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Leila Seidaliyeva*, Lyailim Taizhanova

Yessenov University, Caspian State University of Technologies and Engineering Named After Sh. Yessenov, Aktau, Kazakhstan
***Corresponding author:** leila.seidaliyeva@yu.edu.kz

E-mail: leila.seidaliyeva@yu.edu.kz, lyailim.taizhanova@yu.edu.kz

ENVIRONMENTAL ASSESSMENT OF MICROPLASTIC POLLUTION IN THE WATER AREA OF THE CASPIAN SEA

Annotation. Microplastic pollution has emerged as a persistent environmental issue in the Caspian Sea, yet evidence remains geographically fragmented and methodologically inconsistent. This study systematically reviewed peer-reviewed research on microplastic contamination in the Caspian Sea using the PRISMA framework. Searches of Scopus, Web of Science, and Google Scholar identified 50 potentially relevant records, of which 10 studies met the inclusion criteria. All included studies were conducted in the southern Caspian Sea, mainly in Iranian coastal waters, and focused primarily on sediments, with limited assessment of water and biota. Reported microplastic concentrations varied widely, ranging from 13 to more than 1000 particles/kg in sediments, with consistently higher values in river estuaries, beach sediments, and nearshore areas than in offshore zones. A general west-to-east decline along the southern coast and a nearshore-to-offshore gradient were observed in most studies, although localized hotspots were common. Fibers were the dominant particle shape, while polyethylene, polystyrene, polyethylene terephthalate, and polypropylene were the most frequently reported polymers. The evidence points to rivers, tourism, fishing, and urban runoff as major sources and transport pathways. However, the northern, eastern, and western sectors of the Caspian Sea remain unstudied, and vertical distribution across the water column is still largely unknown. These gaps limit basin-wide assessment and call for standardized, depth-resolved, and geographically expanded monitoring.

Keywords: Microplastic; Macroplastic; Artifact; Fishing Nets; Pollution; Microplastics; Marine Pollution; Environmental Assessment; Caspian Sea; Kazakhstan Sector; Bottom Sediments; Aquatic Environment.

Introduction

Microplastic pollution in the Caspian Sea shows substantial spatial variation, with sediment concentrations ranging from 13 to over 1000 particles/kg [1, 2] across the southern coastal region. Beach sediments contain approximately twice the concentration of offshore sediments (196.67 vs. 103.15 MPs/kg) [3], while river estuaries represent pollution hotspots with mean concentrations of 350.6 ± 232.6 MP/kg [4]. Concentrations generally decrease from west to east along the southern coast [5] and from nearshore to offshore areas [3], though localized sources create hotspots throughout the region [6]. Fibers dominate microplastic composition (68-97% of particles) [2, 5, 6], with polyethylene, polystyrene, and polyethylene terephthalate as the most common polymers [1–3, 7]. Rivers serve as the primary transport pathway, as evidenced by elevated concentrations near river mouths [7] and positive upstream-downstream gradients [8], with tourism and fishing activities also showing significant positive correlations with microplastic

abundance [8]. Critical knowledge gaps limit comprehensive understanding of Caspian Sea microplastic pollution. All ten studies examined only the southern (Iranian) coastal region, leaving the northern, eastern, and western portions uncharacterized. Vertical distribution in the water column remains almost entirely unstudied, with research focused on surface waters [5] or bottom sediments [1, 4, 9] but not intermediate depths. The observation that larger particles (>1000 μm) dominate water samples while smaller particles (250-500 μm) dominate sediments [5] suggests size-selective settling processes, but no studies systematically examined depth-related concentration gradients within the water column. Methodological variations in size thresholds and detection methods contribute to the order-of-magnitude differences in reported concentrations across studies.

Materials and methods

A systematic literature search was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework to identify studies investigating microplastic (MP) pollution in the Caspian Sea, with particular emphasis on spatial distribution, vertical variation, and pollution sources. The search strategy was designed using structured Boolean logic to capture studies addressing microplastic occurrence, concentration, environmental compartments, and transport pathways within the Caspian Sea ecosystem and adjacent coastal or tributary environments. Search queries incorporated database-specific indexing terms, synonymous keyword combinations, truncation operators, and controlled vocabulary to maximize reproducibility and retrieval sensitivity. The generalized Boolean search structure applied across databases was as follows:

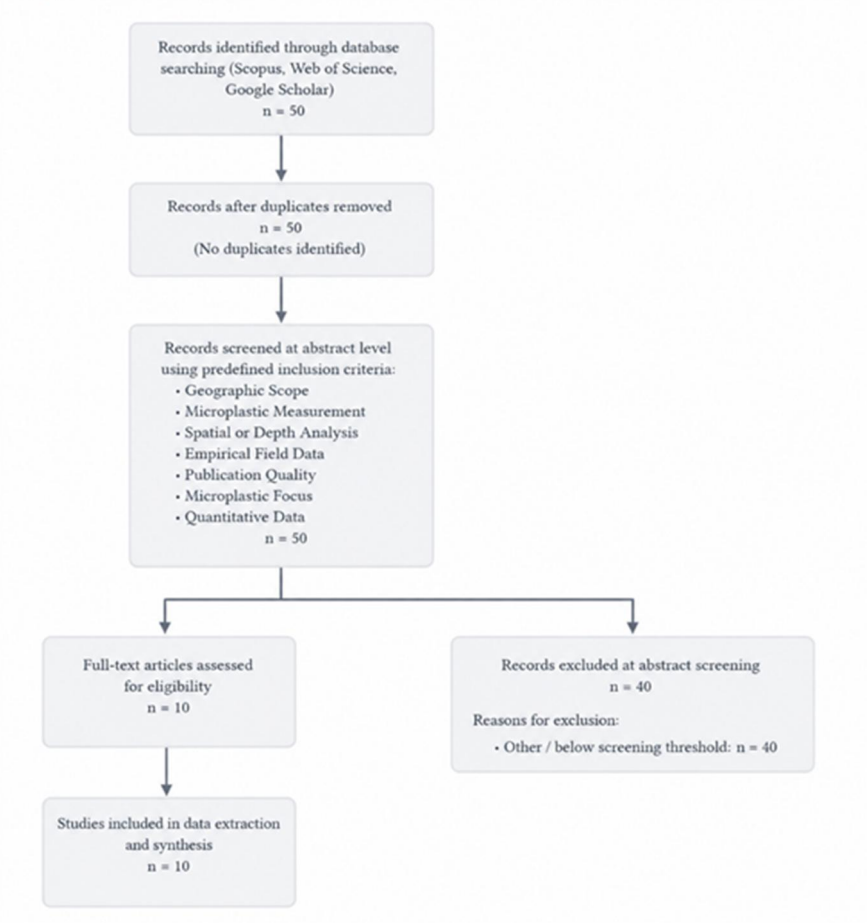


Figure 1 - Paper search and Screening methods

Paper search:

(("microplastic*" OR "plastic debris" OR "plastic particle*") AND ("Caspian Sea" OR Caspian OR "Caspian coastal area*" OR tributaries) AND (distribution OR concentration OR abundance OR sediment OR "surface water" OR "water column") AND (source* OR transport OR pollution OR spatial OR depth OR vertical))

The literature search was performed using the bibliographic databases Scopus, Web of Science, and Google Scholar to ensure comprehensive coverage of peer-reviewed publications related to marine pollution, environmental monitoring, and microplastic contamination. Additional records were identified through backward reference screening of relevant articles and review papers to minimize publication omission and improve dataset completeness. A total of 50 potentially relevant publications were retrieved during the initial search stage.

2.1 Screening, Inclusion, and Exclusion Criteria

The retrieved records were screened based on predefined inclusion and exclusion criteria developed to ensure methodological consistency and direct relevance to the research objectives. Screening was performed primarily using abstracts, followed by full-text evaluation where necessary. Studies were included if they met the following criteria: (1) the study was conducted within the Caspian Sea or its tributaries, coastal zones, or adjacent marine environments; (2) the study quantitatively measured microplastic concentrations, abundance, or distribution; (3) the study reported spatially explicit or depth-related information, including sampling coordinates, regional divisions, or environmental compartments; (4) the study represented original empirical field research, monitoring programs, or environmental surveys involving primary data collection; (5) the publication was peer-reviewed or constituted credible gray literature with transparent scientific methodology; (6) the study focused specifically on microplastics (<5 mm) rather than exclusively on macroplastic debris; and (7) quantitative numerical results for microplastic contamination were reported.

Studies were excluded if they lacked quantitative measurements, focused solely on laboratory simulations or theoretical modeling, addressed macroplastic pollution without microplastic analysis, or did not provide geographically relevant information for the Caspian Sea basin. Following abstract screening and relevance assessment, 40 publications were excluded for failing to meet the predefined inclusion threshold, while the remaining studies were retained for detailed data extraction and synthesis.

2.2 Data Extraction and Synthesis

Data extraction was conducted using a structured extraction protocol supported by large language model-assisted screening and information retrieval. Extracted variables were manually reviewed and standardized to ensure consistency across studies with differing methodologies and reporting units. The extraction process focused on seven major analytical categories relevant to understanding microplastic pollution dynamics in the Caspian Sea.

For microplastic concentrations, quantitative abundance data were extracted together with measurement units (e.g., items/kg, items/m^3), sampling locations, environmental compartments, seasonal timing, and statistical descriptors such as means, ranges, and standard deviations. Geographic coverage data included regional distribution within the Caspian Sea (northern, central, southern, eastern, and western sectors), country-level sampling information, coastal and offshore classifications, and coordinates where available.

Depth-related information included sampling depth, vertical distribution patterns, environmental compartments (surface water, water column, sediment, and beach sediment), and reported concentration gradients across depth profiles. Physical and chemical

characteristics of microplastics were also extracted, including particle size distribution, dominant shape categories (fibers, fragments, films, pellets), color composition, polymer types (e.g., PE, PP, PET, PS), and evidence of weathering or surface degradation.

To evaluate pollution origins, all reported sources and transport pathways were compiled, including riverine discharge, wastewater effluents, urban runoff, industrial activities, fishing operations, shipping, and tourism-related inputs. Where available, source attribution evidence based on polymer composition, spatial clustering, hydrodynamic transport, or statistical correlations was documented.

Spatial distribution patterns were synthesized by comparing regional differences in microplastic contamination across the Caspian Sea, including nearshore-offshore gradients, north-south contrasts, hotspot identification, and environmental factors influencing variability. Methodological details were additionally extracted to assess comparability between studies, including sampling strategies, sample processing protocols, density separation methods, digestion procedures, identification techniques (visual microscopy, FTIR, Raman spectroscopy), quality assurance procedures, detection limits, and sample collection periods.

Results

Ten studies examining microplastic pollution in the Caspian Sea were included in this review. All studies were conducted in the Iranian portion of the southern Caspian Sea region, with sampling occurring between 2019 and 2024. Only one study provided full text access.

Table 1 - Characteristics of Included Studies

Study	**Geographic focus**	**Study type**	**Sample size**	**Compartments sampled**
M. Nematollahi et al., 2020	Southern Caspian Sea, Mazandaran province, Iran [5]	Primary study	32 sediment, 10 water samples [5]	Coastal and sea surface sediments, water [5]
A. Mehdinia et al., 2019	Southern Caspian coastal zones, northern Iran [7]	Primary study	17 surficial sediments [7]	Surficial sediments [7]
Mehdi Ghayebzadeh et al., 2020	Southern coasts of the Caspian Sea [1]	Primary study	96 samples (48 recreational-tourism areas, 48 non-tourist areas) [1]	Beach sediments at 5 and 5-15 cm depth [1]
A. Manbohi et al., 2021	Southern Caspian coasts [3]	Primary study	6 sandy beach stations, 18 inshore-offshore stations (6 transects) [3]	Beach sediment, inshore-offshore sediments [3]
T. Bagheri et al., 2020	Gorgan Bay, Caspian Sea (north, central, south areas) [10]	Primary study	21 stations [10]	Sediments, fish, benthic organisms [10]
Mehdi Ghayebzadeh et al., 2021	Estuary of 17 rivers ending in the Caspian Sea, southern coast [4]	Primary study	Not specified	Bottom sediment at 0-5 cm and 5-15 cm depth [4]

Study	Geographic focus	Study type	Sample size	Compartments sampled
Majid Rasta et al., 2021	Southwest coast of the Caspian Sea [9]	Primary study	3 stations, sampled across 4 seasons (April 2019-February 2020) [9]	Bottom sediment [9]
Mohammad Gholizadeh et al., 2024	Rivers discharging into Gorgan Bay, southeast Caspian Sea [2]	Primary study	57 surface sediment samples from 19 stations [2]	Surface sediment [2]
A. Manbohi et al., 2023	Rivers ending to southern Caspian Sea [8]	Primary study	26 sites in 13 rivers, surveyed in 2 seasons [8]	Bank sediments [8]
V. Taghipour et al. (n.d.)	Southern coasts of the Caspian Sea, Iran (36-38°N, 48-53°E) [6]	Primary study	8 sites, July 2023 [6]	Bottom sediment (upper 3 cm surface layer) [6]

All studies were conducted on the southern coasts of the Caspian Sea, primarily in Iranian waters. The studies employed various sampling approaches, including beach sediments, inshore-offshore transects, river estuaries, and open water sediments at distances ranging from 0.4 to 8.6 km from shore [6]. Sampling depths varied from surface waters [5] to sediment layers at 5-15 cm depth [1, 4]. Microplastic concentrations in the Caspian Sea showed substantial variation across compartments and locations. The following table summarizes concentration data from all studies.

Table 2 - Microplastic Concentration Data

Study	Compartment	Mean concentration	Range/Additional measures	Location notes
M. Nematollahi et al., 2020	Sediment	15 items/kg [5]	Not specified	Southern Caspian Sea, Mazandaran province [5]
M. Nematollahi et al., 2020	Coastal water	710 items/m³ [5]	Not specified	Southern Caspian Sea, Mazandaran province [5]
A. Mehdinia et al., 2019	Surficial sediments	Not specified	25-330 items/kg [7]	Southern Caspian coastal zones [7]
Mehdi Ghayebzadeh et al., 2020	Sediments (5-15 cm)	183.5 ± 154.4 MP/kg [1]	Maximum: 542 MP/kg, Minimum: 13 MP/kg [1]	Southern coasts, recreational and non-tourist areas [1]
A. Manbohi et al., 2021	Sandy beaches	196.67 ± 11.58 MPs/kg [3]	Not specified	Southern Caspian coasts [3]
A. Manbohi et al., 2021	Inshore-offshore	103.15 ± 7.21 MPs/kg [3]	Not specified	Southern Caspian coasts [3]
T. Bagheri et al., 2020	Sediments	Not specified	80 ± 25 to 740 ± 105 n/kg [10]	Gorgan Bay (north, central, south) [10]
T. Bagheri et al., 2020	Fish tissue	39 MP/g dry weight [10]	Neogobius melanostomus [10]	Gorgan Bay [10]

Study	Compartment	Mean concentration	Range/Additional measures	Location notes
T. Bagheri et al., 2020	Mussel tissue	19.8 MP/g dry weight [10]	Cerastoderma lamarcki [10]	Gorgan Bay [10]
Mehdi Ghayebzadeh et al., 2021	River estuary sediments (0-15 cm)	350.6 ± 232.6 MP/kg [4]	Not specified	17 rivers ending in Caspian Sea [4]
Majid Rasta et al., 2021	Sediments	397.7 ± 66.93 items/kg [9]	Maximum: 996 ± 55.07 items/kg at Astara station [9]	Southwest coast [9]
Mohammad Gholizadeh et al., 2024	River surface sediments	333 ± 268 particles/kg [2]	Highest: 1080 ± 380 particles/kg (Qarasu River estuary), Lowest: 80 ± 19 particles/kg (Klak River forest area) [2]	Rivers discharging into Gorgan Bay [2]
A. Manbohi et al., 2023	River bank sediments	214.08 ± 14.35 MPs/kg [8]	Maximum in downstream parts of Chalus, Haraz, and Safarud rivers [8]	26 sites in 13 rivers [8]
V. Taghipour et al. (n.d.)	Mesoplastics	Not specified	14-38 particles/kg dry weight [6]	Southern coasts [6]
V. Taghipour et al. (n.d.)	Microplastics	189.5 ± 71.21 particles/kg dry weight [6]	100-286 particles/kg dry weight [6]	Southern coasts, upper 3 cm sediment [6]

Sediment concentrations ranged widely from 13 MP/kg [1] to over 1000 particles/kg [2], with river estuaries generally showing higher concentrations than open coastal areas. Beach sediments (196.67 ± 11.58 MPs/kg) [3] contained approximately twice the concentration of offshore sediments (103.15 ± 7.21 MPs/kg) [3], indicating a clear nearshore-offshore gradient. Water concentrations were notably higher at 710 items/m³ [5] compared to sediment values.

Microplastic distribution across the Caspian Sea exhibited distinct regional patterns influenced by human activities and hydrodynamic factors.

One study documented a general decrease in microplastic concentrations from west to east along the southern coast [5], potentially reflecting the spreading of microplastic loading from the outlets of major rivers (Sefidrud, Tonekabon, Chalus) entering the Caspian Sea in the western region [5], combined with decreasing touristic and fishery activity toward the east [5].

Multiple studies identified negative microplastic gradients from nearshore to offshore areas. Beach sediments consistently showed higher concentrations than offshore locations [3], with most transects exhibiting concentration decreases moving seaward [3]. This pattern suggests that coastal sources (fishing, tourism, and rivers) are the primary contributors [3].

Rivers ending in the Caspian Sea showed positive microplastic gradients from upstream to downstream [8], with maximum concentrations occurring in the downstream portions of the Chalus, Haraz, and Safarud rivers [8]. This pattern indicates accumulation of microplastics as rivers flow toward the sea.

Several pollution hotspots were identified across studies:

- The Qarasu River estuary showed the highest concentration at 1080 ± 380 particles/kg [2], attributed to accumulation of fishing, boating, and tourism activities [2]
- The Astara station recorded 996 ± 55.07 items/kg [9], the highest concentration in that study
- River estuaries generally represented hotspots with a mean of 350.6 ± 232.6 MP/kg [4], exceeding concentrations in both recreational-tourist and non-tourist coastal areas [4]
- Areas near permanent river mouths and regions with higher fishing and tourism activity showed elevated concentrations [7]

Despite these general patterns, several studies noted patchy and irregular spatial distributions [1, 7]. One study found that contrary to previous reports, higher concentrations occurred in both west and east coast areas [6], and no significant correlation existed between distance from coastline and microplastic concentration on the southern coast [6]. This suggests that environmental conditions (sediment type, hydrodynamic conditions, proximity to pollution sources) play more important roles than simple distance relationships [6].

Limited information was available on depth-related patterns of microplastic distribution in the Caspian Sea water column. Most studies focused on sediments rather than vertical water column profiles.

For sediment sampling, studies examined different sediment depths:

- Surface sediments (0-5 cm depth) [1, 4] and deeper layers (5-15 cm) [1, 4] were sampled in multiple studies
- The upper 3 cm surface layer was specifically targeted in one study [6]
- One study reported mean concentrations at 0-15 cm depth of 350.6 ± 232.6 MP/kg [4]

One study found negative microplastic gradients from nearshore to offshore [3], indicating that concentrations decrease with increasing water depth and distance from shore. However, no studies provided detailed vertical distribution patterns within the water column itself.

The dominant microplastic size in sediments was 250-500 μm [5], while in water samples, the fraction greater than 1000 μm dominated [5]. This size difference between compartments may reflect differential settling rates and transport mechanisms.

Microplastic Characteristics

Physical and chemical characteristics of microplastics in the Caspian Sea showed some consistency across studies but also notable variations.

Table 3 - Shape Distribution

Study	**Dominant shape**	**Secondary shapes**	**Percentage or description**
M. Nematollahi et al., 2020	Fiber [5]	Not specified	97% in both sediment and water [5]
A. Mehdinia et al., 2019	Fiber [7]	Not specified	Most common [7]
Mehdi Ghayebzadeh et al., 2020	Fragment [1]	Film	Fragment: 30.3%, Film: 18.7% [1]
A. Manbohi et al., 2021	Fiber [3]	Not specified	Most common shape [3]
T. Bagheri et al., 2020	Fiber [10]	Not specified	Prevalent [10]
Mehdi Ghayebzadeh et al., 2021	Fiber [4]	Foam	Fiber predominant, foam least prevalent [4]
Majid Rasta et al., 2021	Fiber [9]	Not specified	Dominant [9]

Study	Dominant shape	Secondary shapes	Percentage or description
Mohammad Gholizadeh et al., 2024	Fiber [2]	Not specified	68% [2]
A. Manbohi et al., 2023	Fragment/film [8]	Not specified	Most common [8]
V. Taghipour et al. (n.d.)	Fiber [6]	Fragment, film	Fiber: 87.86% [6]

Fibers constituted the dominant microplastic shape in the vast majority of studies, representing 68-97% of particles [2, 5, 6]. One study found fragments to be most common at 30.3% [1], while another reported fragment/film as most prevalent [8].

Table 4 - Size Distribution

Study	Dominant size class	Size range	Additional details
M. Nematollahi et al., 2020	Sediment: 250-500 μm [5]	Water: >1000 μm [5]	Different size profiles in water vs sediment [5]
A. Mehdinia et al., 2019	250-500 μm [7]	Not specified	Single dominant size class [7]
T. Bagheri et al., 2020	1-2 mm [10]	Not specified	42.4% prevalence [10]
Majid Rasta et al., 2021	1000-2000 μm [9]	Not specified	Dominated by this class [9]
Mohammad Gholizadeh et al., 2024	<1000 μm [2]	Not specified	About 53% [2]
A. Manbohi et al., 2023	<300 μm [8]	Not specified	Most common [8]
V. Taghipour et al. (n.d.)	1.0-2.5 mm [6]	0.1-15 mm [6]	Size classes: 0.1-1.0 mm, 1.0-2.5 mm, 2.5-5.0 mm, >5 mm [6]

Size distributions varied considerably, with dominant classes ranging from less than 300 μm [8] to 1-2 mm [6, 9, 10]. This variation may reflect differences in sampling methods, source characteristics, or genuine spatial heterogeneity.

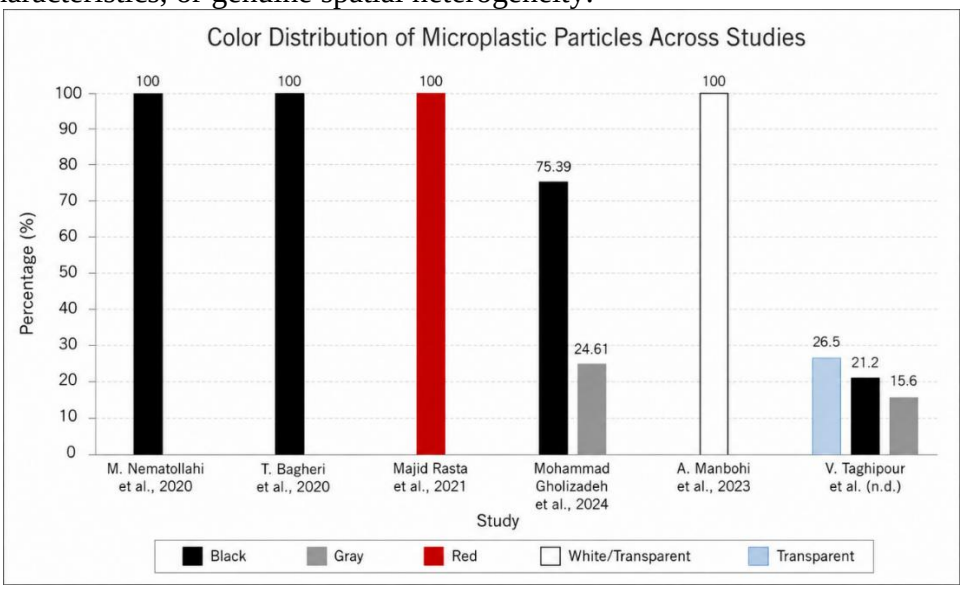


Figure 2 - Color Distribution

Color distributions showed considerable variation across studies. Black or dark colors (black, gray) were commonly reported [2, 5, 6, 10], comprising up to 75.39% of particles in

one study [2]. However, white/transparent colors were also frequently observed [6, 8], with transparent particles representing 26.5% in one study [6].

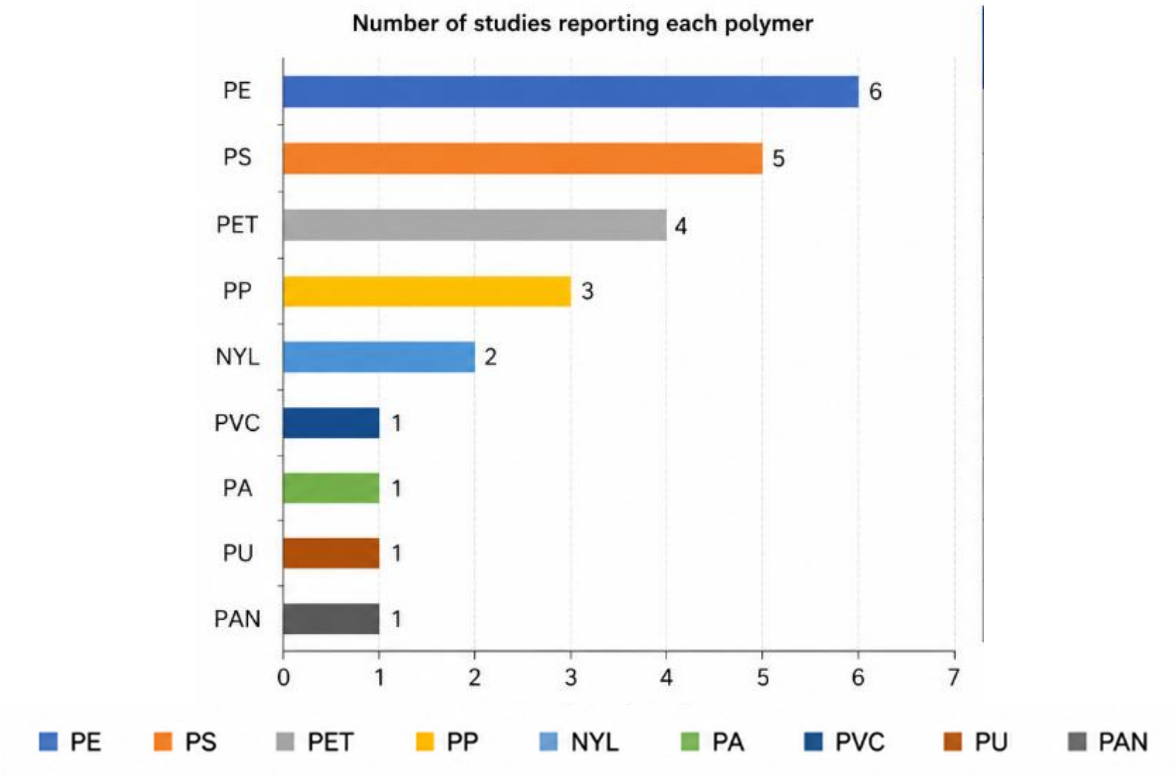


Figure 3 - Polymer Composition

Polymer composition varied across studies, with polyethylene (PE), polystyrene (PS), and polyethylene terephthalate (PET) being most frequently reported. PE appeared in six studies [1, 2, 4, 6, 7] and was the dominant polymer in several locations at 20-37% [1, 2, 4]. PS was identified as a major polymer in five studies [3, 5–8]. PET, polypropylene (PP), and nylon (NYL) were also commonly detected [1–3, 5, 6, 9].

Discussion

Only one study reported surface characteristics of microplastics in the Caspian Sea, describing particles with relatively smooth surfaces and visible signs of weathering [5]. Overall, the reviewed studies indicate that microplastic pollution in the southern Caspian Sea is driven by multiple anthropogenic sources and transport pathways. Rivers appear to be the dominant input route. Higher concentrations were reported near permanent river mouths [7], while major rivers such as the Sefidrud, Tonekabon, and Chalus were associated with increased microplastic loading in the western part of the sea [5]. Estuarine areas showed mean concentrations of 350.6 ± 232.6 MP/kg [4], which were higher than those observed in recreational-tourist and non-tourist coastal zones [4]. A downstream increase in microplastic abundance was also reported in river systems, suggesting progressive accumulation as rivers approach the sea [8]. In Gorgan Bay, rivers entering the system carried concentrations ranging from 80 ± 19 to 1080 ± 380 particles/kg [2]. The spatial decline in concentrations from west to east along the southern coast is consistent with the distribution of major river outlets [5].

Tourism and recreational pressure also contribute to microplastic contamination. Areas with more intensive tourism activity generally showed higher concentrations [7], and recreational-tourism and fishing activities were positively associated with microplastic abundance in rivers [8]. The Qarasu River estuary, which recorded the highest concentration

reported in the reviewed studies at 1080 ± 380 particles/kg [2], was linked to accumulation from tourism-related activities [2]. Fishing is another relevant source. Coastal fishing was identified as an important contributor, especially in areas showing decreasing concentrations from nearshore to offshore waters [3]. Fishing activity was positively correlated with microplastic levels [8], and it was also considered one of the factors affecting the high contamination observed in the Qarasu River estuary [2]. Seasonal hydrological conditions may further intensify these inputs, as higher winter water levels were reported to facilitate microplastic transport from fishing-related sources [9].

Urban and industrial activities add to the burden, although their contributions are less precisely quantified. Domestic wastewater discharges from densely populated areas contribute to local emissions [5], and urban runoff has been identified as a source in highly urbanized coastal zones [1, 5]. Urbanization was among the anthropogenic factors associated with microplastic abundance in sediments [1]. Industrial activity was also mentioned as a contributor, but available studies provide limited quantitative evidence [1, 5]. Transport and accumulation are controlled mainly by rivers and coastal circulation. Rivers carry microplastics from catchments to the sea [4, 8], while west-to-east surface currents help redistribute particles along the coast [1]. The enclosed nature of the Caspian Sea likely promotes retention and accumulation [1]. Sediment properties also matter, with coarse-grained sandy sediments showing greater capacity to store microplastics [2]. Taken together, the available evidence confirms widespread microplastic contamination across the southern Caspian Sea, although reported concentrations vary by more than an order of magnitude, from 13 to over 1000 particles/kg in sediments. This variation likely reflects both true spatial heterogeneity and methodological differences among studies.

The wide range in reported concentrations can be explained by several factors:

*Compartment-specific patterns***:** Beach sediments (196.67 ± 11.58 MPs/kg) [3] consistently showed approximately double the concentration of offshore sediments (103.15 ± 7.21 MPs/kg) [3], indicating that measurements closer to shore naturally yield higher values. Water concentrations (710 items/m³) [5] cannot be directly compared to sediment values due to different units and sampling matrices.

*Proximity to sources***:** The highest concentrations occurred in river estuaries (mean 350.6 ± 232.6 MP/kg) [4] and areas with intensive human activities. The Qarasu River estuary reached 1080 ± 380 particles/kg [2] specifically due to concentrated fishing, boating, and tourism [2], while the forested Klak River area showed only 80 ± 19 particles/kg [2]. Similarly, the Astara station's elevated concentration of 996 ± 55.07 items/kg [9] reflects urban and fishing pressures in that location. These patterns suggest that studies sampling near pollution sources will inevitably report higher concentrations than those in relatively pristine areas.

*Methodological differences***:** Only one study provided full methodological details [6], while most relied solely on abstracts. Detection methods varied from visual microscopy [9] to combinations of FTIR and SEM analysis [1, 2, 4, 6, 7]. Size thresholds differed substantially, ranging from <300 μm [8] to <5 mm [6], which would directly affect particle counts. Density separation techniques also varied, with one study using NaCl at 1.2 g/cm³ [9] and another using $ZnCl_2$ [6], potentially recovering different polymer types.

While most studies found decreasing concentrations from west to east [5] and from nearshore to offshore [3], one study reported no correlation between distance from coastline and microplastic concentration [6], with higher concentrations appearing in both west and east areas contrary to previous reports [6]. This apparent contradiction resolves when considering

that environmental factors (sediment type, hydrodynamic conditions, proximity to specific pollution sources) override simple distance relationships [6]. The general west-to-east decrease reflects the cumulative influence of major western rivers [5], but localized sources can create hotspots throughout the region, as evidenced by the eastern Qarasu River estuary's extreme concentration of 1080 ± 380 particles/kg [2].

Source Attribution Confidence

Multiple lines of evidence converge on rivers, tourism, and fishing as primary sources:

- Spatial correlations show higher concentrations near river mouths [7] and positive upstream-downstream gradients in rivers [8]
- Temporal patterns indicate increased concentrations during high water periods when river transport is enhanced [9]
- Activity-based correlations demonstrate significant positive relationships between tourism/fishing intensity and microplastic abundance [8]

Polymer composition provides less direct evidence for source identification. The predominance of polyethylene (PE), polystyrene (PS), and polyethylene terephthalate (PET) [1, 3, 7] may reflect inputs from packaging materials, household waste, textiles, fishing equipment, and other consumer products. Fibers were the dominant particle type in most studies, accounting for 68-97% of detected microplastics [2, 5, 6], which points to textile-derived emissions and degradation of fishing gear as likely sources. However, one study reported fragments as the dominant form, representing 30.3% of particles [1]. This discrepancy may be related to local pollution sources, hydrodynamic conditions, or differences in sampling and analytical protocols.

A major limitation in the current literature is the absence of detailed water-column profiling. Most studies focused either on surface waters [5] or bottom sediments [1, 4, 9], while vertical distribution patterns within the water column remain poorly understood. Evidence from one study showed that larger particles (>1000 μm) were more common in water samples, whereas smaller particles (250-500 μm) dominated in sediments [5], suggesting size-dependent settling processes. However, no study systematically evaluated variations in microplastic concentration across different water depths. Future investigations should incorporate depth-stratified sampling to improve understanding of vertical transport processes, particle residence times, and sedimentation dynamics in the Caspian Sea.

Conclusion

Microplastic pollution in the southern Caspian Sea shows nearshore-to-offshore and west-to-east decreasing gradients with river estuaries as hotspots, driven primarily by riverine transport, tourism, and fishing, though the northern, eastern, and western regions and water column depth profiles remain unstudied. available evidence shows that microplastic contamination in the southern Caspian Sea is spatially heterogeneous, with river estuaries, coastal beaches, and human-impacted nearshore areas acting as major accumulation zones. Riverine inputs, tourism, and fishing are the most consistent drivers of pollution, while differences in sampling design and analytical methods contribute to the wide variation in reported concentrations. Despite these findings, current knowledge is restricted to the southern Iranian coast, and the central, northern, eastern, and western parts of the basin remain insufficiently characterized. In addition, almost no study has examined the vertical distribution of microplastics in the water column, which prevents a full understanding of transport, settling, and retention processes. Future research should therefore adopt standardized protocols, include depth-stratified sampling, and extend coverage across the entire Caspian basin to support more reliable environmental assessment and management.

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Сейдалиева Л.К., Тайжанова Л.С.

ЭКОЛОГИЧЕСКАЯ ОЦЕНКА ЗАГРЯЗНЕНИЯ МИКРОПЛАСТИКОМ АКВАТОРИИ КАСПИЙСКОГО МОРЯ

Аннотация. Загрязнение микропластиком стало устойчивой экологической проблемой Каспийского моря, однако имеющиеся данные остаются географически фрагментированными и методологически несопоставимыми. В данном исследовании был проведён систематический обзор рецензируемых научных работ о загрязнении Каспийского моря микропластиком с использованием PRISMA-методологии. Поиск в базах Scopus, Web of Science и Google Scholar позволил выявить 50 потенциально релевантных публикаций, из которых 10 исследований соответствовали критериям включения. Все включённые исследования были проведены в южной части Каспийского моря, главным образом в прибрежных водах Ирана, и в основном были сосредоточены на донных отложениях, тогда как водная толща и биота изучались ограниченно. Сообщаемые концентрации

микропластика существенно различались: в донных отложениях они варьировали от 13 до более чем 1000 частиц/кг, при этом более высокие значения устойчиво отмечались в устьях рек, прибрежных пляжных отложениях и прибрежной зоне по сравнению с удалёнными акваториями. В большинстве исследований наблюдалось общее снижение концентраций с запада на восток вдоль южного берега, а также градиент от прибрежной зоны к открытой акватории, хотя локальные очаги загрязнения встречались часто. Доминирующей формой частиц были волокна, а наиболее часто выявляемыми полимерами — полиэтилен, полистирол, полиэтилентерефталат и полипропилен. Полученные данные указывают на реки, туризм, рыболовство и городской сток как на основные источники и пути переноса. Однако северный, восточный и западный секторы Каспийского моря остаются неизученными, а вертикальное распределение в водной толще по-прежнему практически неизвестно. Эти пробелы ограничивают оценку состояния бассейна в целом и обосновывают необходимость стандартизированного, глубинно-дифференцированного и географически расширенного мониторинга.

Ключевые слова: микропластик; макропластик; артефакт; рыболовные сети; загрязнение; микропластики; морское загрязнение; экологическая оценка; Каспийское море; казахстанский сектор; донные отложения; водная среда.

Сейдалиева Л.К., Тайжанова Л.С.

КАСПИЙ ТЕҢІЗІ АКВАТОРИЯСЫНДАҒЫ МИКРОПЛАСТИКАЛЫҚ ЛАСТАНУДЫ ЭКОЛОГИЯЛЫҚ БАҒАЛАУ

Аңдатпа. Микропластикпен ластану Каспий теңізі үшін тұрақты экологиялық мәселеға айналды, алайда қолда бар деректер географиялық тұрғыдан шашыраңқы және әдіснамалық жағынан біркелкі емес болып отыр. Бұл зерттеуде PRISMA тәсілін қолдана отырып, Каспий теңізіндегі микропластикпен ластану туралы рецензияланған ғылыми еңбектерге жүйелі шолу жүргізілді. Scopus, Web of Science және Google Scholar дерекқорларындағы іздеу нәтижесінде 50 ықтимал сәйкес жазба анықталды, олардың 10 зерттеуі ғана іріктеу критерийлеріне сай келді. Іріктелген барлық зерттеулер Каспий теңізінің оңтүстік бөлігінде, негізінен Иранның жағалаулық суларында жүргізілген және көбіне түптік шөгінділерге бағытталған, ал су бағаны мен биотаға қатысты бағалау шектеулі болды. Микропластик концентрациясы айтарлықтай өзгеріп отырды: шөгінділерде ол 13-тен 1000-нан астам бөлшек/кг аралығында болды, әрі ең жоғары мәндер өзен сағаларында, жағажай шөгінділерінде және жағалауға жақын аймақтарда ашық акваторияға қарағанда тұрақты түрде жоғары болды. Көптеген зерттеулерде оңтүстік жағалау бойымен батыстан шығысқа қарай жалпы төмендеу үрдісі және жағалаудан теңіз ішіне қарай азаю градиенті байқалды, дегенмен жергілікті ластану ошақтары жиі кездескен. Бөлшектердің басым пішіні талшықтар болды, ал ең жиі анықталған полимерлер — полиэтилен, полистирол, полиэтилентерефталат және полипропилен. Деректер өзендерді, туризмді, балық аулауды және қалалық ағын суларды негізгі көздер мен тасымал жолдары ретінде көрсетеді. Алайда Каспий теңізінің солтүстік, шығыс және батыс секторлары әлі де зерттелмеген, ал су бағанындағы тік таралуы іс жүзінде белгісіз күйде қалып отыр. Бұл олқылықтар бассейн деңгейінде толық бағалау жүргізуге кедергі келтіреді және стандартталған, тереңдік бойынша жіктелген әрі географиялық тұрғыдан кеңейтілген мониторингтің қажеттігін көрсетеді.

Кілт сөздер: микропластик; макропластик; артефакт; балық аулау торлары; ластану; микропластиктер; теңіз ластануы; экологиялық бағалау; Каспий теңізі; Қазақстан секторы; түптік шөгінділер; су ортасы.