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Seasonal and spatial variation in the monitoring parameters of Gaza Beach during 2002–2003

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Abstract

Seawater pollution problems are gaining interest worldwide because of their public health impact and other issues. Levels of pollutants at Gaza Beach determined the only recreational area for the inhabitants of Gaza were recently determined and shown to be high. Five bathing sites in the Middle Camps area along the Gaza Strip coastal area were monitored for 1 year (fortnightly). Seawater samples were subjected to microbiological analysis (fecal coliforms and fecal streptococci) and physiochemical analysis (water temperature, pH, electroconductivity, dissolved oxygen (DO), biochemical oxygen demand, total, Kjeldahlnitrogen, and ammonia). Results revealed seasonal and locational variation in all of the parameters studied. The highest levels of pollution were detected during winter, especially after a rainfall or after a discharge from Wadi Gaza. Locations associated with sewage discharge had the highest fecal indicator levels. Statistical analysis of the data demonstrated significant linear correlations between several parameters (e.g., DO and biochemical oxygen demand, biochemical oxygen demand and fecal coliforms, biochemical oxygen demand and fecal streptococci).

Keywords: Seawater pollution; Seasonal variations; Gaza Beach; Coliform; BOD

1. Introduction

Gaza Beach is considered the only recreational site for a population of more than 1 million in the Gaza Strip (Afifi, 1998). It is usually very crowded during the summer, mostly with local inhabitants. At the local level, the few studies conducted by the Environmental and Rural Research Center (Afifi, 1998), revealed heavily contaminated recreational seawater along the Gaza Strip.

Recreational water generally contains, in addition to indigenous microorganisms, a mixture of pathogenic and nonpathogenic microbes derived from sewage effluents, industrial processes, farming activities, and wildlife. This mixture poses a hazard to bathers in whom an infective dose of pathogen colonizes a suitable growth site in the body and leads to disease (World Health Organization (WHO), 1998).

The extent of seawater pollution varies according to the quantity and quality of the pollutant. However, the problem of seawater pollution is acknowledged worldwide. As a result of recreational activities, many individuals contract diseases that range from self-limiting gastrointestinal disturbances to severe, life-threatening infections. Disease incidence is dependent on several factors: the extent of water pollution, time and type of exposure, immune status of user, and other factors (Bartram and Rees, 2000).

Seawater and beach quality monitoring and assessment are considered vital parts of any integrated coastal management program (Afifi et al., 2000). In this context, social, cultural, environmental, and economic factors should be taken into consideration because of the great variation from one area to another.

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The main source of pollution in the coastal zone of Gaza is the discharge of untreated wastewater along the shoreline, both by the Palestinians and by Israeli settlements. The beaches in front of Gaza City, Beach Camp, and Deir El-Balah are polluted by sewage discharges, and individual sewage drains ending either on the beach or a short distance from the seashore (Afifi et al., 2000).

About 80% of the wastewater that is generated in Gaza is currently discharged without treatment into the sea (50,000 m^3/day). The pollution presents a major health risk for swimmers and marine life; there are also indications that the quality of fish is influenced by coastal pollution. Tourism development in the Gaza strip will depend largely on the extent to which the beaches and coastal cliffs are cleared and remain clean from solid waste, and the extent to which the sewage effluent entering the surf zone of the coastal waters is reduced (Ministry of Environmental Affairs and Palestinian National Authority (MEnA), 2001).

This study attempted to assess the microbiological and chemical quality of seawater along Gaza Beach for 1 year. Hence, it is expected to assist local authorities in developing plans and policies and in implementing actions to reduce the pollution to acceptable levels. It may prove helpful in setting standards and guidelines. Statistical analysis was used to detect significant correlations between various parameters. The relationship between seasonal conditions and pollutant levels was also evaluated.

2. Materials and methods

2.1. Sampling site selection and identification

A total of five sampling locations were selected for the assessment of seawater. Site description, identification data, and global positioning system (GPS) data are recorded in Table 1.

2.2. Sample collection

Sampling was done according to the World Health Organization (1995) Manual for Recreational Water and Beach Quality Monitoring and Assessment (1995). The sampling frequency was fortnightly. Sample collection lasted from May 2002 to 2003.

2.3. Physiochemical analysis

2.3.1. pH, temperature, dissolved oxygen (DO) and electroconductivity (EC)

A field pH meter electrode (Hanna, HI 1280) was used to measure both pH and temperature. Samples were stirred gently and stable readings were recorded (Grasshoff, 1983). DO was measured on site using a DO meter (Jenway 9070). Electroconductivity was recorded using a calibrated EC meter (Jenway, 4310).

2.3.2. Biochemical oxygen demand (BOD)

All BOD measurements are expressed as BOD_5. A graduated cylinder was used to measure 432 mL of the sample (the recommended volume for BOD values of 0–40 mg/L). The sample was transferred to an OxiTop (WTW) bottle, in which a magnetic stirring rod was placed. The rubber quiver was placed in the neck of the bottle to which two sodium hydroxide tablets were added. Measurements were made according to the manufacturers instructions.

2.3.3. Turbidity

The turbidometer (HACH, 2100 A) was calibrated using 2 and 20 nephlometeric turbidity unit (NTU) standards. The sample was gently shaken, and the cuvette was filled and recapped. The cuvette was placed in its position and the light shield replaced. The most stable reading was recorded (American Public Health Association (APHA), 1995).

2.3.4. Total Kjeldahl nitrogen (TKN) and ammonia

TKN and ammonia were measured according to the Standard Methods for the Examination of Water and Wastewater (American Public Health Association (APHA), 1998).

2.3.5. Orthophosphate

A bunch of 0.45-μm membrane filters were soaked in 2 L of distilled water to remove any phosphorus. A drop

Table 1
Sampling site identification information

Location	City	Permanent mark	GPS location	
			N	E
1	South Deir Elbalah	Resort	31.25.03.6	34.19.43.0
2	North Deir Elbalah	Elementary school	31.25.50.6	34.20.34.7
3	Al-Zawida	Resort	31.26.37.8	34.21.22.2
4	South Wadi Gaza	Army station	31.27.40.7	34.22.23.7
5	North Wadi Gaza	Lifeguard station	31.27.56.2	34.22.37.9

of phenolphthalein indicator was added to 50 mL filtered sample. Activated carbon was used to remove excess color. Thirty-five milliliters of sample was placed in a 50 mL volumetric flask containing 10 mL of vandate–molybdate reagent and diluted to the mark with distilled water. The absorbance was read after 10 min at 490 nm, and the concentration was calculated from a standard curve (Keeper, 1998).

2.4. Microbiological analysis

2.4.1. Fecal coliform

A 0.45-μm Millipore sterile membrane was placed on the filter support assembly. The funnel portion was placed and fitted. The sample or sample dilution was mixed by shaking it at least 30 times, the required volume was poured into the funnel, and vacuum was applied to assess rapid filtration. The membrane filter was aseptically removed and placed in the center of a prelabeled mFC culture plate, which was then was sealed and incubated in a water bath incubator at 44.5±0.2 °C. The plates were incubated for 24 h and blue colored colonies were counted (Donnison and Cooper, 1990). Three to five colonies from each plate were picked and biochemical tests were performed to confirm the identity (APHA, 1995).

2.4.2. Fecal streptococci

Fecal streptococci were analyzed similarly to fecal coliforms, however, the membrane filters were transferred to Slanetz and Bartely medium instead of mFC. Plates were incubated at 37 °C for 4 h and at 44 °C for 44 h. Red, maroon, or pink colonies were counted as presumptive fecal streptococci. Colonies were confirmed by subculture on MacConkey No. 2 (Oxoid) and with the bile esculine test (APHA, 1995).

2.5. Statistical analysis of data

Data obtained from seawater samples were entered as Microsoft Excel sheets, uploaded to SPSS software, and analyzed using the Pearson correlation coefficient (a measure of linear association) and paired sample t test to detect significant variations among parameters in different locations.

3. Results

3.1. Temperature

Seawater temperature differed little by location, as indicated by the overall average. This variation may be due to the amount of sewage input and runoff. Temperature varied from 14.4 to 31.1 °C. Statistical analysis (the Pearson correlation) showed that temperature correlated significantly with DO in most locations (Fig. 1) and with EC in all locations.

3.2. pH

Most pH measurements were found to be in the acceptable range, 7.5–8.5 (Harvey, 1955) for all locations during the whole monitoring period, except for winter when there was a slight increase in pH. This might be related to the drop in electroconductivity as shown by the significant correlations between pH and EC in three locations (Fig. 2).

3.3. Electroconductivity

Electroconductivity measurements did not vary significantly with location or time. EC correlated significantly with temperature at all locations; with pH at locations 1, 4, and 5; and with fecal streptococci at locations 4 and 5. From Fig. 3, it can be seen that locations 4 and 5 exhibited a similar pattern during the monitoring period. Slightly lower values were obtained during the rainy season; these values started to rise at the end of the season.

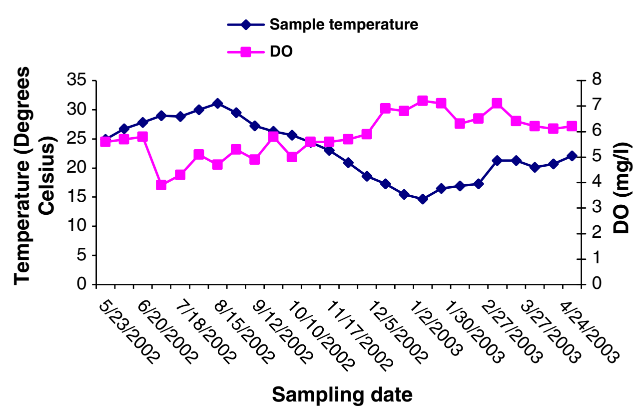

Fig. 1. Temperature and dissolved oxygen levels in location 4.

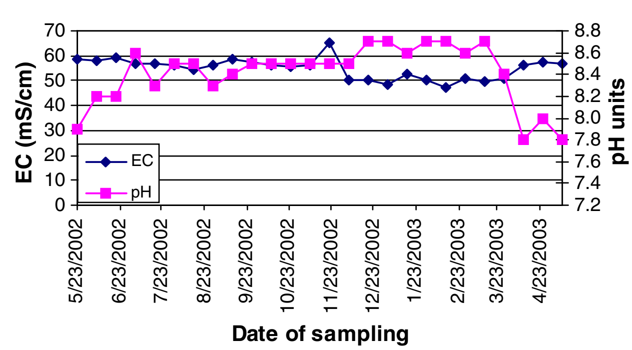

Fig. 2. pH and electroconductivity levels in location 4.

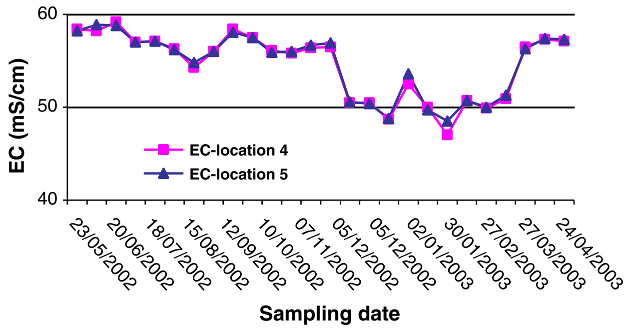

Fig. 3. Electroconductivity levels in locations 4 and 5.

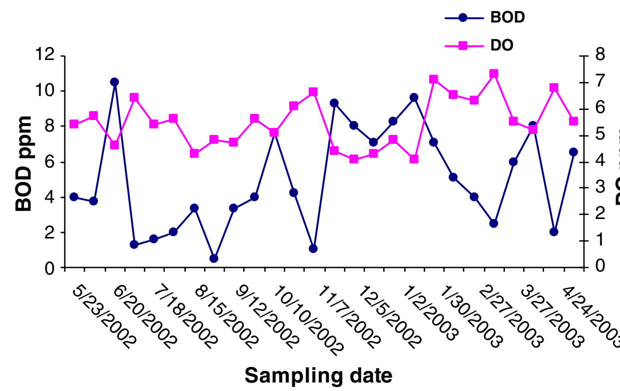

Fig. 4. Biochemical oxygen demand and dissolved oxygen levels in location 5.

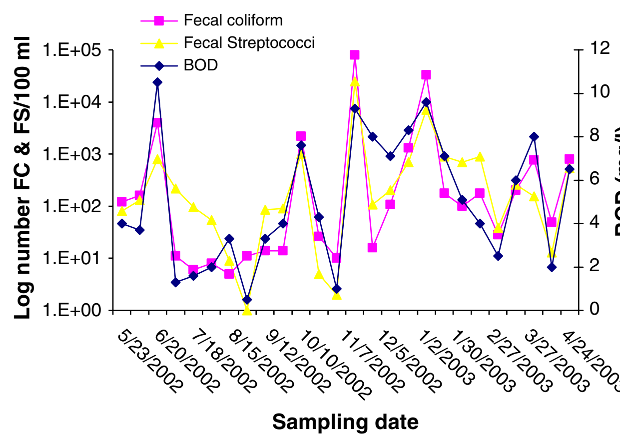

Fig. 5. BOD in relation to FC and FS in location 5.

3.4. Turbidity

There was considerable variation between locations. Also, turbidity was higher in winter than in summer. Location 2 had the highest turbidity most of the time, and this may be attributed the large amount of raw sewage input and subsequent algal growth. Turbidity correlated positively with BOD, DO, ammonia, TKN, and both fecal coliforms and fecal streptococci.

3.5. Dissolved oxygen (DO)

DO dropped to alarming levels at almost all locations during certain collection periods. The average did not vary greatly but it is evident that DO was inversely related to BOD as shown in Fig. 4 which illustrates the seasonal variation in both DO and BOD at in location 5.

3.6. Biochemical oxygen demand

There is a clear difference in BOD levels at all locations studied. This difference may be related to the distance and the direction of a given location from a sewage discharge point.

The lowest average BOD scores were measured at locations 1 and 3 that these sites were indicating the least polluted with organic matter. Location 2, 5, and 4 had the highest BOD levels. Thus, organic pollutant input to the various locations is not consistent, as indicated by the wide difference between the minimum and maximum BOD values at all locations. To illustrate the relationship between BOD and fecal indicators, the researchers selected location 5, which is heavily contaminated with sewage. From Fig. 5, it is clear that a high BOD value is almost associated with high fecal coliform and fecal streptococcus counts and vice versa.

Seasonal variation in BOD is illustrated in Fig. 5, which demonstrates relatively low levels during dry months in comparison to the wet season, during which rainfall and runoff add organic materials from land-based sources and the Wadi Gaza floods. It can also be seen that BOD levels reached very low levels (<1 mg/L). This clearly indicates the possibility of rehabilitation due to the dilution and high self-purification capacity of the sea in a relative short period, as it was noticed that the Wadi Gaza stopped charging into the sea the preceding month.

3.7. Total Kjeldahl nitrogen and ammonia

Ammonia is the form of nitrogen most readily available to marine life and microorganisms. The presence of ammonia and nitrogenous sources in large amounts may result in eutrophication, leading to algal blooms and anoxic conditions.

Locations 1 and 3 had the lowest ammonia and TKN concentrations, where as location 2 had the highest concentrations. Although a part of TKN, ammonia did not statistically correlate linearly with TKN except at location 1. This might be due to the relative ease with which marine organisms consume ammonia compared with other nitrogen sources measured by the TKN method. Ammonia correlated with turbidity (1, 3, and 5), with BOD at locations 2, 4, and 5, and with fecal indicators at locations 2 and 3. Fig. 6 summarizes the ammonia and TKN concentrations in seawater during the monitoring period at location 1.

The data collected for both ammonia and TKN did not exhibit an obvious seasonal trend; however, both parameters exhibited a similar pattern, suggesting a similar source.

3.8. Orthophosphate

Orthophosphate concentrations were highest at location 5 followed by location 2 (Fig. 7). Both locations are surrounded by agricultural areas, which may contribute to these relatively higher levels. That is in addition to the wastewater outlet at location 2 and the Wadi Gaza outlet at location 5. No significant correlation was observed between orthophosphate and any other parameter at any location.

Almost all high concentrations of orthophosphate were followed by algal blooms, as evident by visual observation of both water color (greenish) and the deposits of algae on the sandy beach at Location 5. This enforces the proposed role of phosphorus in the process of eutrophication.

3.9. Fecal coliforms and fecal streptococci

Runoff, floods, and sewage discharge release large numbers of microorganisms, including fecal indicators, into seawater. This was clearly demonstrated by the high fecal coliform and fecal streptococcus contents of sites adjacent to discharge points (e.g., locations 2 and 5). Although, location 4 is near a discharge point (south of Wadi Gaza), fecal coliforms and streptococci were relatively low when compared with location 5 (north of Wadi Gaza). Location 3 seems to be affected by the pollution of location 2 as evident by higher levels of fecal streptococci than coliforms (fecal) streptococci survive longer than coliforms and are considered as an indicator of relatively old sewage pollution).

Fecal coliform levels correlated significantly with fecal streptococcus levels at locations 2, 3, and 5 and with BOD at locations 4 and 5, whereas fecal streptococcus levels correlated with BOD only at location 5.

Location 2 had the highest percentage of failures. Unfortunately, during the monitoring period, there were no public notifications in any form and bathers were observed in large numbers during the bathing season.

The results for both fecal coliforms and fecal streptococci, which covered the four seasons, indicated an increase during winter and after almost every rainfall, as illustrated by (Figs. 8 and 9). Note that at all locations, concentration peaked within the rainy season. Failures to comply with EU standards occurred mainly during the rainy season. This increase is thought to be mainly the result of runoff and floods that carry organic and microorganisms.

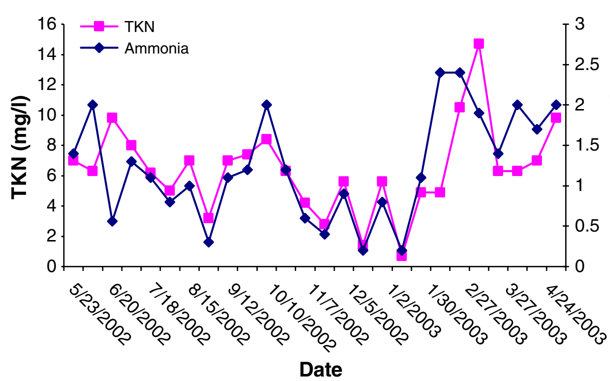

Fig. 6. TKN and ammonia levels in location 1 during the monitoring period.

3.10. Spatial variations

Paired t tests were used to detect variations in the measured parameters with location in the study area. Pearson's correlation was used to detect linear correlations between various locations. Table 2 summarizes the paired t test results and the Pearson correlations of ammonia, BOD, DO, and EC in seawater samples.

The results indicated no significant difference in the EC values measured at all locations, but significant differences were noted for BOD, ammonia, and DO. These significance differences justify the performance of these tests over a short distance and prove that there is a

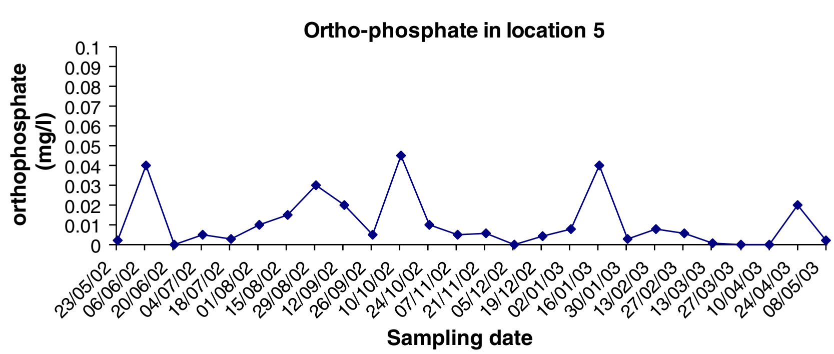

Fig. 7. Ortho-phosphate level in location 5 during 2002–2003.

real difference between the locations chosen. As indicators of organic pollution, BOD levels did not vary significantly between locations 1 and 3 (both sites proved less polluted than others) and 4 and 5 (which received similar amounts of organic pollution from Wadi Gaza). Table 3 illustrates the results of statistical analysis (paired *t* test and Pearson correlation) of FC, FS, turbidity, and TKN in seawater samples.

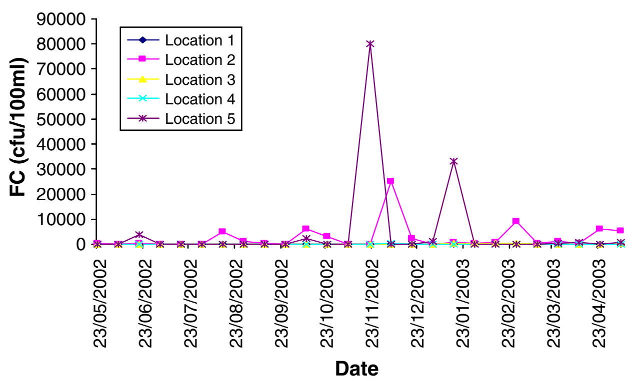

Fig. 8. Fecal coliform from all locations during the study period.

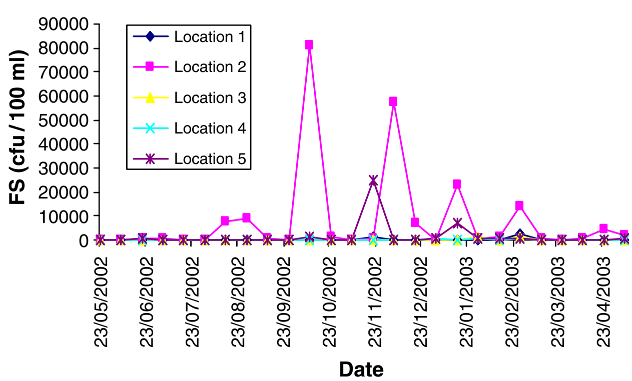

Fig. 9. Fecal streptococci from all locations during the study period.

Fecal coliform and fecal streptococcus levels had similar variations with location, with one exception. Levels of both varied significantly between locations 1 and 2, 2 and 3, and 2 and 4. Despite the fact that location 3 seems to be affected by pollution coming from location 2, levels of fecal coliforms and fecal streptococci both varied significantly and this variation may be due to the dilution effect and the distance between the two locations.

Turbidity also varied significantly with location, almost similar to levels fecal coliforms and streptococci. TKN values were highly correlated linearly.

Table 4 summarizes the results of statistical analysis (paired *t* test and the Pearson correlation) of pH, phosphorus, temperature, and fecal coliform/fecal streptococcus ratio in seawater samples.

pH and temperature almost showed 100% linear correlation among the various locations with one exception for temperature, which varied significantly between locations 2 and 5. This could be explained by the fact that these two particular locations received the largest amount of wastewater, which may affect the temperature during the measuring period.

4. Discussion

Seawater pH typically ranges between 7.5 and 8.5 and is influenced by temperature, pressure, and the photosynthetic and respiratory activities of microorganisms (Harvey, 1955). An acidic pH (~5.0) was found to be most favorable to survival of *Escherichia coli* (in the 5.0–9.0 range) in both seawater and NaCl solutions, and sensitivity increased with the increase in pH (Carlucci and Pramer, 1960). The former authors concluded that seawater pH, normally about 8.0, contributes to the deleterious effects on *E. coli* survival.

Almost all pH values measured were within the normal range; however, All locations showed higher

Table 2
Paired *t* test and the Pearson correlation results for ammonia, BOD, DO, and EC in seawater samples[a]

Paired locations	Ammonia		BOD		DO		EC	
	Pearson	*t* test	Pearson	*t* test	Pearson	*t* test	Pearson	*t* test
1 & 2	0.124	**0.000**	**0.017**	**0.000**	**0.002**	0.674	**0.003**	0.389
1 & 3	**0.018**	0.670	0.650	0.549	**0.004**	0.406	**0.000**	0.592
1 & 4	**0.001**	0.058	**0.032**	**0.090**	**0.000**	0.325	0.063	0.302
1 & 5	**0.032**	0.086	0.727	**0.001**	0.661	0.042	**0.087**	0.234
2 & 3	**0.004**	**0.000**	**0.004**	**0.000**	**0.000**	0.586	**0.000**	0.364
2 & 4	0.080	**0.004**	**0.009**	**0.001**	**0.000**	0.185	**0.000**	0.385
2 & 5	0.285	**0.006**	0.074	**0.013**	0.316	**0.020**	**0.000**	0.221
3 & 4	**0.014**	0.239	0.453	**0.016**	**0.000**	**0.025**	**0.000**	0.296
3 & 5	**0.024**	0.239	0.525	**0.000**	0.696	**0.021**	**0.000**	0.205
4 & 5	**0.004**	0.993	**0.028**	0.179	0.547	0.131	**0.000**	0.088

[a]Significant values in boldface. Correlations are significant at the ⩽0.05 level.

Table 3
Paired t test and the Pearson correlation results for fecal streptococci, turbidity, and TKN in seawater samples[a]

Paired locations	Fecal coliforms		Fecal streptococci		Turbidity		TKN	
	Pearson	t test	Pearson	t test	Pearson	t test	Pearson	t test
1 & 2	0.244	**0.019**	0.924	**0.041**	0.067	**0.001**	0.097	**0.003**
1 & 3	**0.001**	0.144	**0.002**	0.974	**0.027**	0.383	0.084	0.596
1 & 4	**0.000**	**0.002**	0.076	0.650	**0.001**	0.975	**0.032**	0.635
1 & 5	0.908	0.162	0.029	0.172	0.419	0.053	**0.000**	0.398
2 & 3	0.649	**0.021**	0.992	**0.041**	**0.001**	**0.001**	**0.009**	**0.013**
2 & 4	0.080	**0.020**	0.961	**0.040**	0.068	**0.000**	**0.002**	**0.009**
2 & 5	0.539	0.548	0.933	0.095	0.966	0.216	0.214	**0.023**
3 & 4	**0.013**	0.909	**0.000**	0.409	**0.000**	0.144	**0.000**	0.936
3 & 5	0.961	0.165	0.872	0.192	0.071	0.117	**0.041**	0.996
4 & 5	0.801	0.165	0.887	0.176	**0.001**	**0.002**	0.055	0.956

[a]Significant values are in boldface. Correlations are significant at the ⩽0.05 level.

Table 4
Paired t test and the Pearson correlation results for pH, orthophosphate, temperature, and fecal coliform/fecal streptococcus (FC/FS) ratio in seawater samples[a]

Paired locations	pH		Orthophosphate		Temperature		FC/FS ratio	
	Pearson	t test	Pearson	t test	Pearson	t test	Pearson	t test
1 & 2	**0.000**	0.736	0.144	0.385	**0.000**	0.551	0.642	0.924
1 & 3	**0.000**	0.778	0.181	0.201	**0.000**	0.477	**0.032**	**0.010**
1 & 4	**0.000**	0.034	0.089	0.203	**0.000**	0.393	0.573	0.161
1 & 5	**0.000**	0.015	0.888	0.365	**0.000**	0.421	0.075	**0.025**
2 & 3	**0.000**	1.000	0.368	**0.049**	**0.000**	0.178	0.498	0.134
2 & 4	**0.000**	0.073	**0.001**	**0.012**	**0.000**	0.069	0.943	0.170
2 & 5	**0.000**	0.107	0.993	0.528	**0.000**	**0.022**	0.841	**0.028**
3 & 4	**0.000**	0.115	0.357	0.954	**0.000**	0.281	0.614	0.077
3 & 5	**0.000**	0.137	0.880	0.208	**0.000**	0.312	0.825	**0.003**
4 & 5	**0.000**	1.000	0.873	0.207	**0.000**	0.531	0.000	0.955

[a]Significant values in boldface. Correlations are significant at the ⩽0.05 level.

values at some points during the monitoring period. This may be explained by algal growth and depletion of CO_2, which is conversely related to pH. When all seawater measurements were pooled and statistically analyzed using the Pearson correlation coefficient, pH correlated negatively with EC, temperature, ammonia, and TKN. These factors (temperature, ammonia, and TKN) are important in the process of algal growth and therefore could be considered to be a factor controlling CO_2 and, consequently, affecting pH values. This finding is supported by Schulze et al. (2001). Algal blooms, which are often initiated by an overload of nutrients, can cause pH to fluctuate dramatically over a few-hour period; greatly stressing local organisms.

DO concentrations in surface waters are influenced by several factors. DO results are considered by many as difficult to interpret (Schulze et al., 2001). In this study, DO concentrations ranged from 3.9 to 8.2 and varied greatly between various locations and within a particular location. Statistical analysis revealed a positive correlation between DO and turbidity and a negative correlation between DO and temperature, EC, temperature, and fecal coliforms. The positive correlation between turbidity and DO can be explained by the turbulence, which caused turbidity, increasing the chance of molecular oxygen dissolving in water. The negative correlation of DO with temperature is well documented (Bartram and Rees, 2000; Schulze et al., 2001). Fecal coliforms are known to be facultative anaerobes, and when present in high concentrations use oxygen. However, this finding was totally different from that of Guillen et al. (2000), in which DO was positively correlated with fecal coliforms. This difference in results may be attributed to other factors such as temperature and level of pollutants.

Unpolluted natural waters have a BOD of 5 mg/L or less (Schulze et al., 2001). The BOD levels at all locations were in this study were higher levels on at least one sampling occasion. Average values were ⩽5 mg/L except for location 2, at which the average was 7.6 mg/L. Interestingly, BOD levels correlated well with nutrients (ammonia and TKN), turbidity, and fecal coliforms. These positive correlations are logical and can be explained by the fact that the presence of nutrients under normal conditions supports the growth of bacteria as well as other microorganisms, leading to higher BOD levels as well as a corresponding increase in the fecal coliform count. This finding is supported by a different researcher (Jannasch, 1968), who demonstrated that *E. coli* competed successfully with five marine bacterial isolates in nutrient-enriched seawater. Lopez-Torres et al. (1988), in their study of *Klebsiella pneumoniae* and *E. coli* in membrane diffusion chambers located at coastal areas in Puerto Rico, showed increased survival of *E. coli* and to a lesser extent, *K. pneumoniae* in a site receiving rum distillery effluents. The density of *E. coli* declined immediately after the effluent discharge stopped, suggesting that the organic load improved their survival, as already shown by Carlucci and Pramer (1960), who found that *E. coli* survival improved with increasing concentrations of nutrients, both organic and inorganic. The effect of organics was pronounced when peptone and sewage volatile solids were added, but not glucose. Rozen and Belkin (2001) indicated that while the presence of nutrients actually allows *E. coli* to grow in seawater, their absence does not necessarily affect survival (colony formation) of nongrowing cells.

Orthophosphate in the water comes mainly from fertilizers, and in general, excess phosphates enter water bodies from water treatment plants, sewage, and soils. In recent years there has been a change to more intensive agricultural production, especially animal production. This change has resulted in the buildup of soil phosphorus to levels rarely encountered in the past. As a result, there is increased potential for phosphorus losses to surface water (Rodecap, 2000).

There are no criteria for phosphates; however, the following criteria have been proposed. To prevent the development of biological nuisances and to control eutrophication, orthophosphate should not exceed 0.05 mg/L in a stream discharging into a reservoir, and the concentration should not exceed 0.02 mg/L within a reservoir (Environmental Protection Agency (EPA), 1986). Restoration of most eutrophic waters requires the reduction of nonpoint inputs of P and N (Carpenter et al., 1998). Increased growth of algae and also aquatic weeds can degrade water quality and interfere with use of the water for fisheries, recreation, and industry. As overabundant nuisance plants die, bacterial decomposers proliferate; as they work to break down plant matter, the bacteria consume more DO from the water. The result can be oxygen shortages that cause fish kills. Eutrophication can lead to loss of habitats such as aquatic plant beds in fresh and marine waters and coral reefs along tropical coasts. Thus, eutrophication plays a role in the loss of aquatic biodiversity.

High levels of turbidity over long periods can greatly diminish the health and productivity of the marine ecosystem. Turbid waters decrease light penetration into the water, thereby reducing the area available for submerged aquatic plants to grow. In this study, turbidity levels varied among the various locations. Location 2 had the highest average level. Interesting findings are those statistical correlations between turbidity and BOD, DO, ammonia, TKN, fecal coliforms, and fecal streptococci. From these findings, one might consider turbidity an excellent parameter in monitoring seawater quality.

Seasonal variation was prominent in almost all of the pollution indicators. Several factors can be used to justify such variations. Research has proven that in the absence of sunlight, fecal indicators survive for days in seawater samples, whereas in the presence of sunlight, 90% of fecal coliforms and fecal streptococci are inactivated within 30–90 and 60–180 min, respectively (Fujioka et al., 1981). The same authors were able to demonstrate that sunlight was able to penetrate at least 3.3 m of clear seawater.

The highest concentration of fecal indicators was found in an area receiving land runoff during the rainy season. In another study and during the summer period, no *E. coli* were isolated from all sampling points, whereas in autumn, the organism was isolated in most of sampling points used in the study (Divizia et al., 1997).

In a study by Vidal and Lucena (1997), the impact of heavy rains on the microbiological quality of water persisted a few days and depended on the amount and intensity of rain and weather conditions after the rain episode.

5. Conclusion

The results of this study demonstrate that high levels of pollutants are associated with sewage input and runoff. Most of the parameters varied with location and season. Understanding the seasonal variation may be helpful in determining the actions necessary to minimize pollution sources, as well as the risks associated with pollution.

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