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Investigation of microplastics and heavy metals contamination in southwestern Caspian Sea Gammarus

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ABSTRACT

Plastic is considered the main component of waste and sometimes accumulates on beaches. The studied stations are located in the coastal areas, approximately 35 km long in the Caspian Sea in Gilan province, Iran. This study aims to quantitatively and qualitatively investigate the presence of microplastics and their combined impact with heavy metals in the environment (water and sediment) as well as in aquatic organisms (specifically Gammarus) within the southwestern area of the Caspian Sea. The results of this research have shown that the highest average concentration of microplastics was found in the water environment samples from the 4th station (13400±658 pieces per liter), while the lowest average concentrations were recorded in the first and fifth stations (5200±370) and (5600±357) pieces per liter, respectively. Microplastics in the form of purple fragments in the size of 0.5 to 1 mm with a magnification of 40 are the most abundant. Heavy metals, notably copper and chromium, have been identified in Gammarus specimens. Additionally, polymers were detected in both water and Gammarus samples, potentially originating from fishing nets and general waste in the area. The presence of microplastics in study stations has increased the concentration of heavy metals in Gammarus and the water environment. The ANOVA test also showed that there is a direct and significant relationship at the 1% level between the concentration of heavy metals and microplastics. These results indicate the mutual and important synergistic effects between microplastics and heavy metals on the marine environment of the Caspian region.

1. Introduction

As population growth, urbanization, and society's well-being, increase environmental concerns, health, and hygiene has become more prominent. The recent growth of industrial activities and non-compliance with environmental requirements resulted in the entry of a significant volume of emerging pollutants, including plastic and pharmaceuticals, into the environment [1]. Their stabilization and bioaccumulation properties make these pollutants a significant danger. Plastics are responsible for the majority of waste in water and marine environments. The problems related to microplastics in water are of global concern cause for aquatic animals through ingestion. In addition, microplastics, which are carriers of heavy metals and organic substances, are strengthened when they enter the food chain and can have unpredictable effects on aquatic life and humans [2,3]. Types of plastics are macroplastics, microplastics and nanoplastics. Macroplastics are particles larger than 5 mm. Microplastics are small particles that are less than 5 millimeters in size, and they are usually made by degradation of plastics in the marine environment by ultraviolet rays and wave power. Nanoplastics are a subgroup of microplastics that have a nanometer size range, usually less than 1 micron in diameter. These nanoparticles can come from a variety of sources, including microplastics that have been broken down into smaller particles, nanoplastic fibers released from synthetic textiles, or intentionally engineered nanoparticles that are used in products such as personal care items or as additives in industrial processes [4].

Microplastics are classified into primary and secondary groups. The primary type of products is designed to be used for commercial, transportation, medical, pharmaceutical, cosmetics, paint, and agricultural purposes. Secondary microplastics are produced when macroplastics break down during continuous weathering and sunlight in marine environments, and they come in many sizes, shapes, colors, and polymer types [5]. Various types of plastic pollution in the seas and oceans have been extensively studied in the past few years, when plastic pollution was negligible until the 1970s [6]. Marine animals are affected by microplastics' small size and high dispersion as they enter their food chain [2]. Every year, thousands of aquatic animals, such as whales, dolphins, turtles, and sea birds, are suffocated [7]. Fish, birds, and marine mammals have experienced negative effects such as inflammation, decreased energy reserves, and decreased feeding after ingestion of microplastics [8]. Gammarus is used as a sample for studying marine water pollution due to its high sensitivity to chemical and physical changes in the environment, its widespread presence in various marine and freshwater habitats, its important role in the marine food chain, and its ease of collection and study [9]. These organisms act as effective bioindicators because of their ability to accumulate various pollutants, including heavy metals and microplastics, and their impacts on other marine species [10]. Additionally, the research background on Gammarus allows researchers to compare and analyze their findings with previous studies, making them a valuable tool for assessing the health of marine ecosystems [11, 12]. In the aquatic environment, microplastics, which are considered an inert carbon flux, are known to carry heavy metals and have diverse interactions [13, 14]. However, these interactions, particularly the mechanisms that drive them, pose risks to living organisms. Heavy metals have a variety of effects on living organisms, such as chromium, which is believed to be carcinogenic and toxic to aquatic organisms, animals, and humans. Pollutants entering aquatic environments are mostly deposited by various flows, such as surface runoff, wastewater treatment plants, and storms . The high population density in the southwestern parts of the Caspian Sea in Gilan province (Talesh coast) has resulted in harm to marine organisms. Microplastic particles, which are small and have a similarity to natural food, are intentionally or accidentally swallowed by a fish. Since fish is a protein source for humans, this contamination is a result of toxicological effects. The safety of seafood can be compromised by microplastics [16]. The impact of sea pollutants on endocrine glands can be disruptive, and microplastic surfaces can carry harmful compounds. Toxic effects affect marine organisms at different nutritional levels when accumulated in biological tissues. Immune and reproductive responses are just some of the effects that vary depending on the sensitivity of species and ocean currents, as well as the overlap of marine organisms [17]. Consumption of some heavy metals such as zinc and copper in low doses is beneficial for the physiological functions of the human body [18]. According to the European Union, the maximum tolerance of lead, cadmium and mercury metals in edible fish tissue is 0.3, 0.05-0.30 and 1.00-0.5 mg/kg [19]. However, toxic heavy metals at high doses harm the diversity of Gammarus and ecosystems, as well as ultimately harm human health by transferring through the food chain [20,11,12]. Studying the interactions between heavy metals and microplastics in Gammarus of the Caspian Sea is crucial because these organisms play a key role in the marine food chain and act as sensitive bioindicators of environmental changes. Gammarus can accumulate various pollutants, including heavy metals and microplastics, in their bodies, and examining these accumulations can reveal how these pollutants simultaneously affect marine life. Understanding the combined effects of these pollutants on Gammarus can aid in developing strategies for pollution management and reduction, help protect biodiversity in the Caspian Sea, and safeguard human health. Therefore, the aim of this research is investigated the quantitatively and qualitatively microplastics and the synergistic effect with heavy metals in the environment (water and sediment) and Gammarus of the southwestern Caspian Sea.

2. Materials and methods

2.1. Study area and sampling stations

In the winter of 2023, the samples of Gammarus and the surrounding environment of Gammarus (water and sediment which is sandy) from 5 stations of the southwestern shores of the Caspian Sea were taken. The sites selection was according to different land uses 1- landfill station (37° 50' 30.30"N; 48° 58' 17.00"E) 2- Gisoom recreational beach area (37°40' 53.30"N; 49° 2' 48.70"E) 3- Before the power plant (37° 39' 26.70" N; 49° 4' 24.50" E) 4- Surroundings of the Paresar power plant (37° 38' 25.40" N; 49° 5' 44.70"E) 5-The Shafarood River (37° 35' 39.90"N; 49° 9' 41.00"E), respectively. The location of the sampling stations is shown in Figure 1.

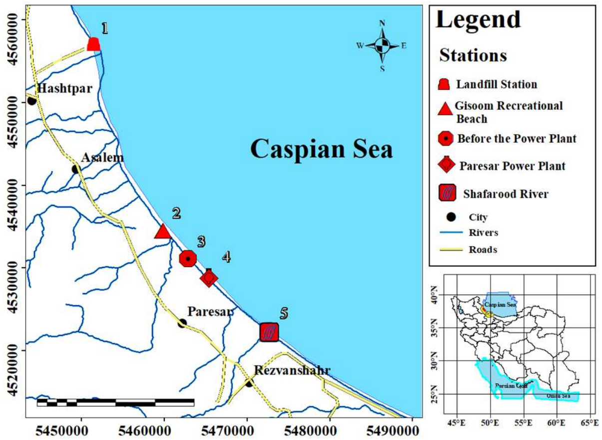

Figure 1. Location map of the sampling stations

The studied stations have been selected based on field observations and land use as the possible source of pollution. The station number one is considered a source of pollution due to the large amount of leachate emitted from landfill site due to the slope of the area towards the Caspian Sea. In addition, due to the winds direct that pass over this place, it causes pollution to be transferred through the air to the sea. The pollutants in these places are plastics in different sizes and categories, and heavy metals (such as copper, lead, cadmium, and zinc) [21, 22]. In the stations number 2 and 5 in the Gisoom area and around the Shafarood river, due to the lack of sufficient legal regulations, improper collection of garbage and its long-term accumulation in the place and its distribution due to the wind, in addition to the lack of educational activities and increasing the awareness of travelers to collect garbage causes to be a source of the pollution. The lack of appropriate forces to collect garbage from certain places on time has led to an increase in pollution in these areas. By swimming in seawater and public showers in coastal areas, cosmetics like sunscreens that contain microplastics are transported to the sea. The quantity of smoking on beaches is significant. Even though cigarette butts are considered normal waste, they are considered dangerous waste due to their exposure to various pollutants [23,24]. According to a research, cigarettes contain a considerable concentration of lead, cadmium, chromium, zinc, copper, and nickel. The long persistence of cigarette butts in the environment leads to an increase in the release of heavy metals, which is considered a source of beach pollution [25]. Station number 3 is located prior to the power plant while station number 4 is situated next to it. It has been proven in many studies that power plants introduce different types of heavy metals into the environment based on their type. The health of living organisms can be significantly impacted by the contamination of heavy metals in groundwater by power plants [26]. According to this study, the seasonal concentration of heavy metals was higher for aluminum, arsenic, lead, iron and manganese exceeded acceptable levels of national and international agencies and even exceeded US standards, affecting the pediatric population more than adults. In addition, high levels of toxic metals were observed during the post-monsoon season, although human activities are not without influence on the amount of these pollutants [27].

2.2. Collection of Gammarus and surrounding environment samples and digestion to measure heavy metals

Gammaros samples were collected from beach sand using a 1.180 mm sieve and 16 meshes, with 5 repetitions for each studied station. The number of Gammarus in each half-hour attempt at each station was recorded as 58, 125, 26, 32, and 16 cases in the stations, respectively. After initial washing with seawater, the samples were moved from the sieve into special containers, and then the containers containing the samples were placed in ice pack and transported to the laboratory [23]. After ensuring the identification of the species [28], the samples were first washed with distilled water and then about 15 g of Gammarus were placed at 105°C for 24 hours to dry. After evaluating the dry weight based on reaching a constant weight, the samples were pounded in a mortar and homogenized. In the next step, 1g of each sample was weighed using a digital scale with an accuracy of 0.0001g and 10 mL of concentrated nitric acid along with 2 mL of hydrogen peroxide were added to it. Then the samples were placed on the digestion reactor for acid digestion for 3 hours at a temperature of 95 degrees Celsius and then the digestion solution was filtered through a 0.45 m nitrocellulose filter and prepared for heavy metals reading [29]. After filtering, the samples of the environment around the gammarus were poured into 15 mL beakers with station labels. Then, five milliliters of concentrated nitric acid (HNO_3, Merck, Germany) was added and each sample was placed on a sand bath at 150°C for 4 to 5 hours or until they were slowly digested. After cooling with deionized water, the samples were brought to a volume of 10 mL, then filtered through 0.45 µm filter paper (nitrocellulose). The concentration of heavy metals in the tissue of gammarus and the surrounding environment of gammarus was measured with a graphite furnace atomic absorption device (ContrAA 700, Analytik Jena AG, Germany).

2.3. Identify Gammarus species in the study area

Gammarus refers to a genus of small shrimp-like crustaceans commonly found in freshwater environments such as rivers, lakes, and streams. These organisms, also known as amphipods or freshwater shrimp, are integral components of aquatic ecosystems, serving as both herbivores and insectivores. They play a crucial role in the food web by consuming algae, plant matter, and decaying organic material, thereby providing a food source for various aquatic predators.

At each station, three samples were collected using a dredge sampler, fixed in 5% formalin, and transferred to the laboratory. Several keys to the Gammarus were used to identify these species [30, 31] to the species level. After laboratory operations, four species of Gammarus are present, including *Gammarus lacustris, Gammarus duebeni, Gammarus tigrinus,* and *Gammarus pulex*. These species contribute significantly to the ecosystem as scavengers, aiding in the recycling of nutrients by feeding on organic matter. They are also important prey for numerous fish and invertebrates, and their abundance and diversity serve as indicators of the Caspian Sea's ecosystem health.

2.4. Determining the presence and type of microplastics in the tissue of Gammarus

The collected Gammarus were washed with distilled water and dried on a heater at a temperature of 50 degrees Celsius and ground in a mortar. In order to determine the presence and type of microplastics, 0.05 grams of each powdered sample was separated and used for micro FTIR analysis. For quick and direct identification of plastic polymers, it was achieved by comparing the resulting spectra with existing reference spectra [11].

2.5. Determining the frequency, shape, color, size and type of microplastics in the environment around Gammarus

The samples were taken from five study stations with five points per station, and then mixed to create a composite sample for each station. The resulting samples were sieved through a stainless steel sieve and stored in glass bottles. Then 100 mL of it was mixed with 10 mL of H2O2 at room temperature for 48 hours. The samples were subjected to a glass microfiber filter (1.2 mm) after being passed through it. An optical microscope, such as the Olympus BX41, was used to determine the amount, pattern, hue, and size of microplastics. To count microplastics in seawater, 5 mL of water sample collected from the beach was checked as one drop on a slide by repeating 5 drops under a microscope with 40x magnification and the number, color, shape and size of microplastics were recorded. To ensure that the glass bottles are free of microplastics, a control sample was run alongside the studied samples.

2.6. Determination of salinity, pH and temperature of the studied stations

Before implementing the laboratory protocols in sampling, the physico-chemical characteristics of the water environment and the habitat of the Gammarus were measured. pH values range from 7.20 to 7.66 (mean 7.42± 0.278), with electrical conductivity (EC) ranging from 13.51 to 19.12 mS/cm (mean 16.61± 3.13), and temperature ranges from 10 to 15ºC (average 12.5± 3.53).

2.7. Statistical analysis

SPSS version 23 software was used for data analysis and the Shapiro-Wilk test was used to check the normality of the data. Also, Excel software was used to perform the necessary calculations and draw graphs. In this research, in order to investigate the effects of different uses as well as the synergistic effects of microplastics with heavy metals were studied. The existence of a significant difference in the level of 1% concentration of heavy metals and microplastics between Gammarus samples and water environment in different stations. One-way ANOVA analysis of variance LSD test was used.

3. Results and discussion

In this study, 25 water samples were collected in the 100mL bottles, with 5 repetitions conducted at 5 stations. Given that most of these stations are directly exposed to various pollutants, the results showed varying levels of microplastics and heavy metals (Tables 1 and 2).

The highest average number of microplastics was found in the water environment samples from the 4th station (13400±658 pieces per liter), while the lowest average concentrations were recorded in the first and fifth stations (5200±370) and (5600±357) pieces per liter, respectively. The highest average abundance of Gammarus (measured over half an hour) was observed at the 2nd station with 125 individuals, while the lowest frequency was recorded at the 5th station with 16 individuals (Table ۱).

In the water, the highest concentration of copper was observed at the first station, measuring 0.0088 mg/L, while in Gammarus specimens, the fourth station showed the highest concentration at 0.589 mg/kg. Conversely, the lowest copper concentration in water was recorded at the fourth station, measuring 0.0017 mg/L, while in Gammarus, the lowest concentration was observed at the first station, measuring 0.3747 mg/kg. Regarding chromium, the highest concentration in water was detected at the fifth station, observing 0.0897 mg/L, whereas in Gammarus, the fourth station exhibited the highest concentration at 0.233 mg/kg. Conversely, the lowest chromium concentration in water was found at the fourth station, measuring 0.839 mg/L, while in Gammarus, the third station showed the lowest concentration at 0.1113 mg/kg. In terms of lead, the highest concentration in water was recorded at the fifth station, measuring 0.1476 mg/L, while in Gammarus, the second station exhibited the highest concentration at 0.1459 mg/kg. Conversely, the lowest lead concentration in water was observed at the fourth station, measuring 0.022 mg/L, while in Gammarus, the third station showed the lowest concentration at 0.0604 mg/kg(Table 2) .

This distribution pattern indicates that Gammarus populations are likely influenced by both the availability of suitable habitats and the levels of

Table ۱: Frequency of counted microplastics and average abundance of Gammarus separately for each station in the study area

Stations	1	2	3	4	5
Microplastics in Water samples (pieces per liter)	5200±370	11000 ±458	9400±482	13400±658	5600±357
Average numbers of Gammarus	58±9	125±16	26±5	32± 5	16±3

pollution, with higher pollution levels potentially reducing their abundance [32, 33].

The results of statistical analysis between salinity, pH and temperature of the studied stations and heavy metal concentration and microplastics studied parameters showed that there is no significant difference between them (Pvalue≥0.05). The statistical analysis shows that there is a significant difference in the concentration of heavy metals in all stations between Water and Gammarus samples at the level of 1%. In addition, the ANOVA test showed that there is a positive and significant relationship at the 1% level between the abundance of microplastics and the mean concentration of heavy metals (Cu, Cr and Pb) in Gammarus. Therefore, it could be concluded that microplastics act as carriers of heavy metals and cause more accumulation of heavy metals. It can act as a carrier of heavy metals and cause more accumulation of heavy metals in the environments where they are present [14, 35]. Following a thorough analysis, it was determined that the uptake of heavy metals by naturally-aged microplastics primarily depended on the presence of oxygen-containing functional groups, such as carboxyl and hydroxyl groups, present on the organic film. Additionally, the assessment of Zeta potential and pH effects indicated that electrostatic interactions predominantly governed the process of heavy metal uptake [36, 37].

Table ۲: Mean and standard deviation of heavy metal concentration in water (mg/L) and Gammarus (mg/kg) by each station in the study area

Samples	Station1		Station2		Station3		Station4		Station5	
	Gammarus	water	Gammarus	water	Gammarus	water	Gammarus	water	Gammarus	water
Cu	0.38 ±0.09	0.008± 0.002	0.54± 0.13	0.002± 0.00	0.42± 0.1	0.002 ±0.00	0.6± 0.15	0.0017 ±0.00	0.48± 0.12	0.006± 0.001
Cr	0.22± 0.05	0.08± 0.02	0.11± 0.027	0.08 ±0.02	0.23 ±0.05	0.08 ±0.02	0.23 ±0.05	0.08 ±0.02	0.12 ±0.03	0.09± 0.02
Pb	0.10 ±0.02	0.07± 0.017	0.08± 0.02	0.07± 0.017	0.06± 0.01	0.12 ±0.03	0.11 ±0.02	0.02± 0.005	0.14± 0.03	0.14 ±0.03
P value	0.001≤		0.001≤		0.001≤		0.001≤		0.001≤	

The highest frequency recorded according to the color of the particles in water samples is related to purple, followed by green, and the lowest value is related to blue and red, which was seen in 1% of all stations (Figure 2). The color of microplastics will have an effect on their properties, so that Chen and colleagues investigated the effects of four colored microplastics (MPs) on Scenedesmus obliquus algal growth and Daphnia magna feeding ability. Initially, algal growth increased due to hormesis stimulation, followed by a decrease at higher MP concentrations [34]. Green MPs showed the lowest inhibition effect, resembling algae, while white MPs significantly inhibited growth, likely due to ethanol presence. Turbulence reduced growth differences but induced slight oxidative stress. Daphnids seemingly couldn't distinguish colored MPs from algae, but ingestion increased when MPs reached 40% of algal cells, possibly due to widened filtering gapes. However, agglomeration led to settling, ending the phenomenon by the third day. Overall, the study underscores the importance of considering MP color in (eco)toxicological studies due to its potential to alter effects [34]. The differential effects observed with various colors of MPs indicate that color can influence the extent of their impact on aquatic organisms. For example, the lesser inhibitory effect of green MPs on algal growth suggests that MPs resembling natural food sources might be less harmful, while those with significant additives can have more pronounced toxic effects [34, 38].

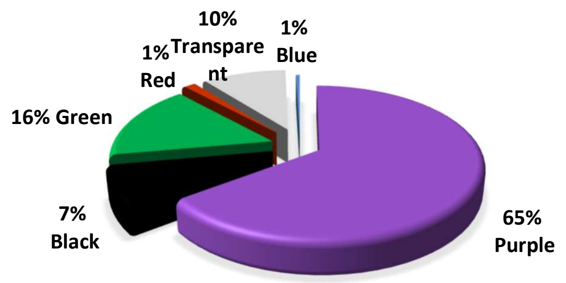

Figure 2: The abundance percentage of microplastics particles in water samples based on color in the studied stations

The highest frequency of microplastics less than 0.5 mm was observed in the second station, followed by the fourth station. For microplastics sized between 0.5 and 1, the highest frequency was recorded in the first station. In the size range of 1 to 1.5, the second station exhibited the highest frequency, while for microplastics sized between 1.5 and 2, the fifth station showed the highest frequency. Similarly, in the size range of 2 to 2.5, the highest frequency was again recorded at the fifth station. Notably, the highest frequency of particles in the size range of 0.5 to 1 was observed with 38 particles (Figure 3) [39]. Tsiaras and colleagues examined the abundance and properties of microplastics (MPs) in sea surface water samples from four coastal areas of the Mediterranean Sea. Using hydrodynamic/particle drift models; it explored MP variability, considering sources like wastewater and river runoff. The Gabes Gulf had the highest MPs abundance, followed by the Ligurian Sea, Saronikos Gulf, and Gulf of Lion. The model generally replicated observed MP levels, though overestimating smaller MPs in the Saronikos Gulf. Biofouling-induced sinking reduced smaller MP quantities offshore, while larger ones could travel further. Wave drift and advection from non-local sources, especially in the Gulfs of Lion and Gabes, affected larger MPs more. Modeling insights provide a better understanding of MP dynamics and guide environmental management to mitigate plastic pollution in the Mediterranean Sea [40]. These differences in the abundance of microplastics across various sizes and locations highlight the importance of more precise and comprehensive studies on the sources, pathways, and behaviors of microplastics in marine environments [41]. Additionally, there is a need to improve predictive models and gain a better understanding of the physical and biological processes that influence the distribution of microplastics. For example, sinking due to biofouling is a key factor in reducing the abundance of smaller particles, while larger particles can be transported over longer distances due to the effects of wave drift and advection from non-local sources [42]. Therefore, these findings can aid in the improvement of environmental management and policy-making. Increasing awareness of pollution sources and identifying high-risk areas can lead to more targeted actions to reduce microplastic pollution in marine environments [43]. In particular, further investigation into the long-term impacts of microplastics on marine ecosystems and human health remains a research priority.

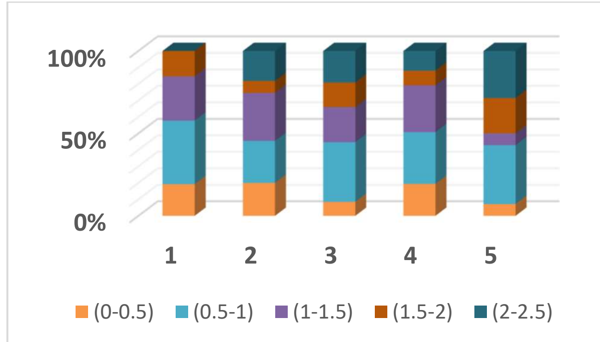

Figure 3. Percentage distribution of microplastic particle size frequency in millimeters at different stations

Fig. 4 presents the shape of microplastics in the study area. In the survey, the highest frequency of different forms of microplastic particles is related to fragment with 74 particles in the first station, pellet with 41 particles in the fifth station, line with 12 particles in the third station, and fiber with 8 particles in the third station. Fig. 5 presents the percentage distribution of microplastic form frequency. Microplaspic particles were abundantly found in beach sediments across four study sites in Virginia and North Carolina. These particles were mainly in two forms: fragments and fibers. Notably, fibers were the predominant form, making up about 93.91% ± 4.74% of the microplastic particles, with the rest being fragments [44].

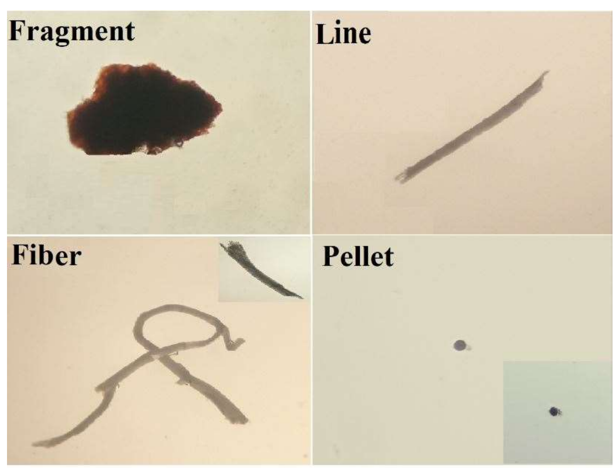

Figure. 4. presents the shape of microplastics in the southwestern Caspian Sea environment

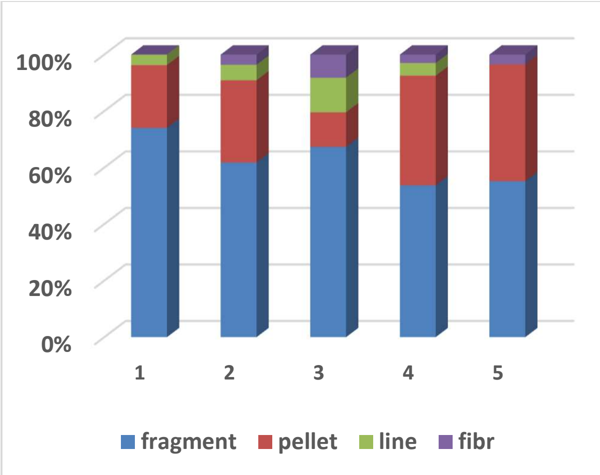

Figure 5. Percentage distribution of microplastics form frequency at different stations

The variation in the abundance and forms of microplastics across different stations highlights the influence of local environmental factors and sources of pollution. For example, the high number of fragments at station one may be due to localized sources of plastic waste and physical degradation processes. Similarly, the predominance of pellets at station five could be attributed to industrial activities or shipping routes in the vicinity [45, 46, 47].

The results underscore the need for detailed and comprehensive studies to understand the sources, pathways, and behaviors of microplastics in marine environments. Improving predictive models and understanding the physical and biological processes affecting microplastic distribution is essential [48]. For instance, biofouling-induced sinking significantly reduces the abundance of smaller particles, whereas larger particles can travel greater distances due to wave drift and advection from non-local sources [40].

As Fig. 6 shows, the results obtained from the FTIR spectrum showed the presence of polyethylene MPs in the analyzed samples. The change in FTIR peaks in the wave number range of 717, 1600, 1680 and 2928 (cm-1) indicated the presence of polyethylene MP [[49]. The methyl-CH_3 group corresponds to the absorption peaks at 2950, 2900, and 1350 (cm^{-1}), while the methylene-CH_2 group corresponds to the absorption peaks at 2800, 2850, and 1450 (cm^{-1}) [50]. Therefore, the detection of polypropylene microplastics occurs. The presence of polystyrene fibers in the sample is confirmed by the characteristics of polystyrene absorption peaks. The peaks were determined as follows: 1767 cm^{-1}, 1404 cm^{-1} (aromatic ring), 1295 cm^{-1} and 1014 cm^{-1} (carboxylic), ester or anhydride, 1092 cm-1 and 1014 cm-1, 971 cm^{-1} (C-C), 872 cm^{-1} (five substituted H in benzene), 847 cm^{-1} (two adjacent H in benzene) and 724 cm^{-1} (heterocyclic aromatics).

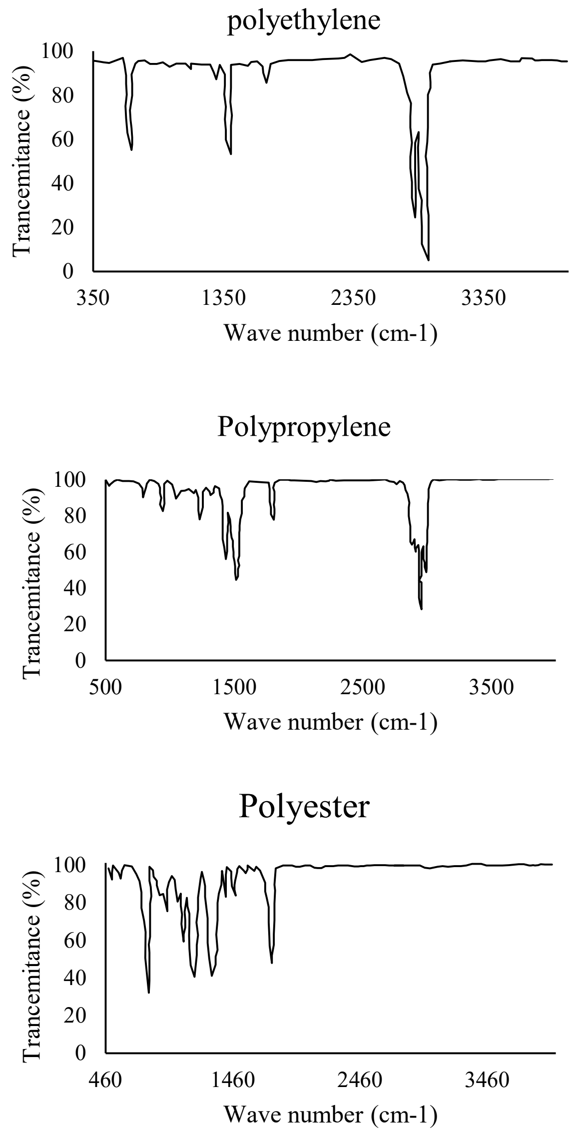

Figure 6: FT-IR spectrum of polyethylene (PE), polypropylene (PP) and polyester (PS) microplastics extracted from the Caspian Sea coasts

Marine microplastic pollution has profound economic and social ramifications, threatening natural resources, disrupting fishing and marine industries, impacting coastal tourism, and jeopardizing public health [51]. Economically, it reduces fishermen's income and the fishing industry's revenue, diminishes earnings from coastal tourism due to aesthetically degraded and unsafe beaches, and escalates healthcare costs as contaminated seafood enters the human food chain, posing serious health risks [52]. Socially, microplastic pollution leads to a decline in aquatic life diversity, affecting ecosystem stability and the cultural, recreational, and economic activities tied to these ecosystems [53, 54, 55]. It also restricts access to clean water resources for communities relying on marine and coastal waters for drinking, cooking, and sanitation [56]. Addressing this pressing issue requires the implementation of effective measures and policies to reduce plastic usage and improve waste management, alongside promoting public awareness and fostering collective action to safeguard marine environments.

4. Conclusions

Regarding the mutual effects of microplastics abundance on heavy metals concentration in Gammarus, the results show that the presence of microplastics has led to an increase in the concentration of heavy metals in Gammarus and the aquatic environment. Statistical analysis also shows that there is a significant direct relationship at the 1% level between the microplastics abundance with the heavy metals concentration in Gammarus. In general, this research shows that the presence of microplastics in the environment can lead to changes in the composition and concentration of heavy metals in aquatic environments, which may have negative effects on the environment and human health. These findings can aid in enhancing environmental management and policy-making. Raising awareness about pollution sources and identifying high-risk areas can lead to more targeted actions to reduce microplastic pollution in marine environments. Furthermore, investigating the long-term impacts of microplastics on marine ecosystems and human health remains a crucial research priority.

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