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Research Article

Assessment of Bacterial Pollution Levels in the Coasts of Aden – Gulf of Aden, Yemen

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Abstract

The coasts of the city of Aden are experiencing significant environmental damage that impacts marine life and human health. The coastal waters receive the majority of household wastewater, which is discharged directly without adequate treatment or is not treated before reaching the city's beaches. The study revealed spatial and temporal variations in the physical, chemical, and microbiological characteristics of the examined waters. It also indicated that the discharge of sewage, industrial waste, and other human activities affected these characteristics. Temperature, pH, salinity, Total Coliform (TC), and Fecal Coliform (FC) levels at the study stations were higher in summer than in winter. Water temperature ranged from 26.30 to 33.00 °C, and the waters off the shores of Aden were slightly alkaline, with a pH of 7.85 - 8.29 and salinity values of 36.50 - 38.40 parts per thousand. The highest total coliform count was recorded at stations 5 and 6, with averages of 1197 and 1119 colonies/100 ml, respectively, while the lowest total coliform count was observed at station 8 (the reference station) with an average of 60 colonies/100 ml. The fecal coliform counts ranged from 0 to 370 colonies/100 ml. According to European standards for recreational marine waters (TC <500/100 ml, FC <100/100 ml), the microbiological results for stations 7, 5, 2, and 1 exceeded the permissible limits, while stations 8, 3, 6, and 4 recorded lower pollution rates and remained within the permissible limits.

1. Introduction

Water, covering approximately 70% of the Earth's surface, is essential for supporting diverse aquatic life in rivers, lakes, and oceans. Aquatic ecosystems play pivotal roles in regulating global climate, contributing to the water cycle, maintaining biodiversity, providing food and energy, and offering recreational opportunities [1,2,3]. This vast expanse of water is not merely a backdrop for human activity but serves an indispensable role in regulating temperature and weather patterns through the intricate processes of the water cycle. However, despite their significance, the quality of marine waters is declining globally due to human activities such as industrial and agricultural waste disposal, urban expansion along coastlines, and infrastructure development [4,5].

These human activities contribute significantly to coastal water pollution, which in turn threatens marine ecosystems and human health. The interconnectedness of water quality and ecosystem health cannot be overstated. Aquatic systems serve as habitats for numerous species, many of which are crucial for human food security through fisheries and aquaculture. Furthermore, these ecosystems offer recreational opportunities that contribute to human well-being and economic activities, underscoring the dual importance of ecological preservation and access to clean waters [6]. Despite their importance, these systems are under increasing threat from anthropogenic pressures, including pollution, climate change, and habitat degradation. As noted by [7], the accumulation of pollutants such as heavy metals, plastics, and runoff from agricultural practices severely degrades water quality and disrupts ecological balance. Consequently, regular monitoring of marine water quality is essential for managing pollution and safeguarding public health. Among

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the key indicators for assessing water quality are Total Coliform (TC) and Fecal Coliform (FC) levels. These coliform bacteria have been widely recognized for over a century as critical biomarkers in evaluating pollution levels and associated health risks in aquatic environments [8,9].

TC represents a broad group of bacteria found in soil, plants, and water bodies, while FC is a subset that indicates contamination from the feces of warm-blooded animals, including humans [10,11]**.** Their presence in coastal and marine environments is critical for detecting contemporary fecal pollution from sources such as sewage discharge, agricultural runoff, and wildlife waste [12,13,14]**.** Detecting coliform bacteria in seawater is essential for assessing fecal contamination levels and evaluating potential health risks for recreational water users. Elevated coliform levels often indicate deficiencies in wastewater treatment systems, uncontrolled runoff, or other sources of pollution **[**15]**.**

Moreover, various environmental factors significantly influence the inactivation of bacteria once they reach receiving waters. Key parameters include: **-pH:** The pH level of water can greatly affect bacterial survival and growth. TC and FC typically thrive in neutral to slightly alkaline environments [16] **-Temperature:** Temperature is a critical factor influencing the growth rate of coliform bacteria. Higher temperatures generally promote faster bacterial growth [17] **-Solar Radiation**: Ultraviolet (UV) radiation can cause DNA damage in microorganisms, including coliform bacteria, reducing their population [18]. **-Predation**: Predatory organisms in marine environments, such as protozoa, feed on coliform bacteria, naturally reducing their population. This biological control helps limit bacterial proliferation [19]. **-Osmotic Stress:** Coliform bacteria are susceptible to changes in salinity. High salinity levels in marine waters can induce osmotic stress, leading to reduced bacterial viability or growth inhibition [20]. Understanding these factors and their interaction with TC and FC levels is crucial for accurate assessments of marine water quality. This research emphasizes the importance of regular water quality monitoring and explores the implications of microbiological indicators, such as TC and FC levels, on the health of marine ecosystems.

2. Materials and Methods

Surface water samples were collected from eight sampling stations along the coastal area of Aden (Figure 1 and Table 1). Water temperature, pH, and salinity (S‰ = ppt) were measured directly in situ using a graduated thermometer, pH meter, and a handheld salinity refractometer. Detection of total and fecal coliform was performed using the membrane filtration technique. Water samples (100 ml each) were filtered using Whatman filter paper with a 125 mm pore size to remove large particles, and then they were re-filtered using a Sartorius membrane filter with a 0.45 µm pore size. One of the filters was carefully transported and placed in sterile Petri dishes containing the growth medium (M-Endo Broth), then incubated at 37 °C for 24 hours to detect the presence of total coliform. The other filter was also carefully transported and placed in a sterile Petri dish containing the growth medium (M-Fc broth), then incubated at 44 °C for 24 hours to detect the presence of fecal coliform. Afterward, the dishes were removed, and the filters were thoroughly examined using a colony counter to identify and count the colonies. The calculation of total and fecal coliform was performed according to the following formula: Total or fecal coliform per gram dry weight = colonies counted x 100 / volume of sample chosen (ml) [21, 22].

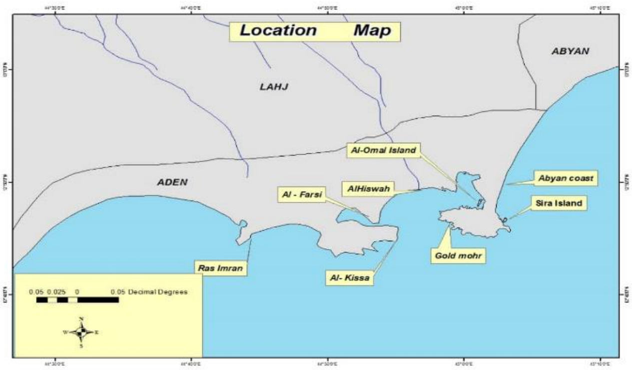

Figure 1: A map showing the locations of the studied samples.

3. Results and Discussion

3.1. Total Coliform (TC)

The total coliform (TC) values ranged from 52 to 1452 MPN/100 ml, as shown in Table2. The TC counts were higher during summer (68-1452 MPN/100 ml) and lower in winter (52-1022 MPN/100 ml) at all stations, as illustrated in Figure 2. The rise in pollution levels during the summer can be attributed to the increase in beachgoers for recreation and tourism from local residents and all governorates of the country. Furthermore, the heightened discharge of wastewater from household use during the hot season, along with frequent swimming in the sea, these findings are consistent with the study conducted by [23] in Jeddah, Saudi Arabia. As showing in figures 3, 4 and 5, Total Coliform increases in stations with higher temperatures, lower salinity, and a neutral to slightly alkaline pH, which suggests that a warm, moderately saline, and neutral pH environment creates favorable conditions for bacterial growth. These conditions are often found in coastal waters near pollution sources like untreated sewage, where large amounts of freshwater or contaminated water flow into the marine system, leading to lower salinity and higher pollution levels.

Table 1: Sampling locations and results of hydrographic parameters in seawater during winter and summer

Stations	Description	Coordinates		Water Temperature (C°)			Hydrogen Ion Concentration (pH)			Salinity (S‰)		
		Latitude	Longitude	W	S	Mean	W	S	Mean	W	S	Mean
Sira Island	St.1	12°46'35"N	45°02'48"E	26.70	32.30	29.50	8.00	8.07	8.04	37.80	38.10	37.95
Al-Omal Island	St.2	12°48'36"N	45°01'06"E	26.80	32.80	29.80	7.90	7.98	7.94	37.90	38.40	38.15
Abyan Coast	St.3	12°50'02"N	45°2'04"E	26.50	32.00	29.25	8.05	8.12	8.09	37.20	37.60	37.40
Gold Mohr Coast	St.4	12°46'28.4"N	44°59'04"E	26.30	31.40	28.85	8.15	8.24	8.20	37.20	37.80	37.50
Al-Hiswah Coast	St.5	12°49'27.4"N	44°55'59"E	27.10	33.00	30.05	7.85	7.89	7.87	36.80	37.10	36.95
Al-Farsi Khour	St.6	12°46'19.2"N	44°53'168"E	26.30	31.50	28.90	8.12	8.22	8.17	37.00	37.60	37.30
Al-Khissa Coast	St.7	12°44'45" N	44°54'26"E	26.80	32.60	29.70	7.92	7.95	7.94	36.50	37.00	36.75
Ras Imran Coast	St.8	12°45'52" N	44°44'52"E	26.40	31.20	28.80	8.23	8.29	8.26	37.40	37.90	37.65
Mean				26.60	32.10	29.35	8.03	8.10	8.07	37.20	37.70	37.45
Rang				**26.30 - 33.00**			**7.85-8.29**			**36.50-38.40**		

Table (2): Results of Total Coliform and Fecal Coliform in Seawater of Aden coasts.

Stations	Total Coliform TC (MPN/100ml)			Fecal Coliform FC (MPN/100ml)		
	W	S	Mean	W	S	Mean
Sira Island St.1	460	692	576	68	170	119
Al-Omal Island St.2	622	840	731	97	192	145
Abyan Coast St.3	412	488	450	33	62	48
Gold Mohr Coast St.4	137	315	226	3	24	14
Al-Hiswah Coast St.5	1022	1216	1119	151	315	233
Al-Farsi Khour St.6	244	470	357	18	53	36
Al-Khissa Coast St.7	942	1452	1197	128	370	249
Ras Imran Coast St.8	52	68	60	0	0	0
Mean	**486**	**693**	**590**	**62**	**148**	**105**
Rang	**52 -1452**			**0 – 370**		

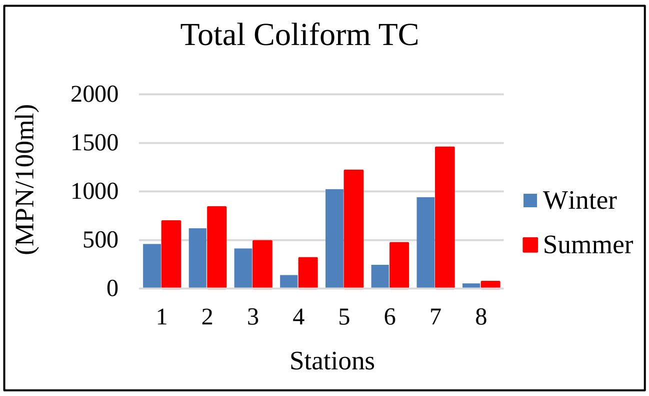

Figure 2: The seasonal differences in Total Coliform (TC) levels across various stations, showing a noticeable increase during summer compared to winter, with clear variations between stations.

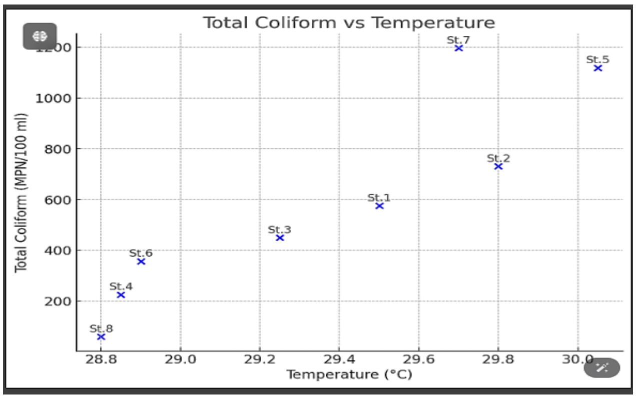

Figure 3: The relationship between the number of Total Coliform bacteria and temperature, illustrating the effect of temperature rise on the increase in bacterial concentration.

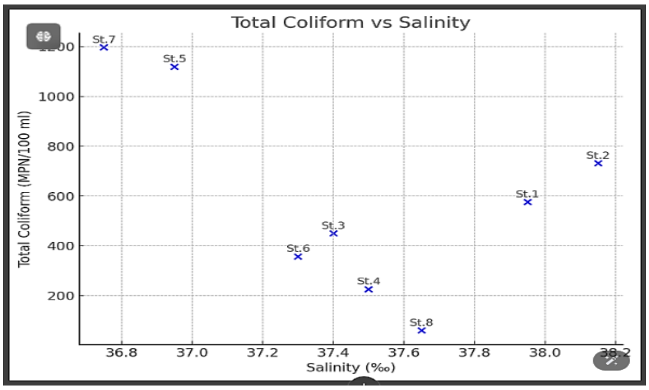

Figure 4: The relationship between Total Coliform concentration and water salinity. The distribution shows a variation in Total Coliform concentration at different salinity levels, reflecting the influence of salinity on coliform growth and distribution.

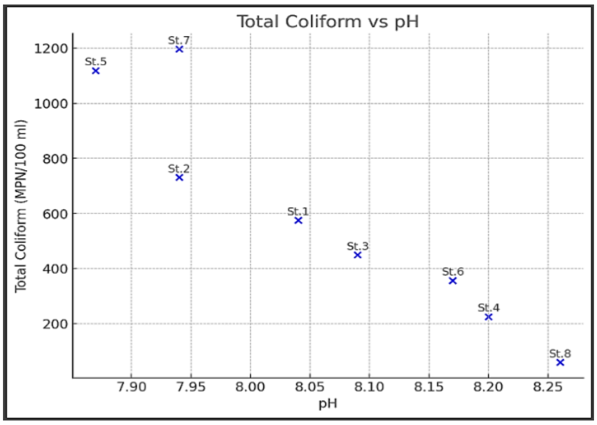

Figure 5: The relationship between the number of Total Coliform and the pH level of water. The distribution shows a variation in Total Coliform numbers with changes in pH values.

Additionally, the current results show the lowest TC value at Station 8 (reference station) with an average of 60 MPN/100 ml, while the highest TC values were recorded at Stations 7 and 5, with averages of 1197 and 1119 MPN/100 ml, respectively, representing increases of 94.99% and 94.64% compared to the reference station. Significant differences in TC counts were observed among all stations (Table 2). The increase in bacterial counts at Stations 7 and 5 may be attributed to the higher discharge of untreated wastewater. Table 1 shows a decrease in salinity at these stations, suggesting significant wastewater release. This salinity decline correlates with a rise in bacterial counts, with average TC of 1197 and 1119 MPN/100 ml, respectively. Stations 2 and 1 recorded average TC counts of 731 and 576 MPN/100 ml. In contrast, the impact of untreated wastewater at Stations 3, 6, and 4 was less pronounced, with lower TC counts of 450 MPN/100 ml at Station 3, 357 MPN/100 ml at Station 6, and 226 MPN/100 ml at Station 4 on the Gold Mohr Coast. The Total Coliform counts (TC) at all study stations were higher compared to the results from Ras Imran Coast Station, the reference station. When comparing the study results presented in Table (2) with the European standards [24] for recreational marine waters (TC < 500/100 ml), it was observed that the results from stations 5, 7, 2, and 1 exceeded the permissible limits. In contrast, stations 3, 6, and 4, which recorded lower levels of contamination, did not surpass the upper allowable limits. Ras Imran Coast (St.8) had an average coliform bacteria TC of 60 MPN/100 ml, which is below the European standards [24].

When comparing the current study results with the guidelines issued by the World Health Organization (TC < 200/100 ml) [25], all study station results were elevated, except for St.4 in winter and the reference station St.8. Furthermore, when comparing TC concentrations in the current study (52-1452 MPN/100 ml) with those in previous studies, it was found that they were lower than those reported by [26] (833-11316 MPN/100 ml) in Libya and [27] in Malaysian lakes (2×10^3 - 35×10^5 CFU/100 ml), but higher than in studies by [28] (59-176 CFU/100 ml) and [29] (0-670 CFU/100 ml) in Mauritius . Meanwhile, the results were consistent with the study conducted on the northern Lebanese coast [30], as shown in Table (3).

3.2. Fecal Coliform (FC)

The analysis results of fecal coliform showed variation among the study stations. This variation in the number of fecal coliform (FC) at different stations may be attributed to several factors: the direct discharge of wastewater into the coast, the quality and quantity of wastewater flowing directly into the coast or being transported by waves and tidal movements from other locations, along with various human activities. The Fecal Coliform numbers at the study stations ranged from 0 at station 8 (the reference station) to 370 MPN/100 ml at station 7 during the summer, as illustrated in Table 3.The study results indicated that the numbers of fecal coliform (FC) were lower in winter compared to summer at all stations, as illustrated in Figure 6.

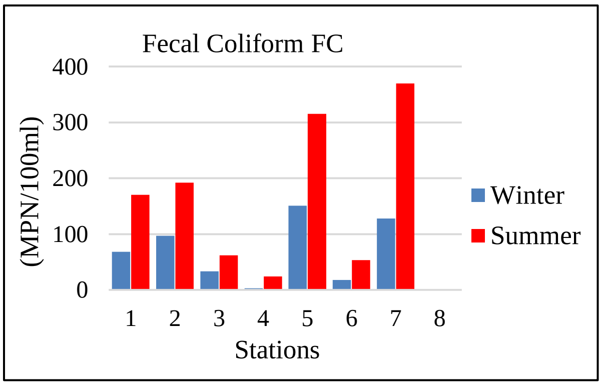

Figure 6: The seasonal variations in Fecal Coliform (FC) counts across different stations, showing a noticeable increase during the summer compared to winter, with differences between the stations.

Statistical analysis revealed a difference in fecal coliform bacteria counts between the two seasons of 58.11%. The increase in fecal coliform bacteria during the summer may be attributed to two factors: first, the rise in wastewater discharge from domestic use, leading to a potential increase in bacteria reaching seawater through direct or indirect wastewater discharges; and second, the elevated seawater temperature during summer, which promotes bacterial activity and reproduction As shown in Figures 7, 8, and 9, fecal coliform bacteria levels rise at stations with elevated temperatures, reduced salinity, and neutral to slightly alkaline pH. This indicates that bacterial contamination in these regions is likely attributable to anthropogenic sources, such as untreated sewage discharge.

Table 3: Comparison of (TC) results in the coasts of Aden - Yemen with other locations

Studies	Concentrations	Reference
Lebanon	537 CFU/100 ml	30
Tripoli City –Libya	833-11316 MPN/100 ml	26
Malaysia	2×10^3 - 35×10^5 CFU/100 ml	27
Nigeria	59-176 CFU/100 ml	28
Mauritius	0-670 CFU/100 ml	29
Aden City-Yemen	52-1452 MPN/100 ml	Present study
Mean	590 MPN/100 ml	Present study

In the present study, the highest concentrations of faecal coliform bacteria (FC) were recorded at stations 7, 5, 2, and 1, which can be attributed to their proximity to the sewage discharge points. In addition to the influence of wastewater volume on the microbial content of seawater, the distance from the discharge point also plays a role. Since stations 7 and 5 are closest to the discharge points, elevated levels of fecal coliform bacteria (FC) were observed, with average values of 249 and 233 MPN/100 ml, respectively. Stations 2 and 1 also recorded high levels of fecal coliform bacteria during the study period, with averages of 145 and 119 MPN/100 ml, respectively.

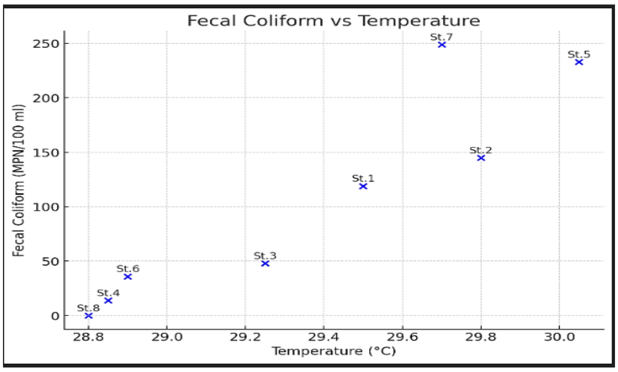

Figure 7: The correlation between the number of fecal coliform bacteria and temperature, demonstrating that an increase in temperature leads to a rise in bacterial count.

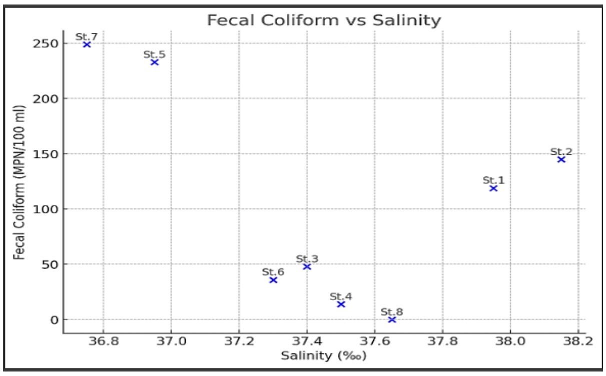

Figure 8: The relationship between the concentration of fecal coliform bacteria and salinity levels, demonstrating that an increase in salinity leads to a decrease in the number of fecal coliform bacteria.

Table 4: Comparison of (FC) results in the coasts of Aden - Yemen with other locations

Studies	Concentrations	Reference
Lebanon	327 CFU/100ml	30
Mauritius	0-230 MPN/100ml	29
Iceland	170-16000 CFU/100ml	31
Aden City-Yemen	0-370MPN/100 ml	Present study
Mean	105MPN/100 ml	Present study

These numbers may be attributed to the semi-enclosed nature of these coastlines, where the wastewater flowing into them, although low in volume, remains untreated. The limited wave action contributes to the growth and proliferation of bacteria. Station 3 recorded a decrease in fecal coliform bacteria counts compared to the other studied stations, with an average of 48 MPN/100ml, despite the discharge of untreated sewage into this site, particularly after the local wastewater treatment plant was shut down. We attribute this decrease to the beach's openness and the lack of rocks or barriers that could trap the water. Consequently, this beach is directly influenced by waves and marine currents, which limit the growth of bacterial colonies along the coast in these waters. Stations 6 and 4 also showed a decrease in FC numbers compared to the earlier stations, with averages of 36 and 14 MPN/100 ml, respectively, indicating that the impact of wastewater is minimal at these sites. In Figure 10, which illustrates the relationship between Total Coliform and Fecal Coliform, a positive relationship was observed between the two variables, with fecal coliform bacteria generally increasing alongside total coliform bacteria at most stations. This indicates the potential for bacterial contamination, whether from natural sources or from human or animal waste.

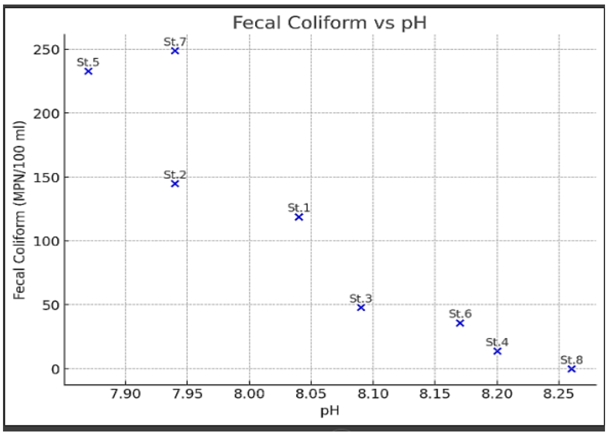

Figure 9: shows the relationship between fecal coliform concentration and pH levels. The distribution shows a decrease in the number of fecal coliform bacteria as pH concentration increases.

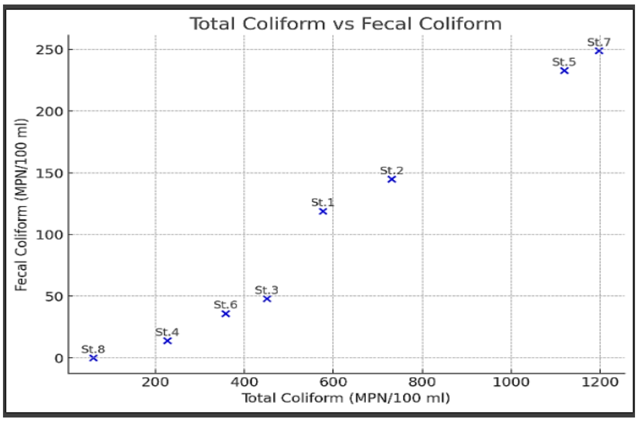

Figure 10: The relationship between the number of fecal coliform and total coliform. The data reveal a positive correlation, where the number of fecal coliform increases proportionally with the number of total coliform, reflecting the interrelationship between the two types in the coastal environment of the region.

According to European standards [24] for recreational marine waters (FC < 100/100 ml), the FC levels at stations 5, 7, 2, and 1 exceed permissible limits, while stations 3, 6, and 4, which recorded lower pollution levels, do not exceed these limits. Meanwhile, station 8 (the reference station) did not show any fecal coliform FC contamination due to its distance from the impacts of human activities. When comparing the concentrations of fecal coliform bacteria in the analyzed water samples (0-370MPN/100 ml) with previous studies, it was found that they are lower than those reported by [31] (170-16000 CFU/100ml) and [30] (327 CFU/100ml) but higher than those in the study by [29] **(** 0-230 MPN/100ml), as shown in Table 4.

3. Conclusions

The pollution of the coasts of Aden with coliform bacteria is linked to the discharge of untreated or inadequately treated wastewater into the sea. Pollution increases significantly in areas near wastewater outlets and residential areas, and the concentration of coliform bacteria rises in the summer due to higher temperatures and increased flow of sewage.

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Disclosure
The authors declare that they have no known financial conflicts of interest or personal relationships that could have influenced the work reported in this paper.

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بحث علمي

تقييم مستويات تلوث البكتيريا في سواحل عدن - خليج عدن

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مفاتيح البحث

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كلمات مفتاحية:
التلوث البكتيري، البكتيريا القولونية الكلية، البكتيريا القولونية البرازية، سواحل عدن

الملخص

تواجه سواحل مدينة عدن أضراراً بيئية كبيرة تؤثر على الحياة البحرية وصحة الإنسان. تستقبل المياه الساحلية غالبية مياه الصرف الصحي المنزلي التي يتم تصريفها مباشرة دون معالجة كافية أو لا تتم معالجتها قبل أن تصل إلى شواطئ المدينة. كشفت الدراسة عن تباين مكاني وزماني في الخصائص الفيزيائية والكيميائية والميكروبيولوجيه للمياه المدروسة. كما أشارت إلى أن تصريف مياه الصرف الصحي والنفايات الصناعية والأنشطة البشرية الأخرى أثر على هذه الخصائص، كانت قيم درجة حرارة الماء ودرجة الحموضة والملوحة والبكتيريا القولونية الكلية (TC) والبكتيريا القولونية البرازية (FC) في محطات الدراسة أعلى في الصيف مقارنة بالشتاء. تراوحت درجة حرارة الماء من 26.30 إلى 33.00 درجة مئوية، وكانت مياه سواحل عدن قلوية قليلاً، حيث بلغ الرقم الهيدروجيني لها 7.85 - 8.29، وقيم الملوحة 36.50 - 38.40 جزء في الألف. وسجلت أعلى تعداد للبكتيريا القولونية الكلية في المحطتين 5 و6 بمعدل 1197 و1119 مستعمرة/100 مل على التوالي، بينما سجلت أدنى تعداد للبكتيريا القولونية الكلية في المحطة 8(المحطة المرجعية) بمعدل 60 مستعمرة/100 مل. وتراوحت تعداد البكتيريا القولونية البرازية من 0 إلى 370 مستعمرة/100 مل، وفقاً للمعايير الأوروبية للمياه البحرية الترفيهية (TC<500/100ml FC<100/100ml) ، تجاوزت النتائج الميكروبيولوجية للمحطات 5،7، 1،2 الحدود المسموح بها، بينما المحطات (8، 3،6، 4) سجلت معدلات تلوث أقل وكانت ضمن الحدود المسموح بها.

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