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Digital Object Identifier:
Received 28 November 2025
Accepted 13 December 2025
Available online 1 September 2026

Seasonal Assessment of (*Escherichia coli*) Contamination Resulting from Untreated Wastewater in Marine Ecosystems of Al-Mukalla and Broom Mayfa, Hadhramout, Yemen

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This is an open-access article under production of [Hadhramout University Journal of Natural & Applied Science](#) with eISSN 2790-7201

Abstract: Assessing fecal pollution and monitoring pathogenic microorganisms such as coliform bacteria in coastal environments influenced by discharged wastewater is a fundamental measure for determining the quality of aquatic ecosystems. This study aimed to assess pollution from (*Escherichia coli*) in the marine ecosystems along the coasts of Al-Mukalla and Broom Mayfa in Hadhramaut Governorate-Yemen. Marine sediment and seawater samples were subjected to bacteriological analysis using a number of tests such as (MPN), confirmatory test and Indole test. The work also included the measurement of some ecological parameters and compared them with standards recommended by (WHO) and approved Yemeni standards. The study results revealed varying levels of bacterial contamination in all samples, and pollution was observed to be most pronounced in raw wastewater samples from treatment plant 19 station- (Fsw), during both seasons, appeared in Fw; Sw during the first period and Mws; Hs during the second period. This contamination is characterized by the appearance of a metallic green sheen or a rose-colored ring, which are distinctive diagnostic signs in microbiological tests. The study also showed that seasonal fluctuations in the ecological parameters in studied samples- under influenced by discharge rates and population density-play a crucial role in bacterial survival and growth. Therefore, these findings underscore the urgent need to improve the efficiency of treatment processes and strictly enforce both international and local to protection of marine ecosystems

Keywords: Aquatic ecosystems; Broom Mayfa; Ecological parameters; *Escherichia coli*; Marine sediment; Mukalla; Wastewater

1. Introduction

Water is an essential component of ecosystems that play a role in their balance and a vital link for the feeding of food chains. Despite its abundance, 50% of global diseases are caused by contaminated water, and 3.3% of global deaths are linked to water quality. With increasing pressures from human activities such as industrial, domestic, and agricultural waste [1,2,3,4]. Activities contribute

significantly to the degradation of coastal environments by introducing chemical compounds, and microbes into marine ecosystems, causing serious negative changes. These pollutants often include many wastes from different resources that find their way into the marine environment [5,6,7,8]. Previous studies have showed that the volume of wastewater discharged into waterways amounts 2 million tons globally, about 80% being disposed of untreated and

containing various pollutants that can deplete DO and high BOD [9,10,11,12,13]. Yemen faces significant challenges with wastewater management, ranking last among Arab countries. Its increasing population density is a major cause of the deteriorating health situation, as treatment plants don't meet national quality standards [14,15]. Poor sanitation and contaminated water are key factors behind 90% of the 2,000

daily global deaths from diarrhea in children under five, according to UNICEF. Additionally, an unpublished report from Yemen's parliament reveals a severe local crisis where water-borne diseases threaten 75% of the population, contributing annually to 55,000 child deaths and three million hepatitis cases [14,16].

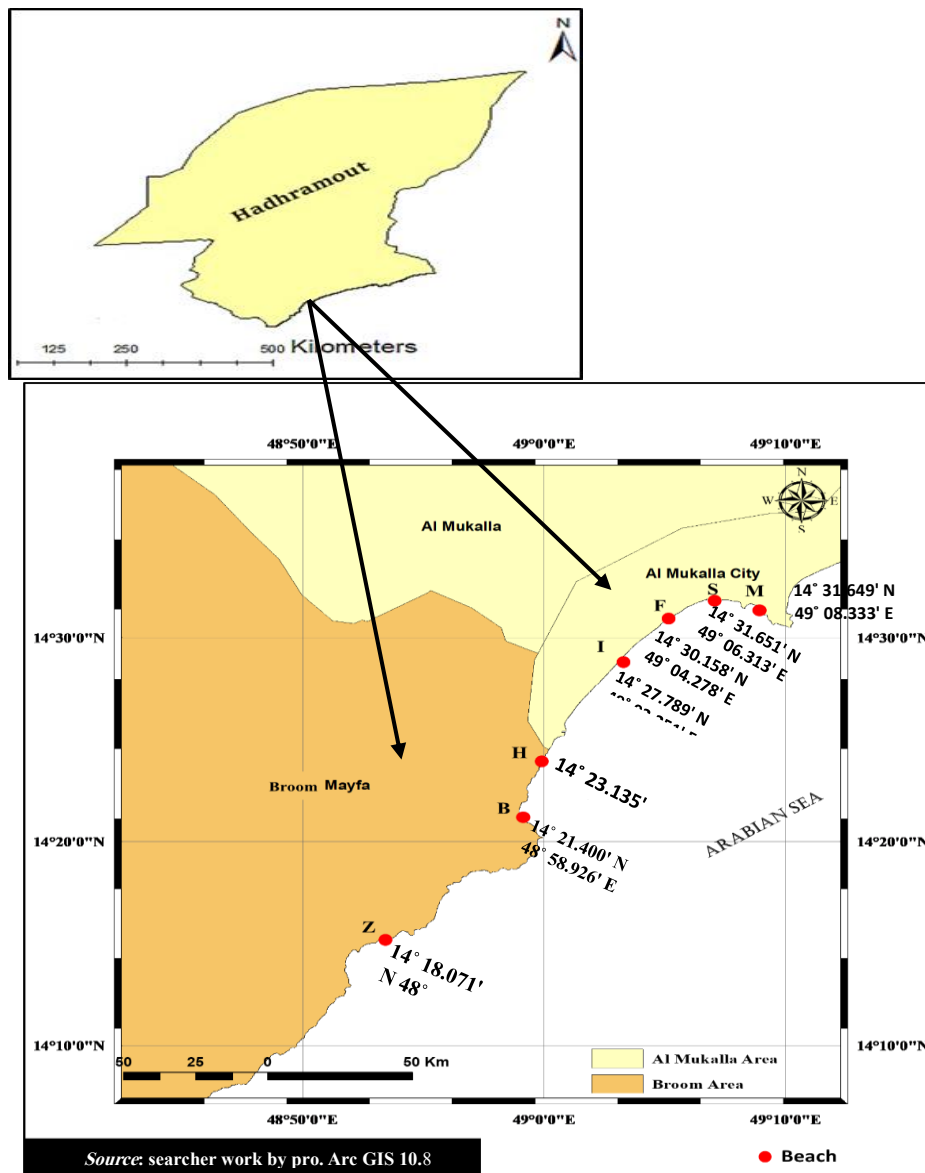


Figure 1. Sampling Sites on the Coasts of Al-Mukalla and Broom Mayfa.

Because wastewater is associated with microbial pollution, it causes significant damage across various biological levels, from living cells to entire marine ecosystems. It involves a diverse range of microorganisms, including the Enterobacteriaceae, which comprise a large group of bacterial species [12,17]. Among the most important and common species causing foodborne and gastrointestinal infections is the coliform group, which primarily includes *Escherichia coli* (*E. coli*). *E. coli* is present in the intestines of humans and warm-blooded animals [18]. It belongs to the family Enterobacteriaceae, thrives at temperatures of approximately 44–45°C, and grows on complex media. It also plays a role in the

fermentation of lactose sugar and Mannitol, producing acid and gases as byproducts. Certain species have the ability to survive in aerobic conditions, and others are non-motile. The *E. coli* is commonly found in human and animal fecal matter, and concentration reaching (910/g) in fresh feces. Moreover, it is also found in soil and plants, with certain strains demonstrating high viability. These strains are often linked to sewage or natural water sources contaminated with feces [4, 17, 19, 20]. Therefore, it is considered a common cause of some diseases as gastrointestinal infections, urinary tract and wound. The presence of *E. coli* in water serves as a broad indicator of contamination (indicator of fecal pollution) [4,18, 21]. This study focuses on evaluating the

microbiological contamination in marine sediments and seawater on the coasts of Al-Mukalla and Broom Mayfa districts, with a specific emphasis on *E. coli* as the standard indicator for fecal pollution originating from untreated wastewater discharge. To this end, the study involves collecting and analyzing samples seasonally from selected sites near the discharge points of untreated wastewater treatment plants. This analysis aims to assess the level of *E. coli* contamination and compare it with international and Yemeni standards for coastal water quality. It also seeks to determine the temporal and spatial distribution and survival rates of *E. coli* in the marine environment, in addition to studying the impact of external and ecological factors on the health of the ecosystem.

2. Materials and Methods

2.1 Study Area

Al-Mukalla and Broom Mayfa districts were chosen as study areas. Al-Mukalla is considered as one of the coastal largest areas in the Hadramout Governorate [22], whose population is estimated at approximately 566,000 people [23]. The area is located on the northeastern coast of the Gulf of Aden, at latitude 14.33° and longitude 49.10° [15]. The coastline of Al-Mukalla is characterized by unique marine biodiversity, with the estuaries of wadis forming nutrient-rich environments in certain areas, making them of natural habitats for the reproduction of many marine organisms of great economic importance to local fishermen. The presence of various species of migratory and resident birds also enhances the value of these environments [24,25,26]. Broom Mayfa is one districts of Hadramout Governorate and located in western coastal strip at 14.2°N

48.75°E, the population was 17,327. It is characterized by Wadi Mayfa, which flows throughout the year, and Dam Batis, Mayfa [27, 28]. It is known for its sandy beaches surrounded by high rocky cliffs .

2.2 Sampling Sites

Eight sites – [seven shallow sites were chosen across the coasts of Al-Mukalla, Al-Sharg, Bajrash, Ibn Sina, Al-Shageen, Broom, Zaluma, and treatment wastewater plant [19 station- (Fsw)]. Marine sediment and seawater samples were collected during two seasons, pre-monsoon and post-monsoon, in 2024 (Figure 1). A Global Positioning System (GPS) was used to record the exact locations of the sampling sites in decimal degrees to ensure accurate identification.

2.3 Sampling and Measurement

Surface marine sediments were collected at a depth of 0-10 cm and seawater samples were collected near wastewater treatment plants at a distance of approximately within 5 ± 2 m according to method [29,30], and added one wastewater sample from a wastewater treatment plant 19-Station is located in Bajrash neighborhood at 14°30'12"N, 49°04'17"E, on the coastal Fuwah area. During sampling, marine sediment samples were stored in sterile bags, while seawater samples were placed in sterile, opaque bottles and kept cool for transportation to the laboratory. All collected samples were analyzed within 24 hours for accuracy. Some ecological parameters measured directly in the field and some other in laboratory such as: Temp, pH, E.C, Sal or TDS, DO, BOD₅ using HANNA, HI 8751; HI 9813-6; HI 9829; HI 9142 [31,32,33,34,35].

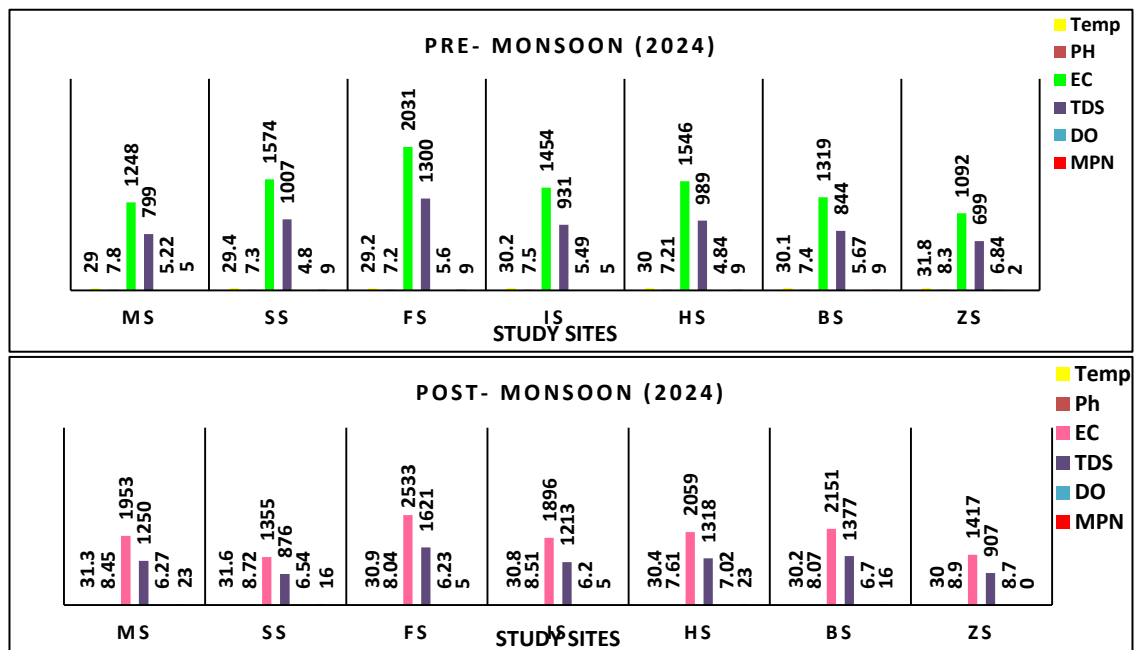


Figure 2. Seasonal Variations of most Probable Number (MPN) for *E. coli* and Ecological Parameters during (Pre & Post-Monsoon) in Marine Sediments Samples.

2.4 Detection Tests- Most Probable Number (MPN/T)

The multiple-tube technique was used to detect the presence of *E. coli* bacteria in contaminated samples (sediments and seawater). All glassware was sterilized in a dry heat oven at

170°C for 1h and loop needles were sterilized using a flame [36]. Then, MacConkey broth with neutral red medium was prepared at double concentration, and sterilized at 121°C for 15 minutes, as described in [31,37]. Several tests were

conducted, including: the estimation of the presumptive test (Most Probable Number Test- MPN/T): by preparing tubes: Study samples of (seawater or marine sediment) were added to five test tubes containing MacConkey Broth W/Neutral Red with inverted Durham tubes. The tubes were incubated at 37°C for 48 h. Following the incubation period, the tubes were examined to identify positive reactions. A tube was considered positive if it exhibited microbial growth, evidenced by a change in the media color or the presence of gas bubbles trapped within the Durham tubes. The number of positive tubes in each dilution group was recorded, and according to a special standard table, the Most Probable Number (MPN) of microbe was determined [32,38]. To confirm the results, two tests for the pathogenic microorganism were performed: a confirmatory test, in which the previously prepared contaminated samples were

cultured on EMB agar plates, which were then incubated at 37°C for 24–48. Additionally, a confirmatory indole test was performed using peptone water medium, and the tubes were incubated at 37°C for 24–48 h [39,40].

2.5 Data Analysis

All statistical aspects were measured by using, the Statistical Program for Social Sciences (SPSS program version 23.0) and Microsoft Office Excel. According to the statistical system, the maximum, minimum of mean and Pearson's correlation coefficient (*R*) were extracted to show the relationship between the values and physical and chemical properties at the sites during two seasons, Moreover, Fecal microbes were detected, and the most probable number (MPN) for *E. coli* bacteria was determined, along with its association with ecological factors [32,41].

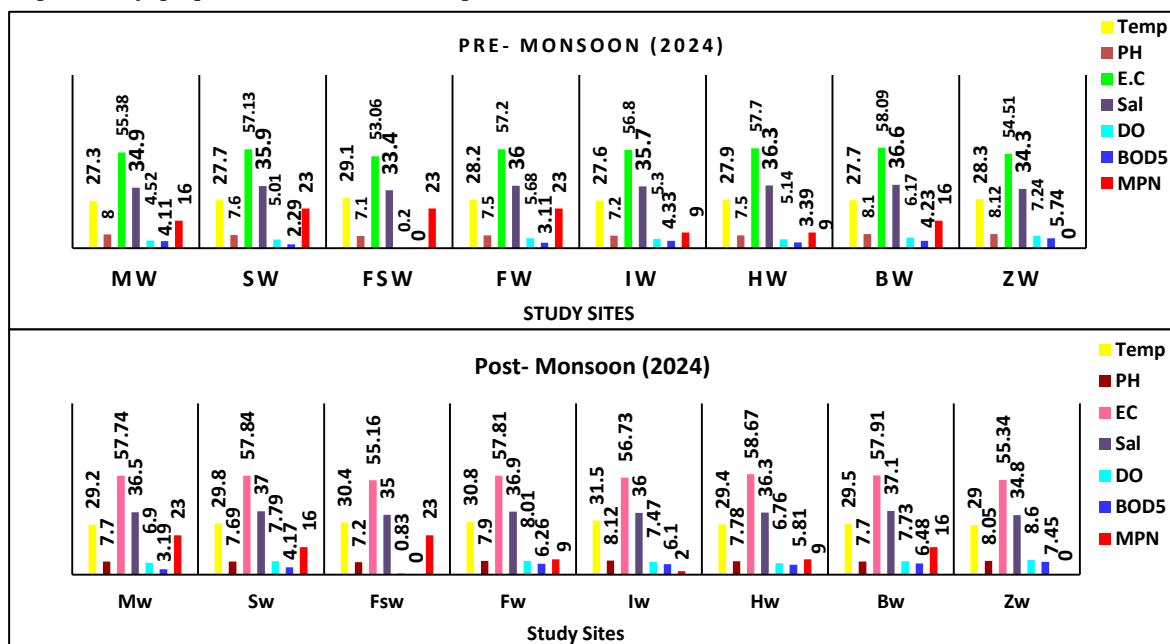


Figure 3. Seasonal Variations of most Probable Number (MPN) for *E. coli* and Ecological Parameters during (Pre & Post-Monsoon) in Seawater Samples.

3. Results and Discussion

3.1 Investigation of Ecological Parameters

The findings of this study revealed significant variations in the estimated numbers of pathogenic microbe in marine sediment and seawater samples across all monitored sites. These levels exceeded the permissible limits defined by Yemeni specifications and the 2004 WHO standards, serving as a clear indicator of pollution. These results were linked to several important ecological parameters that play a role in the survival and spread of pathogenic microbes in seawater and sediment samples. The results revealed the lowest mean of ecological parameters in marine sediments and seawater samples during both periods, they included: temperature,

pH, E.C, and TDS were (29 - 30°C) at Ms, Zs; (7.2 - 7.61) at Fs, Hs; (1092 - 1355 μ S/cm and 699 - 876 mg/l) at Zs, Ss; to the highest value was reached to (31.8 - 31.6°C) at Zs, Ms; (8.3 - 8.9) at Zs; (2031 - 2533 μ S/cm and 1300 - 1621 mg/l) at Fs, while in seawater samples the lowest reached to (27.3 - 29°C) at Mw, Zw; (7.1 - 7.2, and 53.06 - 55.16 ms/cm) at 19 stations- (Fsw) and (33.4 - 34.8 ppt) at 19 stations- (Fsw), Zw, to the highest was (29.1 - 31.5°C) at 19 stations- (Fsw), Iw; (8.12) at Zw, Iw; (58.09 - 58.67ms/cm) at Hw, Bw and (36.6 - 37.1ppt) at Bw; during the same period of pre-monsoon (Table. 1, 2).

Table 1. Mean of Ecological Parameters: Temp, pH, Salts – TDS & Sal, DO of *E. coli* in Marine Sediment Samples at the Study Area during Pre- Monsoon and Post- Monsoon

Sample		Marine Sediment									
Season		Pre-Monsoon					Post-Monsoon				
Area	Site	Temp. °C	pH	E.C μS/cm	TDS mg/l	DO ppm	Temp °C	pH	E.C μS/cm	TDS mg/l	DO ppm
Al-Mukalla	Ms	29	7.8	1248	799	5.22	31.3	8.45	1953	1250	6.27
Al-Sharg	Ss	29.4	7.3	1574	1007	4.8	31.6	8.72	1355	876	6.54
Bajrash	Fs	29.2	7.2	2031	1300	5.6	30.9	8.04	2533	1621	6.23
Ibn-Sina	Is	30.2	7.5	1454	931	5.49	30.8	8.51	1896	1213	6.2
Al-Shageen	Hs	30	7.21	1546	989	4.84	30.4	7.61	2059	1318	7.02
Broom	Bs	30.1	7.4	1319	844	5.67	30.2	8.07	2151	1377	6.7
Zaluma	Zs	31.8	8.3	1092	699	6.84	30	8.9	1417	907	8.7
Min		29	7.2	1092	699	4.8	30	7.61	1355	876	6.2
Max		31.8	8.3	2031	1300	6.84	31.6	8.9	2533	1621	8.7

The results indicated an increase in temperatures exceeding the permissible limits by Yemeni standards and WHO during both seasons at all sites. This makes temperature an indicator of pollution with increased reaction rates in the ecosystem like metabolic processes and DO consumption, while the other parameters as pH value was within Yemeni specifications and WHO in both samples, it's the mean pH fluctuated between neutral and alkaline, and the highest mean in marine sediment samples reaching 8.9, its considered an indicator of the balance of CO_2 , CO_3^{3-} , and HCO_3^{3-} , and affects several chemical and biological processes and the distribution of organisms. These results are consistent with what was mentioned by [13,14,29,42,43]. This distribution was associated with

electrical conductivity and salinity, it depends on the concentration and valence of ions in dissolved water. The results showed that the values exceeded the permissible limits during the second period, except at Zs in the sediment samples. Moreover, the increase was more evident in the seawater samples, with the highest mean value of 58.67 mS/cm recorded at Hw during the same period. This finding reflects the extent of pollution from domestic and industrial wastewater, which is consistent with what was reported by [44,45,46]. The observed increase may also have been influenced by natural factors, such as rainfall, wind and wave activity, and tidal currents. These results are consistent with what was reported by [1,4,19,20,35,47].

Table 2. Mean of Ecological Parameters: Temp, pH, Salts – TDS & Sal, DO, BOD₅ of *E. coli* in Seawater Samples at the Study Area during Pre- Monsoon and Post- Monsoon

Sample		Seawater											
Season		Pre-Monsoon						Post-Monsoon					
Area	Site	Temp °C	pH	E.C mS/cm	Sal ppt	DO ppm	BOD ₅ ppm	Temp °C	pH	E.C mS/cm	Sal ppt	DO ppm	BOD ₅ ppm
Al-Mukalla	M _w	27.3	8	55.38	34.9	4.52	4.11	29.2	7.7	57.74	36.5	6.90	3.19
Al-Sharg	S _w	27.7	7.6	57.13	35.9	5.01	2.29	29.8	7.69	57.84	37	7.79	4.17
19 Station	F _{sw}	29.1	7.1	53.06	33.4	0.2	0	30.4	7.2	55.16	35	0.83	0
Bajrash	F _w	28.2	7.5	57.2	36	5.68	3.11	30.8	7.9	57.81	36.9	8.01	6.26
Ibn-Sina	I _w	27.6	7.2	56.8	35.7	5.3	4.33	31.5	8.12	56.73	36	7.47	6.1
Al-Shageen	H _w	27.9	7.5	57.7	36.3	5.14	3.39	29.4	7.78	58.67	36.3	6.76	5.81
Broom	B _w	27.7	8.1	58.09	36.6	6.17	4.23	29.5	7.7	57.91	37.1	7.73	6.48
Zaluma	Z _w	28.3	8.12	54.51	34.3	7.24	5.74	29	8.05	55.34	34.8	8.6	7.45
Min		27.3	7.1	53.06	33.4	0.2	0-2.29	29	7.2	55.16	34.8	0.83	0-3.19
Max		29.1	8.12	58.09	36.6	7.24	5.74	31.5	8.12	58.67	37.1	8.6	7.45

Notes: F_{sw}: Fuwaha Sewage or 19 Station discharge; Standard according to [World Health Organization (WHO), 2004 – 2011]. [16,49]

The results also showed a varying decrease in DO level in marine sediment was found some sites as Bs, Fs, Is, Ms with concentration level 5.69, 5.6, 5.49, 5.22 ppm, except at Zs, was high to 6.84 ppm, and at Ss; Hs were 4.8 and 4.84 ppm during the first period of pre- monsoon, while during the second period it increased clearly at all sites, especially at Zs and Hs, with concentration level 8.7 and 7.02 ppm (Figure. 2; Table. 1). Whereas results showed in

the seawater samples during the both seasons (pre- monsoon and post-monsoon) the lowest mean of DO with concentration level (0.2 - 0.83 ppm) respectively, at 19 station-(F_{sw}), to the highest ranged between (7.24 - 8.6 ppm) at Z_w, it noted decreasing at all sites, especially at M_w and 19 station- (F_{sw}) during the first period, while during the second period it increased clearly at all sites, except the 19 station- (F_{sw}), and also the lowest of BOD₅ value with

concentration level (0 and 2.29ppm) at 19 station- (Fsw); Sw and (0 - 3.19 ppm) at 19 station- (Fsw); Mw, to the highest value between (5.74 – 7.45ppm) at Zw during both seasons (Figure. 3; Table. 2). The decrease in DO levels is attributed to the impact of human waste from sewage and its high rates, as well as the role of organisms and bacteria in Oxygen consumption. and the lowest values of BOD₅ recorded after the incubation period in seawater at Sw, Fw and Mw, it reached to 2.29, 3.11, 3.19 ppm, that indicating

serious human pollution, which the decline reflects the extent of change in the nature of the marine environment and the increase in pressures in the need for DO, especially in active areas, and this indicated by [9,43], while during second period the rising was due to the increase in DO concentration level in surface waters through the process of surface exchange with air by the wind, waves movements and upwelling phenomenon, in addition to rainfall. This is consistent with what was mentioned by [9,48].

Table 3. Mean of Ecological Paramerters (MPN, Indole/Test, and. Petri dishes) of *E. coli* in Marine Sediment and Seawater Samples at the Study Area during Pre- Monsoon.

Season		Pre- monsoon							
Sample		Marine Sediments				Seawater			
Area	Site	N.	MPN/T 10ml	Iod/T	EMP P.d	N.	MPN/T 10ml	Iod/T	EMP P.d
Al-Mukalla	M _{s,w}	2	5	+2 t	1 P.d	4	16	+2 t	3 P.d
Al-Sharg	S _{s,w}	3	9	+2 t	3 P.d	5	>23	+2 t	3 P.d
19 Station	Fsw	-	-	-	-	5	>23	+2 t	3 P.d
Bajrash	F _{s,w}	3	9	+2 t	3 P.d	5	>23	+2 t	3 P.d
Ibn-Sina	I _{s,w}	2	5	+2t	2 P.d	3	9	+2 t	2 P.d
Al-Shageen	H _{s,w}	3	9	+2 t	1 P.d	3	9	+2 t	2 P.d
Broom	B _{s,w}	3	9	+2 t	2 P.d	4	16	+2 t	3 P.d
Zaluma	Z _{sw}	1	2	-V	-V	0	0	-V	-V
Min		1	2	Non	Non	0	0	Non	Non
Max		3	9	+2 t	3 p.d	5	>23	+2 t	3 p.d

Notes: MPN/T: Most Probable Number Test, Ind/T: Indole Test, t: Number of tubes, N. P.d: Number of Petri Dishes; 3/10ml; 0/100ml, by WHO, 2004-2011.

3.2 Diagnostic Tests for Pathogenic *Escherichia coli*

The results of the presumptive and confirmatory tests indicated their role in the detection of the microorganism. The presumptive test (Most Probable Number, MPN) for *E. coli* showed that, during the first (pre-monsoon) period, the MPN values in the marine sediment samples ranged from a low of 2 at Zs to a high of 9 at Ss, Fs, Hs, and Bs, whereas the values at Ms and Is were 5. In the confirmatory test,

colonies appeared on all Petri dishes, especially at the Ss and Fs sites. However, the number of colonies decreased at the remaining sites, except at Zs, where no green colonies appeared. In contrast, the Most Probable Number (MPN) of *E. coli* in the seawater samples during the presumptive test ranged from zero at Zw to the highest value (>23) at Sw and Fw, while the value was 19 at the Fsw station.

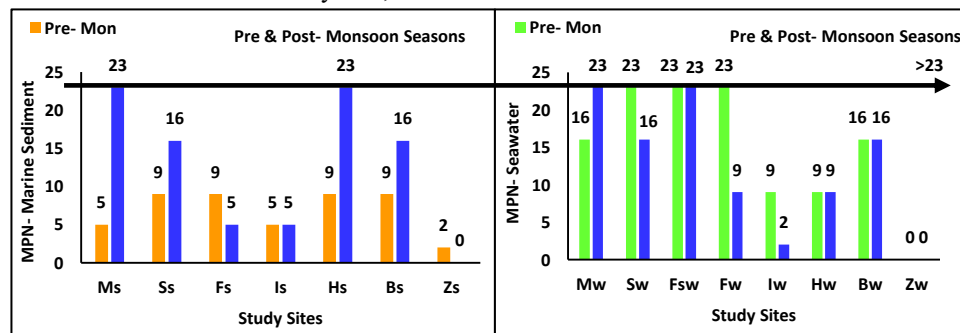


Figure 4. Seasonal Variations of most Probable Number (MPN) of *E. coli* Between (Pre & Post- Monsoon Seasons) in Marine Sediment and Seawater at the Study Sites.

The colonies appeared during the confirmatory test in all dishes, especially at Mw, Sw, Fw, Bw, 19 station- Fsw, but it decreased at Iw and Hw, as well as no colonies appeared at Zw. The results detected also the presence of *E. coli* in all Indole test tubes and result was (+V) through the appearance of Rose's ring in all samples except at Zs and Zw (Figure. 4, 5; Table. 3). During the second period of post-monsoon, where the (MPN) of *E. coli* in both samples ranged between the lowest number was Zero at Zs and Zw to the highest number (N >23) at Ms; Hs, Fw; 19 stations- (Fsw). The green colonies appeared in marine sediments samples during the confirmatory test in some petri dishes

and less compared with the first period, ranged from (1 - 2 dishes) of total dishes, while in the seawater samples, the colonies appeared in 1 dish at Sw, Fw, Iw, Bw, except at Mw, 19 stations- (Fsw), appeared in (2 - 3 dishes) of total dishes, and no colonies appeared at Hw, Zs, Zw, while Rose ring appeared in some Indole test tubes with (+V) result, ranged from (1 - 2 tubes), without appeared at Zs and Zw (Figure. 4, 5; Table. 4). As noted through the results data, the number of bacteria exceeded the permissible limits in both seasons, reached to (N >23) at Ms, Hs, Mw, Sw, Fw, 19 stations- (Fsw), respectively in the marine sediment and seawater samples. This pathogen was considered a good

indicator of human fecal pollution in both marine sediments and seawater, from the bacteria presence at all sites except at Z, which was considered far from the pollution sources, especially during the second season, despite the tubes color changed during detection of lactose fermentation in presumptive test at a very low number in the marine

sediments during the first season compared to the other sites. Due to non-adequate wastewater treatment before discharge into the marine environment, especially when the microbe's clear present in the discharge water from 19 station at Bajrash area during both seasons, and this is consistent with many previous studies [10,35,47].

Table 4. Mean of Ecological Parameters (MPN, Indole/Test, and. Petri dishes) of *E. coli* in Marine Sediment and Seawater Samples at the Study Area during Post- Monsoon

Season		Post- monsoon							
Sample		Marine Sediments				Seawater			
Area	Site	N.	MPN/T 10ml	Iod/T	EMP p.d	N.	MPN/T 10ml	Ind/T	EMP P.d
Al-Mukalla	M _{s,w}	5	>23	+2 t	2 P.d	5	>23	+2 t	2 P.d
Al-Sharg	S _{s,w}	4	16	+1 t	1 P.d	4	16	+2 t	1 P.d
19 Station	F _{s,w}	-	-	-	-	5	>23	+2 t	3 P.d
Bajrash	F _{s,w}	2	5	+2 t	1 P.d	3	9	+2 t	1 P.d
Ibn-Sina	I _{s,w}	2	5	+2 t	2 P.d	1	2	+2 t	1 P.d
Al-Shageen	H _{s,w}	5	>23	+2 t	1 P.d	3	9	+1 t	-V
Broom	B _{s,w}	4	16	+1 t	1 P.d	4	16	+1 t	1 P.d
Zaluma	Z _{s,w}	0	0	-V	-V	0	0	-V	-V
Min		0	0	Non	Non	0	0	Non	Non
Max		5	>23	+2	2 P.d	5	>23	+2 t	3 P.d

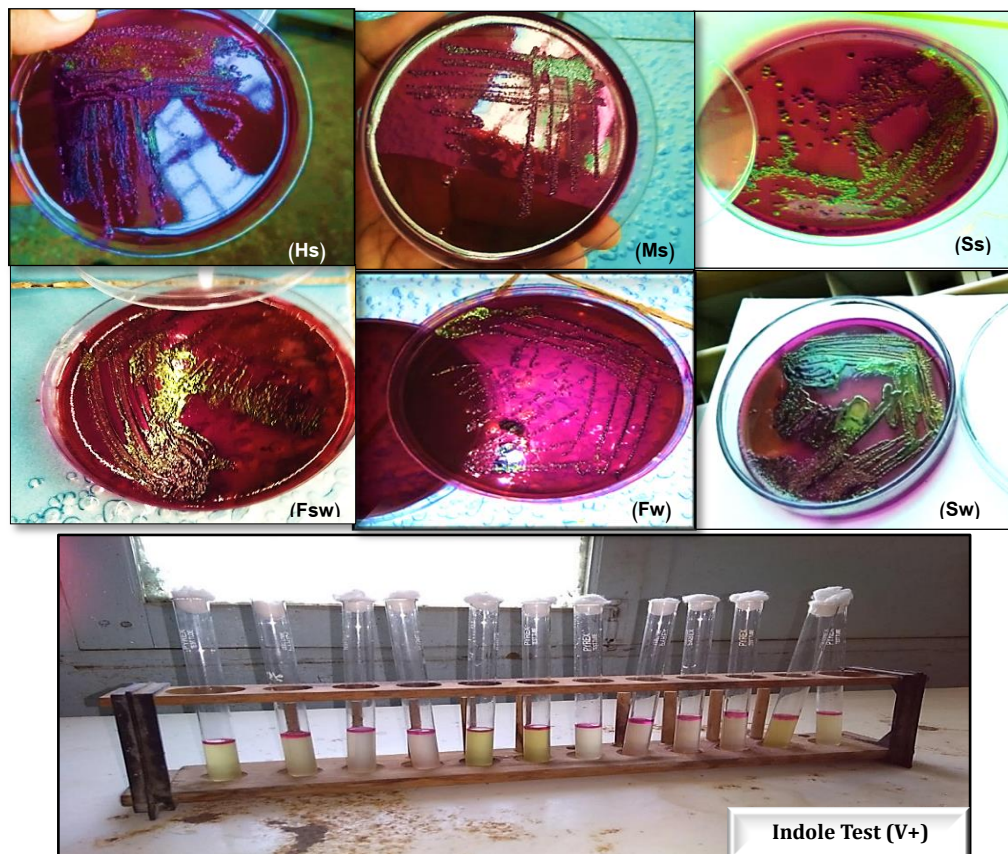


Figure 5. *Escherichia coli* growth on EMB Agar as Colonies with a Distinct Green Metallic Sheen and Rose ring on Peptone Water media.

3.3 Relationship Between Ecological Parameters and the Pathogenic Microbe (*Escherichia coli*)

The statistical analysis data showed a correlation between the ecological parameters of marine sediment studied, where noted a strong positive and negative correlation were ranged

between $R = (1, 0.79, 0.78, 0.67, \text{ and } -0.78, -0.58)$, during pre- monsoon and ($R = 1, \text{ and } -0.77, -0.67 -0.53$) respectively, during post- monsoon. Then, the correlation coefficient decreased to a weak positive and negative correlation $R = 0.36, 0.21, -0.43, -0.12, -0.11$. The statistical

analysis data showed also a strong positive and negative correlation between the ecological parameters and microbial numbers (N) was $R = 0.69, -0.95, -0.74, -0.67$, during first period, and $R = -0.54, -0.56$, during the second period, with a weak correlation ranged between $R = 0.20, 0.21, -0.42$. Whereas in seawater samples during the first period of pre-monsoon, there were a strong positive and negative correlation ranged between $R = (1, 0.66, 0.59, \text{ and } -0.65, -0.57)$, whereas during post-monsoon correlation $R = 0.9, 0.84, 0.52$. Then, the correlation coefficient decreased to a weak positive and negative correlation $R = 0.19, 0.17, 0.13, 0.1, 0.05, -0.43, -0.004, -0.16, -0.4$.

The statistical analysis data also showed a correlation between the ecological parameters in seawater samples and microbial numbers (N), ranged between a strong negative correlation $R = (-0.56, -0.5)$, during first period and $R = (-0.62, -0.5)$, during the second period, with a weak correlation $R = 0.42, 0.40, 0.18, 0.17, 0.03, -0.13$. While the statistical analysis data showed a correlation between both seasons, with a strong positive correlation between all ecological parameters, with correlation $R = 0.73, 0.69, 0.60, 0.63, 0.59$ in marine sediment and $R = 0.95, 0.84, 0.83, 0.82, 0.74$ in seawater, except (Temp with Temp and N), which had a strong negative correlation $R = (-0.79, -0.5)$ respectively, this is consistent with [38] (Table. 5).

Table 5. Correlation Coefficient (R) between Ecological Parameters: Temp, pH, EC, TDS - Sal, DO and MPN of *E. Coli*, at the Study Area in Marine Sediment and Seawater. [Pre- Monsoon, Post- Monsoon, and between Seasons]

Pre- Monsoon											
Samples	Analysis Variation	Temp & pH	Temp & EC	Temp & Salt	Temp & DO	PH &EC	PH &Salt	pH &DO	EC &Salt	EC &DO	Salt &DO
Sea Sediment	Corr. (R)	0.67	-0.58	-0.58	0.79	-0.78	-0.78	0.78	1	-0.43	-0.43
Seawater	Corr. (R)	-0.43	-0.65	-0.65	-0.57	0.17	0.19	0.66	1	0.59	0.59
Samples	Para. & N.	Temp & N		PH & N		EC & N		Salt & N		DO & N	
Sea Sediment	Corr. (R)	-0.67		-0.95		0.69		0.69		-0.74	
Seawater	Corr. (R)	0.03		-0.5		0.17		0.18		-0.56	
Post- Monsoon											
Samples	Analysis Variation	Temp & pH	Temp & EC	Temp & Salt	Temp & DO	PH &EC	PH &Salt	pH &DO	EC &Salt	EC &DO	Salt &DO
Sea Sediment	Corr. (R)	0.21	-0.12	-0.11	-0.67	-0.77	-0.77	0.36	1	-0.53	-0.53
Seawater	Corr. (R)	0.13	-0.004	0.05	-0.16	0.05	0.1	0.84	0.9	-0.4	0.52
Samples	Para. & N.	Temp & N		PH & N		EC & N		Salt & N		DO & N	
Sea Sediment	Corr. (R)	-0.42		-0.54		0.20		0.21		-0.56	
Seawater	Corr. (R)	-0.13		-0.62		0.42		0.40		-0.5	
Pre & Post – Monsoon											
Samples	Analysis Variation	Temp & Temp		pH & pH		EC & EC		Salt & Salt	DO &DO		N & N
Sea Sediment	Corr. (R)	-0.79		0.69		0.59		0.60	0.73		0.63
Seawater	Corr. (R)	0.15		0.74		0.83		0.84	0.95		0.82

Notes: Temp: Temperature; N: number; Para: Parameters; Salts: (TDS: in marine sediment, Sal: in seawater), Corr. R: Pearson's correlation coefficient.

4. Conclusion

Microbial analysis confirms that seasonal variations-under the influence of natural dynamic factors notably between pre- and post-monsoon periods, and the influx of untreated wastewater are key factors driving the substantial fluctuations and prolonged survival of pathogens (e.g. *E.coli*) in marine sediments and seawater, consequently escalating public health risks through both direct contamination or via the secondary mechanism of resuspension of pathogenic microorganisms from the sediments into the water column

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التقييم الموسمي للتلوث ببكتيريا (*Escherichia coli*) الناتج عن مياه الصرف الصحي غير المعالجة في النظم البيئية البحرية في المكلا وبروم ميفع - حضرموت، اليمن

المخلص: تُعدّ عملية تقييم التلوث البرازي ومراقبة الكائنات الحية الدقيقة المُمرضة، كـبكتيريا القولون (*Coliform*) وغيرها، في البيئات الساحلية المتأثرة بمياه الصرف الصحي المُصرّفة، من الإجراءات الأساسية لتحديد جودة الأنظمة البيئية المائية. استهدفت الدراسة تقييم التلوث في النظم البيئية البحرية لبكتيريا (*Escherichia coli*) على سواحل منطقتي المكلا وبروم بمحافظة حضرموت - اليمن. خضعت عينات الرواسب البحرية ومياه البحر لتحليل بكتريولوجي باستخدام عدد من الاختبارات، مثل العدد الأكثر احتمالاً (MPN)، الاختبار التأكدي واختبار الإندول. كما شمل العمل قياس بعض المعايير البيئية ومقارنتها بالمعايير الموصي بها من قبل منظمة الصحة العالمية (WHO) والمعايير اليمنية المعتمدة. كشفت نتائج الدراسة عن مستويات متفاوتة من التلوث البكتيري في جميع العينات، ولوحظ أن التلوث كان أكثر وضوحاً في عينات مياه الصرف الصحي الخام من محطة المعالجة 19-Fsw، في خلال كلا الموسمين، وظهورها في المواقع Sw, Fw خلال المدة الأولى والمواقع Hs, Mws خلال المدة الثانية. تميز هذا التلوث بظهور لمعان أخضر معدني أو حلقة وردية، وهي علامات تشخيصية مميزة في الاختبارات الميكروبيولوجية. كما أظهرت الدراسة عن التقلبات الموسمية في المعايير البيئية للعينات - تحت تأثير معدلات التصريف والكثافة السكانية - تؤثر تأثيراً حاسماً في بقاء البكتيريا ونموها. لذلك، تؤكد هذه النتائج على الحاجة الملحة لتحسين كفاية عمليات المعالجة والتطبيق الصارم للقوانين الدولية والمحلية لحماية أنظمة البيئة البحرية.

كلمات مفتاحية: النظم البيئية المائية، الرواسب البحرية، مياه البحر، المعلمات البيئية، مياه الصرف الصحي، الإشريكية القولونية، المكلا، بروم ميفع، حضرموت.