly aluminum chloride
particles/kg	Particles per kilogram
particles/m²	Particles per square meter
particles/m³	Particles per cubic meter
PE	Polyethylene
PES	Polyester
PET	Polyethylene terephthalate
POPs	Persistent organic pollutants
PP	Polypropylene
PS-MPs	Polystyrene microplastics
PVC	Polyvinyl chloride
ROS	Reactive oxygen species
rpm	Revolutions per minute
TPE	Thermoplastic elastomers
WHO	World Health Organization

REFERENCES

Acharya, S.; Rumi, S.S.; Hu, Y.; Abidi, N., (2021). Microfibers from synthetic textiles as a major source of microplastics in the environment: A review. Text. Res. J., 91(17-18): 2136–2156 **(21 pages)**.

Andrady, A.L., (2011). Microplastics in the marine environment. Mar. Pollut. Bull., 62(8): 1596–1605 **(10 pages)**.

Atmarita, A.; Jahari, A.B.; Sudikno, S.; Soekatri, M., (2017). Asupan gula, garam, dan lemak di Indonesia: Analisis survei konsumsi makanan individu (SKMI) 2014. Gizi Indonesia., 39(1): 1–14 **(14 pages)**.

Barboza, L.G.A.; Dick Vethaak, A.; Lavorante, B.R.B.O.; Lundebye, A.K.; Guilhermino, L., (2018). Marine microplastic debris: An emerging issue for food security, food safety, and human health. Mar. Pollut. Bull., 133: 336–348 **(13 pages)**.

Buwono, N.R.; Risjani, Y.; Soegianto, A., (2021). Distribution of microplastic in relation to water quality parameters in the Brantas River, East Java, Indonesia. Environ. Technol. Innovation. 24(2021): 101915 **(10 pages).**

Buwono, N.R.; Risjani, Y.; Soegianto, A., (2022). Spatio-temporal patterns of occurrence of microplastics in the freshwater fish Gambusia affinis from the Brantas River, Indonesia. Environ. Pollut., 311: 119958 **(9 pages).**

Cheng, W.; Li, X.; Zhou, Y.; Yu, H.; Xie, Y.; Guo, H.; Wang, H.; Li, Y.; Feng, Y.; Wang, Y., (2022). Polystyrene microplastics induce hepatotoxicity and disrupt lipid metabolism in the liver organoids. Sci. Total Environ., 806(1): 150328 **(13 pages).**

Cordova, M.R.; Nurhati, I.S.; Shiomoto, A.; Hatanaka, K.; Saville, R.; Riani, E., (2022). Spatiotemporal macro debris and microplastic variations linked to domestic waste and textile industry in the supercritical Citarum River, Indonesia. Mar. Pollut. Bull., 175: 113338 **(11 pages).**

Cordova, M.R.; Purwiyanto, A.I.S.; Suteja, Y., (2019). Abundance and characteristics of microplastics in the northern coastal waters of Surabaya, Indonesia. Mar. Pollut. Bull., 142: 183–188 **(6 pages).**

Desforges, J.-P.W.; Galbraith, M.; Dangerfield, N.; Ross, P.S., (2014). Widespread distribution of microplastics in subsurface seawater in the NE Pacific Ocean. Mar. Pollut. Bull., 79(1-2): 94–99 **(6 pages).**

Deswati; Sutopo, J.; Putra, A.; Suparno., (2023). Mikroplastik, sampling dan analisisnya. Graha Ilmu., **(170 pages).**

Di Fiore, C.; Sammartino, M.P.; Giannattasio, C.; Avino, P.; Visco, G., (2023). Microplastic contamination in commercial salt: An issue for their sampling and quantification. Food Chem., 404: 134682 **(10 pages).**

Ehzari, H.; Safari, M.; Samimi, M.; Shamsipur, M.; Gholivand, M.B, (2022). A highly sensitive electrochemical biosensor for chlorpyrifos pesticide detection using the adsorbent nanomatrix contain the human serum albumin and the Pd: CdTe quantum dots. Microchem. J., 179: 107424 **(10 pages).**

Fadare, O.O.; Okoffo, E.D.; Olasehinde, E.F., (2021). Microparticles and microplastics contamination in African table salts. Mar. Pollut. Bull., 164: 112006 **(8 pages).**

Fotopoulou, K.N.; Karapanagioti, H.K., (2012). Surface properties of beached plastic pellets. Mar. Environ. Res., 81: 70–77 **(8 pages).**

Geyer, R.; Jambeck, J.R.; Law, K.L., (2017). Production, use, and fate of all plastics ever made. Sci. Adv., 3(7): 1700782 **(6 pages).**

Goodman, K.E.; Hua, T.; Sang, Q.-X.A., (2022). Effects of polystyrene microplastics on human kidney and liver cell morphology, cellular proliferation, and metabolism. ACS Omega., 7(38): 34136–34153 **(18 pages).**

Gray, A.D.; Weinstein, J.E., (2017). Size and shape-dependent effects of microplastic particles on adult dagger blade grass shrimp, *Palaemonetes pugio*. Environ. Toxicol. Chem., 36(11): 3074–3080 **(7 pages).**

Gündoğdu, S., (2018). Contamination of table salts from Turkey with microplastics. Food Add. Contam. - Part A Chem., 35(5): 1006–1014. **(9 pages).**

Ha, D.T., (2021). Microplastic contamination in commercial sea salt of Vietnam. Vietnam. J. Sci. Technol., 59(3): 333–344 **(12 pages).**

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. Environ. Sci. Technol., 46(6): 3060–3075 **(16 pages).**

Huang, Y.; Xu, E.G., (2022). Black microplastic in plastic pollution: undetected and underestimated? Water Emerg. Contam. Nanoplastics., 1(14): 1-7 **(7 pages).**

Hussain, N.; Jaitley, V.; Florence, A.T., (2001). Recent advances in the understanding of uptake of micro particulates across the gastrointestinal lymphatics. Adv. Drug Deliv. Rev., 50(1–2): 107–142 **(36 pages).**

Iñiguez, M.E.; Conesa, J.A.; Fullana, A., (2017). Microplastics in Spanish Table Salt. Sci. Rep., 7(8620): 1–7 **(7 pages).**

Jambeck, J.R.; Geyer, R.; Wilcox, C.; Siegler, T.R.; Perryman, M.; Andrady, A.; Narayan, R.; Law, K.L., (2015). Plastic waste inputs from land into the ocean. Science., 347(6223): 768–771 **(4 pages).**

Jung, M.R.; Horgen, F.D.; Orski, S.V.; Rodriguez C.V.; Beers, K.L.; Balazs, G.H.; Jones, T.T.; Work, T.M.; Brignac, K.C.; Royer, S.-J.; Hyrenbach, K.D.; Jensen, B.A.; Lynch, J.M., (2018). Validation of ATR FT-IR to identify polymers of plastic marine debris, including those ingested by marine organisms. Mar. Pollut. Bull., 127: 704–716 **(13 pages).**

Jung, Y.S.; Sampath, V.; Prunicki, M.; Aguilera, J.; Allen, H.; LaBeaud, D.; Veidis, E.; Barry, M.; Erny, B.; Patel, L.; Akdis, C.; Akdis, M.; Nadeau, K., (2022). Characterization and regulation of microplastic pollution for protecting planetary and human health. Environ. Pollut., 315: 120442 **(10 pages).**

Käppler, A.; Windrich, F.; Löder, M.G.J.; Malanin, M.; Fischer, D.; Labrenz, M.; Eichhorn, K.-J.; Voit, B., (2015). Identification of microplastics by FTIR and Raman microscopy: A novel silicon filter substrate opens the important spectral range below 1300 cm^{-1} for FTIR transmission measurements. Anal. Bioanal. Chem., 407: 6791-6801 **(11 pages).**

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. Mar. Pollut. Bull., 174: 113239 **(10 pages).**

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. Sci. Rep., 7(46173): 1-9 **(9 pages).**

Kasmini, L.; Batubara, A.S., (2023). Microplastic contamination and growth pattern of oyster; Crassostrea gigas in a coastline. Global J. Environ. Sci. Manage., 9(4): 753-764 **(12 pages).**

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. Environ. Sci. Technol., 52(21): 12819–12828 **(9 pages).**

KKP., (2021). Produksi Garam tahun 2020. Balai Besar Riset Sosial Ekonomi Kelautan dan Perikanan, Badan Riset dan SDM Kelautan dan Perikanan Indonesia.

Koelmans, A.A.; Mohamed Nor, N.H.; Hermsen, E.; Kooi, M.; Mintenig, S.M.; De France, J., (2019). Microplastics in freshwaters and drinking water: Critical review and assessment of data quality. Water Res., 155: 410–422 **(13 pages).**

Lee, H.-J.; Song, N.-S.; Kim, J.-S.; Kim, S.-K., (2021). Variation and Uncertainty of Microplastics in Commercial Table Salts: Critical Review and Validation. J. Hazard. Mater., 402: 123743 **(13 pages).**

Löder, M.G.J.; Kuczera, M.; Mintenig, S.; Lorenz, C.; Gerdts, G., (2015). Focal plane array detector-based micro-Fourier-transform infrared imaging for the analysis of microplastics in environmental samples. Environ. Chem., 12(5): 563–581 **(19 pages).**

Lusher, A.L.; Tirelli, V.; O'Connor, I.; Officer, R., (2015). Microplastics in Arctic polar waters: The first reported values of particles in surface and sub-surface samples. Sci. Rep., 5(14947): 1-9 **(9 pages).**

Ma, B.; Xue, W.; Ding, Y.; Hu, C.; Liu, H.; Qu, J., (2019). Removal characteristics of microplastics by Fe-based coagulants during drinking water treatment. J. Environ. Sci., 78: 267–275 **(9 pages).**

Makhdoumi, P.; Hossini, H.; Nazmara, Z.; Mansouri, K.; Pirsaheb, M., (2021). Occurrence and exposure analysis of microplastic in the gut and muscle tissue of riverine fish in Kermanshah province of Iran. Mar. Pollut. Bull., 173: 112915 **(11 pages).**

Makhdoumi, P.; Pirsaheb, M.; Amin, A.A.; Kianpour, S.; Hossini, H., (2023). Microplastic pollution in table salt and sugar: Occurrence, qualification and quantification and risk assessment. J. Food Comp. Anal., 119(2): 105261 **(11 pages).**

Mamun, A.Al.; Prasetya, T. A. E.; Dewi, I. R.; Ahmad, M., (2023). Microplastics in human food chains: Food becoming a threat to health safety. Sci. Total Environ., 858: 159834 **(17 pages).**

Maulana, M.R.; Saiful, S.; Muchlisin, Z.A., (2023). Microplastics contamination in two peripheral fish species harvested from downstream river. Global J. Environ. Sci Manage., 9(2): 299-308 **(10 pages).**

Nakat, Z.; Dgheim, N.; Ballout, J.; Bou-Mitri, C., (2023). Occurrence and exposure to microplastics in salt for human consumption, are present on the Lebanese market. Food Control. 145: 109414 **(9 pages).**

Nilawati.; Sunarsih.; Sudarno., (2020). Microplastic pollution from sea salt: Its effect on public health and prevention alternatives-a review. E3S Web Conf., 202: 06018 **(10 pages).**

Noda, I.; Dowrey, A.E.; Haynes, J.L.; Marcott, C., (2007). Group Frequency Assignments for Major Infrared Bands Observed in Common Synthetic Polymers. J. E. Mark (Ed.). Phys. Prop. Polym. Handb. Springer New York., 395–406 **(12 pages).**

Pedrotti, M.L.; Petit, S.; Elineau, A.; Bruzaud, S.; Crebassa, J.-C.; Dumontet, B.; Martí, E.; Gorsky, G.; Cózar, A., (2016). Changes in the floating plastic pollution of the Mediterranean Sea in relation to the distance to land. PLoS One. 11(8): 1-14 **(14 pages).**

Possatto, F.E.; Barletta, M.; Costa, M.F.; Ivar do Sul, J.A.; Dantas, D.V., (2011). Plastic debris ingestion by marine catfish: An unexpected fisheries impact. Mar. Pollut. Bull., 62(5): 1098–1102 **(5 pages).**

Priya, A.; Anusha, G.; Thanigaivel, S.; Karthick, A.; Mohanavel, V.; Velmurugan, P.; Balasubramanian, B.; Ravichandran, M.; Kamyab, M.; Kirpichnikova, I.M.; Chelliapan, S., (2023). Removing microplastics from wastewater using leading-edge treatment technologies: a solution to microplastic pollution—a review. Bioprocess Biosyst Eng 46; 309–321 **(13 pages).**

Pushparaj, K.; Liu, W. C.; Meyyazhagan, A.; Orlacchio, A.; Pappusamy, M.; Vadivalagan, C.; Robert, A. A.; Arumugam, V. A.; Kamyab, H.; Klemeš, J. J.; Khademi, T.; Mesbah, M.; Chelliapan, S.; Balasubramanian, B., (2022). Nano- from nature to nurture: A comprehensive review on facets, trends, perspectives, and sustainability of nanotechnology in the food sector. Energy., 240; 122732 **(15 pages).**

Qiao, R.; Deng, Y.; Zhang, S.; Wolosker, M.B.; Zhu, Q.; Ren, H.; Zhang, Y., (2019). Accumulation of different shapes of microplastics initiates intestinal injury and gut microbiota dysbiosis in the gut of zebrafish. Chemosphere., 236: 124334 **(12 pages).**

Rainieri, S.; Barranco, A., (2019). Microplastics, a food safety issue? Trends Food Sci. Technol., 84: 55–57 **(3 pages).**

Rakib, M.R.J.; Al Nahian, S.; Alfonso, M.B.; Khandaker, M.U.; Enyoh, C.E.; Hamid, F.S.; Alsubaie, A.; Almalki, A.S.A.; Bradley, D.A.; Mohafez, H.; Islam, M.A., (2021). Microplastic pollution in salt pans from the Maheshkhali Channel, Bangladesh. Sci.

Rep., 11: 23187 **(10 pages).**
Renzi, M.; Blašković, A. (2018). Litter & microplastics features in table salts from marine origin: Italian versus Croatian brands. Mar. Pollut. Bull., 135: 62–68 **(7 pages).**
Rieux, A.des.; Ragnarsson, E.G.E.; Gullberg, E.; Préat, V.; Schneider, Y.-J.; Artursson, P., (2005). Transport of nanoparticles across an in vitro model of the human intestinal follicle-associated epithelium. Eur. J. Pharm. Sci., 25(4–5): 455–465 **(11 pages).**
Rubio-Armendáriz, C.; Alejandro-Vega, S.; Paz-Montelongo, S.; Gutiérrez-Fernández, Á.J.; Carrascosa-Iruzubieta, C.J.; la Torre, A.H., (2022). Microplastics as Emerging Food Contaminants: A Challenge for Food Safety. Int. J. Environ. Res. Public Health, 19(3): 1174 **(14 pages).**
Sabilillah, A.M.; Palupi, F.R.; Adji, B.K.; Nugroho, A.P., (2023). Health risk assessment and microplastic pollution in streams through accumulation and interaction of heavy metals. Global J. Environ. Sci. Manage., 9(4): 719-740 **(22 pages).**
Samimi, M.; Mohammadzadeh, E.; Mohammadzadeh, A., (2023). Rate enhancement of plant growth using Ormus solution: optimization of operating factors by response surface methodology. Int. J. Phytoremediation, 1-7 **(7 pages).**
Samimi, M.; Shahriari-Moghadam, M., (2023). The Lantana camara L. stem biomass as an inexpensive and efficient biosorbent for the adsorptive removal of malachite green from aquatic environments: kinetics, equilibrium and thermodynamic studies. Int. J. Phytoremediation, 25(10): 1-9 **(9 pages).**
Selvam, S.; Manisha, A.; Venkatramanan, S.; Chung, S.Y.; Paramasivam, C.R.; Singaraja, C., (2020). Microplastic presence in commercial marine sea salts: A baseline study along Tuticorin Coastal salt pan stations, Gulf of Mannar, South India. Mar. Pollut. Bull., 150: 110675 **(7 pages).**
Seth, C.K.; Shriwastav, A., (2018). Contamination of Indian sea salts with microplastics and a potential prevention strategy. Environ. Sci. Pollut. Res., 25: 30122–30131 **(10 pages).**
Siddique, M.A.M.; Uddin, A.; Bhuiya, A.; Rahman, S.Md.A.; Kibria, G., (2023). Occurrence, spatial distribution, and characterization of microplastic particles in the salt pans from the Southeastern part of the Bay of Bengal. Reg. Stud. Mar. Sci., 61: 102846 **(10 pages).**
Song, Y.K.; Hong, S.H.; Jang, M.; Kang, J.-H.; Kwon, O.Y.; Han, G.M.; Shim, W.J., (2014). Large Accumulation of Micro-sized Synthetic Polymer Particles in the Sea Surface Microlayer. Environ. Sci. Technol., 48(16): 9014–9021 **(8 pages).**
Stock, V.; Böhmert, L.; Lisicki, E.; Block, R.; Cara-Carmona, J.; Pack, L.K.; Selb, R.; Lichtenstein, D.; Voss, L.; Henderson, C.J.; Zabinsky, E.; Sieg, H.; Braeuning, A.; Lampen, A., (2019). Uptake and effects of orally ingested polystyrene microplastic particles in vitro and in vivo. Arch. Toxicol., 93: 1817–1833 **(17 pages).**
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: A case study in Benoa Bay, Bali, Indonesia. Mar. Pollut. Bull., 163: 111979 **(14 pages).**
Sutherland, W.J.; Atkinson, P.W.; Butchart, S.H.M.; Capaja, M.; Dicks, L.V.; Fleishman, E.; Gaston, K. J.; Hails, R.S.; Hughes, A.C.; Le Anstey, B.; Le Roux, X.; Lickorish, F. A.; Maggs, L.; Noor, N.; Oldfield, T. E. E.; Palardy, J. E.; Peck, L. S.; Pettorelli, N.; Pretty, J.; Spalding, M. D.; Tonneijck, F. H.; Truelove, G.; Watson, J. E. M.; Wentworth, J.; Wilson, J. D.; Thornton, A., (2022). A horizon scan of global biological conservation issues for 2022. Trends Ecol. Evol., 37(1): 95—104 **(10 pages).**
Syakti, A.D.; Bouhroum, R.; Hidayati, N.V.; Koenawan, C.J.; Boulkamh, A.; Sulistyo, I.; Lebarillier, S.; Akhlus, S.; Doumenq, P.; Wong-Wah-Chung, P., (2017). Beach macro-litter monitoring and floating microplastic in a coastal area of Indonesia. Mar. Pollut. Bull., 122(1–2): 217–225 **(9 pages).**
Tang, Y.; Zhang, S.; Su, Y.; Wu, D.; Zhao, Y.; Xie, B., (2021). Removal of microplastics from aqueous solutions by magnetic carbon nanotubes. Chem. Eng. J., 406: 126804 **(11 pages).**
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 J. Environ. Sci. Manag., 8(2): 183-196 **(14 pages).**
Tibbetts, J., (2015). Managing marine plastic pollution: Policy initiatives to address wayward waste. Environ. Health Perspect., 123(4): A90–A93 **(4 pages).**
UNEP, (2016). Marine plastics debris and microplastics Global lessons and research to inspire action and guide policy change.
Vidyasakar, A.; Krishnakumar, S.; Kumar, K.S.; Neelavannan, K.; Anbalagan, S.; Kasilingam, K.; Srinivasalu, S.; Saravanan, P.; Kamaraj, S.; Magesh, N.S., (2021). Microplastic contamination in edible sea salt from the largest salt-producing states of India. Mar. Pollut. Bull., 171: 112728 **(6 pages).**
Waring, R.H.; Harris, R.M.; Mitchell, S.C., (2018). Plastic contamination of the food chain: A threat to human health? Maturitas., 115: 64–68 **(5 pages).**
WHO, (2012). Guideline: Sodium intake for adults and children. World Health Organization., **(56 pages).**
Yang, D.; Shi, H.; Li, L.; Li, J.; Jabeen, K.; Kolandhasamy, P., (2015). Microplastic Pollution in Table Salts from China. Environ. Sci Technol., 49(22): 13622–13627 **(6 pages).**
Yaranal, N. A.; Kumari, S.; Narayanasamy, S.; Subbiah, S., (2020). An analysis of the effects of pressure-assisted osmotic backwashing on the high recovery reverse osmosis system. J. Water Supply Res. Technol. – Aqua., 69(3); 298–318 **(21 pages).**
Yuan, Z.; Nag, R.; Cummins, E., (2022). Human health concerns regarding microplastics in the aquatic environment - From marine to food systems. Sci. Total Environ., 823: 153730 **(19 pages).**
Zhang, K.; Shi, H.; Peng, J.; Wang, Y.; Xiong, X.; Wu, C.; Lam, P.K.S., (2018). Microplastic pollution in China's inland water systems: A review of findings, methods, characteristics, effects, and management. Sci. Total Environ., 630: 1641–1653 **(13 pages).**
Zhang, Q.; Xu, E.G.; Li, J.; Chen, Q.; Ma, L.; Zeng, E.Y.; Shi, H., (2020). A Review of Microplastics in Table Salt, Drinking Water, and Air: Direct Human Exposure. Environ. Sci Technol., 54(7): 3740–3751 **(12 pages).**
Zhao, X.; Wang, J.; Yee Leung, K.M.; Wu, F., (2022). Color: An Important but Overlooked Factor for Plastic Photoaging and Microplastic Formation. Environ. Sci Technol., 56(13): 9161–9163 **(3 pages).**

AUTHOR (S) BIOSKETCHES

Syamsu, D.A., M.Si., [1]Department of Chemistry, Faculty of Mathematics and Natural Science, Andalas University, Padang, Indonesia. [2]Indonesian Food and Drug Authority (FDA), Jambi, Indonesia.
- Email: *desmita.adriani@pom.go.id*
- ORCID: 0009-0006-6437-2905
- Web of Science ResearcherID: NA
- Scopus Author ID: NA
- Homepage: https://jambi.pom.go.id/

Deswati, D., Dr., Professor., Department of Chemistry, Faculty of Mathematics and Natural Science, Andalas University, Padang, Indonesia.
- Email: *deswati@sci.unand.ac.id*
- ORCID: 0000-0002-8655-9838
- Web of Science ResearcherID: AAC-6589-2021
- Scopus Author ID: 55682368600
- Homepage: http://kimia.fmipa.unand.ac.id/sivitas/dosen/166-deswati

Syafrizayanti, S., Dr. Rer.Nat., Associate Professor, Department of Chemistry, Faculty of Mathematics and Natural Science, Andalas University, Padang, Indonesia.
- Email: *deswati@sci.unand.ac.id*
- ORCID: 0000-0002-4896-2722
- Web of Science ResearcherID: AAE-8090-2021
- Scopus Author ID: 56017949100
- Homepage: http://kimia.fmipa.unand.ac.id/sivitas/dosen/189-dr-rer-nat-syafrizayanti

Putra, A., Ph.D. Candidate, Department of Medical Laboratory Technology, Syedza Saintika College of Health Sciences, Padang, Indonesia.
- Email: *adewirliputra@gmail.com*
- ORCID: 0000-0001-6500-6241
- Web of Science ResearcherID: HLV-6865-2023
- Scopus Author ID: 57849105300
- Homepage: https://syedzasaintika.ac.id/web/adewirli/

Suteja, Y., Dr., Department of Marine Science, Faculty of Marine and Fisheries, Udayana University, Bali, Indonesia.
- Email: *yuliantosuteja@unud.ac.id*
- ORCID: 0000-0002-7824-5177
- Web of Science ResearcherID: AAP-5075-2020
- Scopus Author ID: 57201496119
- Homepage: https://fkp.unud.ac.id/pages/view/yulianto-suteja-s-kel-m-si

HOW TO CITE THIS ARTICLE

Syamsu, D.A.; Deswati, D.; Syafrizayanti, S.; Putra, A.; Suteja, Y., (2024). Presence of microplastic contamination in table salt and estimated exposure in humans. Global J. Environ. Sci. Manage., 10(1) 205-224.

DOI: 10.22034/gjesm.2024.01.14

URL: https://www.gjesm.net/article_707785.html