HEALTH RISK AND ECOLOGICAL RISK ASSESSMENT FROM MICROPLASTIC CONTAMINATION IN SEA SALT : CASE STUDY IN BAN LAEM SALT FIELD, PHETCHABURI, THAILAND

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A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Science in Industrial Toxicology and Risk Assessment
Department of Environmental Science
Faculty Of Science
Chulalongkorn University
Academic Year 2023

การประเมินความเสี่ยงทางสุขภาพและระบบนิเวศจากการปนเปื้อนไมโครพลาสติกในเกลือทะเล : กรณีศึกษานาเกลือบ้านแหลม จังหวัดเพชรบุรี ประเทศไทย

น.ส.กุสุมาลย์ พรหมดนตรี

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
สาขาวิชาพิษวิทยาอุตสาหกรรมและการประเมินความเสี่ยง ภาควิชาวิทยาศาสตร์สิ่งแวดล้อม
คณะวิทยาศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย
ปีการศึกษา 2566

Thesis Title	HEALTH RISK AND ECOLOGICAL RISK ASSESSMENT FROM MICROPLASTIC CONTAMINATION IN SEA SALT : CASE STUDY IN BAN LAEM SALT FIELD, PHETCHABURI, THAILAND
By	Miss Kusuman Promdontree
Field of Study	Industrial Toxicology and Risk Assessment
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กุสุมาลย์ พรหมดนตรี : การประเมินความเสี่ยงทางสุขภาพและระบบนิเวศจากการปนเปื้อนไมโครพลาสติกในเกลือทะเล: กรณีศึกษานาเกลือบ้านแหลม จังหวัดเพชรบุรี ประเทศไทย. (HEALTH RISK AND ECOLOGICAL RISK ASSESSMENT FROM MICROPLASTIC CONTAMINATION IN SEA SALT : CASE STUDY IN BAN LAEM SALT FIELD, PHETCHABURI, THAILAND) อ.ที่ปรึกษาหลัก : ผศ. ดร.วรพจน์ กนกกันฑพงษ์

ไมโครพลาสติกเป็นพลาสติกขนาดเล็กที่แพร่กระจายอยู่ในสิ่งแวดล้อมทั้งบนบกและในน้ำทั่วทุกแห่ง ในงานวิจัยนี้ทำการศึกษาการปนเปื้อนไมโครพลาสติกในเกลือทะเลที่ผลิตจากนาเกลือแบบดั้งเดิมและนาเกลือพลาสติกและในน้ำทะเลที่ใช้เป็นวัตถุดิบในการผลิตเกลือทะเลในนาเกลือบ้านแหลม จังหวัดเพชรบุรี ทำการประเมินความเสี่ยงต่อสุขภาพและระบบนิเวศ เก็บตัวอย่างแบบสุ่มจากเกลือ 2 ชนิด ได้แก่ เม็ดเกลือ และดอกเกลือในนาเกลือทั้ง 2 ประเภท รวมถึงน้ำทะเลทั้งหมด 14 จุด จุดละ 3 ซ้ำ รวมทั้งหมด 42 ตัวอย่าง ใช้สารละลายโซเดียมคลอไรด์ 5 โมลาร์ ในการแยกความหนาแน่น และย่อยสารอินทรีย์โดยใช้เฟอร์รัสซัลเฟต 0.05 โมลาร์ และไฮโดรเจนเปอร์ออกไซด์ ร้อยละ 30% จำแนกลักษณะรูปร่างและสีของไมโครพลาสติกโดยใช้กล้องจุลทรรศน์กำลังขยาย 30 เท่า และตรวจสอบจำนวน ขนาด และชนิดพอลิเมอร์ของไมโครพลาสติกด้วยเทคนิคไมโครฟูเรียร์ทรานส์ฟอร์มอินฟราเรดสเปกโตรสโคปี (µFTIR) ผลการศึกษาพบไมโครพลาสติกปนเปื้อนในเกลือทะเลที่ผลิตจากนาเกลือดั้งเดิมดังนี้ เม็ดเกลือ 424 (186-642) ชิ้น/กิโลกรัม, ดอกเกลือ 415 ชิ้น/กิโลกรัม และเกลือทะเลที่ผลิตจากนาเกลือพลาสติกมีปริมาณการปนเปื้อนไมโครพลาสติกดังนี้ เม็ดเกลือ 273 (145-533) ชิ้น/กิโลกรัม ดอกเกลือ 540 ชิ้น/กิโลกรัม และพบการปนเปื้อนไมโครพลาสติกในน้ำทะเล 166 (18-456) ชิ้น/ลิตรโดยรูปร่างของไมโครพลาสติกที่พบคือ แบบเศษและแบบเส้นใย สีของไมโครพลาสติกที่พบมากที่สุดคือ สีน้ำเงินและสีใส ขนาดของไมโครพลาสติกที่พบอยู่ในช่วง 16-100 ไมโครเมตรเป็นส่วนใหญ่ รองลงมาคือ 101-500 ไมโครเมตร ชนิดของไมโครพลาสติกที่พบได้แก่ โพลีเอไมด์ โพลีเอทิลีน โพลีโพรไพลีน โพลีไวนิลอะซีเตท โพลีสไตรีน โพลีไวนิลคลอไรด์ และโพลีเอทิลีนความหนาแน่นสูง ผลการศึกษายังบ่งชี้ว่าช่วงอายุที่อาจได้รับสัมผัสไมโครพลาสติกจากการบริโภคเกลือทะเลสูงที่สุดคือในเพศชายที่มีช่วงอายุ 16-18 ปี ซึ่งมีปริมาณการรับสัมผัสไมโครพลาสติกเฉลี่ย 905.20 ชิ้นต่อคนต่อปี ค่าความเสี่ยงของสารอันตรายจากไมโครพลาสติกที่ปนเปื้อนในเกลือทะเลพบว่า เกลือทะเลที่ผลิตจากนาเกลือทั้ง 2 ชนิด มีค่าความเสี่ยงอยู่ในระดับที่ 2 ผลการประเมินดัชนีภาระมลพิษรวม (PLI_{zone}) ของน้ำทะเลมีค่าเท่ากับ 2.15 อยู่ในความเสี่ยงระดับที่ 1 หรือความเป็นพิษต่ำ การประเมินความเสี่ยงต่อระบบนิเวศ (PER) ของไมโครพลาสติกมีค่าเท่ากับ 14.99 อยู่ในระดับต่ำ การศึกษานี้ชี้ให้เห็นถึงระดับของการปนเปื้อนไมโครพลาสติกที่อาจส่งผลกระทบต่อผู้บริโภคเกลือทะเล ซึ่งผู้ผลิตเกลือทะเลรวมถึงผู้กำหนดนโยบายสามารถนำข้อมูลไปใช้เพื่อหาวิธีลดการปนเปื้อนไมโครพลาสติกในเกลือทะเลที่ใช้บริโภคต่อไป

สาขาวิชา	พิษวิทยาอุตสาหกรรมและการประเมินความเสี่ยง	ลายมือชื่อนิสิต ....
ปีการศึกษา	2566	ลายมือชื่อ อ.ที่ปรึกษาหลัก ....

6470080823 : MAJOR INDUSTRIAL TOXICOLOGY AND RISK ASSESSMENT
KEYWORD:

Kusuman Promdontree : HEALTH RISK AND ECOLOGICAL RISK ASSESSMENT FROM MICROPLASTIC CONTAMINATION IN SEA SALT : CASE STUDY IN BAN LAEM SALT FIELD, PHETCHABURI, THAILAND. Advisor: Asst. Prof. VORAPOT KANOKKANTAPONG, Ph.D.

Microplastics are ubiquitous in all terrestrial and aquatic environments. In this research, microplastic contamination in sea salt produced from traditional and plastic salt fields was studied. Including seawater used as a raw material for producing sea salt in Ban Leam salt fields, Phetchaburi, Thailand. Random samples were collected 3 replicates per point, for a total of 42 samples. 5M NaCl solution was used to separate the density and digest the organic substances using 0.05 M Fe (II) and 30% H_2O_2. The shape and color of the microplastics were characterized using a 30x magnification microscope. The amount, size, and polymer type of microplastics were examined using the micro-Fourier transform Infrared spectroscopy (µFTIR) The results of the study found microplastic contamination in sea salt produced from traditional salt fields as follows: Salt grains 424 (186-642) particles/kg, Salt flower 415 particles/kg, and sea salt produced from plastic salt field has the following amounts of microplastic contamination: salt grains 273 (145-533) particles/kg, Salt flower 540 particles/kg and seawater 166 (18-456) particles/L. The common microplastic shapes were fragments and fibers. The most common colors were blue and transparent. The size of microplastics found ranges from 16-100 µm, followed by 101-500 µm. Types of microplastic polymers found include polyamide (PA), polyethylene (PE), polypropylene (PP), polyvinyl acetate (PVA), polystyrene (PS), polyvinyl chloride (PVC), high density polyethylene (HDPE). The results of the study also indicate the age group that may be most exposed to microplastics from sea salt consumption was between the ages of 16 -18 years in males, which has an average exposure microplastics of 905.20 particles/person/year. The risk of hazardous substances from microplastics contaminated in sea salt was found at risk level 2. The ecological risk assessment found that the Pollution load index of microplastic concentration in seawater raw material was level I, low toxic (PLI = 2.15), and the potential ecological risk of microplastics concentration in seawater raw material was at the minor level (PER = 14.99). This study points to the level of microplastic contamination that may affect consumers of sea salt. Manufacturers and policymakers can use this information to find ways to reduce microplastic contamination in sea salt.

Field of Study:	Industrial Toxicology and Risk Assessment	Student's Signature ....
Academic Year:	2023	Advisor's Signature ....

ACKNOWLEDGEMENTS

All praise be to God, Jesus the lord of all things, the glorious, the merciful.

First, I would like to thank my advisor Ass. Prof. Dr. Vorapot kanokkantapong for his kindness, and valuable experience as a master's degree student and also overall teacher that encourage me throughout the study.

I would also like to give thanks to my committee and examiner: Ass. Prof. Dr. Sarawut Srithongouthai, Ass. Prof. Dr. Sumeth Wongkiew, Ass. Prof. Dr. Manaporn Wongsoonthornchai,

Secondly, I would like to extend Dr. Pathompong Vibhatabandhu, Researcher in laboratory, Chulalongkorn University for his selfless advice and assistance throughout the research.

Finally, My family and siblings for their prayer and sacrifice, and many best friends that always support me, especially Dr. Ekarat Sombatsawat, Mr. Surakit Klinthong who have been through and helped me almost all the time during my master study.

Kusuman Promdontree

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INTRODUCTION

1.1 Background

The world's oceans and seas have been full of an abundance of floating plastic debris and the oceans are receiving an increasing amount of plastic waste approximately 4.8-12.7 million tons annually (Haward, 2018). Thailand ranks as the sixth-largest manufacturer of plastic garbage globally (Jambeck et al., 2015) according to the Plastic Waste Management Subcommittee (2018) by generating and utilizing more than 45,000 million plastic bags annually. 517,054 tons of plastic waste accumulated in 2017 were plastic bags, single-use cups, straws, and styrofoam food containers which this plastic trash accumulates and increases in quantity each year.

Microplastics are plastics smaller than 5 millimeters in size. Currently, microplastics are proliferating and contaminating the environment. Microplastics can be divided into two groups, primary microplastics and secondary microplastics. First, primary microplastic contamination in nature occurs from the use of products containing microplastics, such as the use of skin care products, exfoliating creams, liquid soap for showers, facial cleansers, surface cleaners, or direct utilization of microplastic granules or products made from diverse types of plastic. Second, secondary microplastics are plastics used in daily life that generally break down to less than 5 mm in size and contaminate the environment. The incidence and contamination rate in nature of secondary microplastics depends on various factors in nature causing the reduction of the size of the plastic, the duration of which is different. Although the methods of contaminating the nature of the two types of microplastics are different, it has been found that naturally contaminated microplastics eventually accumulate in natural surface water sources, i.e., rivers, canals, and eventually converge in the seas and/or oceans (Li et al., 2018).

"Salt" is one factor that plays an important role in human life historically and currently. Humans need to use salt for ingestion and consumption whether it is utilized in food preparation, food preservation, or medication. Furthermore, salt is an important basic element that is required by the human body to maintain water balance and aid in metabolism. Thailand has an estimated salt farming area of 81,485 rai. Phetchaburi province currently has the largest area (47.0 %), followed by Samut Sakhon (43.1 %), Samut Songkhram (7.7 %), Chonburi (1.0 %), Chanthaburi (0.6 %), Pattani (0.4 %), and Chachoengsao (0.2 %). The process of manufacturing sea salt, which involves pumping seawater into salt fields, relies on the wind and heat from the sun to help evaporate the water and concentrate the brine to a certain level. This will crystallize the salt. The main products from salt fields are salt flowers and salt grains which can be consumed. Unfortunately, the salt might additionally contain microplastics. Vidyasakar at el. (2021) investigated the presence of microplastics in table salt in India's largest salt-producing state. It found that Gujarat had a number of microplastics ranging from 46 to 115 particles per 200 g of salt. In the state of Tamil Nadu, polyethylene, polyester, and polyvinyl chloride were the most common microplastics derived from marine salt production units (Vidyasakar et al., 2021).

Considering the World Health Organization's recommendations on the amount of sodium that is appropriate for the body to maintain fluid balance in the human should not be greater than 2,000 milligrams per day. It was discovered to be equivalent to a daily salt intake of about 5 g (Danopoulos et al., 2020; Lee et al., 2021). The average person consumes 9-12 grams of salt per day, which is more than double the recommended amount. This means if the salt products consumed by people are contaminated with microplastics, they will be harmful to the human body.

Consequently, the aims of this research are to examine microplastics in salt fields produced in the Ban Laem district, Phetchaburi Province, which produces the most salt in Thailand and then perform health and environmental risk assessments to increase awareness about the critical situation of microplastic pollution in the sea. This might lead to the contamination of table salt as well. It was information that may be utilized to find ways to prevent these contaminations prior to potentially serious consequences for human health and the environment in the future.

1.2 Objectives

1.2.1 To determine the amount and compare of microplastics in unrefined sea salt produced from traditional and plastic salt field processes in Ban Laem district, Phetchaburi province.

1.2.2 To analyze the type, size, shape, and color of microplastics found in unrefined sea salt produced from traditional and plastic salt field processes in Ban Laem district Phetchaburi Province.

1.2.3 To evaluate the health risks associated with microplastic contaminated salt consumption and evaluation of the ecological risk posed by microplastic contaminated in seawater raw materials.

1.3 Definition

1.3.1 Sea salt is salt made from seawater by pumping seawater into the trap in the fields relies on wind and heat from the sun's rays to help evaporate the water, concentrating the brine to a certain level.

1.3.2 Salt flowers are salt crystals which float on the water's surface. The appearance is light, clean, and pure, as well as the sodium chloride level is lower than normal. It has a mild taste that is not excessively salty.

1.3.3 Salt grains are salt crystals that are large, thick, short, and indeterminate in shape.

1.3.4 The Ban Laem salt field is a location that is utilized to produce sea salt. By channeling seawater from the Gulf of Thailand into the salt fields, which are located in the Ban Laem District in the Phetchaburi Province.

1.3.5 Traditional salt fields are regions where sea salt is generated by transporting saltwater from the ocean to the land and relying on the heat from the sun to evaporate the water, causing the salt to crystallize.

1.3.6 Plastic salt fields are a salt production area which is produced by channeling seawater onto plastic covered ground. This boosts the temperature so that the salt can evaporate and crystallize more quickly. The resultant salt is small and clean.

1.3.7 Health risk assessment examines the chance that danger in a community will have an adverse impact on the health of its residents.

1.3.8 Environmental risk assessment refers to the evaluation of the chance that microplastic pollution in plastic salt fields will have an adverse effect on the environment.

1.4 Research outcome

1.4.1 The microplastic content of sea salt can be used to evaluate its influence on human health and the environment.

1.4.2 The information from this work can be utilized for assessing the cause of the problem and to be aware of microplastic pollution in the environment.

CHAPTER 2

THEORETICAL BACKGROUND

2.1 Sea salt

2.1.1 Explanation

The salt produced from seawater is known as sea salt. The brine is concentrated to a certain degree by pumping seawater into rice field traps and relying on wind and solar radiation to evaporate water. The salt will initiate crystallization. The provinces of Samut Songkhram, Samut Prakan, Samut Sakon, Chonburi, and Phetchaburi produce sea salt.

2.1.2 Chemical characteristics of salts

Table salt or sodium chloride (NaCl) are salt particles. NaCl is a transparent, colorless solid composed of cubic crystals. As a result of sodium ions and Ionic bonds, chloride ions are bound together by chemical bonds (bonds formed by electrical attraction). Static exists between positive and negative ions because of electron transfer.

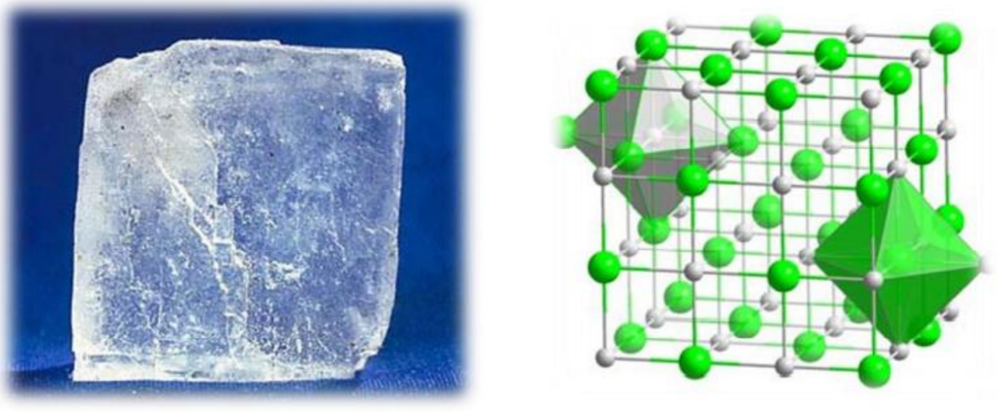


Figure 2.1 Structure of sodium chloride

The structure of sodium chloride comprises sodium ions and chloride ions organized in alternate rows to form a mesh structure. Each ion is surrounded by six ions with opposite charges. This structure is regarded as the fundamental structure present in numerous minerals. General characteristics of sodium chloride, or table salt, include an atomic weight of 5,834 specific gravity with a point of 2.165 It has a melting point of 800.8 °C, a boiling temperature of 1465 °C, and a freezing point of 21.12 °C for brine.

2.2 Alternative Sources of Salt in Thailand

2.2.1 Rock salt is generated from the layers of soil and rock. It has three antecedents:

2.2.1.1 Soil surface salt deposition as the soil is dissolved in water, it turns salty.

2.2.1.2 Saline wells or groundwater sources are formed when surface water flows through the rock salt mineral layer and dissolves salt, resulting in the formation of wells. The application of salt water can be accomplished by pumping up the water.

2.2.1.3 Layer of subterranean rock salt drill a hole into the rock layer and squeeze water to dissolve the rock salt minerals to obtain salt. The saltwater is subsequently pumped up for usage. The brine can be sun dried or cooked to evaporate the water to produce salt. until the salt saturation point the ions of salt will crystallize. Rock salt is produced in the northeastern region, which includes Chaiyaphum, Maha Sarakham, Yasothon, Ubon Rattanaburi, and Udon Thani, as well as the northern region, which includes Bo Kluea, Nan, etc.

2.2.2 Plastic salt fields are a concept native to Korea. Due to the topography of Korea, salt farming is infrequent. Hence, a request was made to hire a farmer who cultivates plastic salt farms. Identifiable features of plastic salt fields the salt fields have been covered with black plastic. To prevent air from getting beneath the plastic on the ridge by placing it over the ridge to avoid soil erosion, it must be tight and smooth. Putting the plastic increases the temperature. Hence, crystallization is accelerated. The size of salt grains is tiny.

2.3 Major Salt Production Regions in Thailand

As a raw material, seawater is necessary for the manufacturing of sea salt. Thus, the producing source must be near the coast. Despite Thailand's 2,600 kilometers of coastline, only a few sources are suitable for sea salt production. The landscape must be flat. The type of soil must be clay. Absorbs water efficiently and prevents salt water from reaching the soil. and prevent the infiltration of fresh water into the soil wind and sunlight contribute to the crystalline form of salt. The major sources of production were divided into two groups:

2.3.1 The group with the highest output, accounting for approximately 90.0 percent of total output, was concentrated in three central provinces: Phetchaburi, Samut Sakhon, and Samut Songkhram.

2.3.2 The small production groups, accounting for about 10% of total production in the country, are located in four provinces in the central and southern regions, namely Chonburi, Chanthaburi, Chachoengsao, and Pattani. Thailand has a total salt farming area of about 81,485 rai, with 47.0% in Phetchaburi Province, 43.1% in Samut Sakhon Province, 7.7% in Samut Songkhram Province, 1.0% in Chonburi Province, 0.6% in Chanthaburi Province, 0.4% in Pattani Province, and 0.2% in Chachoengsao Province.

2.4 Principles of sea salt manufacturing

Crystallization is a chemical process used to purify compounds by separating solids from liquids. It is used to separate solids from liquids in the manufacturing of table salt, or sodium chloride, from seawater. Using a compound's solubility in water or saturation point, which decreases as the temperature rises, Solubility decreases These compounds separate from the solution to form solids with geometric shapes known as crystals but must have varied solubility.

2.5 Types of Chemical Compounds of Crystallized Sea Salt

Salt production ionized particles can be found in seawater. which includes positive ions like sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), and magnesium (Mg^{2+}) as well as negative ions like chloride (Cl^-) and sulfate (SO_4^{2-}). When exposed to sunlight, burn until the water evaporates into steam, and the sea becomes more concentrated. Ions of various elements that are less soluble to the point where they cannot be dissolved will clump together and crystallize first. In salt fields, three important crystallizing compounds exist: gypsum ($CaSO_4$), table salt ($NaCl$), and epsom salt ($MgSO_4$)

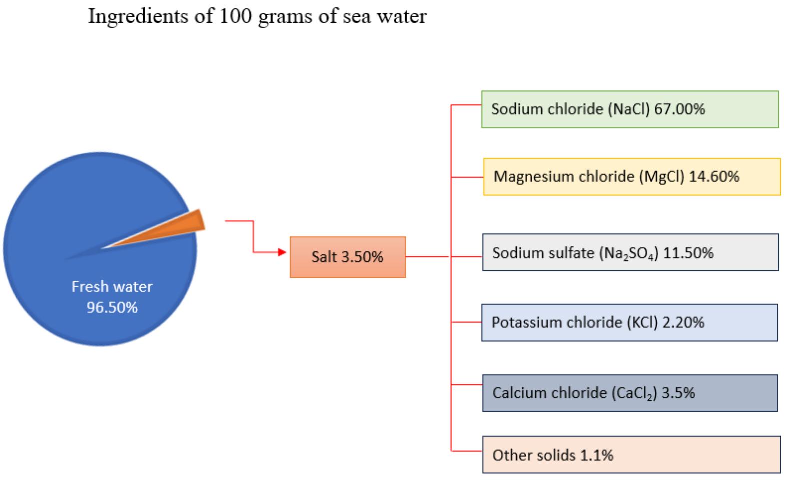


Figure 2.2 100 grams of seawater components

2.5.1 Unsalted salt or gypsum ($CaSO_4$) has the lowest water solubility. It crystallizes in the sterile media, which contains 20 to 25 degrees of salinity. Salt farmers like to utilize unsalted salt to create chalk powder. Chalk is used to write on blackboards, as an ingredient in toothpaste, etc.

$$Ca^{2+}\,(aq) + SO_4{}^{2-}\,(aq) \longrightarrow CaSO_4(s) \qquad (2.1)$$

2.5.2 Table salt (NaCl) crystallizes during seawater salinity at 25 degrees. It looks like a translucent cube. The table salt grains have 2 genders, namely male salt, shaped like a long, sharp grain. It is popular to mix drugs to sweep the throat of children. believed to have anti croup effects (fever) and female salt. It has a square shape and can be used for consumption, pickling, as well as being an ingredient in various industries.

$$Na^{2+}\,(aq) + Cl^{-}\,(aq) \longrightarrow NaCl(s) \qquad (2.2)$$

2.5.3 Epsom salt ($MgSO_4$) is a salt that tastes bitter and salty. This salt crystallizes at salinities greater than or equal to 27 degrees. It resembles a sharp needle. The salt farmers would be dissatisfied because allowing the salt fields to have a high amount of salt until the salt crystallized would result in poor grade table salt that became damp easily. consistently into the field to prevent saltiness Epsom salts, however, have therapeutic effects. It is a laxative, a medicine for constipation, and a parasite treatment.

$$Mg^{2+}\,(aq) + SO_4{}^{2-}\,(aq) \longrightarrow MgSO_4(s) \qquad (2.3)$$

2.6 Production of salt

The season for salt farming begins in October. The initial step is field preparation. By leveling the land and reinforcing the salt farm ridge, create channels for water to easily flow between the shallow fields. The minimum acreage required for salt farming is 25 rai, as drying water requires a great deal of space. There will be little salt fields scattered throughout the salt fields. Upon the arrival of November. At this time, the rains begin to halt or end, and salt farmers begin to transfer water from the fields, which is a plot used to collect seawater from the canal to provide water for salt farming, into the field. The water will then be pushed into the sterile field to gently increase salinity and remove contaminants. It is a plot of land used to allow water to be exposed to the sun and gradually evaporate. It is a time in which the salinity of the ocean increases. The level of salt salinity at which crystallization is possible is 22 to 25 degrees, which is close to the saturation point. When seawater has the appropriate salinity for crystallization, salt farmers refer to this process as salt culture. Salt farmers will drain the water into the fields. It is a place where saltwater concentration is so high that it crystallizes into salt tablets. Before extracting the salt from the salt heap, the salt farmer would allow it to crystallize for around 9-10 days on the field. and scooped the salt into the bucket before transporting it to the salt barn to dry and be prepared for sale. The harvested table salt will yield between four and nine tons per rai, or between two and six kilograms per square meter of salt field.

2.7 Benefits of Salt

The requirement for salt refers to the necessity for food consumption; the remainder consists of salt's requirements and saltiness.

2.7.1 Food preservation

Salt is used to pickle vegetables, fruits, eggs, and even meat. to extend the shelf-life of food the salt will aid in inhibiting the growth of spoilage-causing microbes.

2.7.2 Industry of cold storage

Salt has been used to preserve food for ages. Due to the characteristics of salt, adding table salt to ice in a ratio of 1:3 decreases the freezing point of water to -18 degrees Celsius.

2.7.3 Chemical industry

Salt is a precursor to numerous chemicals, including chlorine, caustic soda, and hydrochloric acid.

2.7.4 Cosmetics industry

Salt is utilized in the spa business to manufacture beauty products such as body washes, spa salts, and aromatic salts because it can open pores on the skin. boost the skin's absorption of vitamins and other nutritious ingredients, according to ancient Thai medicine texts Salt is a drug used to treat a wide range of ailments. The iodine compounds in salt, which are used for both disinfection and toothache relief, can help prevent goiter.

2.8 The Development of Plastics

2.8.1 History of Plastics

Nitrocellulose was synthesized in 1856. (nitrocellulose) or Parkesine, a polymeric material the first variety to be produced by reacting cotton with nitric acid. It was first created in the United Kingdom by Alexander Parkes. John Wesley Hyatt later created it after discovering the dissolving of cellulose nitrate. In the presence of heat, it interacts with camphor to produce celluloid, a material that can be shaped using heat and pressure. Bakelite was categorized as a thermoplastic prior to the discovery of a process for creating synthetic phenol formaldehyde resin (phenol formaldehyde resin) or Bakelite by Leo Baekeland in 1907. Bakelite was the world's first truly synthetic plastic. A form of plastic setting with strong resistance to heat, sluggish ignition, and poor heat conduction. Hence, it is frequently utilized as a handle for cooking utensils and various electrical equipment. Moreover, Bakelite may be transformed into a foam that is often used to create buoyancy and to reinforce airplanes. Leo Baekeland's discovery of Bakelite prompted the hunt for a way. The manufacturing of novel synthetic polymers the usage of plastic to create a variety of plastic items has resulted in the continued expansion of the plastics industry.

Beginning in 1926, polyvinyl chloride was developed because of the discovery of new synthetic plastic production techniques during a period of nearly fifty years (1907-1954). (PVC), Polystyrene (PS) was introduced in 1931, followed by polyethylene (PE) in 1933. The introduction of Polyethylene Terephthalate

(Polyethylene Terephthalate: PET) and Polypropylene (Polypropylene: PP) in 1941 and 1954, respectively, led to the industrial manufacture of numerous types of plastics. And manufacture a range of useful objects from this plastic. Plastic that does not absorb water has spread to every country in the world due to its qualities. Temperature, chemical, and microbe infestation resistance. Plastic is also easy to shape and affordable relative to other materials, allowing it to be used in a variety of consumer goods. Since the introduction of plastics into everyday life, the accumulation of plastic trash in the environment has been a global concern. Since many plastic items are disposable, this is the case. When paired with the low cost of manufacturing plastic products. It cannot absorb water due to its physical characteristics. Temperature, chemical, and microbe infestation resistance. resulting in plastic garbage discharge into the environment not susceptible to deterioration or microbial infection. It does not decay rapidly and can persist in nature for centuries. In contrast to other materials, they can last in the environment for an extended period before degrading.

Physical and chemical processes that shatter or rip plastic trash can contribute to its decomposition in the natural environment. This causes plastic waste to deform and shrink to the point where it is no longer identifiable as a large piece of plastic. Plastics are not susceptible to further degradation by microorganisms that produce biochemical changes and return to the elements or substrates used as raw materials due to their resistance to microbial infestation. (For example, cellulose, lignin, and hemicellulose degrade to carbon) The majority of these fragments retain their biodegradability. Microplastics are plastic particles smaller than 5 millimeters in diameter. The global distribution of microplastics in the natural environment, particularly in freshwater and saltwater basins. In addition, it accumulates in plankton, aquatic insects, aquatic plants, and aquatic mammals.

2.9 The origin of microplastics

As mentioned previously, microplastics are polymers smaller than 5 millimeters. Currently, microplastics are pervasive and pollute the ecosystem. The two types of microplastics are primary microplastics and secondary microplastics. Primary microplastics is a plastic pellet that has been manufactured from the outset to be smaller than 5 millimeters. This little plastic granule is used for scrubbing and cleaning. There are microbeads in skin care and body care products like body scrubs, body washes, face washes, and toothpastes. Since the 1980s, it has been patented under the brand name microbeads. Microspheres, microbeads, or scrubs (Fendall et al., 2009; Cole et al., 2011). PE, PP, PET, polymethyl methacrylate (PMMA), and nylon are the most often utilized cleaning products (Gouin et al., 2015; Eriksen et al., 2013). In addition, plastic grit is used in the industrial sector to scrub, clean the surface, polish rust, and remove paint from the metal surface. With an instrument known as an air blasting machine, microbeads comprised of acrylic, melamine, or polyester are utilized multiple times until they are eliminated. Before being released into the environment, microbeads lose their scrubbing capacity. This may result in metal and/or heavy metal contamination of microplastics of various sorts (Cole et al., 2011).

The second group is secondary microplastics. This type of plastic was not initially small but was created by reducing the size of plastic waste in the environment through various processes until the plastic is less than 5 millimeters in diameter; the reduction in plastic size can be caused by a physical process. Biological and chemical processes, such as abrasion, heat, ultraviolet light, enzymes, and oxidation, etc., that cause large pieces of plastic to fracture, tear, and shrink proportionally (macroplastic) As part of the formation of fibrous microplastics, various plastic shapes smaller than 5 millimeters are also present. Small size resulting from slipping or a lack of plastic fibers used in the textile production process, from the washing process, from the tearing of plastic fibers used in daily life in general, including the tearing of plastic fibers of fishing gear such as nets, nets, and fishing line. (Napper et al., 2015)

2.10 Environmental microplastic contamination pathways

Figure 2.3 depicts the paths of microplastic contamination in the environment, which can be divided into two methods based on the source of microplastics, i.e., the most prevalent process of microplastic contamination in nature. and the contamination of secondary microplastics in nature. Microplastics containing skin care products, scrub creams, liquid bath soaps, facial cleansers, and surface cleaners or the direct use of disposable microplastics, such as the use of abrasive plastic beads, or scrubbing the surface to remove dirt. It is a micro drop as well. Large quantities of plastic are released directly into the environment. notably as a result of the use of skin care products and clean the body because it is used in the daily routine of the individual. Consequently, primary microplastics have been continuously dumped into nature for decades.

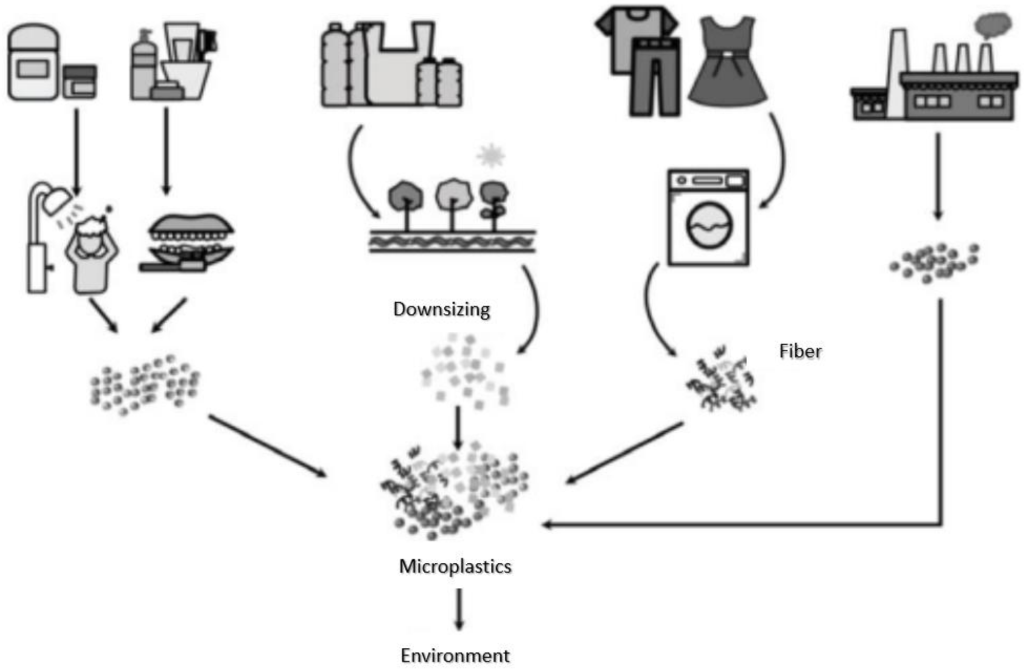


Figure 2.3 The contamination pathway of microplastics in the environment

Whereas secondary microplastic contamination occurs naturally during the reduction process. Large plastic items that are discarded into the environment include containers, bags, plastic fibers, and products made from various types of plastic, including plastic fibers used in the textile manufacturing process from the washing process. Everyday plastic fibers typically degrade to less than 5 millimeters and pollute the environment. When products made from these plastics are discarded into the environment, they shrink due to physical, biological, and chemical processes that cause fracture, tearing, and shrinkage. to become secondary microplastics less than 5 mm in size. The incidence and rate of secondary microplastic contamination in nature are determined by several environmental factors that cause the plastic to shrink. That will be distinctive. Although the two types of microplastics are contaminated differently. Nevertheless, as depicted in Figure 4, naturally contaminated microplastics eventually accumulate in natural surface water sources such as rivers, canals, and ultimately converge in seas and/or oceans (Li et al., 2018).

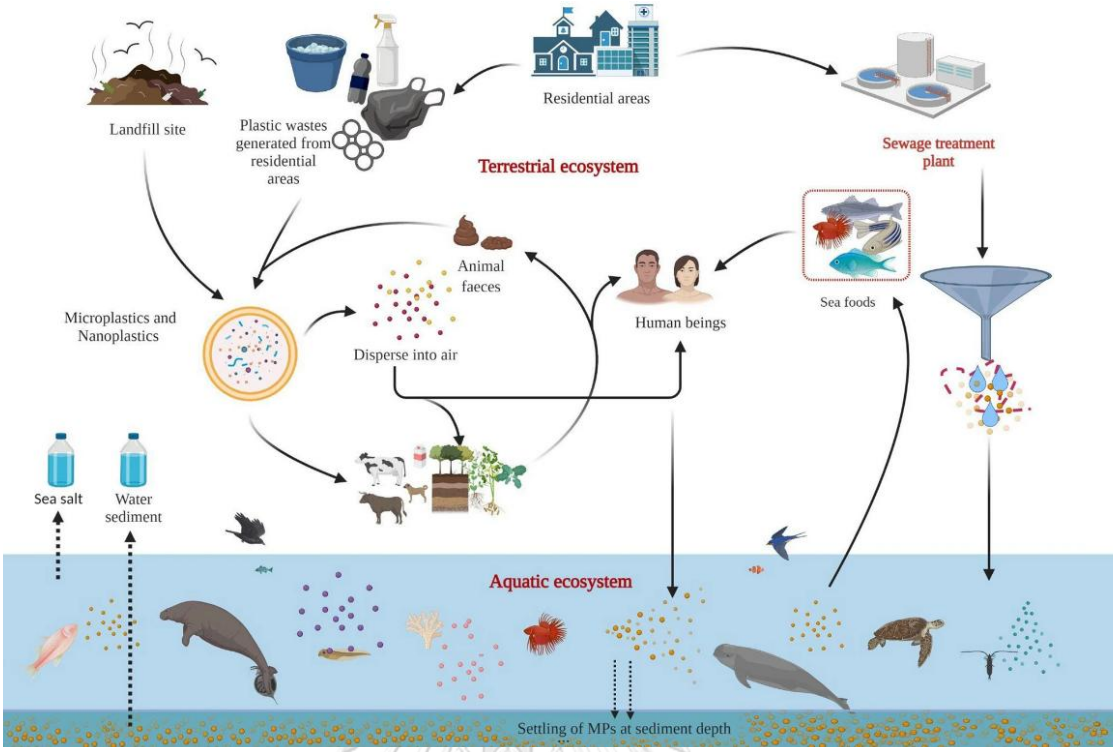


Figure 2.4 Microplastic contamination in water, plants, animals, and humans (Lamichhane et al., 2022).

2.11 The Microplastics Situation in Thailand

Education, calculation, and a concrete report on the quantity of primary microplastics in the environment are lacking in Thailand. and based on estimates from research as well as a variety of body types, the amount of microplastics found in facial cleansing products. According to the findings of Napper et al. (2015), when using facial cleansing products and a body containing microplastics for one time, between 4,594 and 94,500 microplastics will be released into the water. In addition, Gouin et al. (2015) determined that the weight of microplastics contaminating water bodies when the product was used per person per day was 2.4 grams, or roughly 0.877 kilograms per person per year. When this number is multiplied by the population of Thailand in 2019, which is estimated to be around 70 million, it is determined that approximately 50 percent, or 35 million people, will use the product, indicating that microplastics are contaminated. An estimated 30,660 tons of water per year are lost due to the use of microplastic containing products in Thailand for the past 10 to 15 years. Thailand has an abundance of them.

Additionally, Thailand was discovered to be the sixth largest waste plastic waste country in the world (Jambeck et al., 2015). According to the Plastic Waste Management Subcommittee (2018), Thailand produces and uses more than 45 billion plastic bags annually. In 2017, Thailand produced 517,054 tons of plastic waste, including 241,233 tons of single-use plastic cups, 3,873 tons of plastic straws, and 29,248 tons of Styrofoam food containers. For instance, if you estimate the amount of secondary microplastics from plastic waste to be between 5 and 10 percent of total plastic waste in 2017, the amount of secondary microplastics entering the environment is between 39,570.4 and 79,140.8 tons per year. The size can therefore be reduced at any time to become secondary microplastic in the environment.

However, Thailand has conducted several environmental studies on microplastics, the majority of which were conducted in the ocean. For example, contamination of bivalves near beaches with microplastics. Chao Lao and Kung Wiman Beach, Province of Chanthaburi on Chao Lao Beach, microplastics were discovered in snail shells. and Haad Kung, 3.13±2.75 pieces per animal and 2.98±3.12 pieces per animal, respectively. West coast microplastic waste Phuket which concludes the report Microplastics of various sizes, shapes, and types were discovered in Thailand's sediments and marine species. Researchers discovered that fibrous microplastics were the most prevalent. followed by type having no distinct form (Punyauppa, 2020).

2.12 The influence of microplastics on the ecosystem

Microplastics acquire all the properties of each type of plastic, just like large plastics. However, the degradation of plastics has led to the proliferation and contamination of plastics in water, soil, and living organisms on a larger scale. As a result, microplastic contamination is now detectable in many water supplies around the globe (Alencastro, 2012) and also detected micro plastic in aquatic animals such as sea turtles (Duncan et al., 2019), fish (Alshawafi et al., 2018), molluscs, larvae, aquatic insects, and plankton (Setälä et al., 2014), microplastics in seaweed (Besseling et al.,2014)

Also reported are the effects of microplastics on many aquatic organisms. Microplastics inhibit photosynthesis in phytoplankton and algae. In the tissues of aquatic animals and zooplankton, it accumulates. It impacts the respiratory system, digestion, reproduction, and development, leading to abnormal embryo development. Zhang et al. (2017) reported the effect of 1 m PVC polluting water sources. can influence the growth and photosynthesis of Skeletonema costatum. Cole et al. (2013) reported the impact of PS microplastics on Centropages typicus and Calanus helgolandiae. The accumulation of microplastics was discovered in the tissues of plankton.

Table 2.1 *Research summary on microplastic contamination in edible salt (Nur et al., 2022; Altunışık et al., 2023)*

Country	Salt sample type	Extraction	Filter pore (μm)	Abundance (Items/kg)	Dominant type	Detection method	Polymer type	Mps size range (μm)	Reference
Bangladesh	Processed Unprocessed	30 % H_2O_2	5	95 - 220 120 - 320	Fiber (94%) Fiber(79.24%)	Stereomicroscope,FTIR	PET, PP, PE, PS, Nylon	5-5000	As-Ad et al. (2022)
Australia	Processed	17 % H_2O_2	2.7	46	Fragment(67%)	Stereomicroscope,FTIR	PS, PET, PP	100-1000	Kim et al.(2018)
Brazil	Processed	17 % H_2O_2	2.7	24	Fragment(100%)	Stereomicroscope,FTIR	PET, PP	100-1000	Kim et al.(2018)
China	Processed	30 % H_2O_2	5	550 - 680	Fragment	Stereomicroscope,μ-FTIR	PS, PET, PP PB, CP	45-4300	Yang et al.(2015)
Croatia	Processed	UW	0.45	13,500 - 19,800	Fiber (>80%)	Stereomicroscope,μ-FTIR	PP	15-4628	Renzi and Blaskovic, 2018
India	Processed	30 % H_2O_2	0.45	103±39-56±49	Fragments (~63%)	Digital microscope,μ-FTIR	PS, PA, PE, PET	< 2000	Seth and Shriwastav (2018)
Italy	Processed	17 % H_2O_2	2.7	4 - 30	Fragments(50-80%	Stereomicroscope,FTIR	PE, PET, Nylon	100-4000	Kim et al.(2018)
Koria	Processed	17 % H_2O_2	2.7	161.3	Fragments (90%)	Stereomicroscope,FTIR	PE, PP, PET	100-4000	Kim et al.(2018)
Senegal	Processed	17 % H_2O_2	2.7	48	Fragments (62%)	Stereomicroscope,FTIR	PE, PET, PP	100-3000	Kim et al.(2018)
Spain	Processed	UW	5	50 - 280	Fiber	Stereomicroscope,FTIR	PE, PET, PP	30-3500	Iniguez et al,2017

Table 2.2 Research summary on microplastic contamination in edible salt (Nur et al., 2022; Altunışık et al., 2023)

Country	Salt sample type	Extraction	Filter pore (µm)	Abundance (Items/kg)	Dominant type	Detection method	Polymer type	Mps size range	Reference
Taiwan	Processed	UW	5	2.5 - 20	Fragments (93%)	Stereomicroscope, FTIR	PP, PE, PS, PET, PES, PP, PU, PA, PVC	89.7 - 1474.9	Lee et al. (2019)
Turkey	Processed	30% H2O2	0.2	16-84	Fiber (>70%)	Stereomicroscope, Raman spectroscopy	PE, PET, PP, PU, PA, PVC	20 - 5000	Gundogdu et al. (2018)
USA	Processed	17% H2O2	2.7	32	Fragment (100%)	Stereomicroscope, FTIR	PE	100 - 4000	Kim et al. (2018)
Thailand	Unprocessed	30% H2O2	0.2	145 - 642	Fragments (58.53%) Fiber (41.59%)	Stereomicroscope, FTIR	PA, PE, PP, PVA, PS, PVC, HDPE	16 - 1200	This study

*UW- Ultrapure water.

2.13 Health Risk Assessment (HRA)

HRA is the estimation of the probability or opportunity for a person to be simultaneously exposed to one or more environmental hazards. whether to demonstrate the health effects of any level of exposure. The procedure evaluates:

- The composition and kind of the substance
- The potential to cause injury.
- The possible routes of human exposure include direct contact, inhalation of airborne particles, and consumption of food and water.
- How long individuals are exposed and to the extent that they could be exposed.

A health risk assessment's quality is contingent on the precision of the information accessible regarding each of these aspects.

2.14 Translocation of microplastics and nanoplastics

The investigation of the translocation and adverse effects of microplastics and nanoplastics on the human body is currently incomplete. The present comprehension is predominantly founded on laboratory data obtained from various test models. Several studies have found the accumulation of microplastics and nanoplastics in the intestines, with some also detecting these particles in the feces (Schwabl et al., 2019; Cocca et al., 2020). Nanoplastics have demonstrated the ability to effectively penetrate and traverse many biological barriers, such as those found in the colon, lungs, brain, and placenta. Oral exposure to microplastics and nanoplastics results in an accumulation of these particles in the digestive tract, with a portion of them being eliminated (Prüst et al., 2020; Campanale et al., 2020; da Silva Brito et al., 2022). Nanoplastics can cross the barrier between the lumen and blood, moving blood vessels and distant organs. Certain nanoplastics can traverse the blood-brain barrier, leading to their accumulation in the brain. Research conducted on fish has demonstrated that nanoplastics can enter the circulatory system, cross the blood-brain barrier, and accumulating up in the brain. (Guerrera et al., 2021). Furthermore, it has been discovered that nanoplastics can traverse the placental barrier and have been identified in human placentas (Ragusa et al., 2021). The ability of nanoplastics to cause harm to human health is an issue of serious concern. However, there remains a considerable lack of understanding regarding the specific health consequences of both microplastics and nanoplastics on humans; Catarino et al., 2019). The process through which microplastics and nanoplastics were transported within animals and related their transport to multiple adverse impacts on organs. These effects occur when animals are exposed to microplastics and nanoplastics by several pathways, specifically the skin, respiratory system, and digestive tract.

2.15 Mechanism of microplastics and nanoplastics toxicity

Upon entering a biological environment, microplastics and nanoplastics interact with important biological macromolecules, such as proteins and lipids. Nanoplastics can were transferred and absorbed into cells through passive or active pathways. Passive transport relies on the differential in concentration of nanoplastics between the interior and outside of the plasma membrane. Conversely, active transport operates in opposition to the concentration gradient and relies on the expenditure of ATP. Both mechanisms operate simultaneously to transport and internalize nanoplastics from their surrounding environment (Huang et al., 2021). Under normal physiological conditions, nanoplastics can only move through the cell membrane passively if they were able to fit into the surface pores. A pertinent illustration can be observed in cancer cells, where nanoplastics traverse and relocate to the cell membrane due to enlargement of the surface pores. Large nanoplastics are obstructed by the passive transport mode, which only allows smaller nanoplastics to pass and be transported. The toxicity of nanoplastics is linked to their ability to cause alterations in the mitochondria, endoplasmic reticulum, and lysosomes. Previous studies have emphasized the detrimental impact of nanoplastics on the structure of mitochondria and their ability to carry out respiration, leading to metabolic and functional problems. BEAS-2B human epithelial cells exposed to nanoplastics received a comprehensive in vitro assessment, which unveiled notable functional alterations, such as an aberrant energy metabolism. It has been observed that nanoplastics alter the function of mitochondria in zebrafish models by increasing oxygen consumption (Pitt et al., 2018). In a C. elegans model, exposure to nanoplastics has been associated with anti-apoptotic signaling of Bcl-2–caspase8. Exposure of Sterechinus neumayeri cells to nanoplastics resulted in elevated concentrations of antioxidant activity, encompassing metallothionein, superoxide, and catalase, as well as anti-apoptotic signaling via Bcl-2–caspase8 (Bergami et al., 2019). Nanoplastics have been linked to the stimulation of stress-induced autophagy and oxidative stress pathways in the endoplasmic reticulum. This results in the increased expression of Grp78 and Grp170 in coelomocytes.

2.16 Ecological risk assessment

The basic preconditions for prevention and control of pollution are ecological risk assessment. Multivariate methods are conducted to identify potential pollution sources and to indicate relationships pollutant. Currently, there are no standardized models to assess the ecological risk assessment of microplastics. Xu et al. (2018) and Li et al. (2020) have developed models to evaluate the ecological risk of microplastics in water and sediment.

Ecological risk assessment of microplastics Li et al. (2020) presented the ecological risk of microplastic in the mangroves of Southern China. Microplastics were found to present ecological risks base on a comprehensive using the potential ecological risk factor (Ei), potential ecological risk (PER), and pollution load index (PLI).

CHAPTER 3
METHODOLOGY

3.1 Material

3.1.1 Equipment for microplastics analysis

1) FT-IR Microscope (BRUKER, LUMOS II, Germany)
2) Spectro microscope
3) Glass bottle for collecting salt samples
4) Metal spoon for collecting salt samples
5) Filter set and pump
6) Filter paper

   (Anodisc^{TM} 25 filter membrane, pore size 0.2 µm, diameter 25 mm, Whatman^{TM})
7) Erlenmeyer flask
8) Petri dishes
9) Incubators
10) Hood
11) Net pore size 16 µm
12) Squirt bottle containing distilled water
13) 500-mL glass beaker
14) Analytical balance (precise to 0.1 mg)
15) Metal spatula
16) Hot air oven (65 ^{o}C)
17) Stir bar
18) Laboratory hot plate
19) Watch glass
20) Standard metal forceps
21) Density separator

3.1.2 Chemicals

1) 30% H_2O_2

2) DI water

3) Iron (Fe(II)) solution (0.05 M): prepared by adding 7.5 g of $FeSO_4.7H_20$ (= 278.02 g/mol) to 500 mL of water and 3 mL of concentrated sulfuric acid

4) Sodium chloride (commercial table salt is sufficient)

3.2 Sample processing

In this research, samples of sea salt produced from the Ban Laem, Phetchaburi Province salt fields were sampled. Three types of sea salts from the traditional salt field, plastic salt field, and sea water were collected. All samples were quantified in the amount, type, color, size, and shape of microplastics in the Department of Environmental Science, Faculty of Science, Chulalongkorn University. The details are as follows *Figure 3.1.*

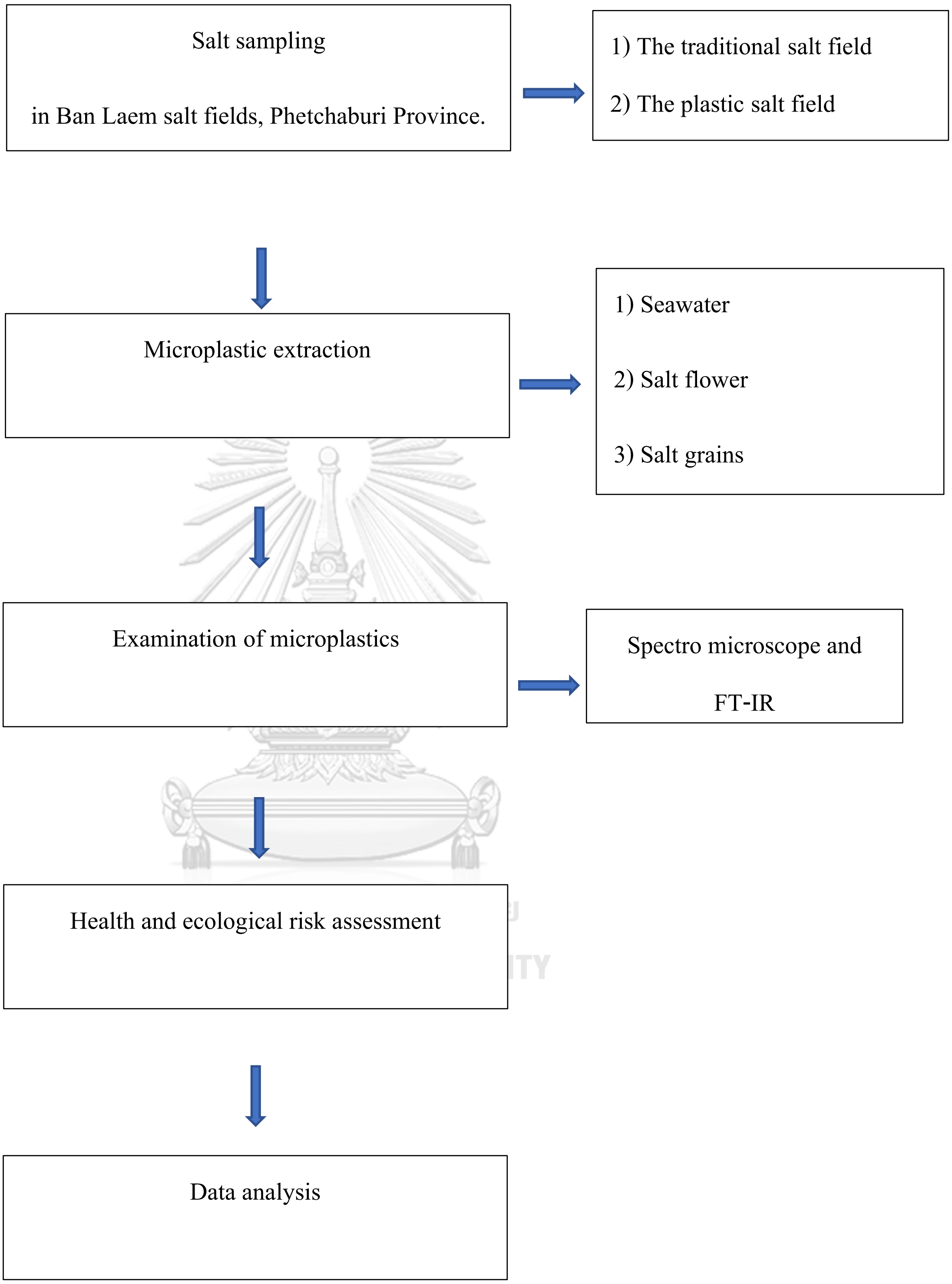


Figure 3.1 Sample processing summary.

3.2.1 Salt sampling

3.2.1.1 The traditional salt field was collected for 2 samples i.e., 1) salt flowers, 2) salt grains as shown in *Figure 3.2*

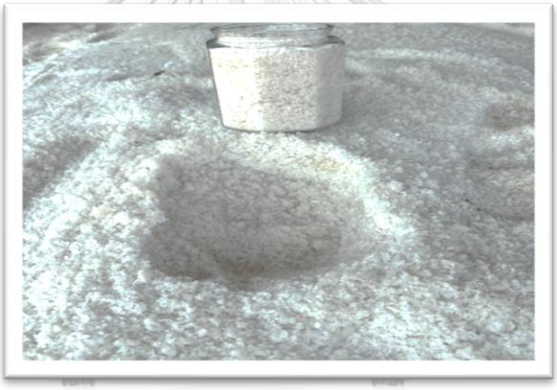
a) The traditional salt field *b) Salt flowers*

c) Salt grains

Figure 3.2 Sample for analysis from the traditional salt field.

3.2.1.2 The plastic salt field was collected for 2 samples i.e., 1) Salt flowers and 2) Salt grains as shown in *Figure 3.3*

a) The plastic salt field *b) Salt flowers*



C) Salt grains

Figure 3.3 The plastic salt field

3.2.1.3 Seawater raw material for produced sea salt was collected as shown in *Figure 3.4*

Figure 3.4 Seawater raw material

3.2.2 Number of samples

In this research, a total of 42 samples were randomly collected 1 kilogram of each salt sample at each location S1-S4 and 1 liter of each seawater at each location S5-S8 with three replicates per location.

In general, salt production in the field was done only during January – April 2023. This work was used in two types of the salt field in the experiment.

3.2.2.1 Traditional salt field sampling: Two types of samples from this kind of salt field are as follows:

1. Salt flower samples were collected for 1 kg per sample (total of 3 samples). This sample was randomly sampled by salt farmers because it is a process with a particular storing procedure.
2. Salt grains were collected from 4 points (S1 – S4) of the salt field as shown in Figure 3.5 (total of 12 samples). One kg per point was conducted.

3.2.2.2 Plastic salt field sampling: Two types of samples from this kind of salt field are as follows:

1. Salt flower samples were collected for 1 kg per sample (total of 3 samples). This sample was randomly sampled by salt farmers because it is a process with a particular storing procedure.
2. Salt grains were collected from 4 points (S5 – S8) of the salt field as shown in Figure 3.5 (total of 12 samples). One kg per point was conducted.

3.2.2.3 Sea water raw material

Seawater for producing sea salts from the traditional and plastic salt field was collected from 4 points (S9 – S12) as shown in Figure 3.5 (total of 12 samples). One liter per point was conducted.

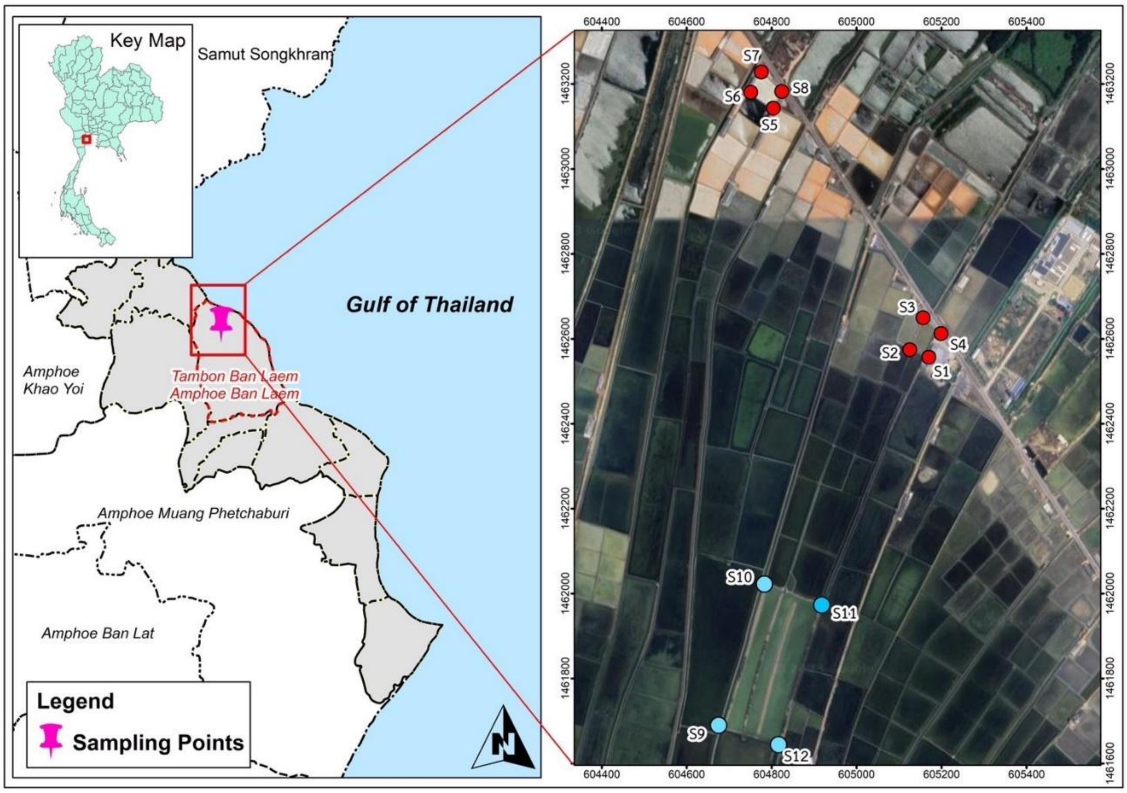
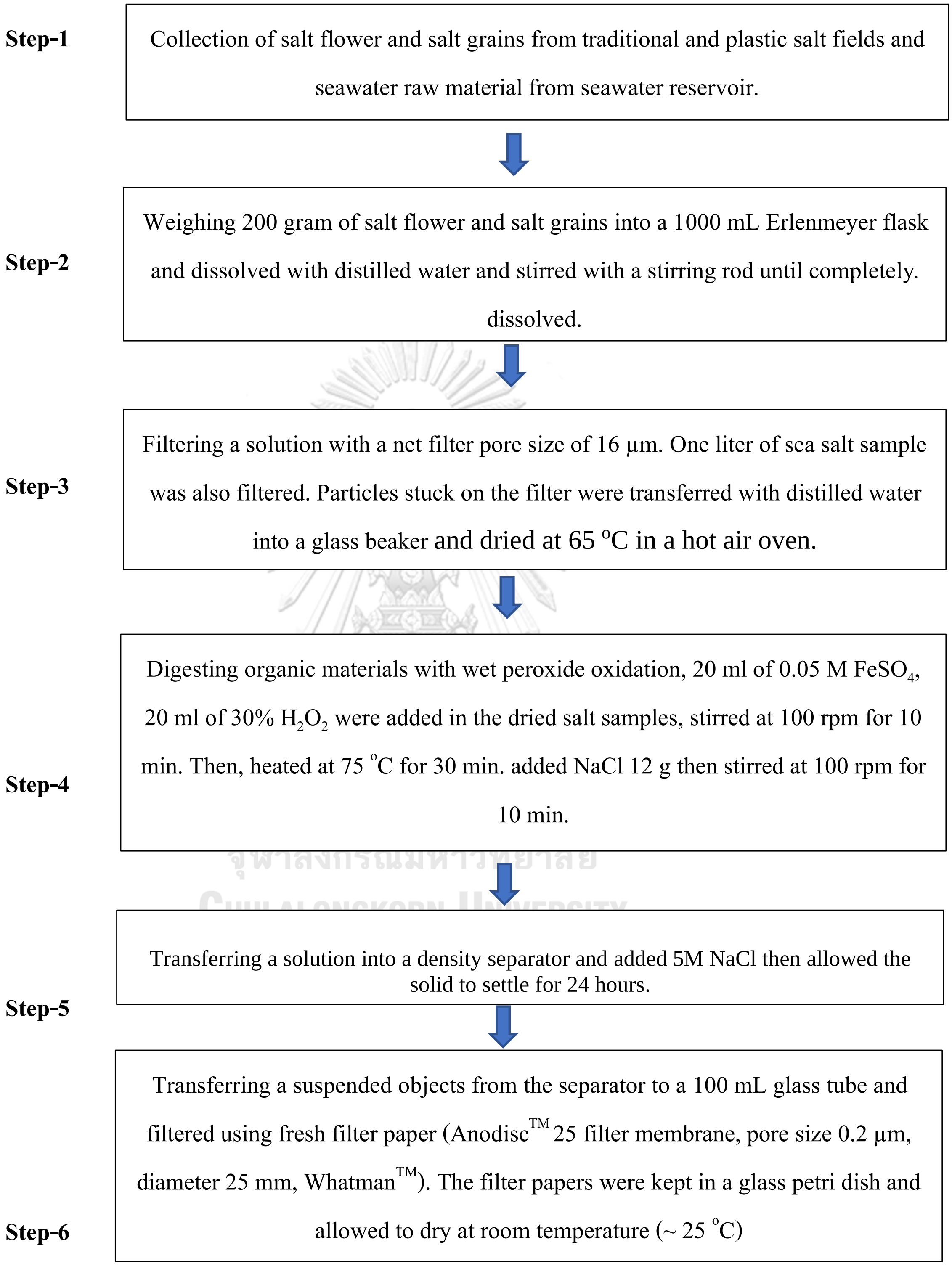


Figure 3.5 The geographic location of sampling points at Ban Leam salt field, Phetchaburi, Thailand

3.2.3 Microplastics extraction from salt flower, salt grains and seawater raw material



Step-1 Collection of salt flower and salt grains from traditional and plastic salt fields and seawater raw material from seawater reservoir.

Step-2 Weighing 200 gram of salt flower and salt grains into a 1000 mL Erlenmeyer flask and dissolved with distilled water and stirred with a stirring rod until completely. dissolved.

Step-3 Filtering a solution with a net filter pore size of 16 µm. One liter of sea salt sample was also filtered. Particles stuck on the filter were transferred with distilled water into a glass beaker and dried at 65 °C in a hot air oven.

Step-4 Digesting organic materials with wet peroxide oxidation, 20 ml of 0.05 M $FeSO_4$, 20 ml of 30% H_2O_2 were added in the dried salt samples, stirred at 100 rpm for 10 min. Then, heated at 75 °C for 30 min. added NaCl 12 g then stirred at 100 rpm for 10 min.

Step-5 Transferring a solution into a density separator and added 5M NaCl then allowed the solid to settle for 24 hours.

Step-6 Transferring a suspended objects from the separator to a 100 mL glass tube and filtered using fresh filter paper (Anodisc™ 25 filter membrane, pore size 0.2 µm, diameter 25 mm, Whatman™). The filter papers were kept in a glass petri dish and allowed to dry at room temperature (~ 25 °C)

Figure 3.6 The process of extraction microplastics from salt flower, salt grains and seawater (Modification method of Yang et al. (2015) and NOAA method).

3.2.4 Examination of microplastics with a microscope

This process was to check the shape, size, and color of microplastics before analyzing the amount and polymer type of microplastics identified with the FT-IR.

3.2.5 Examination of microplastics with FT-IR

The chemical constituents of the suspected materials from the samples were nondestructively identified by FTIR model LUMOS, BRUKER brand, Germany, in which scans were performed at a resolution of 2 cm^{-1} wavelength between 4000 to 1200 cm^{-1}. However, scanned spectra were used to identify the polymers made by comparing the measured spectra with reference spectral libraries using the base.

3.2.6 Quality of control

Before removing all microplastics, be sure to inspect them from the exterior. This allows 70% of the cleaning of the table surface to be performed within a fume hood and at the same time extracting extracts of microplastics and extraction initiating crucibles after filtering the sample, microplastics and the sample dish may need to be kept always sealed to prevent contamination. The blank measurement procedure was performed to reduce the error percentage during sample processing and microscopic examination (Dris et al., 2016). To measure the procedural contamination/blank contamination level, 80 mL of prefiltered H_2O_2 was kept in a glass bottle, and the remaining procedure for the extraction process was the same. The blank measurement must show negative results and the absence of microplastic contamination in the lab environment.

3.2.7 Microplastic characterizations

1) Size (16-100, 101-500, 501-1000 and > 1000 µm)

2) Shapes (fiber, fragment, film, foam, pellet, and unshaped)

3) Colors

4) Chemical polymer types

3.3 Health Risk Assessment

In order to start a health risk assessment, the average daily dose of each desired microplastics through ingestion contact was calculated. Potential health risk assessment was analyzed by calculating the hazard quotient to assess the non-carcinogenic risks for each individual microplastics via ingestion.

3.3.1 Exposure Assessment

The exposure of humans to microplastics was calculated based on the models developed by the Environmental Protection Agency of the United States (US EPA). According to the Exposure Factors Handbook, the average daily dose (EDI) of a pollutant through ingestion contact can be estimated using equation (3.1) :

$$\mathrm{EDI} = (S_i \times C_m) \qquad (3.1)$$

Where *EDI* stands for the estimated daily exposure (microplastic particles /day), S_i is the amount of consumed sea salt (g/day), C_m means the amount of microplastic (particles/g).

3.4 Ecological risk assessment

3.4.1 Polymer risk index

The hazard scores of plastic polymer and polymer type as an important index to evaluate its ecological harm was used to assess the risks of microplastics based on polymer properties as follows:

$$H = \sum P_n \times S_n \qquad (3.2)$$

Where P_n is the proportion of each MP polymer type at each sampling site (C_s/C_n), Cs is the amount of each polymer type detected and C_n is the total amount of microplastics detected in sampling site, S_n is the score for the polymers comprising the microplastic from Lithner et al. (2011).

Table 3.1 Classification of risk index (H)

Risk Index (H)	Level of Risk Index
< 10	I
10 - 100	II
100 - 1000	III
> 1000	IV

Hazard ranking model has been developed in order to categorize hazardous ingredients and compared the different polymers, based on risk of affecting the environment and human health. All substances which are identified as used in the production of each polymer type are classified as hazard data that reflected the intrinsic hazardous properties of a substance. The procedure for calculating the sum of hazard score for the polymer is based on the classifications of the monomer that the polymer is made of.

3.4.2 The pollution load index (PLI)

Pollution load index (PLI) is an index for total assessment of the degree of microplastic contamination in sea water and is calculated as the nth root of the number of multiplied CF values based on the following formula (Tomlinson et al., 1980).

$$CF_i = C_i / C_{oi} \tag{3.3}$$

$$\text{PLI} = \sqrt{CF_i} \tag{3.4}$$

$$\text{PLI}_{\text{zone}} = \sqrt[n]{PLI_1 \times PLI_2 \times \ldots \times PLI_n} \tag{3.5}$$

Where

CF_i is microplastic concentration factors.

C_i is the microplastic concentration in seawater at each station.

C_{oi} is the background level of microplastic concentration in seawater. Due to a lack of available background data on microplastics, this study adopted minimal of microplastic in seawater (station S12) 18 particles/L as the background value.

Table 3.2 Classification of Pollution Loading Index (PLI)

Pollution Loading Index (PLI)	Level of contamination
< 10	I
10 - 20	II
20 - 30	III
> 30	IV

Note: I = low toxic, II = moderate toxic, III = considerable toxic, and IV = high toxic

3.4.2 The potential ecological risk (PER) of microplastics

Microplastics were found to present ecological risk assessment based on a comprehensive evaluation as follows :

$$E_r^i = T_r^i \text{ x } (CF_i) \tag{3.6}$$

$$PER = \sum_{n=1} E_r^i \tag{3.7}$$

Where CF_i is microplastic concentration factors as follows equation (3.3)

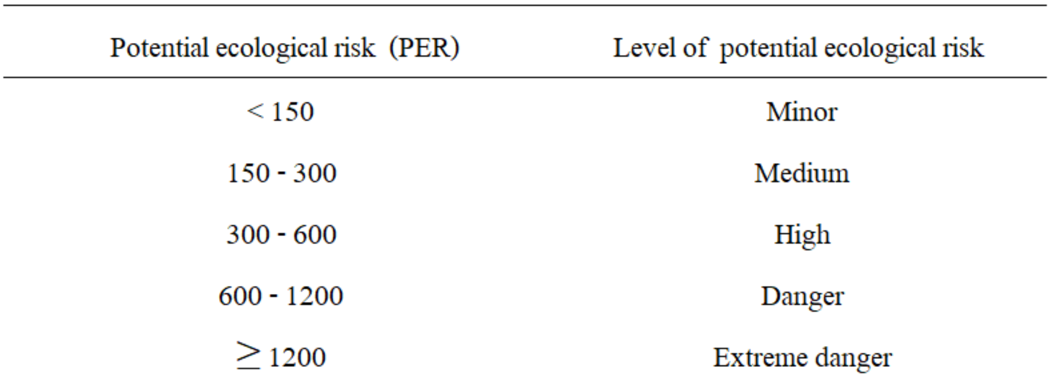
E_r^i is the potential ecological risk index of an individual microplastic.

T_r^i is the toxicity coefficient for the constituent polymer which is the summation of the % of specific polymer in the sample (P_n/C_i) multiplied by the hazard score of plastic polymers (S_n)

Table 3.3 Classification of Potential ecological risk index (E_r^i)

Potential ecological risk index (E_r^i)	Level of potential ecological risk index
< 40	Minor
40 - 80	Medium
80 - 160	High
160 - 320	Danger
≥ 320	Extreme danger

Table 3.4 Classification of Potential ecological risk (PER)



Potential ecological risk (PER)	Level of potential ecological risk
< 150	Minor
150 - 300	Medium
300 - 600	High
600 - 1200	Danger
≥ 1200	Extreme danger

3.5 Data analysis

Descriptive statistical analyses including the calculation of mean, standard deviation and trend lines were performed in Microsoft Excel (2010), SPSS software. Due to the non-distribution of the data, a Mann-Whitney U test at significant value p-value < 0.05 was conducted for the differences in microplastics content in samples.

CHAPTER 4

RESULTS AND DISCUSSION

The results of the study were divided into 6 parts: 1) Quality control 2) Abundance of microplastics in salt grains, salt flowers and seawater 3) Microplastic characteristics in salt grains, salt flowers and seawater 4) Comparison of microplastic contamination in sea salt 5) Health risk assessment, and 6) Ecological risk assessment.

4.1 Quality control

In this study, quality control was established by preparing 3 replicate blank controls using the same method as the preparation of samples for analysis; however, salt samples were not incorporated into the preparation of the blank controls. The objective was to reduce errors in the quantitative analysis process of microplastics in sample by quantifying microplastic contamination during the analysis process.

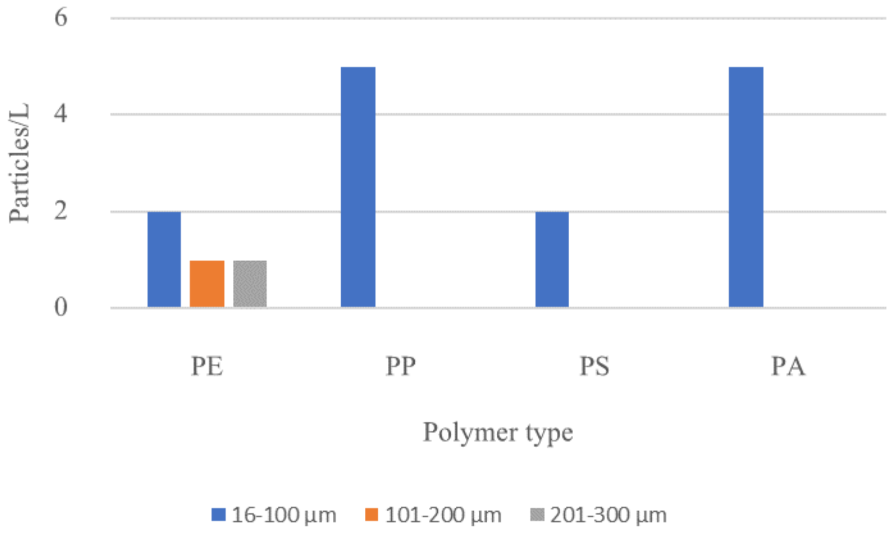


Figure 4.1 Average amount of microplastic contamination in blank controls

As a result, 4 polymer types of microplastics were detected and total amount of microplastics were detected in blank control as follow: Polyethylene (PE) 4 particles/L, Polypropylene (PP) 5 particles/L, Polystyrene (PS) 2 particles/L, Polyamide (PA) 5 particles/L. The results are shown in *Figure 4.1*. The microplastic particles may have been contaminated by the net used for filtering the salt solution or from contamination in distilled water, air, or adhering to containers utilized in the experimental process.

4.2 Abundance of microplastics

Sea salt samples produced from the traditional salt field and plastic salt field, including salt grains and salt flowers, as well as seawater, a raw material for sea salt production, were analyzed to amount, size and polymer type of microplastics using µFT-IR model LUMOS, BRUKER brand, Germany, in which scans were performed at a resolution of 2 cm^{-1} wavelength between 4000 to 1200 cm^{-1} in transmission mode, a match score of ≥ 70 % (Horton et al.,2017) and the software were used for all FT-IR analyses and library scanning. The results are presented as follows:

4.2.1 Abundance of microplastics in a traditional salt field

The membrane filter of 12 salt grain samples from sampling points S1-S4 and 3 salt flower samples from the traditional salt field were analyzed for abundance of microplastics using µFT-IR. The results are shown in *Figure 4.2.*

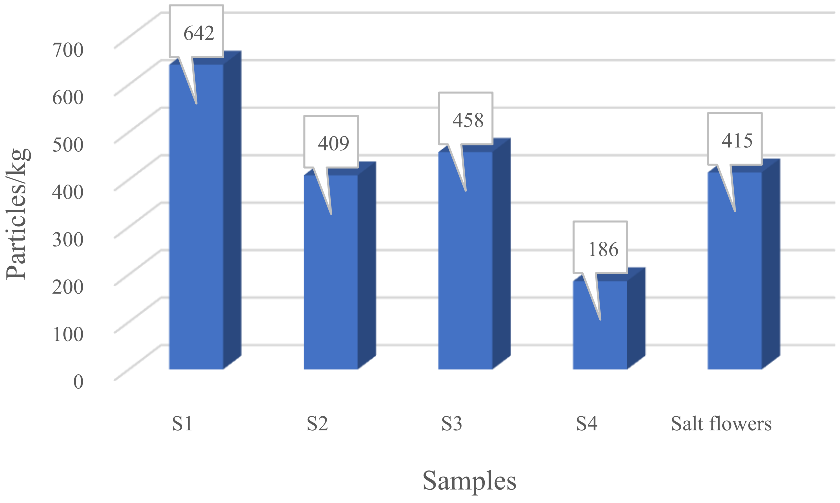


Figure 4.2 Abundance of microplastics in the traditional salt field (salt grains and salt flowers)

Microplastics were detected in every sampling point of sea salt. The abundance of total microplastics in salt grains among the sampling points (S1 – S4) ranged from 186-642 particles/kg with an average of 422 (186-642) particles/kg. The incidence of microplastics in salt grains and salt flowers followed a decreasing order of S1 (642 particles/kg) > S3 (458 particles/kg) > Salt flower (415 particles/kg) > S2 (409 particles/kg) > S4 (186 particles/kg) as shown in *Figure 4.2*.

4.2.2 Abundance of microplastics in a plastic salt field

The membrane filter of 12 salt grain samples from sampling points S5-S8 and 3 salt flower samples from the plastic salt field were analyzed for abundance of microplastics using µFT-IR. The results as shown in *Figure 4.3*.

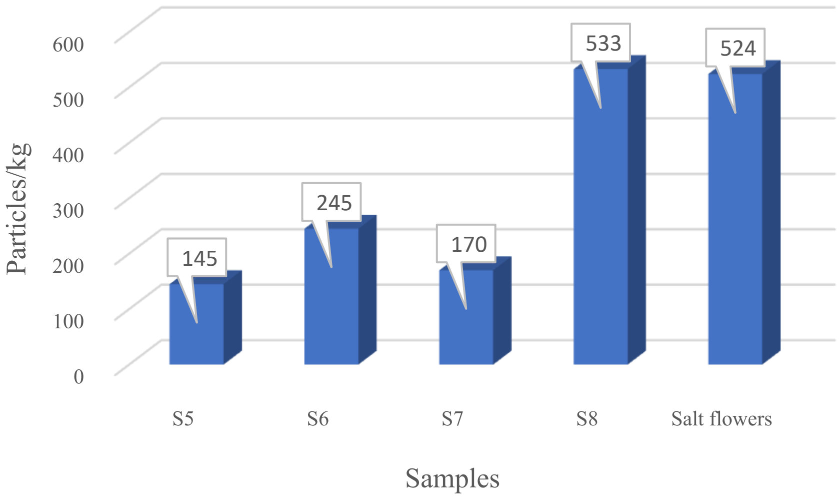


Figure 4.3 Abundance of microplastics in the traditional salt field (salt grains and salt flowers)

The abundance of total microplastics in salt grains among the sampling points (S5 – S8) ranged from 145-533 particles/kg with an average of 323.40 (145-533) particles/kg. The incidence of microplastics in salt grains and salt flowers followed a decreasing order of S8 (533 particles/kg) > Salt flower (524 particles/kg) > S6 (245 particles/kg) > S7 (170 particles/kg) > S5 (145 particles/kg) as shown in *Figure 4.3*.

4.2.3 Abundance of microplastics in seawater raw materials

The membrane filter of 12 seawater, raw materials for sea salt production from sampling points S5-S8 were analyzed for abundance of microplastics using µFT-IR. The results are shown in *Figure 4.4.*

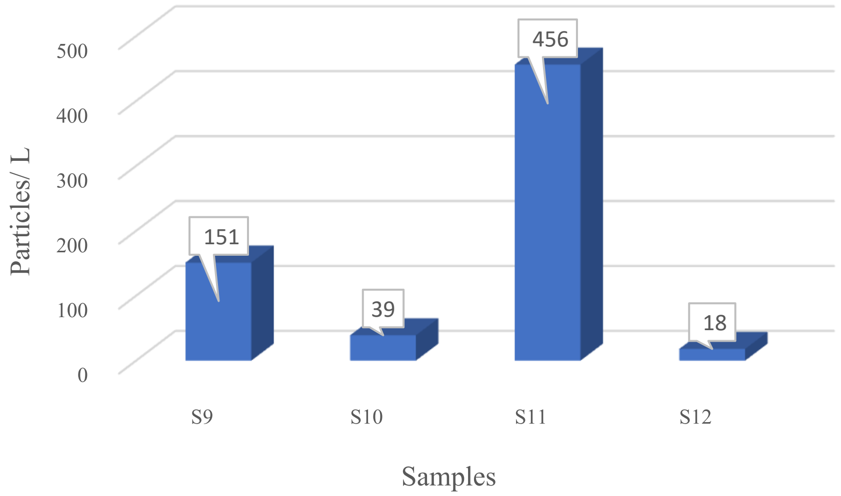


Figure 4.4 Abundance of microplastics in seawater raw materials

The occurrence of microplastics in seawater raw materials ranged from 18 – 456 particles/L with an average of 166 (18-456) particles/L. The occurrence of microplastics in seawater indicated a decreasing order of S11 (456 particles/kg) > S9 (151 particles/kg) > S10 (39 particles/kg) > S12 (18 particles/kg) as shown in *Figure 4.4.*

The abundance of microplastic contamination was identified in both sea salt produced from a traditional salt field and sea salt produced from a plastic salt field. Comparing the quantities of microplastics identified in this study to those identified in other research indicates that the amount of microplastics in sea salt was comparable to that which was discovered in China and Vietnam, in contrast to Italy, Korea, and Bangladesh, exhibited comparatively reduced levels of microplastic contamination. However, it had a higher level of microplastic contamination than India, Iran, Spain, Turkey, Sri Lanka, and Indonesia as shown in *Table 4.1 - 4.2*. This depends on geography, the sea salt production process in each area. Including microplastic analysis processes with different analytes may result in differences in the microplastic quantities measured.

Table 4.1 Abundance, shape, color, size, polymer type, and annual human intake of microplastics (Altunışık et al., 2023; Nur et al., 2022)

Country	Particles/kg	MPs shape	MPs color	MPs size (µm)	Polymer type	EDI (Particles /year)	References
Italy	1570-8230	Fragment, fiber, film, foam, granule	Black, grey, blue, orange, brown, green, pink, yellow, purple	4-2100	NA	40.6– 1085.2	Renzi and Blašković, 2018
Turkey	16-84	Fiber, film, fragment	NA	>1000	PU, PP, PET, PE, PA, PVC	249-302	Gündoğdu, 2018
China	550-681	Fragment, fiber	Black, red, white, blue	<200	PET, PE, cellophane	NA	Yang et al., 2015
Spanish	50-280	Fiber	Black, red, blue, white, transparent	30-3500	PET, PP, PE	510	Iñiguez et al., 2017
Iran	55 –151	Fragment, fiber	red, blue, green, colorless	1000-5000	PE, PP	15.54	Makhdoumi et al., 2023
India	56-103	Fiber, fragment	Black, red, brown, blue, purple	500-2000	PES, PET, PA, PE, PS	NA	Seth and Shriwastav, 2018
Bangladesh	560- 1253	Fiber, fragment, foam, line, film, pellet	Black, transparent, yellow, red, gray, blue, green	300-5000	PP, PE, PET, PS	1021.74 – 2286.76	Siddique et al., 2023

Table 4.2 Abundance, shape, color, size, polymer type, and annual human intake of microplastics (Altunışık et al., 2023; Nur et al., 2022)

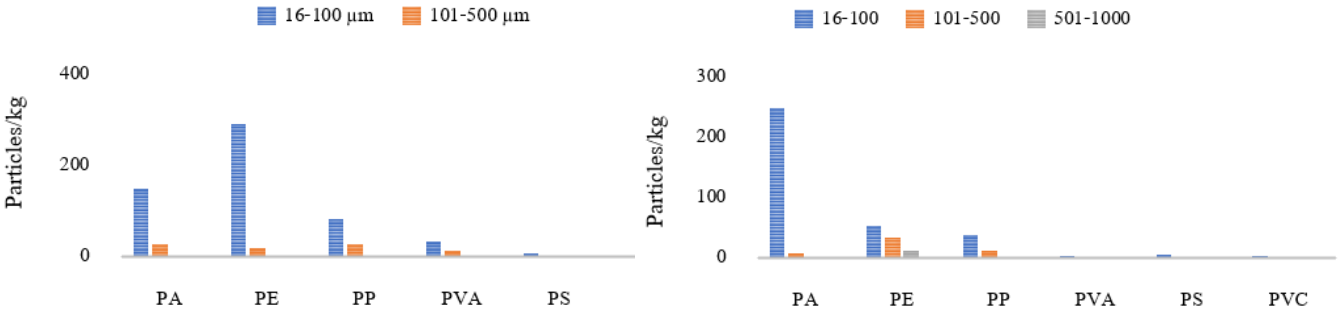
Country	**Particles/kg**	**MPs shape**	**MPs color**	**MPs size (µm)**	**Polymer type**	**EDI (Particles /year)**	**References**
Italy	1653	Fiber, fragment, sphere	Blue, red, black. white	0–500	PP, PA, PE	NA	Di Fiore et al., 2023
Lebanon	0–635	Fiber	Transparent, white, yellow, blue, black	NA	PE, Plasticized Rubber, PP.	0–2372.5	Nakat et al., 2023
Croatia	27 –32	Fiber, film, fragment, granule	Blue, black, white, yellow	15–4628	PP	NA	Renzi and Blašković, 2018
Sri Lanka	11–193	Fiber, fragment	Transparent, red, blue, white, black	65–2500	LDPE, resin dispersion, HDPE	158	Kapukotuwa et al., 2022
Korea	2395	Fragment, fiber	NA	63–100	PP, PE, PS, PET, PVC	12.0	Lee et al., 2021
Vietnam	340–878	Fiber, fragment	Blue, grey, black, yellow, white, red	100–700	PE, PP, PS	637– 1270	Ha, 2021
Indonesia	33–313	Fragment, fiber, film, pellet	Black, blue, yellow, red, transparent	≥100–300	PE, PP, PET, PES	60.225– 571.225	Syamsu et al.,2023
Thailand	142 - 642	Fragment, fiber	Blue, transparent, black, red, white, pink, brown, green, yellow, purple	16 - 1200	PA, PE, PP, PVA, PS, PVC, HDPE	208.05 - 905.20	This study

4.3 Microplastic characteristics

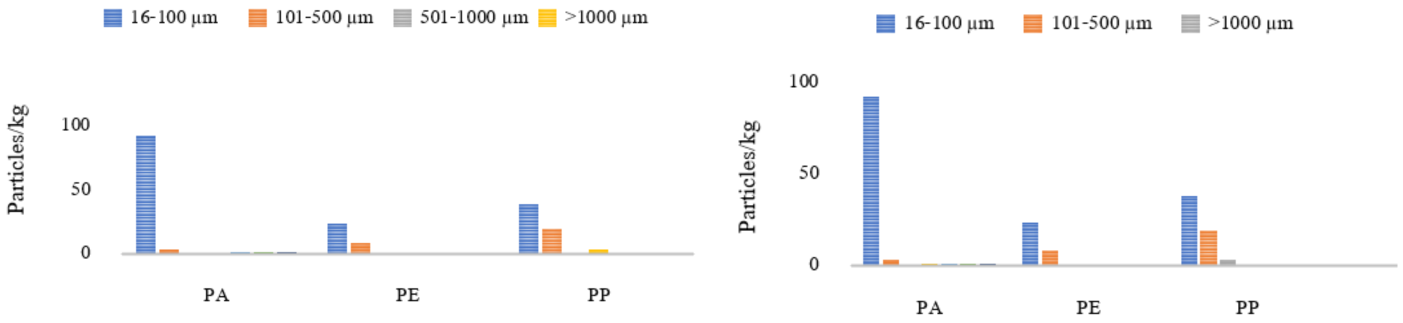
4.3.1 Polymer type of microplastics

4.3.1.1 Polymer types of microplastics in the traditional salt field

(1) Salt grains



(a) S1 (b) S2



(c) S3 (d) S4

Figure 4.5 Polymer types of microplastics in the traditional salt field (salt grains).

A total of 12 salt grain samples were taken and verified through µFT-IR analysis from the traditional salt field (S1-S4). A total of 6 polymer types were found in samples. The mean composition of microplastics in salt grains followed the order of polyamide (PA) 34.81% (73.75±87.09 particles/kg), polyethylene (PE) 31.98% (36.13±77.80 particles/kg), polypropylene (PP) 29.56% (32.07±42.46 particles/kg), polyvinyl alcohol (PVA) 2.89% (16.33±15.28 particles/kg), polystyrene (PS) 0.59% (5±0 particles/kg) and polyvinyl chloride (PVC) 0.18% (3±0 particles/kg), respectively as shown in *Figure 4.5*.

(2) Salt flowers

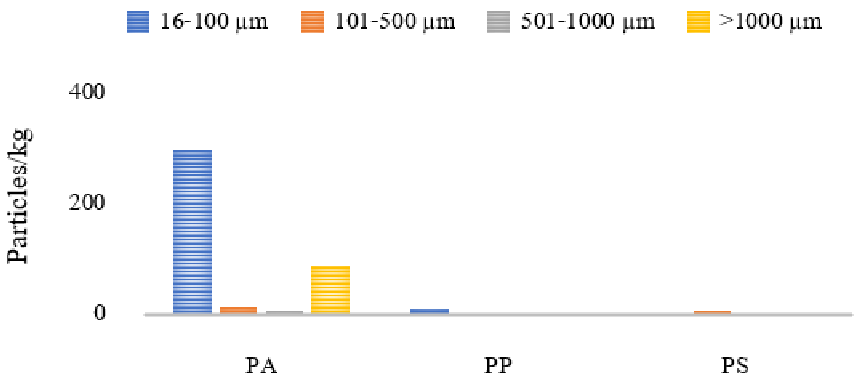
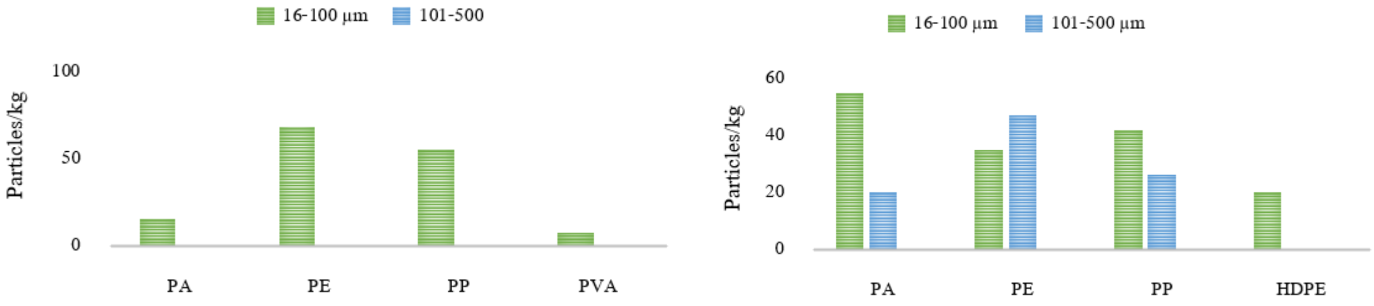


Figure 4.6 Polymer types of microplastics in the traditional salt field (salt flowers).

A total of 3 salt flower samples were found in 3 polymer types. The mean composition of microplastics in salt flowers followed the order of polyamide (PA) 96.87% (100.5±134.67 particles/kg), polypropylene (PP) 1.93% (8±0 particles/kg), polystyrene (PS) 1.20% (5±0 particles/kg), respectively as shown in *Figure 4.6*.

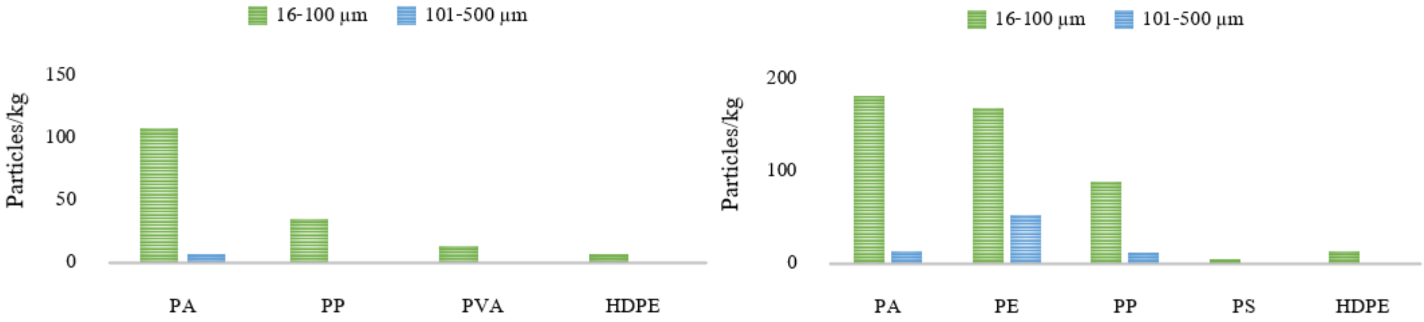
4.3.1.2 Polymer types of microplastics in the plastic salt field

(1) Salt grains



(a) S5

(b) S6



(c) S8

(d) S9

Figure 4.7 Polymer types of microplastics in the plastic salt field (salt grains)

A total of 12 salt grain samples were taken and verified through µFT-IR analysis from the plastic salt field (S5-S8). A total of 6 polymer types were found in samples. The mean composition of microplastics in salt grains followed the order of polyamide (PA) 36.60% (50±63.77 particles/kg), polyethylene (PE) 33.94% (61.83±54.90 particles/kg), polypropylene (PP) 23.51% (36.71±28.29 particles/kg), high density polyethylene (HDPE) 3.66% (13.33±6.51 particles/kg), polyvinyl alcohol (PVA) 1.83% (10±4.24 particles/kg) and polystyrene (PS) 0.46% (5±0 particles/kg), respectively as shown in *Figure 4.7*.

(2) Salt flowers

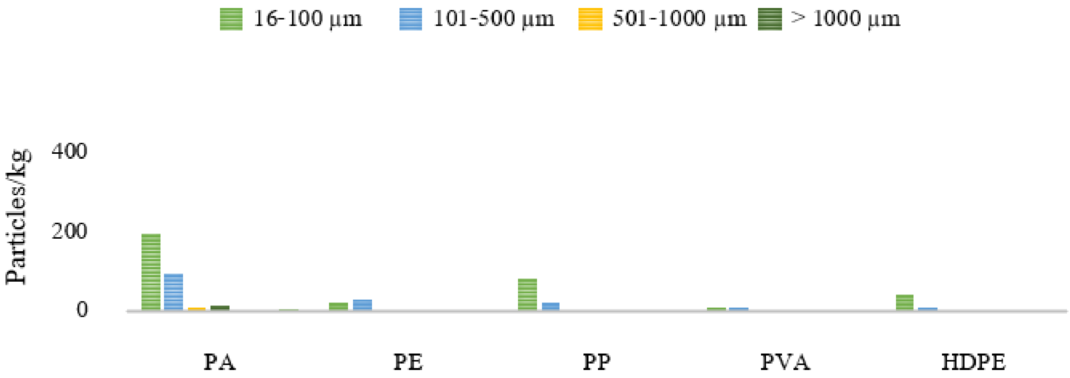
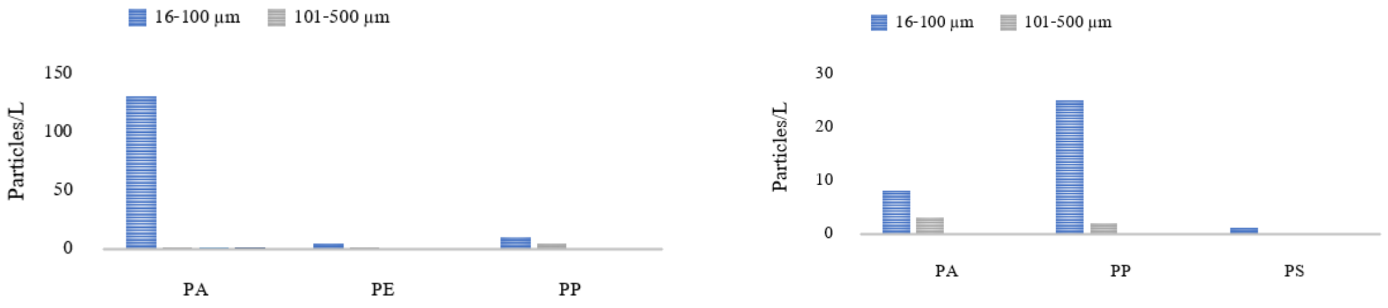


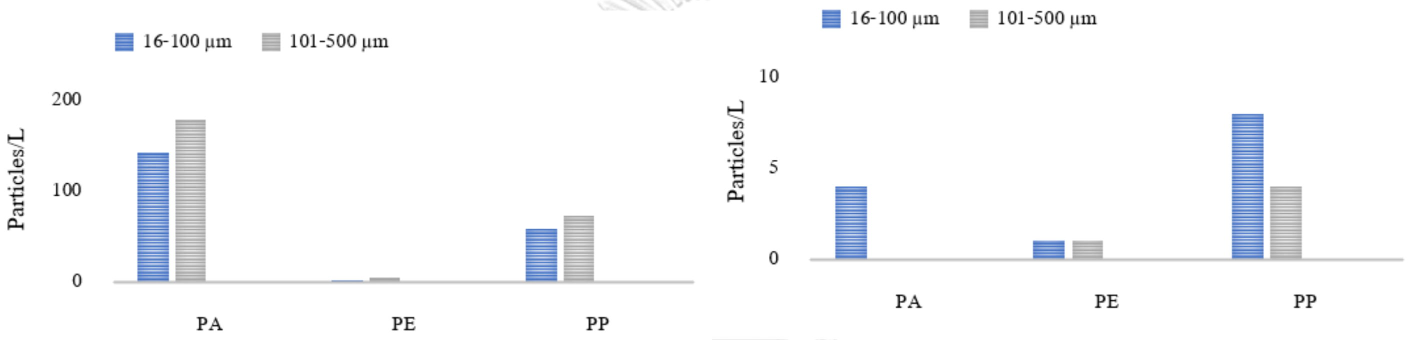
Figure 4.8 Polymer types of microplastics in the plastic salt field (salt flowers)

A total of 3 salt flower samples were found in 5 polymer types. The mean composition of microplastics in salt flowers followed the order of polyamide (PA) 59.73% (39.13±65.80), polypropylene (PP) 19.47% (34±41.67), polyethylene (PE) 9.16% (12±6.63), high density polyethylene (HDPE) 8.97% (23±23.33), polyvinyl alcohol (PVA) 2.67% (7±0), respectively as shown in *Figure 4.8*.

4.3.1.3 Polymer types of microplastics in seawater raw materials



(a) S9 (b) S10



(c) S11 (d) S12

Figure 4.9 Polymer types of microplastics in saltwater raw materials

A total of 12 seawater samples were found, 4 polymer types. The mean composition of microplastics in seawater followed the order of polyamide (PA) 70.33% (51.89±65.80), polypropylene (PP) 27.56% (16.63±23.25), polyethylene (PE) 1.96% (1.63±1.19), polystyrene (PS) 0.15% (1±0), respectively as shown in *Figure 4.9.*

PA, PP, and PE were found in all sea salt samples whereas PS was found only in salt flowers in a traditional salt field and seawater raw material. These findings were in accordance with some other investigations conducted worldwide for sea salt samples (Iniguez et al., 2017; Kim et al., 2018; Rakib et al., 2021; Yang et al., 2015). These polymers are widely used as packaging materials, fishing nets, and clothing which contribute to plastic pollution in the environment (Enyoh et al., 2019). PA's dominance in sea salt can be explained by its higher density (1.16 g/cm^3), which makes the polymers more prone to sedimentation during specialized procedures like crystallization (Yang et al., 2015). PVA and PVC were found in sea salt both in traditional and plastic salt fields but not found in seawater raw material. This type of plastic contamination might come from the manufacturing process that transports seawater into the salt field using PVC plastic pipes, equipment and packaging used in salt fields. HDPE was found in salt grains and salt flower produced from plastic salt fields but not found in sea salt produced from traditional salt field. The examination showed that the HDPE plastic utilized for paving the salt fields had been in operation for almost a decade. Consequently, the plastic might have undergone erosion, detachment, and subsequent contamination with sea salt.

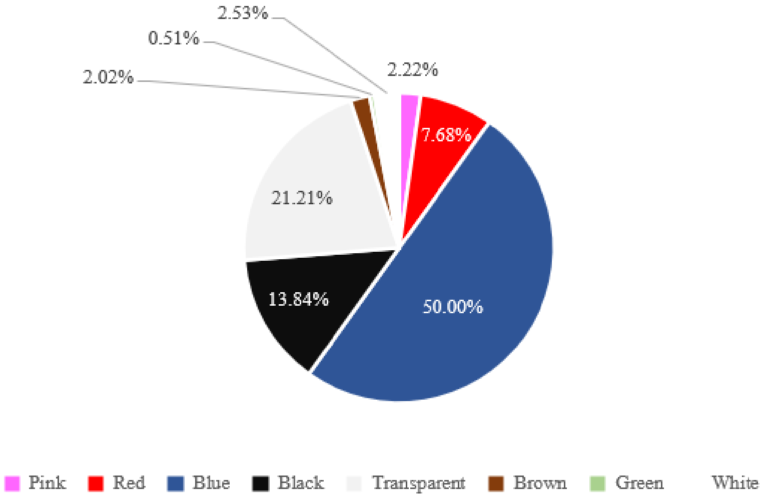
4.3.2 Size of microplastics

In the present study, microplastics were detected with sizes of 16 – 100 µm, 101-500 µm, 501-1000 µm and >1000 µm. The most dominant size range of microplastics was 16 – 100 µm in both sea salt and seawater followed by 101-500 µm and was rarely found in sizes greater than 500 µm. These results were consistent with previous research that demonstrated a higher prevalence of small size microplastics. This could be due to the rapid degradation of small plastic debris by wind-driven waves, rain, water temperature, and ultraviolet radiation (Brahney et al., 2021). The potential origins of microplastic particles identified in seawater include intake from rivers, industrial discharges, laundry and wastewater effluents, ghost fishing, canal transportation, development, and tourism activities (Browne et al., 2021). These sources ultimately contribute to the presence of microplastics in saltwater.

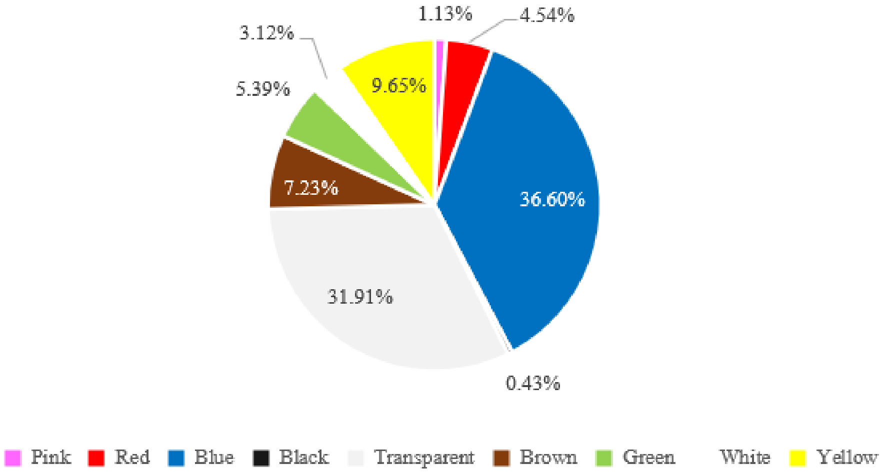
4.3.3 Shapes and colors of microplastics

4.3.3.1 Traditional salt field

(1) Salt grains



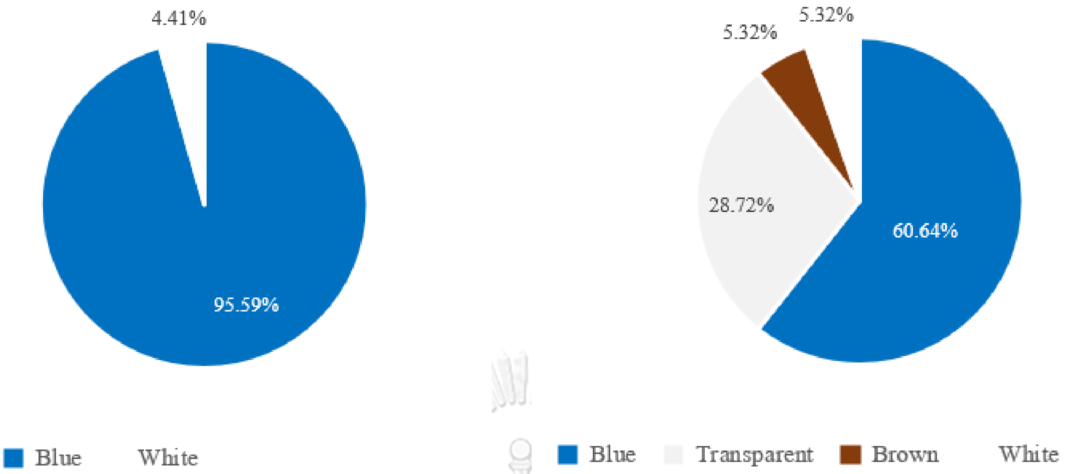
(a) Fragment



(b) Fiber

Figure 4.10 Shapes and colors of microplastics in the traditional salt field (salt grain)

(2) Salt flowers



(a) Fragment

(b) Fiber

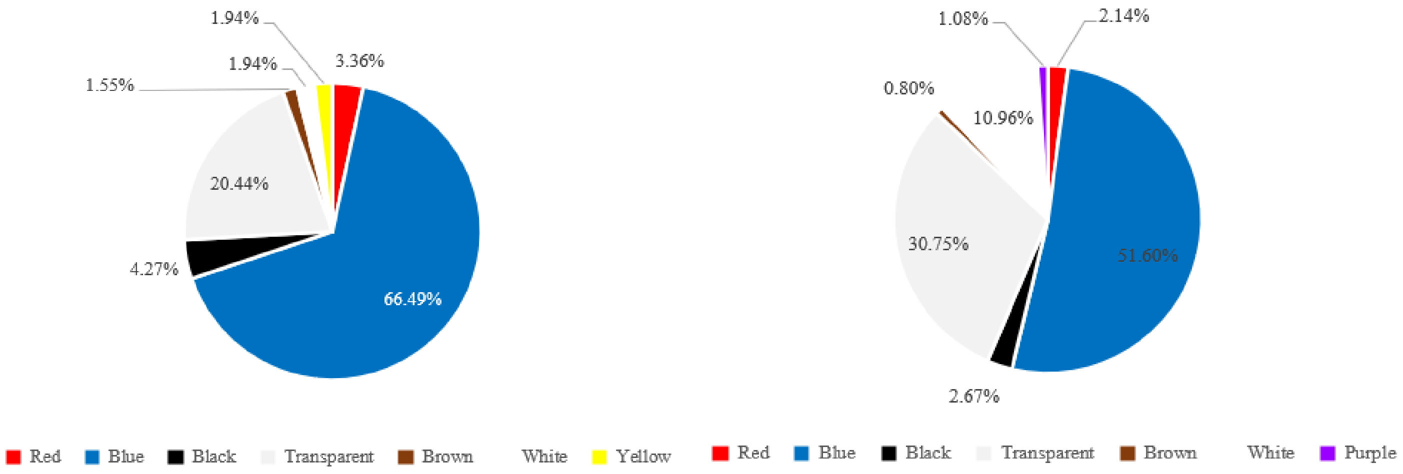
Figure 4.11 Shapes and colors of microplastics in the traditional salt field (salt flowers).

In the case of salt grains in traditional sea salt, fragments were most abundant at 58.41% and fibers at 41.59%. The colored microplastic fragments in salt grains followed the decreasing order of blue (50.00%) > transparent (21.21%) > black (13.84%) > red (7.68%) > white (2.53%) > pink (2.22%) > brown (2.02%) > green (0.51%) whereas the colored microplastic fiber in salt grains followed the decreasing order of blue (36.60%) > transparent (31.91%) > yellow (9.65%) > brown (7.23%) > green (5.39%) > red (4.54%) > white (3.12%) > pink (1.13%) > black (0.43%), respectively as shown in *Figure 4.10.*

Salt flowers in traditional sea salt, fragments were most abundant at 54.70% and fibers at 45.30%. The colored microplastic fragments in salt flowers followed the decreasing order of blue (95.59%) > white (4.41%) whereas the colored microplastic fiber in salt flowers followed the decreasing order of blue (60.64%) > transparent (28.72%) > white (5.32%) and brown (5.32%), respectively as shown in *Figure 4.11*.

4.3.3.2 Plastic salt field

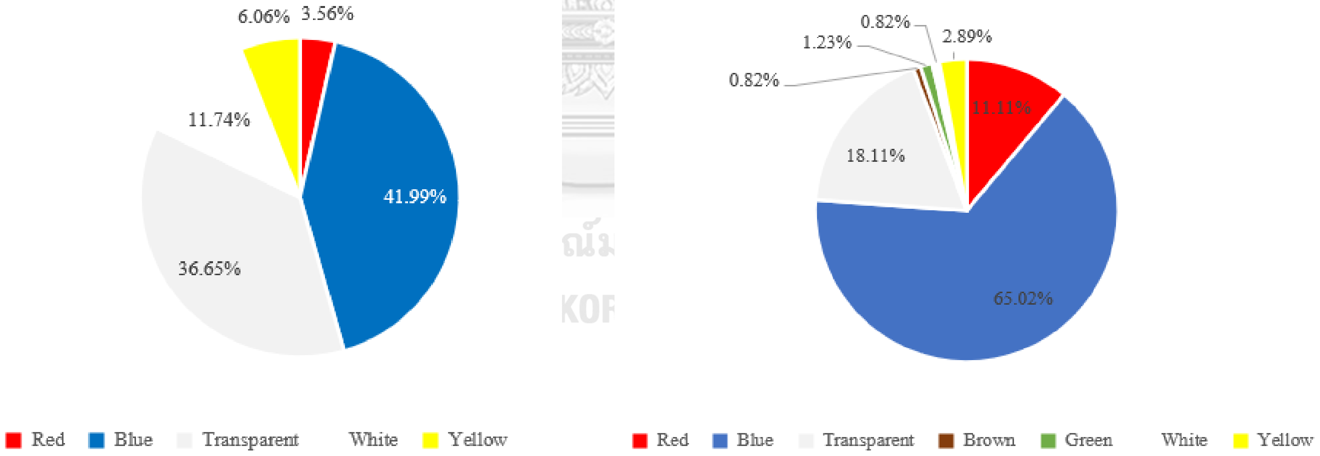
(1) Salt grains



(a) Fragment (b) Fiber

Figure 4.12 Shapes and colors of microplastics in plastic salt field (salt grains)

(2) Salt flowers



(a) Fragment (b) Fiber

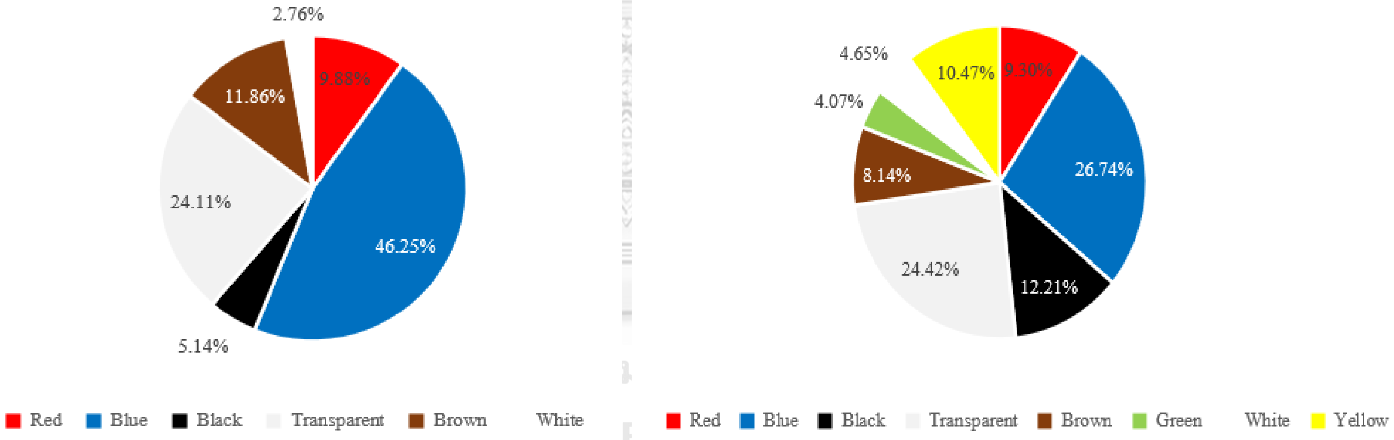
Figure 4.13 Shapes and colors of microplastics in plastic salt field (salt flowers)

In the case of salt grains in plastic sea salt, fragments were most abundant at 67.39% and fibers at 32.61%. The colored microplastic fragments in salt grains followed the decreasing order of blue (66.49%) > transparent (20.44%) > black (4.29%)

> red (3.36%) > white (1.94%) and yellow (1.94%) > brown (1.55%) whereas the colored microplastic fiber in salt grains followed the decreasing order of blue (51.60%) > transparent (30.75%) > white (10.96%) > black (2.67%) > red (2.14%) > purple (1.07%) > brown (0.80%), respectively as shown in *Figure 4.12.*

Salt flowers in plastic sea salt, fragments were the most abundant at 53.63% and fibers at 46.37%. The colored microplastic fragments in salt flowers followed the decreasing order of blue (41.99%) > transparent (36.65%) > white (11.74%) > yellow (6.06%) and red (3.56%) whereas the colored microplastic fibers in salt flowers followed the decreasing order of blue (65.02%) > transparent (18.11%), red (11.11%), yellow (2.89%), green (1.23%), brown (0.82%) and white (0.82%), respectively as shown in *Figure 4.13.*

4.3.3.3 Seawater raw materials

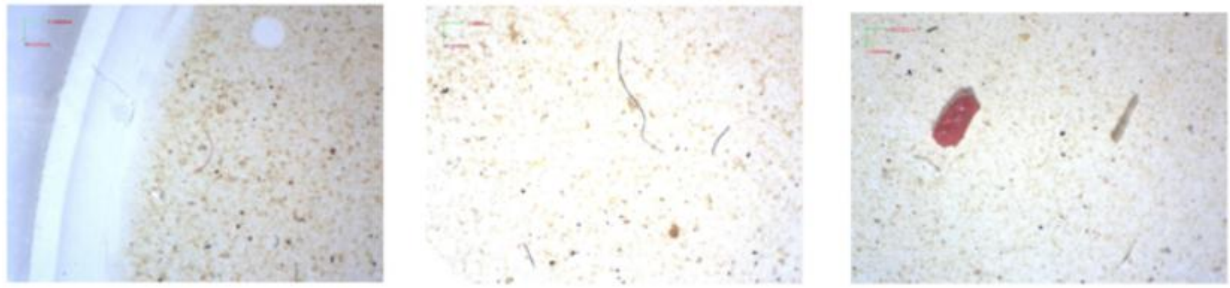


(a) Fragment

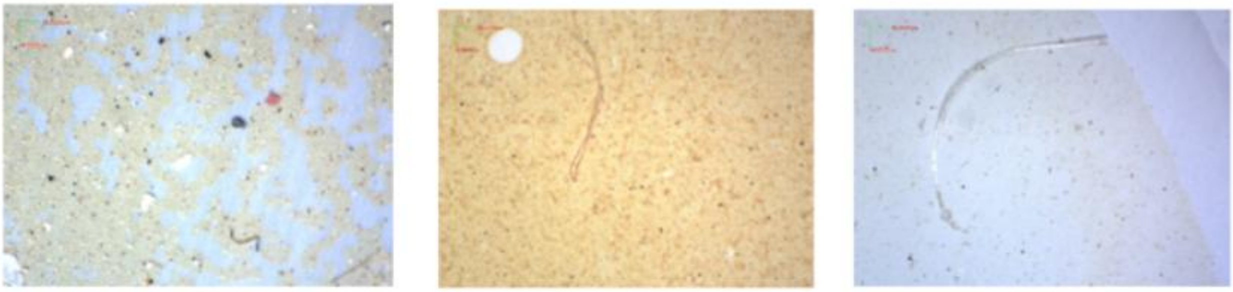
(b) Fiber

Figure 4.14 Shapes and colors of microplastics in sea water

In the case of seawater raw material, fragments were most abundant at 59.53% and fibers at 40.47%. The colored microplastic fragments in seawater followed the decreasing order of blue (46.25%) > transparent (24.11%) > brown (11.86%) > red (9.88%) > black (5.14%), white (2.76%) whereas the colored microplastic fiber in seawater followed the decreasing order of blue (26.74%) > transparent (24.42%) > black (12.21%) > yellow (10.47%), red (9.30%) > brown (8.14%) > white (4.65%), green (4.07%), respectively as shown in *Figure 4.14.*



(a) Fiber (b) Fiber (c) Fragment



(d) Fragment (e) Fiber (f) Fiber

Figure 4.15 Shapes and colors of microplastics, image taken from a microscope at a magnification of 30x.

These findings were consistent with other studies conducted worldwide (Seth et al., 2018). The seawater of the Gulf of Thailand might be contaminated with fragment and filamentous shapes fibers from fishing nets, textile by-products, laundry effluents, and river discharges (Murphy et al., 2016).

The findings in the present study were similar to those of Kim et al. (2018), Selvam et al. (2020), and Yaranal et al. (2021) who also reported that blue and transparent microplastics were dominant in salts. Renzi and Blaskovic (2018) stated that transparent microplastics were primarily recovered from Croatian salts, together with microplastics in colors of blue, black, white, and yellow. On the contrary, Tahir et al. (2019) documented that the sea salt from Indonesia was dominated by red (48.27%) and blue (27.59%) colored microplastics. The variation in color of microplastic may be due to their origin from diverse plastic sources. The presence of colored microplastics in salt confirmed that these microplastics entered the marine environment via synthetic sources such as clothes, fishing gear, and packaging materials. Transparent microplastics, on the other hand, may emerge from colorful materials that eventually turn colorless (Di and Wang, 2018). Microplastics may get discolored as a result of prolonged exposure to sunlight (Martí et al., 2020). More research can be conducted in the future on microplastic types, size ranges and color to attain a preferable conclusion about their potential sources in salt.

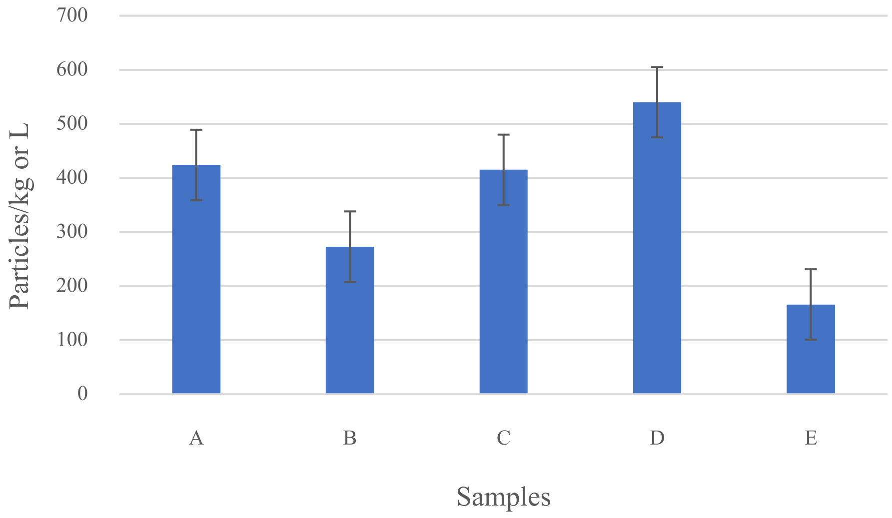
4.4 Comparison of microplastic contamination in seawater and sea salt

The results of the analysis of the difference in the average amount of microplastics found between salt grains produced from traditional salt fields and salt grains produced from plastic salt fields using IBM SPSS version 23 with 24 samples of each type. The data were not normally distributed. Therefore, Mann-Whitney U test statistics were used. It was found that the average amount of microplastics found in salt grains produced from traditional salt fields and salt grains produced from plastic salt fields were significantly different (p-value = 0.03). The difference in the average amount of microplastics found in salt flowers produced from traditional salt fields and salt flowers produced from plastic salt fields found that there was no significant difference (p-value = 0.51) in the amount of microplastics.

Analyzing the difference in the average amount of microplastics found between salt grains produced from traditional and plastic salt field compared to seawater raw materials was found that there were different or significantly different numbers of microplastics (p-value = 0.00) in both cases, possibly because the amount of microplastics detected in 1 liter of seawater was less than that detected in 1 kg of sea salt. In order to produce 1 kilogram of salt takes more than 1 liter of sea salt. In the crystallization process when comparing the same proportions, there was a significant difference in the amount of microplastics found.

Comparing the differences in each type of plastic in each salt production area was found that there were 4 types of polymers for which microplastic differences could not be calculated: PVA, PVC, HDPE, and PS. Since PVA, PVC, and HDPE plastics were not found in seawater, it can be assumed that they may have come from contamination during the production process or the seawater sampling was too small, so these polymers were not found in the sea salt samples. HDPE polymers were found only in plastic salt fields because they were used to pave the salt fields before diversion. Seawater enters the salt fields to help keep the salt clean because it is not in contact with the ground, causing the salt to increase in price. However, the use of this type of plastic over time can cause it to corrode and become contaminated with sea salt as well.

Finally, the analysis concluded that salt grains produced from traditional salt fields had a higher average microplastic content than salt grains produced from plastic fields (A = 424 (186-642) particles/kg > B = 273 (145-533) particles/kg), while salt flowers produced from plastic salt fields had a higher amount of average microplastics content than salt flowers produced from traditional salt fields (D = 540 particles/kg > 415 particles/kg) and seawater raw materials had an average microplastic content of 166 (18-456) particles/L as shown in *Figure 4.16*.



A = Salt grains in traditional salt field, B = Salt grains in plastic salt field
C = Salt flowers in traditional salt field, D = Salt flowers in plastics salt field, E = Seawater

Figure 4.16 Average amount of microplastics in each source.

4.5 Health risk assessment

4.5.1 Exposure assessment to microplastics contaminated with sea salt

Individuals' microplastic exposure caused by the consumption of sea salt was calculated using the following formula according to the deterministic model (U.S. Environmental Protection Agency, 2017) as follows equation (3.1)

Table 4.3 The average salt consumption of the Thai population (g/person/day)

Age (Year)	**The average amount of salt (g/day)**	
	Male	**Female**
1-3	2.15	2.10
4-5	2.60	2.13
6-8	3.00	2.91
9-12	3.20	3.24
13-15	3.20	2.83
16-18	4.60	3.54
19-30	3.93	4.25
31-50	4.26	4.12
51-59	3.95	3.68
60-69	4.00	3.82
70-79	3.61	3.74
>80	4.10	3.65

**Thai Population Health Survey Office, Public Health Research Institute, Ministry of Public Health.

The calculation of daily exposure to microplastic particles divided by gender and age from the traditional and plastic salt fields was conducted. The results are shown in *Table 4.4*.

Table 4.4 Microplastic exposure levels from individual consumption of sea salt

Groups	Age ranges	Consumption amount (g)	Daily exposure (microplastic particles /day)				Annual exposure (microplastic particles /year)			
			Sea salt from traditional salt field		Sea salt from plastic salt field		Sea salt from traditional salt field		Sea salt from plastic salt field	
			Salt grains	**Salt flowers**	**Salt grains**	**Salt flowers**	**Salt grains**	**Salt flowers**	**Salt grains**	**Salt flowers**
Men	1-3	2.15	0.88	0.58	0.88	1.16	321.20	211.70	321.20	423.40
Women		2.10	0.88	0.57	0.88	1.13	321.20	208.05	321.20	412.45
Men	4-5	2.60	1.09	0.70	1.09	1.40	397.85	255.50	397.85	511.00
Women		2.13	0.90	0.58	0.90	1.15	328.50	211.70	328.50	419.75
Men	6-8	3.00	1.26	0.81	1.26	1.62	459.90	295.65	459.90	591.30
Women		2.91	1.22	0.79	1.22	1.57	445.30	288.35	445.30	573.05
Men	9-12	3.20	1.34	0.86	1.34	1.73	489.10	313.90	489.10	631.45
Women		3.24	1.36	0.88	1.36	1.75	496.40	321.20	496.40	638.75
Men	13-15	3.20	1.34	0.86	1.34	1.73	489.10	313.90	489.10	631.45
Women		2.83	1.19	0.76	1.19	1.53	434.35	277.40	434.35	558.45
Men	16-18	4.60	1.93	1.24	1.93	2.48	704.45	452.60	704.45	905.20
Women		3.54	1.49	0.96	1.49	1.91	543.85	350.40	543.85	697.15
Men	19-30	3.93	1.65	1.06	1.65	2.12	602.25	386.90	602.25	773.80
Women		4.25	1.79	1.15	1.79	2.30	653.35	419.75	653.35	839.50
Men	31-50	4.26	1.79	1.15	1.79	2.30	653.35	419.75	653.35	839.50
Women		4.12	1.73	1.11	1.73	2.22	631.45	405.15	631.45	810.30
Men	51-59	3.95	1.66	1.07	1.66	2.13	605.90	390.55	605.90	777.45
Women		3.68	1.55	0.99	1.55	1.99	565.75	361.35	565.75	726.35
Men	60-69	4.00	1.68	1.08	1.68	2.16	613.20	394.42	613.20	788.40
Women		3.82	1.60	1.03	1.60	2.06	584.00	375.95	584.00	751.90
Men	70-79	3.61	1.52	0.98	1.52	1.95	554.80	357.70	554.80	711.75
Women		3.74	1.57	1.01	1.57	2.02	573.05	368.65	573.05	737.30
Men	>80	4.10	1.72	1.11	1.72	2.21	627.80	405.15	627.80	806.65
Women		3.65	1.53	0.99	1.53	1.97	558.45	361.35	558.45	719.05

Exposure assessment to microplastic contaminants in sea salt produced from traditional salt fields and plastic salt fields. The calculation was derived from the quantity of salt ingested by the Thai Population Health Survey Office, Public Health Research Institute, Ministry of Public Health. *(Table 4.3)*. It was found that the Thai population's salt intake exceeds the World Health Organization standard of no more than 2000 milligrams per day since the age of 1 year and found that the Thai population age ranges from 16 years and above, both males and females salt consumption was 1.5 - 2.0 times higher than the World Health Organization specifies. Thai individuals are most significantly exposed to microplastics between the ages of 16-18 years in males. The average annual exposure of males to microplastics in salt flowers was 905.20 particles/person/year. Furthermore, the mean annual exposure to microplastics among females was 697.15 particles/person/year. The lowest amount of exposure to microplastics in salt flowers from the traditional salt field among the Thai population age was 1-3 years in females, averaging 208.05 particles/person/year, as shown in *Table 4.3.* The exposure range of microplastics in salt for the Thai population was higher than in Turkish and Indonesia. Microplastic exposure from salt consumption of male and female individuals of different ages ranges from 249-302, 60-571 particles/ person/year respectively. On the contrary, the exposure range of microplastics in salt for the Thai population was lower than Lebanon, Bangladesh, Italy, and Vietnam as shown in *Table 4.1 -4.2* (Özçifçi et al., 2023).

Although there was a paucity of information regarding the health effects of microplastic exposure (Leslie & Depledge, 2020), it has been found that microplastics can move from the environment into the human body. Pregnant organisms and human white blood cell membranes have been found to contain microplastics introduced from the environment (Ragusa et al., 2021). This suggests that inhalation or ingestion of microplastics at high concentrations could result in adverse health effects. Utilizing microplastic-contaminated products can lead to accumulation within the human body (WHO, 2019). Furthermore, it has been discovered that microplastics influence cellular inflammation within the human body, potentially leading to the development of cancer. The human metabolic system was impacted (Daniel et al., 2021). Consequently, this study points out the effects that may occur in the long term from exposure to microplastics that enter the human food chain.

Previous research has demonstrated that microplastics and nanoplastics can enter the human body and accumulate throughout different organs such as the gastrointestinal system, lungs, brain, and placenta. Once inside, they interact with crucial macromolecules including proteins and lipids. Nanoplastics can be carried and absorbed by cells with passive or active transport mechanisms, which are influenced by the different amounts of nanoplastics inside and outside the plasma membrane. Nanoplastics can penetrate cell membranes if their size is smaller than the pores on the surface. Nanoplastics exhibit toxicity by inducing alterations in the mitochondria, endoplasmic reticulum, and lysosomes, so resulting in disruptions to metabolic and cellular functions. Encompassing the presence of oxidative stress within the endoplasmic reticulum. Previous research has established that the potential of microplastics and nanoplastics to become a threat to human health is an important concern.

4.5.2 Risk assessment of hazardous substances from microplastics contaminated in sea salt.

The hazard scores of plastic polymer and polymer type are important indices to evaluate its ecological harm that was used to assess the risks of microplastics based on polymer properties. The calculation of the total risk index was followed by Eq. 3.2. The results are shown in *Table 4.5*.

Table 4.5 Risk values of hazardous substances from microplastics contaminated in sea salt and sea water raw materials

Type of sea salt	Polymer type	Total amount of microplastics (C_s) (Particles)	Amount of polymer type (C_n) (Particles)	Proportion of polymer type (Pn)	Score for the polymer (Sn)	Risk index	Total risk index
1.Traditional salt field							
1.1 Salt grains	PA	1695	590	0.35	50	17.50	42.75
	PE		542	0.32	11	3.52	
	PP		501	0.30	1	0.30	
	PVA		49	0.03	1	0.03	
	PS		10	0.01	30	0.30	
	PVC		3	0.002	10551	21.10	
1.2 Salt flowers	PA	415	402	0.97	50	48.50	48.82
	PP		8	0.02	1	0.02	
	PS		5	0.01	30	0.30	
2. Plastic salt field							
2.1 Salt grains	PA	1093	400	0.37	50	18.50	23.08
	PE		371	0.34	11	3.74	
	PP		257	0.24	1	0.24	
	PVA		20	0.02	1	0.02	
	PS		5	0.005	30	0.15	
	HDPE		40	0.04	11	0.44	
2.2 Salt flowers	PA	524	313	0.60	50	30.00	32.20
	PE		48	0.09	11	0.99	
	PP		102	0.20	1	0.20	
	PVA		14	0.03	1	0.03	
	HDPE		47	0.09	11	0.99	
3. Sea water raw materials	PA	664	467	0.70	50	35.00	35.56
	PE		13	0.02	11	0.22	
	PP		183	0.28	1	0.28	
	PS		1	0.002	30	0.06	

Note : H <10 = I = Minor, H =10-100 = II = Medium, H = 100 – 1000 = III = High, H > 1000 = IV = Danger

As a result, the risk assessment of hazardous substances from microplastics contaminated in sea salt produced from traditional salt fields and plastic salt fields and sea water raw materials. It was calculated from the proportion of each type of microplastic polymer found in each type of sea salt and sea water. Furthermore, according to the hazard scores of microplastic polymers derived from the plastic type (Lithner et al., 2011; Xu et al., 2018), it was found that all 4 types of sea salt and sea water had a risk value at level II or medium level. Salt flowers produced from traditional salt fields had a hazard score of 48.82, followed by salt grains produced from traditional salt fields with 42.75, seawater raw materials with 35.56, salt flowers produced from plastic salt fields with 32.20, salt grains produced from plastic salt fields 23.08, as shown in the *Table 4.5*. The analysis revealed that the salt flowers produced from traditional salt fields revealed a high hazard score because of the microplastic polymer Polyamide (PA), which was discovered in proportion as high as 0.97, a hazard score of up to 50.

It was attributed to the compounds contained in the microplastic polymer cause effect to removing estrogenic chemicals that cause changes in human cell structures (Nilawati et al., 2020). Additionally, three routes of human exposure to microplastics have been identified: ingestion, inhalation, and dermal contact. Consumption serves as the primary route of direct microplastic exposure, which has adverse effects to human health. For example, polystyrene (PS) microplastics have been found to be absorbed into the system circulates in the blood and accumulates in the liver, kidneys, and intestines of laboratory rats and affects cell inflammation, which may cause cancer cells can also occur in food systems (Prata et al., 2020; Rahman et al., 2021). Additionally, microplastics such as polystyrene (PS) and polyethylene (PE) can act as mediators.

The accumulation and transportation of hazardous substances from the environment, including persistent organic pollutants (POPs), polycyclic aromatic hydrocarbons (PAHs), and polychlorinated biphenyls (PCBs), including the insecticide DDT (Dichlorodiphenyltrichloroethane, DDT), are factors that contribute to environmental pollution (Napper et al., 2015). Furthermore, heavy metal accumulation is a risk factor for human cancer (Crawford and Quinn, 2017; Huang et al., 2021). Heavy metals include mercury (Hg), cadmium (Cd), copper (Cu), lead (Pb), chromium (Cr), and silver (Ag). The elements manganese (Mn) and gold (Au). Heavy metal-containing microplastics influence the immune system. The development and reproductive processes of fish, crustaceans, and algae (Huang et al., 2021).

In addition to microplastics being able to absorb toxins from the environment, microplastics also contain toxic substances as components or additives. Microplastic polymers, including Phthalate and Bisphenol A, have the potential to cause harm to the reproductive system, nervous system, and endocrine glands. There was evidence linking hormonal function with the development of human breast cancer (Cole et al., 2011; Senathirajah et al., 2021). Therefore, it was recommended to reduce exposure. Microplastics from sea salt consumption should include seawater filtration that was the raw material for salt production and strict control of contamination during the production process to reduce the concentration of microplastics in sea salt. In addition, microplastics have been found.

It also contaminates other products such as honey, beer, tap water and bottled water which may enter the human body through consumption and affect health (Cho et al., 2019). Consequently, it was critical to investigate the extent of exposure and accumulation within the human body, as well as the resulting adverse consequences. Furthermore, to ensure precision, standardized methods for microplastic analysis should be established more precisely. In addition, defined standards for micro and nano plastics should exist to evaluate and mitigate risks to human health (Rahman et al., 2021).

4.6 Ecological risk assessment

4.6.1 The pollution load index (PLI)

The PLI was generally used to evaluate the ecological risk in terrestrial and aquatic environments (Tomlinson et al., 1980). In this study, the concentration of microplastics was considered the pollutant to estimate the ecological risk in seawater raw material for producing sea salt. The PLI was evaluated using the following equations (3.3) - (3.5) (Xu et al., 2018; Wang et al., 2021). The results are shown in *Table 4.5*

Table 4.6 Pollution load index (PLI) of microplastics concentration in seawater raw material

Units	**Total amount of microplastics (Particles/L)**	**Contamination Factor (CF_i)**	**Pollution load index (PLI)**
S9	151	8.39	2.90 (I)
S10	39	2.17	1.47 (I)
S11	456	25.33	5.03 (I)
S12	18	1	1 (I)
PLI_{zone}			2.15 (I)

Note: I = low toxic, II = moderate toxic, III = considerable toxic, and IV = high toxic

The PLI was used for monitoring the degree of microplastic concentration from seawater raw material (S9-S12), and their result was illustrated in *Table 4.6*. Before the PLI assessment, the contamination factor (CF_i) was analyzed. In this study, the lowest concentration of microplastics at each study site was used as background (C_{0i}) 18 particles/L. The highest microplastic contamination was presented in seawater S11 (CF_i = 25.33), however, based on C_{0i}, the lowest concentration in seawater S12 was 18 particles, while seawater S11 showed 456 particles. For PLI from S9 – S12 all sites were in risk category I and the PLI zone was in risk category I. The level of microplastic concentration in seawater, the raw material to produce sea salt was low toxic level. However, the detection of high concentrations of microplastic particles led to a high pollution load in the environment.

4.6.2 Potential ecological risk (PER)

Potential ecological risk (PER) refers to the total concentrations of microplastics and the response of the environment. This model was developed based on Hakanson (1980). The PER of all samples was calculated following the Equations. 3.5-3.7. The results are shown in *Table 4.6*.

Table 4.7 The potential ecological risk (PER) of microplastics concentration in seawater

Sampling points	Polymer type	Total amount of microplastics (C_s) (particles)	Amount of polymer type (C_i) (particles)	Proportion of polymer type (P_n)	Hazard score of plastic polymer (S_n)	Toxicity coefficient for the constituent polymer (T_r)	Contamination factor (CF_i)	Potentail ecological risk factor (E_r)	$\sum$Er
S9	PA	151	132	0.88	50	0.33	8.39	2.77	3.44
	PE		5	0.03	11	0.07		0.59	
	PP		14	0.09	1	0.01		0.08	
S10	PA	39	11	0.28	50	1.27	2.17	2.76	4.78
	PP		27	0.69	1	0.03		0.07	
	PS		1	0.03	30	0.9		1.95	
S11	PA	456	320	0.70	50	0.11	25.33	2.79	3.35
	PE		6	0.01	11	0.02		0.51	
	PP		130	0.29	1	0.002		0.05	
S12	PA	18	4	0.22	50	2.75	1	2.75	3.42
	PE		2	0.11	11	0.61		0.61	
	PP		12	0.67	1	0.06		0.06	
PER = $\sum$Er = 14.99									

Note: For Er, < 40 = Minor, 40-80 = Medium, 80-160 = High, 160-320 = Danger, ≥ 320 = Extreme danger.

For PER, < 150 = Minor, 150-300 = Medium, 300-600 = High, 600-1,200 = danger, ≥ 1,200 = Extreme danger.

In this study, PER values were relatively within the extreme risk category in S9 – S12 sites, especially microplastic polymers from seawater (*Table 4.7*), and common microplastic polymers (PA, PE, PP, and PS) were detected. The ∑Er from S10 was 4.78 followed by S9 (3.44) > S12 (3.42) > S11 (3.35) respectively. Polyamide (PA) was the most polymer type commonly detected in every site. As a result, the potential ecological risk (PER) of seawater, the raw material used to produce sea salt was at minor level.

The study found that the potential ecological risk assessment of microplastics in the seawater was similar to the results of the Chinese study on the Yangtze River, which determined that the potential ecological risk assessment was at a minor level (Ji et al., 2023). According to the spatial data of Ban Laem salt fields, Phetchaburi Province has pumped seawater from the sea on the Gulf of Thailand. Therefore, when comparing the morphological characteristics of the sea in the Gulf of Thailand and the Andaman Sea, there are different morphological characteristics (Department of Marine and Coastal Resources, 2021). The Gulf of Thailand was a semi-enclosed bay, and the Andaman Sea was an open sea connected to the Indian Ocean. The currents in the Gulf of Thailand produce an uneven and feeble current. This may lead to a more substantial buildup of plastic debris compared to the Andaman Sea, where monsoon currents are particularly strong. It was discovered that the accumulation and distribution of microplastics were correlated with the circulation of sea currents. Furthermore, the rate at which waste accumulates in coastal regions and seawater was influenced by the arrival of monsoons (Bissen and Chawchai, 2020).

In addition, large amounts of microplastics were found. Contamination of 21 beaches along the Gulf of Thailand was caused by trash that floated in the sea and was washed ashore by waves and human activities. And it was found that most microplastics were fragments and fibers, which may be caused by municipal wastewater drainage into the sea (Wang et al., 2020). In addition to the Gulf of Thailand, microplastics were also found in the sediments of provincial beaches. Phuket which was the source. It was also a popular tourist destination on the Andaman Sea coast of Thailand (Akkajit et al., 2023). Consequently, the majority of microplastic contamination in sea salt derived from the Gulf of Thailand coastal seawater may be influenced by the circumstances regarding microplastic contamination in Thailand's beaches, sediments, and seawater.

Additional activities along the Gulf of Thailand were also found to be contaminated with microplastics, such as commercial fishing, which involves disposing of damaged fishing gear and repairing nets. This includes activities related to fishing on the coast near fishing piers, such as disassembling fishing equipment and throwing it into the sea. In addition, PA, and PS microplastic contamination may occur from tourism activities with tourists and many seafood sellers on beaches, often discard food wrappers and plastic packaging on beaches. Therefore, microplastics can be deposited on beaches and can wash into the sea and coastlines. During high tide (Thushari et al., 2017), microplastics were also found in the coastal area of the Gulf of Thailand, over more than 400 km, in the amount of 420 -200,000 particles/kg. The microplastics found were fragments and fibers. This may come from activities in the dock area and wastewater drainage from industrial sites. The fibrous microplastics found may have come from the fishing industry. Due to the wear and tear of fishing nets and may be caused by the laundry of hotels, resorts, and various accommodations, including activities. Tourism is also the main source of plastic waste (Bissen and Chawchai, 2020), which is consistent with plastic waste found in seawater and coastal areas in Phetchaburi Province. The main sources of plastic waste include water activities such as fishing and shipping. Coastal Activities and Leisure Activities related to smoking. Large waste such as electrical appliances, batteries, and construction materials, car parts and car tires were also found (Department of Marine and Coastal Resources, 2018).

In considering this, the ecological risk assessment results for the seawater utilized in the production of sea salt in the Ban Laem salt fields indicate the following. Therefore, Phetchaburi Province is classified as being at a minor level. The degree of concern regarding direct effects on the ecosystem and human welfare was regarded as such. Consequently, this research highlights potential consequences associated with long-term exposure to microplastics entering the human food chain and their impact on the ecosystem.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This study analyzed the amount of microplastics contaminated in sea salt from two sources: a traditional salt field and a plastic salt field. It was found that salt grains and salt flowers produced from the traditional salt field provided an average amount of microplastics at 424 (186-642) particles/kg and 415 particles/kg. The salt grains and salt flowers produced from the plastic salt field had an average of 273 (145-533) particles/kg and 540 particles/kg of microplastics. There was a significant difference from both production sources (p-value = 0.03) and the amount of microplastics from salt flowers from both production sources was not significantly different (p-value = 0.51). Seawater, which was a raw material to produce sea salt, the average amount of microplastics was found to be 166 (18-456) particles/L. From salt grains, salt flowers, and seawater, the size of most microplastics detected ranged in size from 16 - 100 µm. Blue and transparent hues were the most common colors of microplastics. The shape was discovered in fragments and fiber. Types of microplastic polymers found in sea salt produced from traditional and plastic salt fields include polyamide (PA), polyethylene (PE), polypropylene (PP), polyvinyl acetate (PVA), polystyrene (PS), polyvinyl chloride (PVC), high density polyethylene (HDPE), and types of microplastic polymers found in seawater, raw materials for producing sea salt include polyamide (PA), polyethylene (PE), polypropylene (PP).

According to the results of the health risk assessment, the age group between 1-3 years in females had the lowest exposure to microplastics in sea salt (208.05 particles/person/year), while the age group between 16-18 years in males had the highest exposure (905.20 particles/person/year). Risk assessment of hazardous substances from microplastics contaminated in sea salt was at level II. The pollution load index (PLI) of microplastic concentration in seawater raw material was level I, low toxic, and the ecological risk assessment found that the potential ecological risk (PER) of microplastic concentration in seawater raw material was at the minor level. Hence, the presence of microplastic contamination in sea salt could possibly have adverse effects on human health and the environment. As a result, manufacturers should tackle this problem both eliminating microplastics in seawater raw materials and controlling contamination during the production process to reduce this problem further.

5.2 Recommendation

5.2.1 For the precise detection of microplastics, a wide variety of methods have been developed. For optimal performance, μ-FTIR suggests specifying the polymer type. However, various techniques or apparatus as varying approaches may lead to disparate outcomes, standard procedures for analysis were ascertained.

5.2.2 The purpose of comparison and trend analysis about the microplastic contamination of sea salt in the future, samples should be taken in a variety of seasons.

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APPENDEX

APPENDEX A

Table A1(a): Abundance and polymer types of microplastics in traditional salt field (salt grains).

Position	Material	Size of Microplastics (µm)				
		16-100	101 - 500	501-1000	1001 -1200	Total count (Particles/kg)
S1	PA	148	27	0	0	175
	PE	290	18	0	0	308
	PP	82	26	0	0	108
	PVA	33	13	0	0	46
	PS	5	0	0	0	5
	PVC	0	0	0	0	0
S2	PA	248	7	0	0	255
	PE	53	32	10	0	95
	PP	38	10	0	0	48
	PVA	3	0	0	0	3
	PS	5	0	0	0	5
	PVC	3	0	0	0	3

Table A1(b): Abundance and polymer types of microplastics in traditional salt field (salt grains).

Position	**Material**	**Size of Microplastics (µm)**				
		16-100	**101 - 500**	**501-1000**	**>1000 (1001-1200)**	**Total count (Particles/kg)**
S3	PA	65	0	0	0	65
	PE	108	0	0	0	108
	PP	155	110	20	0	285
	PVA	0	0	0	0	0
	PS	0	0	0	0	0
	PVC	0	0	0	0	0
S4	PA	92	3	0	0	95
	PE	23	8	0	0	31
	PP	38	19	0	3	60
	PVA	0	0	0	0	0
	PS	0	0	0	0	0
	PVC	0	0	0	0	0

Table A2: Abundance and polymer types of microplastics in traditional salt field (salt flowers).

Position	**Material**	**Size of Microplastics (µm)**				
		16-100	**101 - 500**	**501-1000**	**>1000 (1001 -1200)**	**Total count (Particles/kg)**
	PA	295	13	7	87	402
	PE	0	0	0	0	0
	PP	8	0	0	0	8
	PVA	0	0	0	0	0
	PS	0	5	0	0	5
	PVC	0	0	0	0	0

Table A3 (a): Abundance and polymer types of microplastics in plastic salt field (salt grains).

Position	**Material**	**Size of Microplastics (µm)**				
		16-100	**101 - 500**	**501-1000**	**>1000 (1001 -1200)**	**Total count (Particles/kg)**
S5	PA	15	0	0	0	15
	PE	68	0	0	0	68
	PP	55	0	0	0	55
	PVA	7	0	0	0	7
	PS	0	0	0	0	0
	PVC	0	0	0	0	0
	HDPE	0	0	0	0	0
S6	PA	55	20	0	0	75
	PE	35	47	0	0	82
	PP	42	26	0	0	68
	PVA	0	0	0	0	0
	PS	0	0	0	0	0
	PVC	0	0	0	0	0
	HDPE	20	0	0	0	20
S7	PA	108	7	0	0	115
	PE	0	0	0	0	0
	PP	35	0	0	0	35
	PVA	13	0	0	0	13
	PS	0	0	0	0	0
	PVC	0	0	0	0	0
	HDPE	7	0	0	0	7

Table A3 (b): Abundance and polymer types of microplastics in plastic salt field (salt grains).

Position	**Material**	**Size of Microplastics (µm)**				
		16-100	**101 - 500**	**501-1000**	**>1000 (1001 -1200)**	**Total count (Particles/kg)**
S8	PA	182	13	0	0	195
	PE	168	53	0	0	221
	PP	88	11	0	0	99
	PVA	0	0	0	0	0
	PS	5	0	0	0	5
	PVC	0	0	0	0	0
	HDPE	13	0	0	0	13

Table A4: Abundance and polymer types of microplastics in plastic salt field (salt flowers).

Position	**Material**	**Size of Microplastics (µm)**				
		16-100	**101 - 500**	**501-1000**	**>1000 (1001 -1200)**	**Total count (Particles/kg)**
	PA	195	94	10	14	313
	PE	21	27	0	0	48
	PP	82	20	0	0	102
	PVA	7	7	0	0	14
	PS	0	0	0	0	0
	PVC	0	0	0	0	0
	HDPE	40	7	0	0	47

Table A5: Abundance and polymer types of microplastics in seawater raw material.

Position	Material	Size of Microplastics (µm)				
		16-100	101 - 500	501-1000	1001 -1200	Total count (Particles/L)
S9	PA	131	1	0	0	132
	PE	4	1	0	0	5
	PP	10	4	0	0	14
	PVA	0	0	0	0	0
	PS	0	0	0	0	0
	PVC	0	0	0	0	0
S10	PA	8	3	0	0	11
	PE	0	0	0	0	0
	PP	25	2	0	0	27
	PVA	0	0	0	0	0
	PS	1	0	0	0	1
	PVC	0	0	0	0	0
S11	PA	142	178	0	0	320
	PE	1	5	0	0	6
	PP	58	72	0	0	130
	PVA	0	0	0	0	0
	PS	0	0	0	0	0
	PVC	0	0	0	0	0
S12	PA	4	0	0	0	4
	PE	1	1	0	0	2
	PP	8	4	0	0	12
	PVA	0	0	0	0	0
	PS	0	0	0	0	0
	PVC	0	0	0	0	0

Table B1: Comparison of the average value of total microplastic in each area.

Comparison area	**Z**	**p-value**
Traditional salt field : Plastic salt field	-2.07	0.03*
Traditional salt field : Seawater	-2.87	0.00**
Plastic salt field : Seawater	-3.79	0.00**
Salt flowers in traditional salt field : Salt flowers in plastic salt field	-0.67	0.51

*Mann-whitney U test at significant value *p*-value < 0.05=* and 0.01=**

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Table B2: Comparison of the average values of each type of microplastics in each area

Type	**Comparison area**	**PA**	**PE**	**PP**	**PVA**	**PVC**	**HDPE**	**PS**
		Z **p-value**	**Z** **p-value**	**Z** **p-value**	**Z** **p-value**	**Z** **p-value**	**Z** **p-value**	**Z** **p-value**
Salt grains	Traditional salt filed : Plastic salt filed	-0.21 0.83	-0.45 0.65	-1.25 0.21	-0.29 0.77	NC	NC	NC
Salt flowers	Traditional salt filed : Plastic salt filed	-1.23 0.28	NC	-0.45 0.66	NC	NC	NC	NC
Salt grains Seawater	Traditional salt filed : Seawater	-0.82 0.41	-3.29 0.00**	-1.39 0.17	NC	NC	NC	NC
Salt grains Seawater	Plastic salt filed : Seawater	-0.97 0.33	-3.23 0.00*	-2.13 0.03*	NC	NC	NC	NC

*Mann-whitney U test at significant value *p*-value < 0.05=* and 0.01=**, nc = no calculated

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