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Microplastic Pollution in Ship-Sourced Wastewater: Assessment of Pollution Load Risk for Ballast and Bilge Water

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Abstract

The rapid development of maritime transport also causes a number of negative environmental impacts. One of these problems is marine pollution caused by the operation of ships. Pollution from ship sewage includes ballast water (BAL-W) and bilge water (BIL-W), which are regulated under International Convention for the Prevention of Pollution from Ships Annex IV. Both BAL-W and BIL-W samples were analysed in the study. Many of the microplastic (MP) particles detected in the BAL-W samples were micro sized, while the majority of MPs found in the BIL-W samples were macro (>0.5 mm) and micro (1 µm-<5 mm) in size. The findings show that MPs constitute the majority (53%) of the plastics analysed, followed by 25% mesoplastics and 11% nanoplastics (NPs). Plastics with a size class of 50-300 µm were most abundant in both BAL-W and BIL-W. For BAL-W and BIL-W sources, the average MP sizes were calculated to be 0.025-4.99±0.050 mm and 0.05-0.1±0.050 mm, respectively. Rubber/commercial (PNEU), polyethylene (PET) terephthalate, polystyrene (PS), and polyoxymethylene (POM) were the most abundant polymer types found in the BIL-W samples, accounting for 47.82%, 10.86%, 9.78%, and 6.55%, respectively, while PNEU and PE were the most abundant polymer types found in the BAL-W samples, accounting for 22.91% and 7.98%, respectively. The pollution load index was calculated 7.75 (Hazard Category IV) and 12.17 (Hazard Category V) for BAL-W and BIL-W waters. It is now clear that the BAL-W management system needs to be evaluated to eliminate MP pollution due to the presence of polymers in BIL-W and BAL-W.

Keywords: Marine environmental protection, MARPOL 73/78 Annex IV, sewage from ships, microplastic pollution, pollution load index (PLI)

1. Introduction

The massive amounts of plastic in the world's seas and oceans create a serious hazards to their natural ecological live. It is anticipated that 0.8 to 23.0 million tons of plastic wastes are floating in the seas and oceans [1]. Micro and macroplastics (MPs) contribute significantly to marine plastic pollution. With the increase in global maritime trade, the number of merchant ships is growing every year. As more ships transport, in addition to environmental degradation on land, pollution from ships is growing. The pieces of plastic are categorized based on their size: mesoplastics (5-25 mm), MPs (1-5 mm; MPs), and nanoplastics (<1 µm; NPs) [2-4]. MPs, particularly NPs, are tiny particles that may cause a variety of impacts on marine and coastal organisms. Ingestion of these plastics may threaten marine organisms' growth, survival, and reproduction [5]. They may also be hazardous to human health since they accumulate in seafood [6].

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Sources of pollution reaching the seas and oceans include terrestrial origin (44%), atmospheric pollution (33%), pollution from maritime activities (12%), waste and sewage dumping (10%), and offshore drilling and mining (1%) [7,8]. While terrestrial or anthropogenic pollutants are the main sources, pollutants from ships also contribute signific antly to marine pollution. The International Convention for the Prevention of Pollution from Ships (MARPOL 1973/78) is the core international maritime convention adopted by the International Maritime Organization (IMO) to prevent both operational and accidental pollution [9]. The Convention consists of six technical Annexes covering various aspects of marine pollution prevention, e.g., oil, toxic liquids, garbage, and emissions. Two of these annexes are "Annex I. Regulations for the Prevention of Pollution by Oil" and "Annex IV: Prevention of Pollution from Ship Sewage." In addition, The ballast water (BAL-W) Management Convention or BWM Convention (2004) is a treaty adopted by the IMO in order to help prevent the spread of potentially harmful aquatic organisms and pathogens in ships' BAL-W. According to all, the discharge of ship sewage also contributes to marine pollution. Sewage, greywater, debris, oil/water separator effluent, cooling water, boiler and steam generator blow-down, and bilge water (BIL-W) are examples of waste streams on ships [10]. Among these, BAL-W is important for its water-capacity, BIL-W is another waste source with high pollutant potential due to ship operational processes (the engine room and leaks or maintenance operations etc.). Therefore, these two wastewater types were chosen for this study.

Marine pollution is widely described as the hazardous migration of substances or energy that alters physical, chemical, or biological characteristics due to human activity (MARPOL Convention, 1973/78) [11]. However, in this context, organisms carried in BAL-W are regarded as biological agents rather than "substances". BAL-W and BIL-W are regarded as critical vectors for the spread of various pollutants, including MPs, across the world's seas [12,13]. MPs are synthetic plastic particles less than 5 mm in diameter that are persistent and non-biodegradable in the environment [14,15]. These particles not only represent physical pollution, but also threaten the health of ecosystems as they act as carriers for toxic chemicals, heavy metals, and pathogenic microorganisms. BAL-W and BIL-W, in particular, are thought to be key sources of conveyance for the spread of biological pollution and pollutants in the marine environment. However, barely anything has been revealed about the plastics included in BAL-W and BIL-W.

BAL-W: Maritime traffic continues to increase, with around 51,400 merchant ships in operation worldwide and around 3 to 5 billion tons of BAL-W carried by ships every year [7]. Today, BAL-W is one of the most important maritime pollutants and is associated with about one third of documented infestations worldwide. One of the biggest challenges for maritime transport is to find safe solutions for BAL-W management that minimize the environmental impact. To address this issue, following its regular meetings, the IMO has revised Annex IV of MARPOL 73/78 and made it mandatory for large ships to be equipped with a BAL-W management system (BWMS) from September 2025 [11]. This reduces the potential of invasive species spreading as a result of ships discharging untreated BAL-W. However, these waste waters, which are discharged and distributed in vast amounts across the world, are only disinfected for microbiological causes (Table 1) [16,17]. It still allows for the transfer of other pollutant factors, such as MPs. During ballasting, large amounts of seawater are pumped into the ballast tanks of ships. As a result, various creatures and particles prevalent in the maritime environment, including plastics, enter the ballast tanks with the brine and accumulate. Consequently, the collection of BAL-W from polluted territories could lead in MPs entering the port of destination when water treatment does not occur out [18]. In this way, MPs might contribute to marine pollution by BAL-W or BIL-W during marine transportation and act as a reservoir of pollutants.

To meet discharge standards, almost all ships are expected to be equipped with BWMS. Although various technologies such as filtration, chlorination, ozonation, pasteurization,

Table 1. IMO D-2 ballast water discharge standard.

Parameter	The limits for the indicators in the ballast discharge	
	USCG standards [10]	**IMO D2 standards [4]**
Zooplankton, organisms ≥50 µm	<1 viable organisms/100 m^3	<10 viable organisms/m^3
Phytoplankton, organisms 10-50 µm	<1 viable organisms/100 mL	<10 viable organisms/mL
Vibrio cholerae	<1 CFU/100 mL	<1 CFU/100 mL
Escherichia coli	<126 CFU/10 mL	<250 CFU/100 mL
Enterococci	<33 CFU/100 mL	<100 CFU/100 mL

CFU: Colony-forming unit, IMO: International Maritime Organization, USCG: United States Coast Guard and ultraviolet radiation (alone or in combination) are used for water purification [19,20], these are not effective methods for combating MP pollution. Studies have found that the average content of MPs in ship BAL-W and seawater samples were 12.53 and 11.80 units/L, respectively, with a high concentration of MPs in the 50-300 μm size class. The findings identified the main sources of MPs (such as BAL-W), their transport pathways and the associated ecological risks to marine ecosystems [12].

BIL-W: Various harmful substances, consisting of MPs and heavy metals, might enter the sea from ships through a variety of sources, including grey water, wastewater, ship cooling water, and treated sewage. Wastewater from regular ship operations persists and poses a significant risk to coastal aquatic ecosystems [21,22]. The wastewater has a pH range of 6.8 to 9.0, a salinity of 25 to 35 g/L, an oil concentration of 36 to 2953 mg/L, and a high chemical oxygen demand> 3-15 g/L [23]. In addition, studies have found MPs in wastewater [12]. For these reasons, strict environmental regulations on wastewater discharges and the tendency to reuse treated water make wastewater treatment a critical factor. MARPOL 73/78 regulates BIL-W management, limiting oil content to ≤15 mg/L when discharged into the sea. The literature reports on various types of BIL-W treatment methods, including coagulation, flocculation, membrane filtration, electrocoagulation, flotation, and combinations of these processes [24,25].

In addition, investigations have demonstrated that MPs accumulate in a variety of marine animals [26-28], and because of their small size, these particles can be ingested by a wide range of marine organisms [12]. Also, MPs have the ability to adhere to a variety of marine contaminants, including heavy metals, and accelerate their build up in the marine environment [29,30]. Human exposure to MPs and other contaminants that build up in marine food webs may have negative consequences [14]. All of this emphasizes how our seas are affected by MP contamination. Although there is few research on the migration of MPs through BAL-W, there aren't many on the migration of MPs through BIL-W. BAL-W and BIL-W pollutants, which have been studied in small quantities for MPs [12].

The aims of this study were to investigate MPs abundance and their characteristics, including size, polymer type, and chemical composition, in the BAL-W and BIL-W of ships, and to determine the pollution load index (PLI) of MPs in the BAL-W and BIL-W.

2. Materials and Methods

2.1. The Sampling Stations

The sampling work was conducted from April to September, 2024. There were seven sampling stations (Table 1) set up, 4 BAL-W and 3 BIL-W in the different type of ships, and seven waste water samples from ship-originated were obtained by collecting sample at each station. The vessels from which water samples were selected at random from three seas: the Black Sea, the Mediterranean Sea, and the Marmara Sea, regardless of type or tonnage. Table 2 shows information about each of the ships that were sampled for ship sewage, and Table 3 shows the physical and chemical measurement results of the samples. The BAL-W volume of the ships ranged from 500 m^3 to 10,000 m^3.

2.2. Sample Collection

Samples were collected from 7 sampling station (Table 3) as vertically water column. BAL-W sampling depth varied from 2 m to 6 m, while the BIL-W samples were taken from a depth of around 1 m below the surface. For this purpuse, 7 samples the volumes are given in Table 2, were collected with containers to include MPs. Then all the samples were transferred into the glass bottle and treated with hydrogen peroxide (30% v/v, Merck, Germany) to in order to remove organic material [31-33]. The bottles were rinsed several times with ethanol before use. Checked for any potential contamination occurring in the sample in the field and laboratory. Water samples were stored in dark and cold conditions until MP analysis.

Table 2. Information on the sampled ships.

Station	Matrix	Date	Type of vessel	GRT	BWMS	Sampling location	Sample volume (L)
1	BAL	31.09.2024	Oil tanker	3225	D2 UV/filter	Mediterranean/Italy/Ravina	5
2	BIL	31.09.2024	Oil tanker	3225	-	Mediterranean/Italy/Ravina	5
3	BAL	18.05.2024	Chemical tanker	3776	D2 UV/filter	Novorossysk/Russia	5
4	BAL	18.05.2024	Chemical tanker	3776	D2 UV/filter	Novorossysk/Russia	5
5	BIL	04.04.2024	Cargo	1554	-	Tuzla/İstanbul/Türkiye	3
6	BIL	25.04.2024	Tugboat	939	-	Tuzla/İstanbul/Türkiye	3
7	BAL	01.09.2024	Cargo	1243	-	Mersin/Türkiye	5

2-BAL: Dry cargo ship pre-BWMS sample, 3-BAL: Dry cargo ship post-BWMS sample, BIL: Bilge, BAL: Ballast

Table 3. Physical and chemical analysis results of ship sewage samples.

Station	Matrix	pH (-)	Conductivity (mS)	Salinity (g/kg)	Method
1	BAL	7.80	41.3	30.8	Vertical water column
2	BIL	8.20	1.33	0.78	
3	BAL	8.26	34.0	26.7	
4	BAL	8.22	34.6	26.6	
5	BIL	8.24	7.25	0.28	
6	BIL	7.80	2.64	0.25	
7	BAL	8.65	54.9	41.6	

2.3. Analysis

The polymer type of each presumed MP particle was determined by attenuated total reflection Fourier-transform infrared spectroscopy (micro-ATR-FTIR) at the laboratory. The samples were passed through a cellulose pre-filter and then filtered through 13 mm diameter aluminium oxide membrane filters with a 0.1 µm pore size (Whatman Cytiva Anodisc, Germany) into glass petri dishes. The collected samples were left under a fume hood for 2 hours and prepared for measurement with the micro-FTIR device. This technique produces high-quality spectral images of sample areas, with a pixel resolution of 6, 25, 25, or 50 micro meters. The dried filters were stored in a dust-free environment until the time of analysis. The filters were scanned in the imaging mode of the Perkin Elmer FTIR Spotlight 400 device using the Spectrum Image application (optical imaging), and transmittance measurements (chemical imaging) were taken across the entire filter surface. The chemical imaging was performed within a 10 mm x 10 mm area, scanning a 200 µm x 200 µm surface in the IR spectrum range of 690-4000 cm^{-1} using the Spectrum 3 application. Spectra were compiled after applying atmospheric correction, and data processing (MP mapping) was carried out using the siMPle application (Aalborg University-Denmark, Alfred-Wegener Institute-Germany). The results compiled from the siMPle application were used to create a MP distribution table.

2.4. PLI

This method has been commonly employed in earlier investigations of heavy metal pollution in sediment [34,35], and researchers are currently applying it for assessing the risk of MPs [36-38]. The PLI is a standard method for observing and evaluating pollution levels at various locations.

Tomlinson et al. [39] (1980) developed the pollutant load index. The PLI calculates pollution load by taking into account various contaminants (e.g., all metals) at various location. It is a basic geometric mean for the pollution factor (*CF*). The *CF* is calculated according to Equation 1 [40].

$$CF = CF_i / C_o \tag{1}$$

In Equation 1, *CF*; CF_i and C_o are the observed concentration of MPs at sampling location and the lowest concentration/background value of MP detected in the sample, respectively.

The PLI was derived with Equation (2):

$$\text{PLI} = \prod_i^n \left(CF_i \right)^{0.5} \tag{2}$$

Where *i* represents a sample, *n* represents the number of samples, C_i represents the abundance of plastic in sample *i*, and C_o represents the lowest element concentration found in the accessible literature [41]. However, in the lack of background data from similar environments, the lowest baseline limit for MP abundance identified in this study was set at 0.05 units/m^3 based on data from the study conducted by Mutuku et al. [42] (2024) in five major oceans.

3. Results and Discussion

3.1. MPs Size Distribution from Ship-Sewage

MPs were detected in all BAL-W and BIL-W samples. The BAL-W and BIL-W samples presented in Figure 1 and Figure 2 included 96 and 92 plastic particles, respectively. Figure 2 shows the mean number of MPs in BAL-W and seawater. MPs amounts in the BAL-W and BIL-W samples were 5.28 (±3.57) and 6.20 (±3.20) items/L, respectively. There was no significant difference (p-value> 0.05) in the number of MPs between BAL-W and BIL-W. The abundance of MPs in the bilge tanks of the ships was moderately higher (36±4.99 items/L) than in the ballast tanks (5.0±1.39 items/L) (Figures 1 and 2).

The Persian Gulf (Bushehr port and Assaluyeh port) found concentrations ranging from 5.53 to 21.6 items/m^3 [12], whereas our concentrations in the BAL-W samples were similarly level with a range between 4.8 to 27 items/m^3. Furthermore, research by Matiddi et al. [43] investigated levels of MP in the BAL-W of nine commercial ships and found values ranging from 100 to 1410 items/m^3, with a mean of 651 items/m^3.

The BAL-W samples contained 55.6.0% particles between 25 and 50 µm, 38.8% with particles larger than 50 µm, and 5.6% with particles smaller than 25 µm. But, 48.0% of the

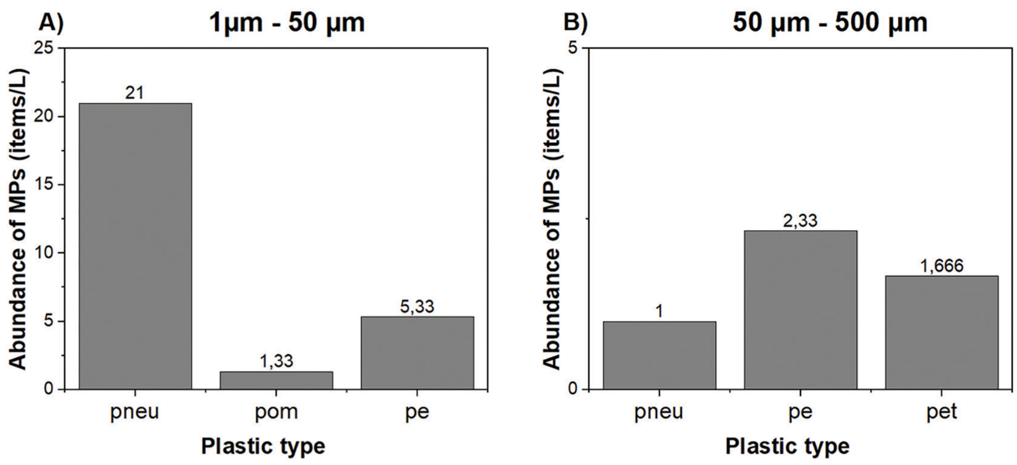

Figure 1. Types of plastic in BAL-W according to size classes 1-50 µm, and 50 -500 µm.

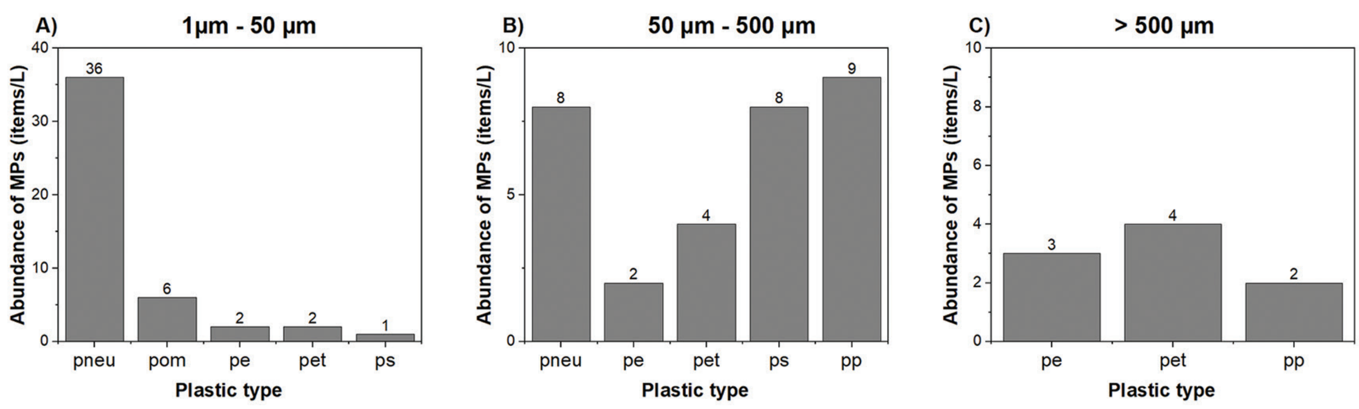

Figure 2. Types of plastic in BIL-W according to size classes 1-50 µm, 50 -500 µm, and >500 µm.

plastics in the SS samples were 0.05-0.1 mm particles, 24.0% were 0.1-0.25 mm particles, and the remaining 28% were plastics larger than 0.25 mm. Previous research found that MPs were most prevalent in seawater in the Persian Gulf, Iran [44], Caspian Sea, Iran [45], and Marmara Sea, Türkiye [46] with sizes of 1000-3000, 1000-5000, and 1-100 µm, respectively.

In BAL-W operations, the point of intake is critical. The plastic particle count per unit volume in the ballast sample is predicted to be high when the ballast intake occurs in a hub or busier port. Conversely, the plastic count density will be low in port locations with limited capacity. Terrestrial pollution is also influenced by the port area's population density and residential layout.

Remarkably high abundances of mezo and macro particles were found in two bilge samples (5 and 6), up to 4.69 and 15.33 items/L. However, 1.55 to 4.8 µm/L particles were quantified in the ballast tank, which is also located in the 7th sample. In samples 5 and 7, which show the highest plastic abundance, it is noticeable that these two sampling sites are commercial port areas with heavy shipping traffic. It is assumed that the intensive commercial activities, population density, and terrestrial contaminants in these areas have contributed to the increase in plastic density.

Particularly in aquatic bodies, MPs gradually degrade into smaller MP and even NP fragments due to regular abrasion [47]. An enormous major threat in the proliferation of these small plastic particles is their potential hazard to organisms that continuously ingest them and their bioaccumulation in living organisms [48,49]. Based on this objective, it is anticipated that the elements of ship sewage tanks might add to the MP pollution that is already there and spread the related chemical and biological pollutants. It is crucial to note that MPs are effective vectors for the transport of heavy metals and chemical pollutants across many miles. The presence of MPs in the marine environment, may migrate to enter of MPs and connected contaminants into food chains and eventually ingested by human [50]. Therefore, it is stressed to adopt strict regulations to minimize MP levels in ship sewage tanks before discharge through effective treatment systems [51].

3.2. Chemical Characterization of Microplastics

This study investigated the presence of MPs in the BAL-W and BIL-W of ships sailing in various seas and ports. The 188 plastic particles in the BS and SS samples belong to six polymer types: polyethylene (PE), polyethylene terephthalate (PET), polyoxymethylene (POM), polypropylene (PP), polystyrene (PS), and Rubber/commercial (PNEU). The chemical composition of the plastics has been confirmed using micro-FTIR spectroscopy. Figure 3 displays the color codes for the different polymer types observed in the BAL-W and BIL-W samples. However, particles containing protein, cellulose, crustaceans and etc. have been excluded from the particle count. Our study of the MP samples from the ship sewage indicates that the main constituent is PNEU (rubber/commercial), with POM and PET being the other two typically identified polymers. PNEU and POM are engineering thermoplastics used for manufacturing specific components with high stiffness, low friction, and superior dimensional stability. Seals and rubbers are commonly utilized in marine machinery and auxiliary operations for both static and dynamic applications. PNEU pneumatic systems provide several advantages. Furthermore, POM polymer is employed in high-performance technical components such as tiny gears, ball bearings, skid plates, fasteners, clamps, and locking mechanisms. As therefore, long-lasting polymers like POM and PNEU are chosen in corrosive and abrasive conditions like seawater. In contrast, PET is generally used in areas such as the food industry, beverage packaging, packaging film, plastic boxes, kitchenware, mechanical engineering and packaging. It is also a preferred material in the manufacture of moving parts that operate under high pressure. Unlike PNEU and POM, emissions in ship-sourced wastewater are assumed to be caused by human or essential activity. Although the maritime environment contains a wide range of plastics, MPs such as polyvinyl chloride, PP, PE, PS, PET, and polyamide are prevalent [32,54]. According to published studies, the most popular polymer types in the Persian Gulf of Iran are PE, PET, and nylon [53], PP and PE are the most prevalent polymer types in the surface waters of China's Yellow Sea region [53], and nylon is the most prevalent polymer type in Antarctica's Ross Sea [46]. For example, pneumatic rubber fenders are used in ports and on ships to minimize structural damage in the event of collisions [54]. However, the rubber broken from these collisions can enter the marine ecosystem and be carried into the tanks during ballast transportation. The findings of this study are coherent with previous studies, but also provide new details about BIL-W that have been little discussion thus far. The differences in the abundance of MPs and the types of polymers may be due to various factors such as traffic, fishing and marine tourism on various coasts of the world.

While most MP particles were observed in BAL-W samples 7 and 1 in Figure 4a, the particles in BIL-W samples 1 and 4 were mostly micro- and mesoplastic (Figure 4b). While sample 2 contained more plastic fragments (Figure 5b), sample 5 contained predominantly mesoplastic particles (Figure 5a). The BIL-W samples contained fewer particles in the 1-5 mm size range, while the BAL-W samples had the most particles in the <50 mm range.

The findings of this investigation indicated that MPs were not eliminated by the BAL-W disinfection system, and that both wastewaters included polymers of various types and sizes.

3.3. Risk Assessment of MP PLI

Pollution indexes are widely used to assess plastic pollution in aquatic and terrestrial environments [38,55]. These indexes provide a quantitative framework for assessing pollution levels and potential ecological risks [37]. As macro-, micro- and NPs mostly originate from anthropogenic sources, the determination of a reference background level (C_o) for the assessment of plastic pollution remains a crucial challenge [56]. As there are no defined standards for assessing for

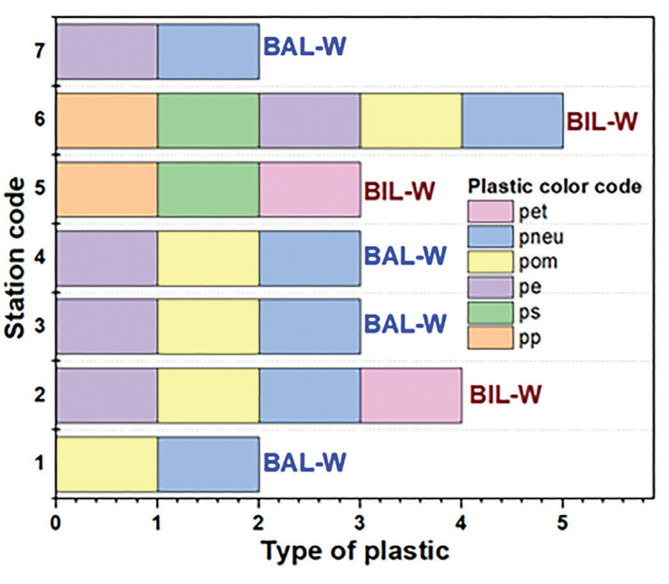

Figure 3. Distribution of MPs detected in ship-sewage sample.

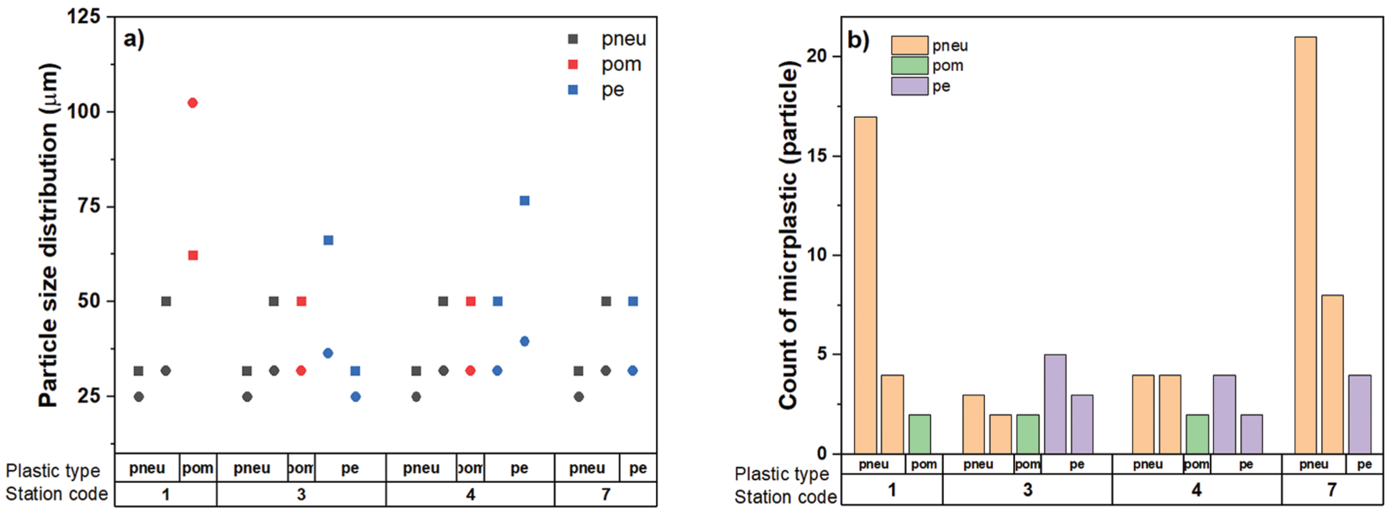

Figure 4. MP analysis in ballast water samples a) size distribution by species, b) Count of MPs.

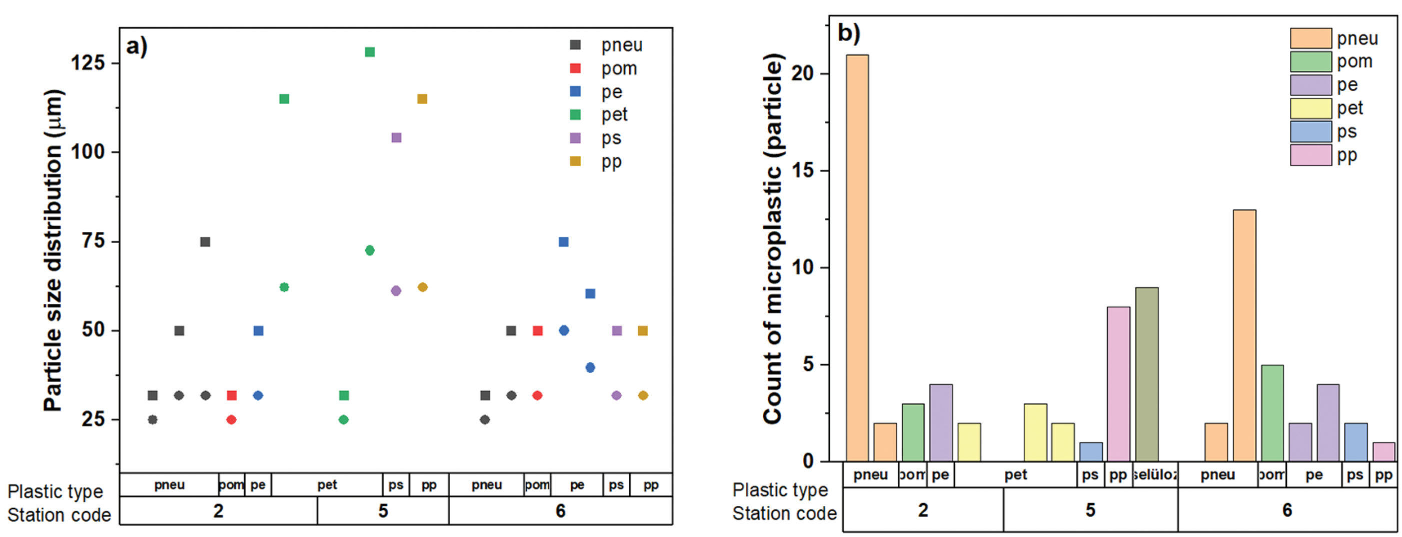

Figure 5. MP analysis in bilge water samples a) size distribution by species, b) Count of MPs.

the risk assessment of plastics, the results of the PLI largely depend on the chosen reference background value of plastic abundance [57]. However, these reference values may vary considerably from study to study. Some research employs probabilistic analytical values based on species sensitivity distributions [58], whereas others utilize the minimal abundance values at the sampling site as baseline concentrations [59]. These methodological inadequacies contribute to large variations in PLI-based risk evaluations for MPs [55]. The concentration of MPs in the seas varies from 0.002 to 22 pc/m^3, revealing a skewed distribution. The average concentration was highest in the Atlantic Ocean (2.58 pc/m^3) and lowest in the Southern Ocean (0.04 pc/m^3) [42].

Table 4 represents the PLI calculated for the BAL-W and BIL-W samples. The estimated pollutant load index indicated significant pollution risks in two BAL-W samples and a very high pollution risk in five samples. A high PLI score indicate the region is contaminated with MPs.

The calculated PLI values for all BIL-W samples were $10.2 \leq \text{PLI} < 12.17$, indicating a very high level of very high pollution (Hazard Category V). The calculated PLI values for BAL-W ranged from Hazard Category IV to Hazard Category V. This type of risk assessment for ship sewage

Table 4. Pollution load index (PLI) calculated for BAL-W and BIL-W samples.

Station	Matrix	CF	PLI	Hazard Level
1	BAL	92	9.6	V, very high pollution
2	BIL	148	12.17	V, very high pollution
3	BAL	60	7.75	IV, significant pollution
4	BAL	64	8.0	IV, significant pollution
5	BIL	104	10.2	V, very high pollution
6	BIL	128	11,3	V, very high pollution
7	BAL	132	11.5	V, very high pollution

C_o: The lowest value found in the literature was set at 0.05 units/m^3. BIL-W: Bilge water, BAL-W: Ballast water, *CF*: Pollution factor.

is unique to this study; similar results have been reported for Categories IV and V in urban sewage [60] and seawater [61,62]. Previous research by Dar and Gani [55] (2025) has found that the PLI ranged from 3.9 (Hazard Category I) to 40 (Hazard Category IV), indicating that glaciers are moderately to severely polluted. The findings of the PLI of MPs reveal that the environmental impact of MP pollution in the oceans, as well as the contribution of ship sewage (BAL-W and BIL-W), represent a significant risk to marine ecosystems. BAL-W and BIL-W wastewater may transport MP particles and pollutants in these plastics between ports.

In addition, MP fragments have the potential to be significant carriers of pollutants [63,64]. These transports can retain pollutants on their surfaces through physical adsorption, depending on potential pollutants such as heavy metals, pharmaceuticals, etc., in the regional marine and ocean ecosystem, and even transfer them to marine organisms or humans that feed on them.

Based on the findings of this study, BIL is an important source of MPs, as it is exposed to intense pollution from ship auxiliary operational processes. BAL is also a potential source of MPs, which can act as a carrier of these particles and related pollutants between different ports and could potentially have harmful effects on the marine environment, aquatic organisms, and, consequently, human health. As a result, macro-, micro-, and NPs are capable of acting as vectors for pollutant transmission, hence their inclusion as an environmental impact element in ship sewage regulations (e.g., MARPOL Annex I or Annex IV) is beneficial and raising awareness is necessary in the maritime sector.

4. Conclusion

The micro-FTIR analysis of BAL-W and BIL-W samples conducted in this work revealed that ship sewage poses a serious environmental risk in terms of MP pollutants. The most prevalent polymers identified in BAL-Ws were POM, PNEU, and PET, whereas POM, PET, PS, and PNEU were found in BIL-Ws. The abundance of MPs in the bilge tanks of the ships was moderately higher (37±0.7 particles/L) than in the ballast tanks (24.0±1.0 particles/L). We concluded that the MP content in BIL-W is often higher than in BAL-W, making BIL-Ws popular places to find MP pollution due to the impacts of various operational and natural factors, such as tank position, personnel activities, environmental conditions, waves, and wind, causing bilge tanks more prone to the accumulation of large amounts of MP. The findings reveal that the BWMS implemented by the IMO as part of the MARPOL Convention for the Protection of the Marine Environment are insufficient for eliminating MPs contamination.

According to the pollutant load index, ship-sewage from BAL-W and BIL-W is rated as Hazard Category IV (significant pollution) and Hazard Category V (extreme pollution), causing serious environmental risk. All of the study's findings highlight the importance of ships in sea ecosystem, as well as their far-reaching influence as a result of their many interactions with the environment. The findings of this study, which focus on the kind and concentration of MPs that collect in ship sewage, can be utilized as primary data to inform future research on the impact of MPs on ships. Based on the findings of the study, it is recommended to implement effective waste management systems, introduce stricter regulations, and raise marine sector awareness.

Footnotes

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