

# Spatial Analysis of Microbiological Behavior in Sub-Tropical Coastal Wetlands

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This study examines the spatial interactions between microbiological indicators and environmental factors, including water flow characteristics, in the coastal wetlands of Chabahar Bay, Iran, to assess ecological risks and guide conservation strategies. The objectives are to quantify Total Coliforms (TCs) and Fecal Coliforms (FCs) at six sampling stations and identify key environmental drivers of microbial proliferation through qualitative analysis. Field sampling was conducted over three days in October 2018 at six stations along a river feeding Chabahar's coastal wetland. Water samples were collected during low tide. In-situ measurements of temperature, pH, humidity, and electrical conductivity were recorded. Microbiological analyses quantified total and fecal coliforms using the Most Probable Number (MPN) method. Total Organic Carbon (TOC) was measured using standard laboratory procedures, and Total Organic Matter (TOM) was determined by the loss-on-ignition method. Duplicate samples ensured data reliability, and data normality was tested with the Kolmogorov-Smirnov test. Descriptive statistics, graphical methods, and matrix analysis assessed relationships between TCs, FCs, temperature, pH, EC, TOC, and TOM. TC counts peaked at S2 (1500 MPN/100 ml), exceeding Iranian Class 2 water quality standards (1500 MPN/100 ml), with FCs detected only at S2 (900 MPN/100 ml) and S3 (23 MPN/100 ml). Temperature ranged from 30.6°C (S6) to 35.9°C (S1), showing an inverse relationship with coliform levels. EC ranged from 1900 to 24,610  $\mu\text{S}/\text{cm}$ , displaying a strong inverse correlation with TCs and FCs due to salinity-induced osmotic stress. TOC and TOM peaked at S3–S4 (TOC: 2.8–3.2%; TOM: 5.1–6.0%), correlating inversely with TCs and FCs, suggesting microbial competition. pH (7.71–8.06) showed no significant correlation with coliform levels. Matrix analysis confirmed a high correlation between total and fecal coliforms ( $p < 0.05$ ), with temperature and pH as independent factors. Sewage inputs at S2 drive significant microbial contamination, with coarse sediments and optimal temperatures facilitating coliform proliferation, while high EC and organic matter in mangrove zones (S3–S4) reduce coliform levels through osmotic stress and microbial competition. Mangroves at S4–S5 act as effective biofilters, mitigating contamination. These findings underscore the need for targeted sewage control and mangrove conservation to protect Chabahar Bay's wetlands from ecological risks. Future research should examine seasonal variations and additional pollutants to improve management strategies.

## KEYWORDS

- ~ Microbial indicators
- ~ Coastal wetlands
- ~ Spatial analysis
- ~ Water quality

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## 1. INTRODUCTION

The contamination of coastal and marine sediments and waters is an urgent global challenge, given its extensive repercussions for ecological integrity and public health (Rangel-Buitrago et al., 2023). Coastal wetlands worldwide have been deteriorating for decades, driven by economic development, urbanization, and the expansion of industrial zones (Luo et al., 2025; Vishnu Sagar et al., 2025).

Microbiological indicators, such as total and fecal coliforms, are widely used to assess water and sediment quality, reflecting the presence of fecal contamination and potential health risks (Garrido-Pérez et al., 2008; Partani, Taherian, et al., 2024; Rodrigues & Cunha, 2017). These indicators are influenced by environmental factors, including sediment texture, water flow, and pollutant loads (Garrido-Pérez et al., 2008). Coarse-grained sediments, for example, provide interstitial spaces that enhance microbial growth by facilitating nutrient and oxygen availability. Heavy metals, often introduced through industrial activities, can also alter microbial communities and ecosystem health (Jahani et al., 2025; Partani, Danandeh Mehr, et al., 2024). When pollutants are transported and accumulate in sediments, they ultimately harm the coastal environment (Çelebi et al., 2024). Understanding these interactions is critical for developing effective conservation strategies for coastal wetlands (Yang et al., 2022).

Several studies have emphasized the microbiological vulnerability of aquatic systems to the impacts of climate change and microbial contamination from improper wastewater and waste disposal (Reinold et al., 2019; Yang et al., 2022). Significant microbial contamination was recorded in Grogan Bay of the Caspian Sea, with increased coliform levels attributed to domestic sewage flow (Shahryari & Safari, 2020). Similarly, Khatib Haghighi and Khoda Parast highlighted the seasonal variability of microbial loads in Anzali Wetland, finding higher concentrations during warmer periods due to intensified bacterial activity (Khatib Haghighi & Khodaparast, 2012). Internationally, moderate to severe bacterial contamination was found in India's Sukhna Lake, underscoring the influence of urban runoff and recreational activities on microbial water quality (Jyoti Dadwal & Kumar, 2014). The dynamics of non-point source pollution in the Sapanca Lake basin, Turkey, were investigated by Serkan Ozdemir et al. in 2025, with the highest nutrient loads attributed to urban environments, leaching from cultivated lands, livestock contributions, and tourism facilities (Ozdemir et al., 2025). Kora et al. assessed Hussain Sagar Lake, India, reporting high coliform and *E. coli* levels due to sewage inflows, alongside antibiotic-resistant bacteria, posing significant public health risks (Kora et al., 2017). Rawal et al. examined Fateh Sagar Lake, India, finding bacteriological and physicochemical parameters exceeding WHO standards, indicating severe pollution (Rawal et al., 2018). In Egypt, Sabae et al. documented seasonal and spatial variations in microbial and physicochemical parameters in the El-Bahr El-Pherony waterway, attributing high fecal coliform counts to sewage discharge (Sabae et al., 2014). Eliku and Sulaiman studied drinking water quality in Adama, Ethiopia, reporting widespread coliform contamination in piped and household systems, underscoring the need for improved water treatment (Eliku & Sulaiman, 2015).

The Chabahar coastal wetlands, with their semi-tropical climate, rich biodiversity, and increasing anthropogenic pressures, represent an ideal natural laboratory for addressing this gap. This study addresses the research question: How do microbiological indicators in Chabahar Bay's wetland interact with water flow characteristics? We hypothesize that water flow influences pollutant retention and microbial distribution. The objectives are to measure microbiological indicators (total and fecal coliforms) across six sampling stations and identify key factors driving ecological impacts. This research contributes to the literature on coastal wetland management by integrating microbiological and physical aspects, offering insights for policymakers and environmental managers.

## 2. MATERIALS AND METHODS

### 2.1. Study Area

The research area is located at 25°24' N latitude and 60°36' E longitude in southeastern Iran, along the Makran coast and the northern part of the Oman Sea. Figure 1 shows the study area. Key environmental concerns in this industrial and free zone include (a) industrial shipping activities, (b) the presence of a petrochemical facility and steel plant (PARTANI et al., 2024), (c) the discharge of domestic wastewater into the marine ecosystem, and (d) large-scale desalination operations. The region receives an average annual rainfall of 117 mm, with significant year-to-year fluctuations influenced by the Indian monsoon (Azmoodehfar & Azarmsa, 2013). Monthly evaporation rates are also provided. Tidal effects impact the area, which covers about 350 hectares, with some zones densely vegetated and others sparsely vegetated or barren. The study stretch extends 4,700 meters from the start of the vegetation to the entrance of Chabahar Bay, connected to the wetland by a 200-meter-long canal just beyond the vegetation line. This region is ecologically significant as a mangrove habitat (Alongi, 2014), supporting a diverse array of wildlife (Moradi & Moradi, 2020). It provides a critical environment for at least 107 fish species (EAGDERI et al., 2019), including two endangered species, as well as six shrimp species, ten crab species, five eel species, and one marine mammal species (EAGDERI et al., 2019; Mehanna et al., 2012). Therefore,

assessing microbiological water and sediment quality in this biodiverse region is essential for identifying potential risks to human health and rare species through food chain contamination.

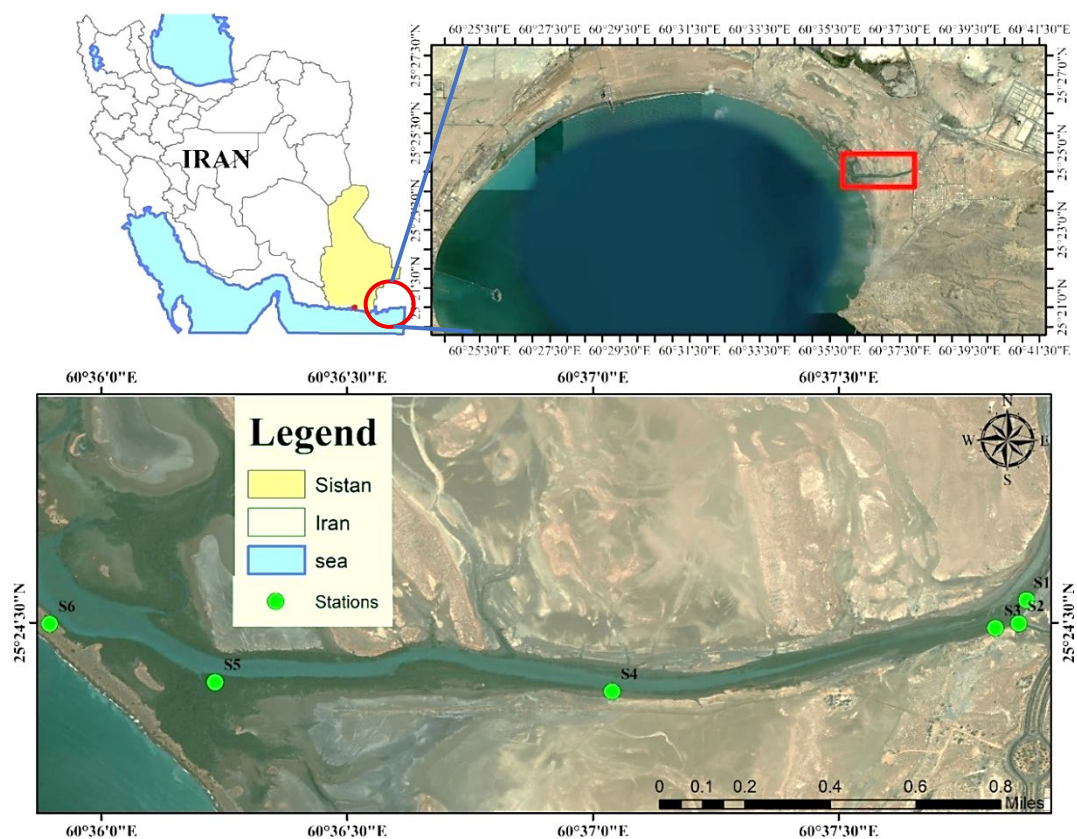


Figure 1. A schematic overview of our study area and the location of taken samples.

## 2.2. Sampling

Field sampling was conducted over three days in October 2018 (12–14 October) at six stations (S1–S6) along a river that feeds into the Chabahar coastal wetland. Stations were chosen based on topographic features, tidal influence, and proximity to pollution sources. Table 1 shows the locations of the sampling stations. Sampling took place during low tide to ensure consistent water levels, with coordinates recorded using a handheld GPS (Garmin eTrex 20). Water samples were collected during low tide to standardize conditions. Water samples (500 mL) were collected in sterile polyethylene bottles and immediately placed in coolers with dry ice for transport (Agency, 2021; Berger, 1991). In-situ parameters (temperature, pH, humidity) were measured with a multiparameter probe (YSI ProDSS) and a hygrometer (Extech RH101).

Stations	Distance from the starting area	Locations
S1	0	100 m before connecting sewer canal
Discharge (S2)	100	Drainage outflow receiving industrial sewage
S3	300	100 m after connecting the sewage canal to the industrial city
S4	1650	Beginning of the connected and massive cover
S5	2720	Mature zone of mangrove habitat
S6	3500	1200 meters before connecting to the sea

Table 1. Location of sampling stations

## 2.3. Measurement methods

Microbiological analyses targeted total coliforms and fecal coliforms, quantified using the Most Probable Number (MPN) method per Standard Methods 11166 and 2946 (Association, 1926; Simmons, 2014). Total Organic Carbon (TOC)

and Total Organic Matter (TOM) were determined using a TOC analyzer (Shimadzu TOC-L) and loss-on-ignition method, respectively.

## 2.4. Quality Assurance and Quality Control (QA/QC)

To ensure data reliability, duplicate samples were collected at each station and stored separately. Two stations' samples were re-analyzed in the laboratory to verify consistency. Data normality was tested using a Kolmogorov-Smirnov test, and analytical precision was maintained within  $\pm 5\%$  for microbiological (Ghafar & El-Masry, 2021; Klesta & Bartz, 1996; Whitney et al., 1998).

## 2.5. Data Analysis

Data were analyzed using descriptive statistics and graphical methods. Spatial variations in microbiological indices were visualized through plots of coliform counts, temperature, pH, and organic matter. Relationships between variables were assessed qualitatively, focusing on trends and inverse correlations. All measurements calibration standards and blanks were used for all instrumental analyses. Figure 2, shows the methodological flowchart process.

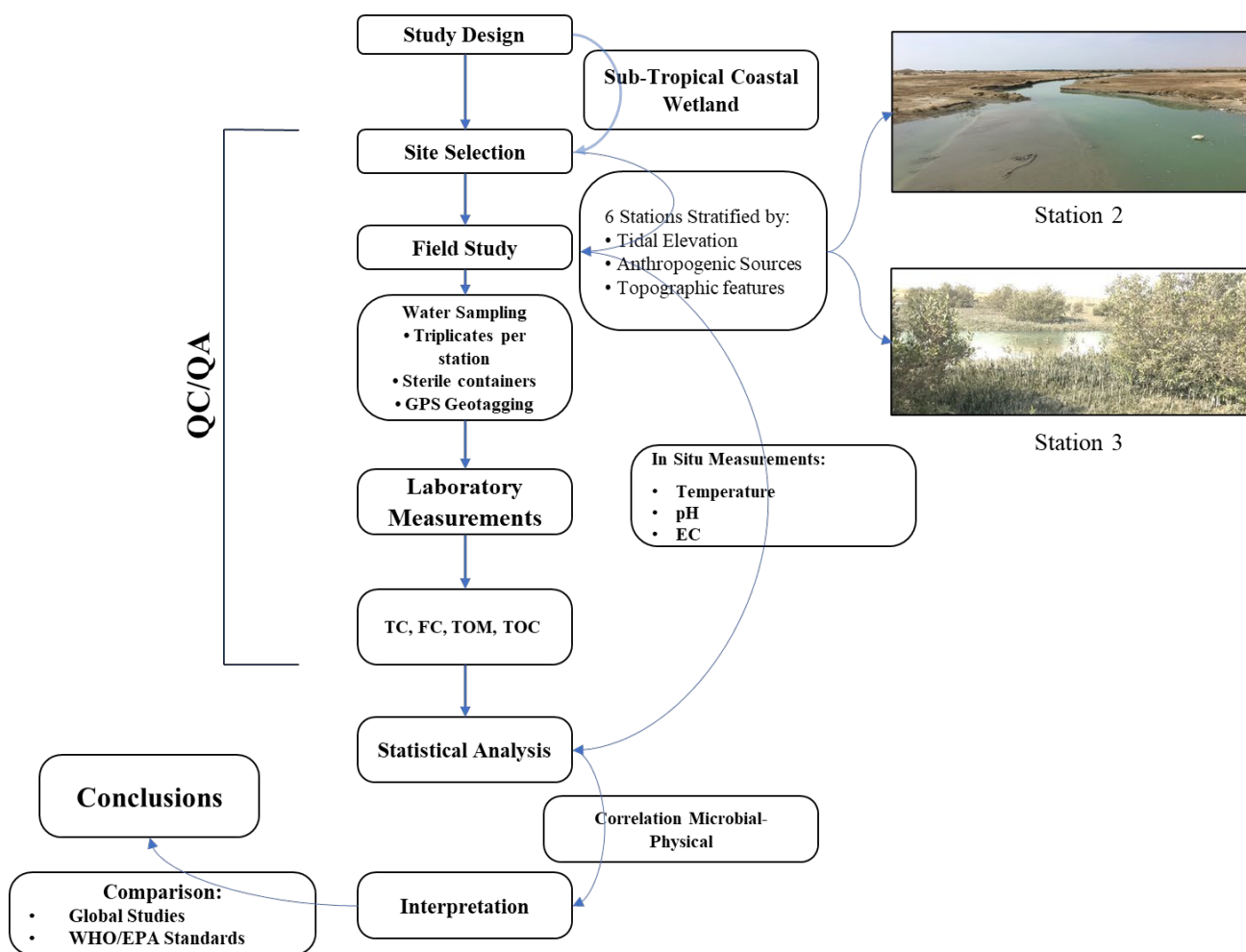


Figure 2. The flowchart of the workflows in this study

## 3. RESULTS AND DISCUSSION

### 3.1. Overview of Environmental Parameters

Total coliforms (TCs) counts (Table 2) were highest at S2 (1500 MPN/100 ml), the sewage-influenced station, and undetectable at S1 and S6. Fecal coliforms (FCs) were present only at S2 (900 MPN/100 ml) and S3 (23 MPN/100 ml), indicating localized contamination from human or animal waste. Compared to Iranian Class 2 water quality standards (1500 MPN/100 ml for total coliforms, 900 MPN/100 ml for fecal coliforms), S2 exceeded permissible limits, posing risks to ecological and human health. The decline in TCs and FCs from S2 to S6 reflects dilution, mangrove filtration, and tidal flushing, consistent with findings from other coastal wetlands (KHATIB et al., 2008; Partani, Danandeh Mehr, et al., 2024).

Stations	Total Coliform (MPN/100ml)	Fecal Coliform (MPN/100ml)	TOC (ppm)	TOM (ppm)	EC (µs/cm)
S1	0	0	0.47	0.84	1900
D(S2)	1500	900	0.156	0.28	7900
S3	930	23	0.331	0.59	8100
S4	1200	0	0.682	1.22	12063
S5	900	0	0.273	0.49	14197
S6	0	0	0.312	0.56	24610

Table 2. Results of variable values at all stations for water environments

Mangrove forests act as natural buffers, restoring the ecosystem from pollutants (Alongi, 2014; Deng et al., 2026; Partani, Danandeh Mehr, et al., 2024). They improve water quality by trapping and breaking down pollutants, including heavy metals, pesticides, nutrients (Howarth et al., 2011), and coliforms (Akram et al., 2023; Alongi, 2014; Deng et al., 2026; Mack et al., 2024). The absence of TCs and FCs at S1 suggests minimal upstream contamination, while their absence at S6 indicates effective natural purification by the wetland. Mangroves at S4 and S5 likely played a critical role in reducing coliform and other pollutant levels (Partani, Danandeh Mehr, et al., 2024) through physical trapping and microbial degradation, as observed in similar ecosystems. However, the presence of fecal coliforms at S2 and S3 highlights the need for targeted pollution control, as these indicators signal potential pathogenic risks (Bitton, 2005). The concentration of these bacteria can be seen in the spatial zoning map in Figure 3. Station 2 exhibited the highest levels of fecal and total coliforms (FCs/TCs), consistent with its role as the primary input point for industrial and agricultural wastewater. As S2 receives substantial untreated domestic and industrial effluent, it cannot function as a stabilization or transfer zone; the organic and fecal load likely exceeds the system's natural assimilative capacity. Therefore, with respect to Station 2, the removal efficiency of microbial and chemical pollutants in wetland systems is largely dependent on input load, which is consistent with previous studies (Ali et al., 2024; Jahani et al., 2025; Msaki et al., 2023; Vymazal, 2010; Vymazal et al., 2010). Thus, stringent control and conservation measures are recommended to mitigate excessive pollution.

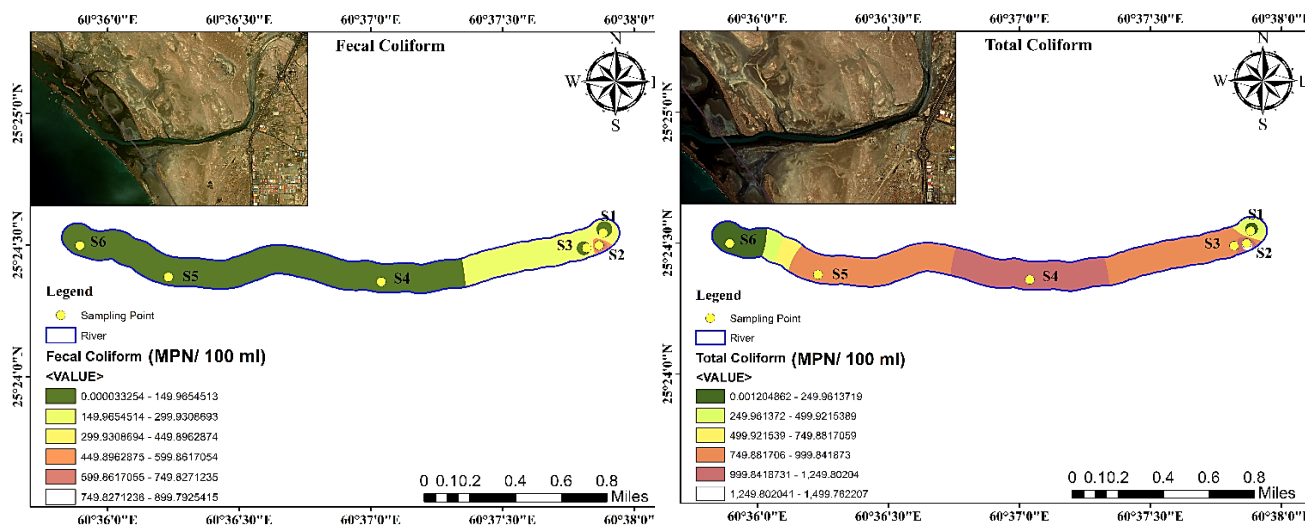


Figure 3. spatial trend map for Fecal Coliform, Total Coliform in study area (unit: MPN/100 ml)

Spanning approximately 350 hectares, the wetland's water quality and microbiological profile are impacted not only by point-source industrial discharges but also by non-point pollution from the wider catchment. A primary contributor is agricultural runoff, which enters the system through surface and subsurface flow, directly affecting nutrient availability, microbial community structure, and overall water quality. This observation is consistent with extensive literature that identifies diffuse nitrogen loading from agricultural areas as a major factor in nutrient enrichment and associated ecological alterations in wetlands and coastal zones (Galloway, 2003; Grizzetti et al., 2011; Gu et al., 2011; Juncal et al., 2023; Partani, Danandeh Mehr, et al., 2024; Van Stempvoort et al., 2023). Relative humidity increased from 51% at S1 to 89% at S5, driven by proximity to open water and dense mangrove cover (Table 3). High humidity likely maintained moist sediment conditions, enhancing microbial survival. These gradients underscore the role of microclimatic conditions in shaping microbial dynamics, particularly in vegetated zones.

Stations	Humidity	Temperature (Air)	pH	Temperature (Water)	Discharge (m <sup>3</sup> /s)
S1	51%	35	7.71	35.9	<b>0.023</b>
D	53%	34.4	7.79	29.4	<b>0.522</b>
S3	54%	34.1	8.06	32.3	<b>0.660</b>
S4	64%	30.5	7.81	31.6	<b>0.999</b>
S5	89%	28.2	7.75	30.6	<b>1.388</b>
S6	79%	29	7.9	30.6	<b>1.618</b>

Table 3. Water quality measurements at Chabahar Mangrove site

## 3.2. Factors affecting microbiological indicators

### 3.2.1. Temperature

Water temperatures ranged from 30.6°C at station S6 to 35.9°C at S1, with air temperatures following a similar trend (29.4–35.9°C). Upstream stations (S1-S3) exhibited higher temperatures due to shallower water depths and greater exposure to sunlight, while downstream stations (S4-S6) were cooler, influenced by tidal inflows and mangrove shading. These temperatures fall within the optimal range for coliform growth (30-37°C), suggesting that thermal conditions supported microbial proliferation across all stations. However, the slight cooling downstream likely contributed to reduced microbial activity.

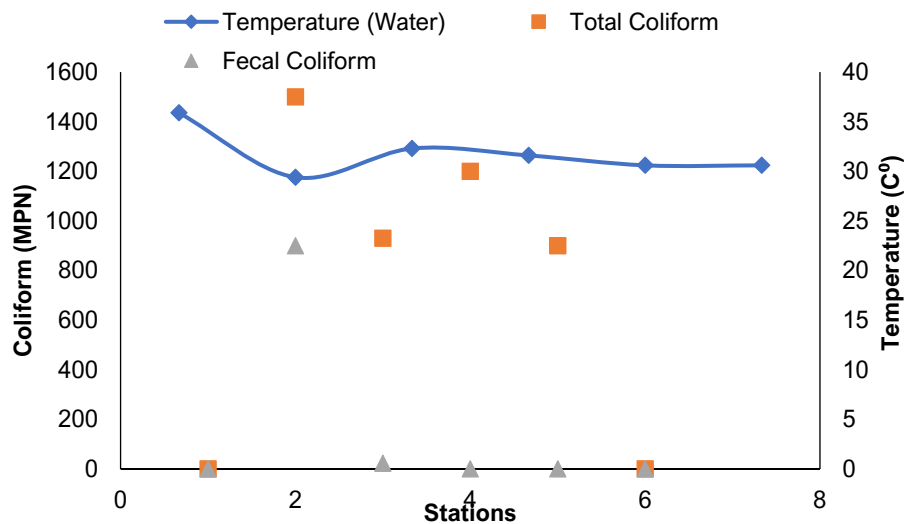


Figure 4. Changes in; Fecal coliform, Total coliform vs. water temperature at each station

Temperature exhibited an inverse relationship with total coliforms. At S2, where TCs and FCs peaked, water temperature was 29.4°C, slightly below the upstream maximum (35.9°C) (figure 4). Downstream cooling (29.4-31.6°C) coincided with reduced coliform counts, suggesting that temperature alone did not drive microbial proliferation. Instead, sewage inputs at S2 likely overwhelmed thermal effects, consistent with findings from tropical wetlands (Harwood et al., 2005). The optimal temperature range for TCs and FCs across all stations indicates that thermal conditions were permissive but not limiting.

### 3.2.2. pH

Water pH varied narrowly from 7.71 (S1) to 8.06 (S3). Both ranges align with Iranian standards for aquatic ecosystems (6.5–8.5) and are conducive to total and fecal coliform survival (Chapman, 2021). The slight alkalinity observed, particularly at S3, may reflect biological processes such as photosynthesis by mangroves and algae, which increase pH through CO<sub>2</sub> uptake (Wurts & Durborow, 1992). The stability of pH across stations (figure 5) suggests it was not a primary driver of microbial variability.

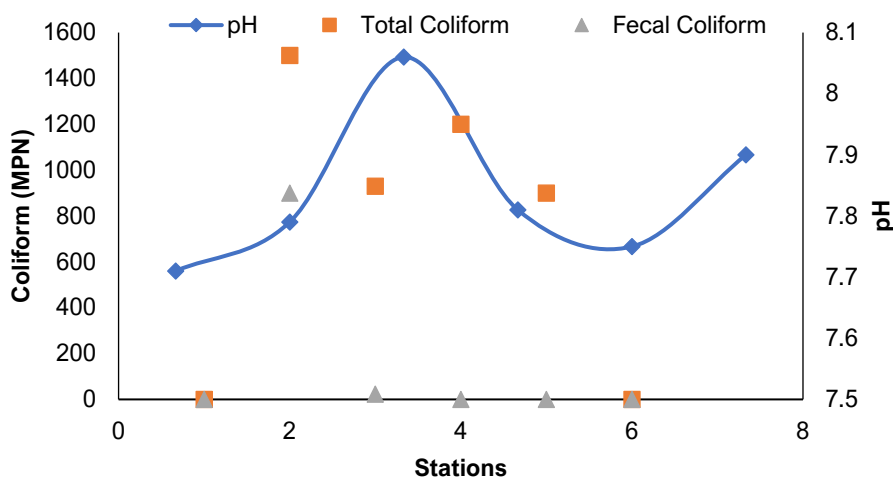


Figure 5. Changes in; Fecal coliform, Total coliform vs. pH at each station

The stable pH range (7.71–8.06) supported microbial growth but showed no strong correlation with coliform levels. The slight pH increases at S3 (8.06) coincided with lower TCs and FCs, possibly due to mangrove-driven alkalinity and enhanced microbial degradation (Wurts & Durborow, 1992). This suggests that pH played a secondary role compared to pollution inputs.

### 3.2.3. Organic Matter

Total Organic Carbon (TOC) and Total Organic Matter (TOM) peaked at S3 and S4 (TOC: 2.8–3.2%; TOM: 5.1–6.0%), corresponding to dense mangrove vegetation and slower water flow (Partani, Danandeh Mehr, et al., 2024). Lower levels were observed at S1 and S6 (TOC: 1.2–1.5%; TOM: 2.0–2.5%), reflecting higher flow velocities and tidal dilution. Organic matter serves as a nutrient source for microbes but can also bind pollutants, affecting microbial survival (Muturi et al., 2017).

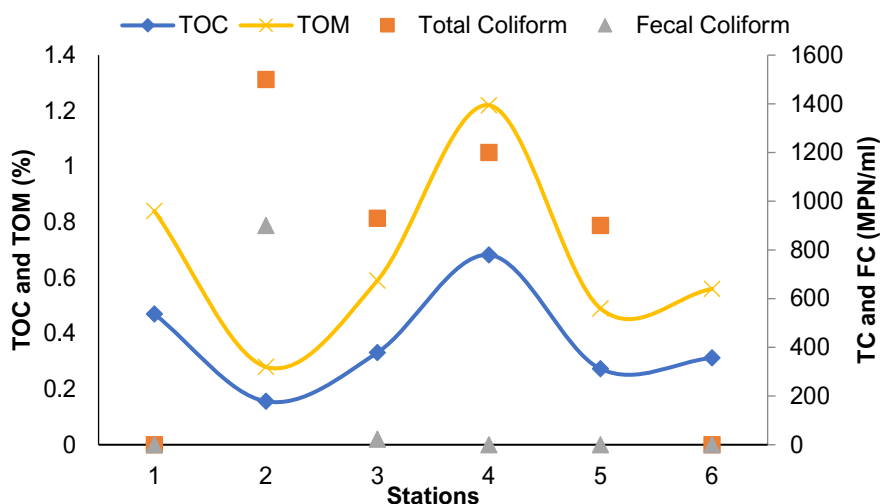


Figure 6. Changes in; Fecal coliform, Total coliform vs. Total Organic matter and Total Organic Carbon for at each station

High TOC and TOM at S3 and S4 corresponded to lower coliform counts, suggesting that organic matter supported microbial degradation rather than proliferation. This inverse relationship may reflect competition between TCs and FCs and other microbes in organic-rich environments, as observed in mangrove wetlands. Organic matter likely acted as a sink for pollutants, reducing coliform survival downstream. Figure 6 shows changes in FC and TC vs. TOM and TOC.

### 3.2.4. EC (Electrical Conductivity)

Electrical conductivity (EC) serves as an indicator for the concentration of conductive ions (salts) in water (Jodhani et al., 2025). Measured EC in this study ranged from 1900 to 24,610  $\mu\text{S}/\text{cm}$ . Numerous studies have established a significant

relationship between EC and microbial properties in water (Shahryari & Safari, 2020). As electrical conductivity in water increases, the level of indicator bacteria decreases. This decrease could be due to seawater properties such as osmotic pressure, tides, and toxicity of mineral salts, which negatively affect these bacteria (Karbasdehi et al., 2017). Figure 7 illustrates the relationship between Electrical Conductivity (EC) and TC concentrations measured across six sampling stations in a water body.

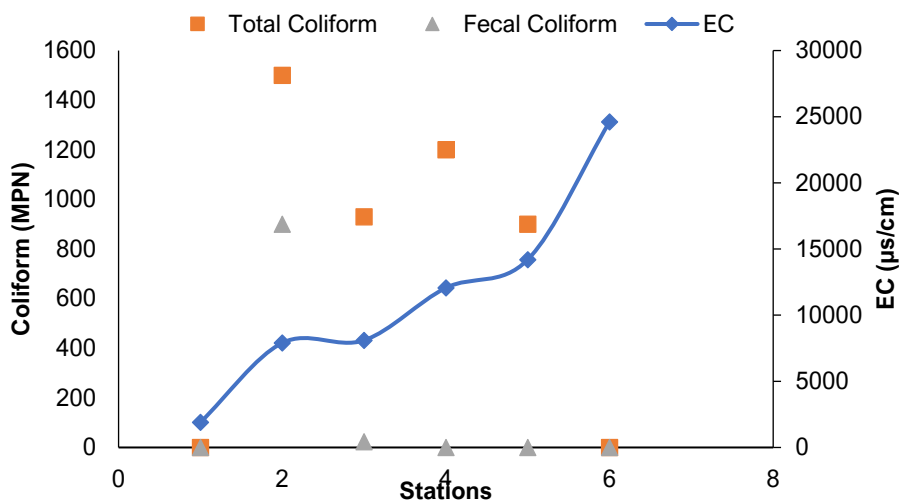


Figure 7. Changes in; Fecal coliform, Total coliform vs. Electrical Conductivity for at each station

The observed inverse relationship between EC and TC bacteria aligns with established principles in aquatic microbiology and water quality research. Elevated EC typically indicates high concentrations of dissolved ions (salts), which can exert osmotic stress on bacterial cells. This stress disrupts cellular functions, inhibits growth, and reduces survival rates of coliform bacteria (Anderson et al., 2005; Garzio-Hadzick et al., 2010).

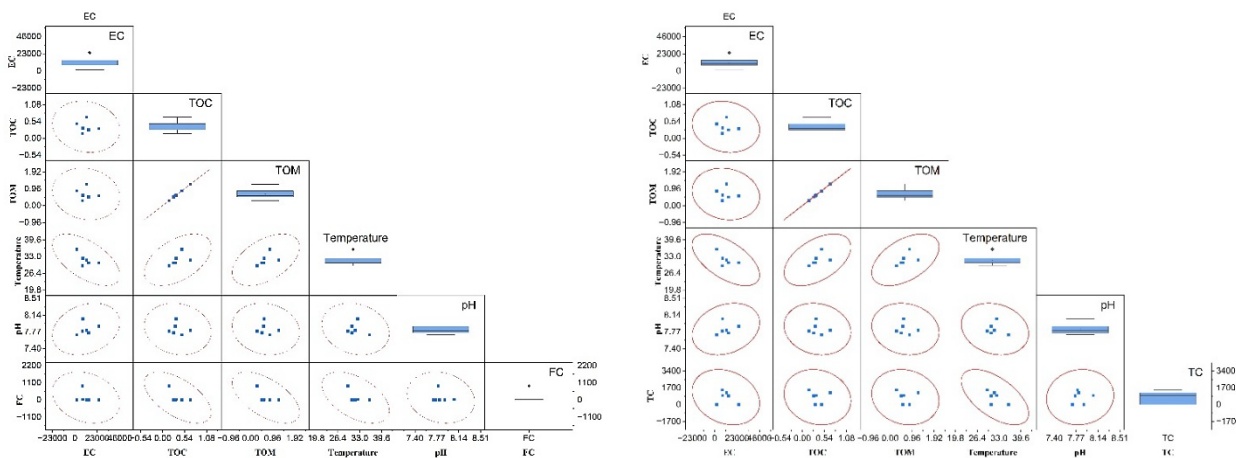


Figure 8. Matrix analysis of the relationship between microbial indicator with pH, TOM, TOC and temperature

In matrix water analysis (Figure 8), water temperature in the range of 29.6-31 has a moderate positive effect on FC growth, indicating accelerated microbial growth in warmer waters. In contrast, pH in the neutral range of 7.8-8.1 shows a weak relationship with FC, indicating a negligible effect of acidity fluctuations on the concentration of this pollution indicator. The dendrogram results show that the TC and FC variables are located in the same cluster, indicating a very high correlation between them. This result is in line with scientific expectations, since both are considered indicators of fecal contamination in water. On the other hand, pH, as a physicochemical variable, is located in an independent cluster, indicating that its behavior is not affected by microbial factors and is probably dependent on factors such as chemical compounds or acid precipitation. Finally, water temperature (temperature) has been identified as a completely independent variable that is probably affected by environmental factors such as seasonal changes and has a weak correlation with other variables.

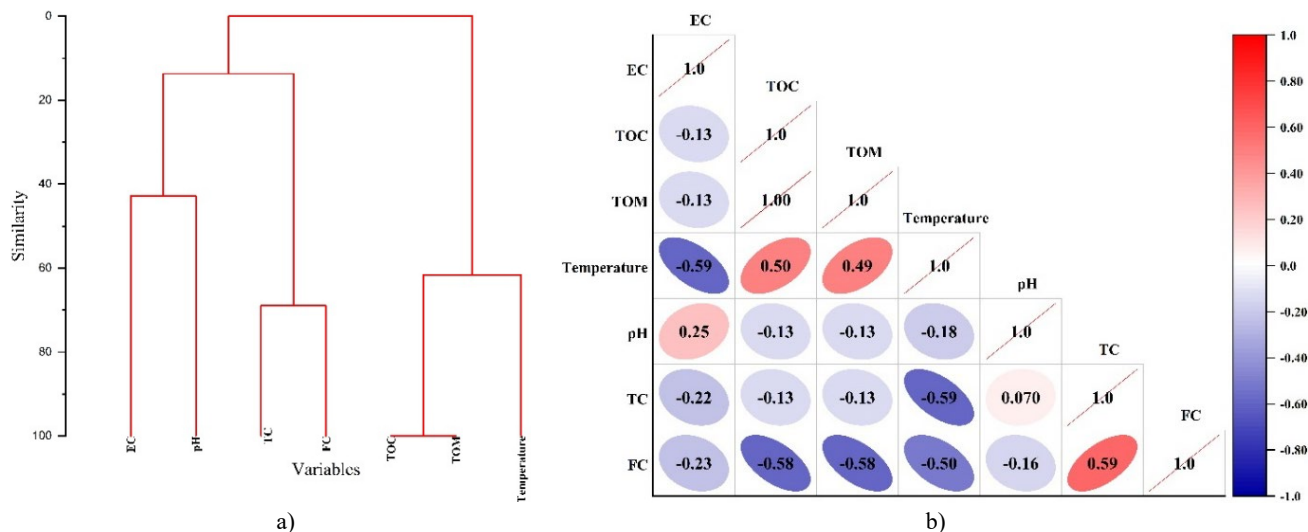


Fig. 9. Clustering analysis of water quality parameters

### 3.3. Ecological and Management Implications

The elevated TC and FC counts at S2 indicate significant sewage pollution, likely from industrial and domestic sources in the nearby estate. This contamination poses risks to aquatic life, as TCs and FCs signal potential pathogens that can disrupt food webs (Bitton, 2005). Mangroves at S4 and S5 effectively reduced TC and FC levels, highlighting their role as natural biofilters. However, their filtration capacity may be overwhelmed by persistent pollution, necessitating active management. Compared to other subtropical wetlands, such as those in the Persian Gulf (Noroozi Karbasdehi et al., 2015), Chabahar's microbial and chemical pollution levels are moderate but warrant concern due to the ecosystem's ecological and economic importance.

The inverse relationships between coliforms and factors like cadmium (Signorini et al., 2023) and organic matter (Nyieku et al., 2022) complex ecological interactions. For instance, high organic matter may foster microbial communities that outcompete coliforms, while cadmium's toxicity may suppress microbial growth. These dynamics highlight the need for integrated monitoring of microbiological and chemical parameters to assess wetland health comprehensively.

### 3.4. Comparison with Regional and Global Studies

The TC counts at S2 (1500 MPN/100ml) are lower than those reported in heavily polluted coastal systems, such as Gorgan Bay (5001 CFU/ml) (SHAHRIARI & GOL, 2008) or Hussain Sagar Lake (high *E. coli*) (Kora et al., 2017), but exceed levels in less impacted wetlands like Anzali (KHATIB et al., 2008). FCs at S2 (900 MPN/100ml) align with Persian Gulf swimming areas (165–540 MPN/100ml) (Noroozi Karbasdehi et al., 2015), indicating comparable sewage impacts.

Unlike studies focusing solely on water quality (Sabae & Mohamed, 2015). The mangrove-driven reduction in TCs and FCs aligns with findings from Hong Kong's Mai Po marshes (Sun et al., 1998), emphasizing the global importance of mangroves in wetland restoration. However, the persistent metal contamination in Chabahar suggests a need for stricter regulations compared to less industrialized wetlands.

Organization	Indicator	Aquatic Environment	Use Category	Standard Value (MPN/100 mL)	Reference
EPA	Fecal coliform	Rivers	Recreational (primary contact)	Geometric mean: $\leq 200$ Single sample: $\leq 400^1$	(Regulations et al., 1986)
EPA	Fecal coliform	Rivers/Wetlands	Irrigation (crops)	$\leq 1,000$ (for unrestricted irrigation) <sup>2</sup>	(EPA, 2012)
WHO	Fecal coliform	Rivers/Wetlands	Recreational (primary contact)	$\leq 100$ (single sample) <sup>4</sup>	(Organization, 2003)
			Irrigation (unrestricted)	$\leq 1,000$ (geometric mean)	(Organization, 2006)
WHO	Total Coliform	Rivers/Wetlands	General water quality	Not specified; use fecal indicators instead	(Edition, 2011)

<b>This Study</b>	Fecal coliform	S1	0
		S2	900
		S3	23
		S4	0
		S5	0
		S6	0
	Total Coliform	S1	0
		S2	1500
		S3	930
		S4	1200
		S5	900
		S6	0

Table 4 Comparison of TC and FC Concentrations in Water with International Standards

This comparative analysis reveals significant insights regarding measured coliform levels relative to established global standards. The study's FC measurements (0, 900, 23, 0, 0, 0 MPN/100 mL) show mixed compliance. Most samples (5 out of 6) are exceptionally low, well below the strictest recreational standards (EPA geometric mean  $\leq 200$ , single sample  $\leq 400$ ; WHO single sample  $\leq 100$ ) and the unrestricted irrigation thresholds (EPA/WHO  $\leq 1,000$ ). However, one sample (900 MPN/100 mL) approaches the irrigation limit, indicating generally good fecal contamination control but suggesting possible intermittent contamination events. In contrast, the TC results (0, 1500, 930, 1200, 900, 0 MPN/100 mL) display substantial variability and frequent high counts. This is especially relevant for drinking water sources, as EPA regulations require treatment to achieve  $\leq 5\%$  positive samples, meaning the raw water in this study would need significant treatment. The high TC levels also contrast with WHO's recommendation to prioritize fecal indicators over TC for general water quality assessment, highlighting its lesser direct health relevance but continued regulatory importance for source water protection and treatment verification in frameworks such as the EPA's. The frequent presence of TCs without corresponding FCs in some samples (e.g., 1500 total vs. 0 fecal) further demonstrates the distinction between these indicator groups observed in the data.

#### 4. CONCLUSIONS

This study presents a detailed assessment of microbiological and chemical dynamics in the coastal wetlands of Chabahar Bay, Iran, revealing significant spatial variability driven by anthropogenic and environmental factors. TC counts peaked at the sewage-influenced station S2 (1,500 MPN/100 ml), exceeding Iranian Class 2 water quality standards, while FCs were detected only at S2 and S3, indicating localized contamination from industrial and domestic waste. The absence of TCs and FCs at upstream (S1) and open-water (S6) stations underscores the wetland's natural purification capacity. Temperature and pH showed inverse relationships with coliform levels. Organic matter (TOC and TOM) was highest in mangrove zones (S3–S4) but correlated inversely with TCs and FCs, suggesting microbial degradation outcompeted proliferation. Mangrove vegetation at S4 and S5 significantly reduced coliform levels through physical trapping and microbial processes, highlighting their critical role as natural biofilters in subtropical wetlands. These findings emphasize the vulnerability of Chabahar's coastal wetlands to sewage and industrial pollution, tempered by the ecosystem's resilience through mangrove filtration. The study contributes to the limited literature on subtropical wetland microbiology by integrating water and environmental analyses, offering insights into pollution dynamics in rapidly industrializing regions.

Future research should focus on long-term and seasonal monitoring of microbiological and physicochemical parameters to capture temporal variability and assess the impacts of tidal dynamics, monsoonal rainfall, and climate-driven changes on microbial contamination. Expanding the set of microbial indicators, including *E. coli* and enterococci, along with chemical pollutants, would provide a more comprehensive assessment of ecological and public health risks. From a management perspective, continuous monitoring of sewage discharge points and the protection and restoration of mangrove habitats are strongly recommended, as these ecosystems function as effective natural biofilters. Integrating such monitoring programs into coastal management strategies can support sustainable wetland conservation and pollution control in rapidly developing coastal regions.

## CONFLICT OF INTEREST

Authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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