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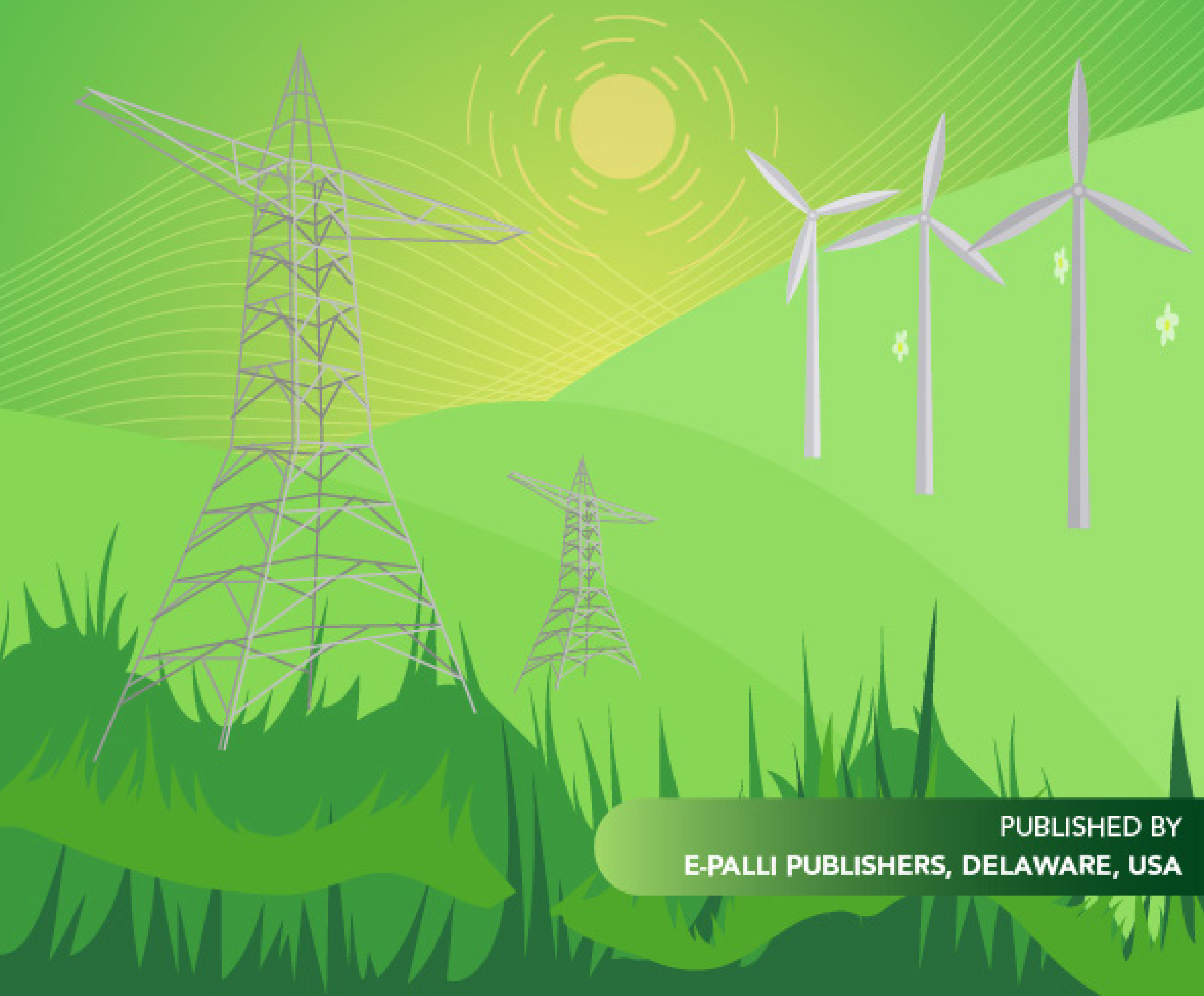

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Microplastic Pollution and Coastal Anthropogenic Pressure in the Caspian Sea Basin Through Systematic Review and Secondary Data Analysis

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ABSTRACT

Microplastic pollution is a new environmental issue in the Caspian Sea Basin, which is facing growing environmental pressures due to waste production, maritime transport, tourism, urbanisation, and recreational activities. The purpose of this study is to prepare a synthesis of the available evidence regarding the presence of microplastic in the Caspian region and to use secondary data analysis to evaluate the anthropogenic pressures in a systematic review. The reviewed peer-reviewed studies and open research data were analysed to retrieve data on study location, environmental matrix, particle abundance, morphology, polymer composition and analytical method. As contextual pressure variables, official statistical indicators on waste generation, maritime freight transport and activity in tourism in Azerbaijan were also analysed. The public coastal zone of Zira and Absheron National Park were included as a pilot case study based on visual-microscopic field observations. The evidence examined reveals that current research is geographically focused on the southern portion of the Caspian region, especially the Iranian coast, and that there are large data gaps in Azerbaijan, Kazakhstan, Russia and Turkmenistan. Fibres are one of the most commonly reported forms of particle in sediment, which is the most commonly investigated environmental matrix. In Azerbaijan, plastic-like anthropogenic particles showing microplastic characteristics were found in the protected coastal area as well as in the public use coastal area; microplastic-like anthropogenic particles were more morphologically diverse in the public use coastal area. Official statistics also show an increase in waste, in maritime pressure, and in tourism pressure. The results show the need for coordinated monitoring procedures, extended spatial sampling, chemical validation of the particles detected, and a better alignment of coastal pollution control with green economy policies.

INTRODUCTION

The presence of microplastic pollution has become more and more a matter of concern in aquatic and coastal ecosystems. Microplastic particles are typically described as being synthetic polymer particles less than 5 mm in size which can be a result of the direct release of such particles or as a result of fragmentation of larger plastic products. They are small, persistent and mobile, which can result in their bio-concentration in water, sediment and living organisms, and pose risks to the functioning of ecosystems, food webs and coastal resource management (Hidalgo-Ruz *et al.*, 2012). While visual and microscopic examination will detect particles that are plastic-like, reliable polymer confirmation will generally require analytical techniques, including Fourier Transform Infra Red (FTIR) spectroscopy and Raman spectroscopy (Xu *et al.*, 2019).

The Caspian Sea is a major environment to study the contamination of microplastic. It is a landlocked water body surrounded by Azerbaijan, Iran, Kazakhstan, Russia and Turkmenistan and is contaminated by rivers, maritime traffic, industrial operations, coastal towns, fish farming, tourism and recreational activities. In combination with the restricted exchange of water outside the basin, these pressures can lead to enhanced longevity of anthropogenic contaminants. Moreover, the ongoing decrease and fluctuation of the Caspian Sea level are modifying coastal morphology, habitats, exposure of infrastructure, sediment dynamics, potentially affecting the transport and redistribution of coastal waste and microplastic particles (Court *et al.,* 2025).

Previous research showed the presence of micro-plastics in various environmental matrices of the Caspian Sea Basin. Microplastics, such as fibres, fragments and particles made of various polymer types, have been documented in the coastal water and sediments from the southern Caspian Sea through research studies (Nematollahi *et al.*, 2020). Sediment studies have also indicated differences between the areas affected by tourism and less intensively used coastal areas, which might indicate that the abundance or morphology of particles could be related to recreational activity and local conditions of waste management (Ghayebzadeh *et al.,* 2020). The same has been documented in the Anzali Wetland, where the presence of microplastic was detected in the surface water and sediment, indicating that wetlands linked with the Caspian system can serve as transport corridors and accumulating areas (Rasta *et al.*, 2020).

Another important source pathway is river systems. The analysis of river estuaries at the southern shores of the Caspian Sea has reported the presence of microplastic in the sediment layers and highlighted the importance of

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river discharge in land to sea transfer of contamination (Ghayebzadeh *et al.*, 2021). Recent studies of rivers that flow into the Gorgan Bay showed significant spatial variations between contaminated estuarine sites and sites that are less polluted, and fibres and common polymers like polyethylene and polypropylene were commonly detected (Gholizadeh *et al.*, 2024). The results of this study suggest that the study of microplastic pollution in the Caspian Sea cannot only be considered as a marine issue, given that the distribution of microplastic pollution is closely related to the generation of inland waste, urbanisation, wastewater discharges and river-basin processes.

Microplastics have been also reported in Caspian biota. Studies on commercially important fish species have shown the ingestion of microplastics, increasing the concern for exposure in the environment and the possibility of transferring contaminants along aquatic food chains (Zakeri *et al.,* 2020). Later research has revealed the presence of particles in the gastrointestinal tract and gills of species in the teleost and sturgeon families, often in the form of fibres (Rasta *et al.*, 2023). Another indicator of microplastic contamination also exists in endangered Caspian seals, which suggests that contamination can reach the higher trophic levels and is not limited to coastal sediments or surface waters (Khaleghi *et al.*, 2026). All of these studies indicate that the issue is impacting more than one environmental compartment and biological group.

The geographic spread of research remains very uneven, given the increasing amount of evidence base. The majority of quantitative works have been carried out along the Iranian coast and comparatively limited information is available for Azerbaijan, Kazakhstan, Russia and Turkmenistan. There are also significant discrepancies between current studies with regards to sampling design, particle-size cut-off, separation method, reporting unit and polymer-identification method. Sediment concentrations have been expressed in a variety of ways including particles per kilogram, water results as particles per cubic metre and biological results as particles per individual or organ. The methodological differences put the provision of a single regional concentration into perspective and highlight the need for structured evidence harmonisation (D'Hont *et al.*, 2021; Manbohi *et al.*, 2021). Another constraint is that microplastic data is rarely combined with other socioeconomic and anthropogenic pressure indicators. For interpretation of the spatial distribution of pollution, waste generation, maritime freight transport, tourism intensity, coastal population and recreation use may be important contextual information. These indicators will not necessarily prove causality alone but can help identify areas where there may be growing environmental pressure. Previous studies in Azerbaijan have indicated that the use of numerical environmental indicators in conjunction with field observations using the photographic method enhances the contextual understanding of industrial, transport, and urban pressures (Arifzade *et al.*, 2026). This holistic approach is also applicable to coastal studies where photographs taken in the field can be used to record sampling conditions, the visibility of waste in the water, the method of flotation and the morphology of any anthropogenic particles.

Institutional, financial, and behavioral change is also needed to effectively manage coastal pollution. Waste prevention, better monitoring systems, circular economy, cleaner maritime activities and environmentally responsible tourism, are all supported by green economy policies. But such measures require, in part, public awareness and institutional trust and access to credible sustainability-oriented financing. In Azerbaijan, evidence suggests that although there is positive environmental attitude, lack of knowledge and information gaps, as well as a lack of trust, can hinder participation in green financial practices. The results are relevant to coastal management as they are important for environmental monitoring, environmental protection against pollution, which not only needs technical assessment but also public participation and longer-term financing mechanisms.

Considering this background, the present study aims to review and harmonize the evidences on the micro plastic pollution in the Caspian Sea Basin and evaluate the selected anthropogenic pressure indicators by secondary data analysis. It also includes the visual-microscopic observations from Absheron National Park and the coastal zone publicly used by Zira as an Azerbaijan pilot case. The aim of the study is: to identify geographical and environmental distribution of existing microplastic research; to compare abundance, morphology and analytical methods for sediment, water and biota microplastic studies; to assess waste, maritime freight transport, and pressure of tourism related activities distribution in Azerbaijan; to discuss implications for sustainable coastal management and green economy policy. The research combines scientific evidence, official statistics and field-based visual documentation, to offer a regional structure to monitor gaps and future management priorities.

MATERIALS AND METHODS

Data extraction and harmonisation

The year of publications, country, location of the studies, environmental matrix, number of samples, abundance of particles reported, unit of measurement, morphology of particles found, color of the particle, size class, dominant polymer and analytical method were retrieved for each source. Where available, information on flotation, filtration, microscopy, FTIR and Raman spectroscopy and contamination-control procedures was also recorded. The results obtained have been synthesized in the Caspian microplastic evidence dataset and subsequently combined in the harmonised analytical dataset used in this study. Common categories for similar particle descriptions were used. For instance, fibres, threads and filaments were all defined as fibres, and irregular plastic pieces, as fragments. However, the original numerical units were kept as the results obtained in different units, such as items per kg, items per cubic metre, or items per individual or item per organ could not be combined without significant methodological error.

The matrices which are associated to the environment were therefore analysed separately. Records of sediment, water and biota were not lumped together to a regional abundance value. This choice is due to varying sampling volumes, mesh sizes, density-separation protocols, and particle-size restrictions and analytical confirmation methods used in the literature (Hidalgo-Ruz *et al.* 2012; Cowger *et al.,* 2020). The strength of particle identification was also categorized as based on visual or microscopic observation, physical separation or polymer identification or chemical confirmation by FTIR or Raman spectroscopy. This distinction was needed because natural fibres, coloured organic substance or mineral fragments could be mistakenly identified as plastics, based on visual identification (Löder and Gerdts 2015; Xu *et al.,* 2019). The study identification and selection process is summarised in Fig. 1.

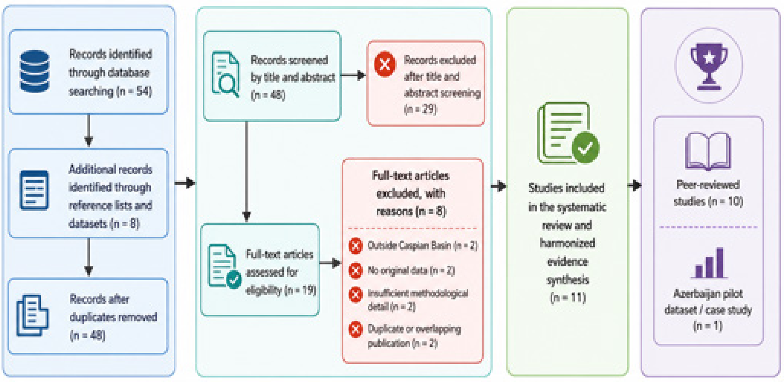

Figure 1: PRISMA flow diagram of literature identification and study selection.

Assessment of coastal anthropogenic pressure

Official statistical indicators were analysed and used to give socioeconomic context to the environmental evidence for Azerbaijan. Such indicators were total waste generation, solid domestic waste, hazardous waste, landfilling, energy recovery, maritime freight transport, foreign linked maritime freight and hotel overnights in selected coastal and coast related economic regions. The waste series spanned from 2020 through 2025, the maritime freight indicators spanned from 2020 through 2024 and the tourism indicators spanned from 2021 through 2025.

The indicators were taken from publications and statistical yearbooks of the State Statistical Committee of the Republic of Azerbaijan. They were analysed on the basis of the annual totals, percentage change, and regional comparison. Official statistics and web-based institutional materials will be cited in footnotes, and not be part of the peer-reviewed reference list, in accordance with the journal's reference policy.

These indicators were used in this study as proxies of anthropogenic pressure and not as a direct measurement of microplastic pollution. The study did not assume that an increase in national waste generation or in maritime freight or tourism would necessarily lead to the particle concentrations measured at the various sampling sites. They were to serve as a general framework to interpret potential paths of pressure and management issues.

Visual evidence and pilot case in Azerbaijan

To link the regional review with evidence from the field, a local pilot case was integrated. Observations were carried out in the coastal zone of Absheron National Park, which is protected, and the coastal zone of Zira, which is used for the public. Within each area there were three sampling points, resulting in six coded observation sites.

Figure 2: Field sampling, sample coding and saltwater flotation stages in Absheron National Park and Zira.

A 20 × 20 cm quadrat was used to record each of beach sand, vegetation/plant remains, shell fragments, and visible anthropogenic materials at each point. Other data collected included coordinates, temperature, humidity, wind and general weather conditions. The main stages of field sampling, sample coding and saltwater flotation are presented in Fig. 2.

The sand samples obtained were saltwater floated, and the light particles separated were viewed with an LCD Digital Microscope DM9. Since it was not used, the observed materials were labelled as "microplastic-like anthropogenic particles" and not chemically identified as microplastics. The original pilot study had indicated a higher diversity of colour, form and material in the public-use zone and there were also anthropogenic fragments in the protected area.

Quadrat sampling, coded sample storage, flotation and separated particles as well as representative microscopic observations from the pilot study will be illustrated by selected photographs. These photographs will be used for contextual visual evidence, and will not be used as independent quantitative measurements.

Mapping and statistical analysis

In QGIS the map of Caspian Sea Basin will be created, which presents the five countries located on the shore of the Caspian Sea, the location of published microplastic studies and two pilot sites of Azerbaijan. Sediment, water, wetland, river and biota studies will be represented by different symbols. If exact co-ordinates are not available then the location will be determined approximately from the geographical description given in the original sources and be marked as approximate.

The analytical stage will primarily be conducted using descriptive statistics in view of the high level of heterogeneity of the evidence base. Analysis will be done to compare the number of studies conducted by year, country and environmental matrix as well as the number of records of the particles by type of analytical method and by chemically confirmed records. Where available, reported means, standard deviations and ranges will be kept. The temporal change and regional distribution of official pressure indicators will be evaluated. A formal meta-analysis will not be conducted, due to the lack of sufficiently standardised reporting of effects sizes or sampling designs and reporting units in the reviewed studies. Rather, structured quantitative synthesis and evidence-gap analysis will be employed. The spatial distribution of the reviewed studies and Azerbaijani pilot observation points is shown in Fig. 3.

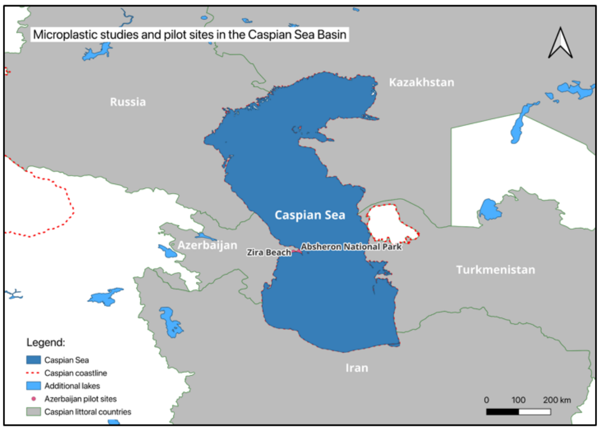

Figure 3: Spatial distribution of reviewed microplastic studies and Azerbaijani pilot observation sites in the Caspian Sea Basin.

RESULTS AND DISCUSSIONS

Distribution of the reviewed evidence

Finally, 11 studies or research datasets and 24 quantitative or qualitative records related to the presence of microplastic in Caspian Sea Basin were collected. The records included marine and coastal sediments, surface waters, wetlands, river estuaries, fish and Caspian seals and visual-microscopic observations from the Azerbaijani coast.

The evidence of these was distributed unevenly geographically. The majority of the quantitative studies was performed in the south of the Caspian Sea, especially in Iran. A smaller sediment data set was available for the northern Caspian and six pilot observation points were available in Absheron National Park and at Zira in Azerbaijan. Within Kazakhstan, Russia or Turkmenistan, no quantitative records, comparable in detail were found for the coastal regions.

Four of the studies included were released in 2020, and three in 2021. Further records were published in 2023, 2024 and 2026. Sediment was the most common environmental matrix examined, followed by examination of biota, combined sediment–water studies and surface-water studies. Seven studied used FTIR, Raman spectroscopy or another chemical confirmation method while all the other sources used polymer identification, physical separation or visual-microscopic observation.

The frequency of studies according to the year of publication, environmental matrix and identification method are shown in Fig. 4.

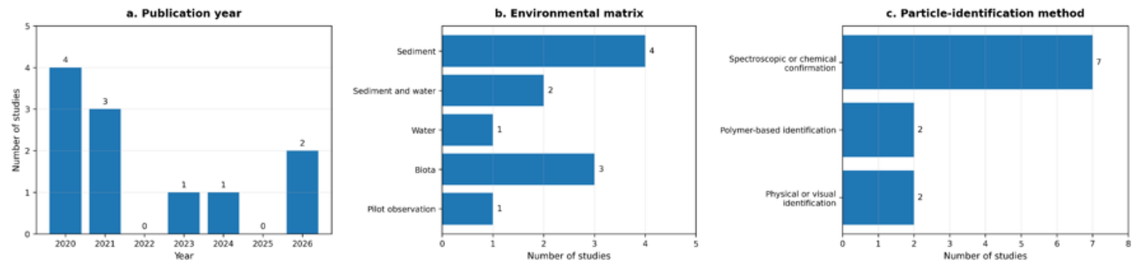

Figure 4: Distribution of the reviewed Caspian microplastic studies by publication year, environmental matrix and particle-identification method.

Table 1: General characteristics of the reviewed Caspian microplastic studies

Study	Study area	Matrix	Sample size	Identification approach
Nematollahi *et al.* (2020)	Southern Caspian coast, Iran	Sediment and water	42	Chemical and polymer identification
Ghayebzadeh *et al.* (2020)	Southern Caspian coast, Iran	Sediment	96	Microscopy and FTIR
Rasta *et al.* (2020)	Anzali Wetland, Iran	Sediment and water	17	ATR-FTIR and microscopy
Zakeri *et al.* (2020)	Southern Caspian Sea, Iran	Fish	111	Visual and polymer identification
Ghayebzadeh *et al.* (2021)	Estuaries of 17 rivers, Iran	Sediment	34	Microscopy and FTIR
Manbohi *et al.* (2021)	Southern Caspian Sea, Iran	Water	13	Polymer identification
D'Hont *et al.* (2021)	Northern Caspian Basin	Sediment	26	Physical and morphological identification
Rasta *et al.* (2023)	Northern Iranian Caspian coast	Fish	62	Raman and SEM/EDS
Gholizadeh *et al.* (2024)	Rivers entering Gorgan Bay, Iran	Sediment	57	FTIR
Khaleghi *et al.* (2026)	Southern Caspian coast, Iran	Caspian seal	17	FTIR
Azerbaijan pilot case	Absheron National Park and Zira	Coastal sand	6 sites	Visual-microscopic identification

Microplastic occurrence in sediment and water

The reviewed sediment studies reported a wide range of microplastic concentrations. Nematollahi *et al.* (2020) reported a mean concentration of 15 items/kg dry sediment along the southern Caspian coast. Ghayebzadeh *et al.* (2020) reported a higher overall mean of 183.5 ± 154.4 items/kg. In the same study, tourism-oriented sites contained 227.1 ± 173.8 items/kg, compared with 139.9 ± 120.7 items/kg at non-tourist sites.

In Anzali Wetland, sediment concentrations ranged from 140 to 2820 items/kg in one sampling period and from 113 to 3690 items/kg in another (Rasta *et al.,* 2020). In the estuaries of 17 rivers, the average abundance was 152.8 ± 107.8 items/kg in the upper sediment layer and 197.8 ± 131.9 items/kg in the deeper layer (Ghayebzadeh *et al.,* 2021).

The northern Caspian sediment record ranged from 80 to 2095 items/kg (D'Hont *et al.,* 2021). In the rivers entering Gorgan Bay, the overall mean concentration was 333 ± 268 items/kg. The Qarasu estuary contained 1080 ± 380 items/kg, while a forest-associated reference site along the Klak River contained 80 ± 19 items/kg (Gholizadeh *et al.,* 2024).

Water concentrations also differed considerably. Nematollahi *et al.* (2020) reported 710 items/m^3 in coastal waters. Manbohi *et al.* (2021) reported a mean of 0.246 ±

0.020 items/m³ in southern Caspian surface waters. In Anzali Wetland, reported concentrations ranged from 0.40 to 4.41 items/m³ during one season and from 0.19 to 2.85 items/m³ during another (Rasta *et al.,* 2020). Fibres were the dominant particle morphology in most sediment and water studies. They accounted for approximately 97% of the particles in one southern Caspian investigation and 68% in the rivers entering Gorgan Bay. Polyethylene, polypropylene, polyethylene terephthalate, polyester, polystyrene and nylon were among the most frequently reported polymers.

Table 2: Selected quantitative microplastic records from the Caspian Sea Basin

Location and matrix	Reported abundance	Unit	Main recorded feature
Southern Caspian sediment	15	items/kg dry sediment	Fibres dominant
Southern Caspian coastal water	710	items/m³	High fibre proportion
Southern coastal sediment	183.5 ± 154.4	items/kg	Overall mean
Tourism-oriented sediment	227.1 ± 173.8	items/kg	Higher than non-tourist sites
Non-tourist sediment	139.9 ± 120.7	items/kg	Lower site mean
Anzali Wetland sediment	113–3690	items/kg	Wide seasonal and spatial range
River-estuary sediment	152.8–197.8	items/kg	Variation by sediment depth
Northern Caspian sediment	80–2095	items/kg	Wide concentration range
Gorgan Bay river sediment	333 ± 268	items/kg	Fibres, PE and PP reported
Qarasu estuary	1080 ± 380	items/kg	Highest site-specific mean
Southern Caspian surface water	0.246 ± 0.020	items/m³	Inshore and offshore stations

Microplastics in Caspian biota

There was a report on the presence of microplastic particles in commercial fish, in sturgeon species and in Caspian seals. The average number of particles per fish was 2.29 in the Zakeri *et al.* (2020) study. The mean abundance of the particles was 2.95 ± 1.98 particle per individual in Chelon aurata and 1.66 ± 1.23 particle per individual in Rutilus kutum. A total of 67.6% of the fish inspected were suspected particles.

Rasta *et al.* (2023) found that the fish examined had a mean number of 1.46 ± 1.17 particles in their gastrointestinal tract and 1.01 ± 0.62 particles in their gills. Fibres accounted for about 74.7% of the particles and nylon was one of the predominant polymers.

Khaleghi *et al.* (2026) found 174 particles in the gastrointestinal tracts of 17 Caspian seals. The mean abundance was 10.2 ± 5.1 particles per gastrointestinal tract and 0.87 particles per gram of dry gastrointestinal content. Fibres accounted for 52.3% of the particles and the most commonly reported polymers were polyethylene and polyester.

Anthropogenic pressure indicators in Azerbaijan

During the periods analysed, official secondary statistics indicated an increase in the waste generated, maritime freight transport and tourism activity. The total waste generation rose from 3486.5 thousand tonnes in 2020 to 4426.4 thousand tonnes in 2025. This was an overall gain of some 27%.

The amount of solid domestic waste rose from 2350.0 thousand tonnes in 2020 to 3251.2 thousand tonnes in 2025, an increase of around 38%. Its share of the total waste rose from 67.4% to 73.5%.

In 2020, maritime freight transport volume was 5981.9 thousand tonnes, rising to 8621.6 thousand tonnes in 2024. The total gain over this period was about 44%, but there were fluctuations from year to year.

In 2025, there were around 4.57 million national hotel overnights compared to around 1.79 million in 2021. Baku had the highest number of overnights and there were also increases in Guba–Khachmaz, Lankaran–Astara, Absheron–Khazi and Shirvan–Salyan. The chosen coastal and coast-related areas accounted for around 80% of national hotel overnights in 2025.

The temporal changes in these indicators are presented in Fig. 5.

Table 3: Selected anthropogenic pressure indicators for Azerbaijan

Indicator	**Initial value**	**Final value**	**Change**
Total waste generation	3486.5 thousand t in 2020	4426.4 thousand t in 2025	+27%
Solid domestic waste	2350.0 thousand t in 2020	3251.2 thousand t in 2025	+38%
Maritime freight	5981.9 thousand t in 2020	8621.6 thousand t in 2024	+44%
National hotel overnights	1.79 million in 2021	4.57 million in 2025	+155%

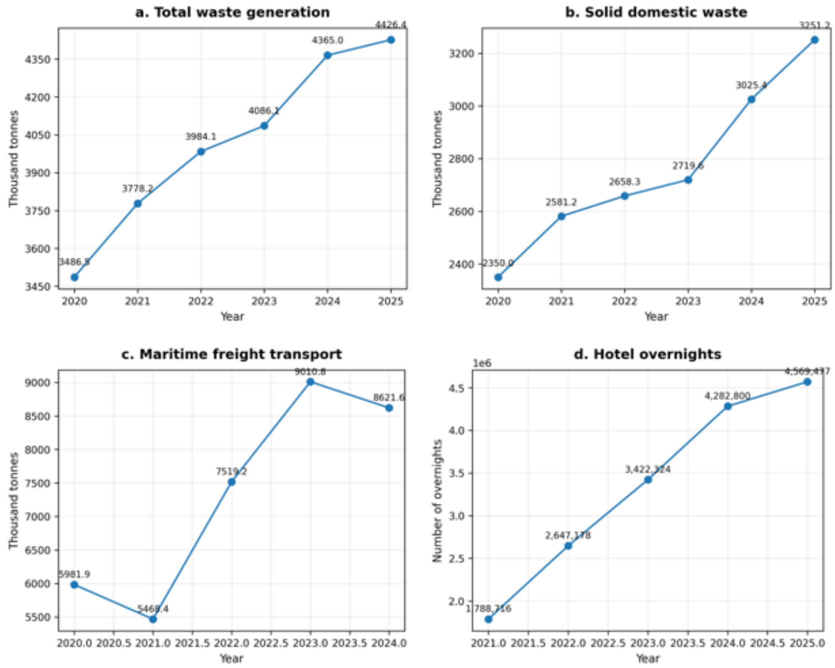

Figure 5: Trends in total waste generation, solid domestic waste, maritime freight transport and hotel overnights in Azerbaijan.

Azerbaijani pilot observations

Microplastic like anthropogenic particles at all of six pilot sites in Absheron National Park and Zira. These materials in the protected-area samples were green, blue and purple pieces with improper edges, smooth or shiny surfaces and evidences of weathering.

White and transparent film-like materials, orange-red fragments, fibrous synthetic material and light-green layered particles were observed in the Zira samples. There was more variation in particle colour, morphology and apparent material type in the public-use coastal zone.

The CHM1-IZ/N2 sample has relatively big coloured fragments and fibrous materials. Samples in the protected areas exhibited less visual diversity, though anthropogenic fragments were still present. All materials were determined to be microplastic-like anthropogenic particles and not chemically confirmed microplastics as no FTIR or Raman spectroscopy was performed.

Representative microscopic images from both zones are presented in Fig. 6.

Table 4: Comparison of the Azerbaijani pilot observation zones

Indicator	Absheron National Park	Zira public-use coastal zone
Management status	Protected coastal area	Public and recreational area
Main recorded colours	Green, blue and purple	White, transparent, orange-red and light green
Main morphologies	Weathered fragments	Films, fragments and fibres
Material diversity	Relatively limited	More visually diverse
Chemical confirmation	Not conducted	Not conducted
Particle classification	Microplastic-like anthropogenic particles	Microplastic-like anthropogenic particles

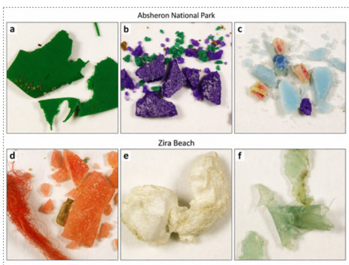

Figure 6: Visual-microscopic comparison of microplastic-like anthropogenic particles from Absheron National Park and Zira.

a–c — representative fragments from the protected coastal zone; d–f — film-like, fibrous and coloured fragments from the public-use coastal zone.

Discussion

Regional evidence and methodological comparability

The studies reviewed in this article show the presence of microplastic contamination in various parts of the Caspian environment such as aquatic organisms, river estuaries, wetlands, surface waters and coastal sediments. The greater number of published works, however, on the Iranian coast should not be seen as an indication that the southern Caspian is necessarily the most polluted part of the basin. It is mainly a result of the imbalance in the geographical distribution of science activity. The available but limited evidence from the northern Caspian and Azerbaijan indicate that contamination is more widespread, and similar evidence exists only for limited areas along the Russian, Kazakhstan and Turkmenistan coasts.

The relatively high results obtained in wetlands and river estuaries are environmentally reasonable as they link waste and depositional environments along the coast. Plastic debris are transported into rivers from settlements and catchments, and slower river flow speeds and sediment deposition may favour particle retention in the river closer to the mouth. River systems have been identified as one of the main pathways for land based plastic wastes, albeit at varying estimates depending on hydrological conditions, population distribution and modelling methods (Lebreton *et al.,* 2017; Meijer *et al.,* 2021). Freshwater reviews also highlight that rivers, wastewater and urban drainage are a linkage and interface between land-based plastic use and ocean plastic pollution (Blettler *et al.,* 2018; Li *et al.,* 2018).

A comparison of the studies reviewed is still difficult due to the lack of direct numerical measurements. Items per kilogram of sediment, items per cubic metre of water or items per organism were used to report the values. Studies also varied in sampling depth, filtered water volume, mesh of filtering used, density of solution and minimum particle size threshold. Comparability is also impacted by the use of different terms, with studies not always using the same definition or size categorisation of what is considered a microplastic (Hartmann *et al.,* 2019; Frias and Nash 2019). Also reviews of analytical practice demonstrated that large variations between datasets can be obtained using different sampling and identification procedures (Prata *et al.,* 2019, Koelmans *et al.,* 2019).

When particles are not chemically confirmed, especially when visible, it is important to keep them. FTIR and Raman spectroscopy are able to differentiate synthetic polymers from natural fibres, minerals and other anthropogenic materials with similar colours or shapes. Quality evaluation of studies using biota has shown that poor contamination control and low polymer verification may compromise the accuracy of results published (Hermsen *et al.,* 2018). The Azerbaijani pilot observations are thus appropriately considered as microplastic-like anthropogenic particles, and not confirmed microplastic.

Anthropogenic pressures and the Azerbaijan pilot case

For Azerbaijan, increases in waste production, maritime traffic and tourism are context indicators of potential coastal pressure. They cannot quantify the amount of plastic that enters the Caspian Sea, and cannot make a direct link to the particles that were seen at the pilot sites. However, they can pinpoint activities and pathways that should be taken into account when developing future monitoring programmes.

It is well understood that land based waste contributes heavily to marine plastic pollution. Aquatic areas can become impacted by mismanaged waste by rivers and drainage systems, wind and direct disposal. Waste generation and waste management conditions play a crucial role in determining plastic inputs from coastal populations, as shown by Jambeck *et al.* (2015); the role of river systems in transporting plastics towards marine systems was highlighted by Lebreton *et al.* (2017) and Meijer *et al.* (2021). After getting into coastal waters, the distribution of the particles is governed by their density, size, shape, wind, waves and currents (Chubarenko *et al.,* 2016; Law 2017). Smaller microplastics can also be formed when larger plastic debris weather on beaches and in coastal waters (Andrady 2011; Cole *et al.,* 2011).

The increased visual diversity of films, fragments and fibres in the Zira public-use zone is consonant with the potential impacts of recreational use, settlement activities in the area and locally generated waste. The presence of anthropogenic particles in Absheron National Park is significant as well, as the protected status does not exclude transportation of the debris by currents, waves or wind. Although the contrast observed is a useful contextual evidence, the small number of samples and the lack of chemical information do not allow for source attribution or statistical comparison of the two zones.

The numerical pressure indicators and visual field evidence is combined using a mixed-evidence approach, which was previously demonstrated in Arifzade *et al.* (2026). In their comparative study of Sumgayit and Almaty, they included indices of PM2.5 and PM10, as well as the photographic observations of the industrial, transport and construction conditions. In the current study, field images also serve to provide spatial context for the statistical indicators, and do not replace quantitative sampling/polymer confirmation.

Management and green economy implications

The results contribute to the development of a common monitoring system for the five Caspian countries. Common protocol should include sampling seasons, environmental matrices, depths of sediments, volumes of water, particle-size classes, and laboratory blanks and polymer-confirmation requirements. Using standardised terminology and reporting would make it easier to separate real geographical variation from variation due to analytical methods (Hartmann *et al.,* 2019; Prata *et al.,* 2019). Given that river mouths, wetlands, ports, recreational beaches and protected areas are all different stages in the transport and accumulation of plastic, monitoring should be performed in these areas.

Priorities for management measures should be prevention at source, not just coastal clean-up. Interventions that are suitable involve decreasing uncontrolled leakage of waste, intercepting waste coming from rivers, enhancing port waste reception, handling fishing related waste and defining waste requirements for coastal tourism structures. The presence of plastics in the marine environment can last long after they enter the system as they can fragment into small particles, and it is generally more effective to prevent plastics being released into the marine system than to remove small dispersed plastics later (Andrady 2011; Law 2017).

Microplastic prevention can be linked to resource efficiency, circular material use, sustainable tourism and protection of ecosystem in a green economy context. Financing can be used to provide support for laboratory capacity, re-useable product systems, river interception infrastructure, and community based monitoring. But environmental finance mechanisms need to be understood by the public and to be reported transparently and trusted institutions. Mammadov (2025) found that green finance is still underdeveloped in Azerbaijan, and highlighted that greenwashing concerns and credibility and access to information can affect public involvement. Coastal pollution programmes should therefore encompass measurable environmental indicators, and public reporting.

Limitations and future research priorities

This study is limited by the small and geographically uneven evidence base. The majority of the quantitative studies available were from the southern part of the Caspian and some littoral countries did not have similar published studies. Meta-analysis was not possible due to differences in environmental matrices, measurement units and analytical methods. Pressure indicators were used as proxies as context only and should not be interpreted as measured contribution to Caspian microplastic pollution. The six pilot sites analyzed in Azerbaijan comprised the pilot case. The anthropogenic particles were documented by visual-microscopic analysis, however the polymer composition was not possible to determine. Future research should involve: seasonal repetition, more extensive coastal sampling, paired sampling of sediment, water and biota, procedural blanks and confirmation by FTIR or Raman. Information should also be provided in consistent units, well-specified particle size classes and open georeferenced datasets. Such improvements would allow for more certainty in the comparability of Caspian countries and enable future trend analysis.

This paper was an attempt to compile existing evidence on microplastic contamination in the Caspian Sea Basin and analyze the correlation between this contamination and the selected indicators of anthropogenic pressure on the coasts of the Caspian Sea. The literature reviewed shows the presence of microplastic in sediments, surface waters, wetlands, river estuaries, fish and Caspian seals. Yet, the evidence base is still very unevenly distributed, with most of what has been published focused on the Iranian coastline, and few comparative data are available for Azerbaijan, Kazakhstan, Russia and Turkmenistan. Sediment was the most commonly studied environmental matrix and fibres were one of the most common particle types reported in studies of sediment, water and biota. Due to significant variations in sampling design, particle-size thresholds, measurement units and analytical methods, a formal meta-analysis and a direct basin-wide comparison could not be performed. These methodological differences illustrate the necessity of harmonization of sampling, contamination-controlling, reporting and polymer-confirming procedures among the five Caspian littoral states. During the pilot observations conducted in Azerbaijan, the Azerbaijani pilot identified anthropogenic particles (micro-plastics) in Absheron National Park and in public use coastal zone of Zira. A higher number of films, fragments, and fibers was found in the public-use zone, and the number of anthropogenic particles in the protected zone demonstrated that the protection does not ensure protection from particles carried by wind, waves, currents, or from neighboring human activities. These observations are preliminary and should be confirmed chemically in the future since FTIR or Raman spectroscopy was not used. The analysis of secondary statistics indicated the growth of waste generation, maritime freight transport and tourism activity in Azerbaijan. These indicators are not necessarily indicative of direct causes, but they indicate pathways of pressures that may be included in future coastal monitoring. River mouths and wetlands, ports, recreational beaches and protected coastal areas are priority areas. The standardised scientific monitoring, waste prevention, improved waste management at port and municipality, river-borne debris control, responsible tourism management and fishing-related material management should be integrated in effective waste management. Incorporating investments in laboratory infrastructure, increasing the reuse of materials, raising public awareness and the transparent financing of the environment within a green economy structure could help ensure long-term protection of the coast. Future research should involve larger geographical areas, seasonal resampling, combination of sediment, water and biota data and FTIR or Raman verification. The studies should be supported by open and georeferenced data to facilitate reliable regional comparison, assessment of trends and coordinated Caspian environmental policy.

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