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Spatial and Temporal Variations in Water Quality along the Coast of Gaza Strip

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Abstract

This study describes the results of monthly sampling of physico-chemical parameters and faecal indicators at five monitoring stations on the Gaza coast over a seven-month period in 2007. The results show spatial and temporal variations in physico-chemical parameters (pH, water temperature, salinity, turbidity and dissolved oxygen) and faecal indicators (faecal coliform and faecal enterococci) that appeared linked with the problems of raw sewage discharge and storm water runoff.

Analysis of variance confirmed that stations close to the raw sewage discharge points had significantly higher faecal coliform and faecal enterococci levels than stations free from any sewage discharge. The data indicates high microbiological contamination of seawater above internationally accepted limits, especially at stations close to sewage outlets. Salinity, turbidity and dissolved oxygen levels also varied significantly, also under thee influence of sewage and storm runoff.

Keywords: physico-chemical parameters; faecal bacteria; Seawater quality; Gaza Strip

1. Introduction

Water quality awareness in the world is constantly growing and stream cleaning projects were a common phenomenon during the last decade, however, great awareness of the importance coastal protection and deterioration of Gaza seawater quality have been recently developed among government departments, universities and research centers in Palestine.

Declining trends in environmental quality of the Mediterranean Sea were evident more than two decades ago, when the countries bordering the Mediterranean convened a meeting in Barcelona to adopt the Mediterranean Action Plan (MAP) in 1975, and the Convention for the Protection of the Mediterranean Sea against Pollution (the Barcelona Convention) in 1976 (METAP, 1998).

Many studies have shown that the changes of physico-chemical and biological seawater quality parameters are a result of sewage discharges and other factors such as storm water runoff, marine traffic and coastal land use conflicts. At the regional level in the Mediterranean Sea, large number of different indicators and parameters has been used in different studies to assess the seawater quality and long-term programme for pollution monitoring and research in the Mediterranean coastal water.

Across the globe in different coastal waters, the effect of sewage discharge and storm water runoff on the seawater quality is well documented (Lipp et al., 2001; Muniz et al., 2002; Al-Sayed et al., 2004). The analysis of monthly physico-chemical and biological data collected from 18 marine monitoring stations showed that the water quality of Victoria Harbour is heavily influenced by the effluents discharged from sewage screening plants outfalls and storm water runoff (Yung et al., 1999).

Numerous epidemic and cases related to swimming in recreational waters have long been reported. Most studies reported a dose-related increase of health risk in swimmers with an increase in the indicator-bacteria count in recreational waters (Fleisher et al., 1993; Fewtrell et al., 1994).

A recent review of more than 22 selected studies has reported gastro-intestinal, eye, ear and skin symptoms as the most common health problem related to the count of indicator bacteria in recreational waters showed that a dose-related increase of health risk in swimmers with an increase in the indicator-bacteria count in recreational waters (Pruss, 1998).

At the local level, attempts to monitoring the seawater quality of Gaza strip are limited. There is a recent and modest quality-monitoring programme done by the Ministry of health in 1999 by measuring some bacterial parameters (Faecal coliform, Total coliform and faecal streptococci) from different sites along the coast. This programme has indicated a high bacterial numbers in seawater especially in locations near sewage outfalls

(MOH, 1999).

The purpose of this study is to assess the spatial and seasonal variation in both the physico-chemical and faecal variables of coastal water along the Gaza Strip. It was intended to assess whether microbiological parameters have changed since earlier studies, whether physico-chemical parameters varied similar way, and whether temporal variation could be attributed to seasonal variation in rainfall and effluent discharge.

2. Material and methods

2.1 Locations and sampling

Gaza Strip is one of the most densely populated areas in the world, with an estimated 1.3 million people living in an area of 365 km2, or around 3,600 people per km2. If one deducts the land that is taken up by Israeli settlements, this yields an even higher population density, which is one of the highest in the world. With a Palestinian population growth rate of around 4.8 percent per annum, which would result in a doubling of the population in 20 years, effective management and sustainable development of Gaza's resources will be a huge challenge for the Palestinian Authority (UNDP, 2002).

Five stations along the Gaza Strip shoreline were selected. Station 1 is located in the northern part of Gaza Strip and station 5 is located south of Wadi Gaza. Both stations 1 and 5 are situated in clear water. It is determined to consider the position in where no obvious sources of pollution. Station 2 is located between Beach camp and El-Sheikh Redwan and station 4 is located in the middle part of Gaza strip shoreline. Stations 2 and 4 lay at the outfall of major raw sewage discharge but station 3 is located north of Wadi Gaza lay at the outfall of a partial treated sewage.

Initially seawater samples and field measurements were collected from a 50cm depth in all and measured from the stations between January 2007 and July 2007. These stations have been chosen to obtain a representative distribution pattern and a general condition of coastal water quality in Gaza Strip.

Field measurements and counting bacterial communities: Temperature, pH, dissolved oxygen, salinity and turbidity were made in situ using a digital glass thermometer, a battery operated pH meter (Radio-meter model pH 82), dissolved oxygen meter (HI 8043) and refractometer (PR/GE 14035) respectively.

Samples for bacterial analysis were collected in sterile glass stopper bottles. All samples were collected and kept in an icebox, transferred to the laboratory. Faecal coliform and faecal enterococci were counted by standard membrane filter procedure using –Faecal coliform agar and Membrane Enterococcus agar media respectively.

This study includes 5 sampling points. Sampling was carried out every month for 7 months (January, February, March, April, May, June and July 2003). At each sampling event four samples were obtained from 50 cm deep of seawater at fixed stations for field measurements and three samples were obtained from the same depth and stations for the bacterial communities.

2.2 Statistical analysis of data

A combined two factor of analysis of variance was used to examine differences between stations and months. Differences between mean concentration of each physical parameter and bacterial communities at each station at different months and locations were tested singly by using one factor of analysis and Post hoc testing. Minitab and Excel software were used to done the statistical analysis.

3. Result and discussions

The average of all physical analyses at each station is presented in Table 1.2. The data revealed spatial and temporal variations in seawater quality along the Gaza Strip shoreline. The observed variations of physical parameters and biological parameters (bacterial communities) among stations and months were statistically analysed using two-way ANOVA (Table 1 and 2). The results showed stations and monthly data of physical parameters main affects as well as their interaction effect on pH, water temperature, salinity, turbidity and dissolved oxygen were significant ($P<0.01$). This result indicates the variations existing between stations except for pH and Water temperature on the other hand; responses between months were variable too, except for salinity and pH. The overall mean for salinity, turbidity and dissolved oxygen parameters at different stations were specifically compared by using (one-way ANOVA) the results indicate significant spatial variations occurred between stations. To understand and explain the variation among each parameter the Post hoc testing was carried out.

The study period was seven months from January-July 2007 which represent the (rainy winter season and dry summer season). The samples were taken from five stations and from each station; four samples were taken at the same time to measure the physical parameters (pH, Seawater temperature, salinity, turbidity and Dissolved oxygen).

Table 1: Summary of calculations of the combined (two-factor) ANOVA of the physico-chemical characteristics of the Gaza coastal water

Parameter	Variation	d.f.	Sum of squares (ss)	Mean square (ms)	F-ratio	P
pH	Stations	4	0.2476	0.0619	2.42	0.053NS
	Months	6	0.1439	0.0240	0.94	0.471NS
	S*M Interaction	24	0.4954	0.0206	0.81	0.719NS
Water temperature	Stations	4	1.67	0.42	0.42	0.797NS
	Months	6	2390.35	398.39	397.52	<0.01*
	S*M Interaction	24	16.66	0.69	0.69	0.849NS
Salinity	Stations	4	6355.61	2370.34	1155.58	<0.01*
	Months	6	94.50	3.55	1.73	0.121NS
	S*M Interaction	24	558.14	3.49	1.7	0.035*
Dissolved Oxygen	Stations	4	530.768	132.692	364.43	<0.01*
	Months	6	13.688	2.281	4.9	0.01*
	S*M Interaction	24	16.817	0.701	0.8	0.689NS
Turbidity	Stations	4	530.2	132.60	145.27	<0.01*
	Months	6	23.89	3.983	4.36	<0.01*
	S*M Interaction	24	223.51	9.313	10.20	0.003*

*Statistically significant at P<0.01; NS: not significant.

Table 2: Variations of the physico-chemical parameters (mean ± standard error) at the five stations.

Sampling Stations	Water Temperature	Salinity	pH	Turbidity	Dissolved Oxygen
Station 1	22.49±4.42	35.83± 1.14	8.271±0.15	0.89± 0.48	9.76±0.87
Station 2	22.67±4.20	22.32± 4.74	8.268±0.17	7.23±1.52	5.35±0.54
Station 3	22.83±4.31	27.23± 4.08	8.311±0.18	4.56±1.03	8.6±0.66
Station 4	22.71±4.24	19.14±3.30	8.375±0.13	7.34± 1.15	5.43±0.47
Station 5	22.63±4.39	35.37±1.58	8.264±0.14	1.14± 1.10	10.12±0.77
ANOVA P	0.999NS	0.000*	0.422NS	0.000*	0.008*

* Statistically significant at P<0.01; NS: not significant.

3.1 Physical-chemical parameters

Statistical comparisons and the combined two-factor analyses of variance for pH revealed non-significant differences between stations as well as months. The pH of Gaza seawater varies between 7.9 and 8.5. Inspection of sea water temperature profile showed that water values at the five stations were similar and no distinct spatial pattern was found on the other hand sea water temperature at all stations exhibited significant monthly variations (ANOVA: d.f. = 6, F= 397.52; P<0.01), sea water temperature at all stations was consistently higher in the dry summer season (April, May, June, and July) than the rainy winter season (January, February and March), the temperature varies from 14.0^{o} to 30.0^{o} C.

Statistical comparisons and the combined two-way ANOVA analyses of variance for dissolved oxygen revealed a high significant difference between stations as well as months. The statistical analysis by using two-way ANOVA shows a spatial variation between the stations (ANOVA: d.f. = 4, F=364.43; *P*<0.01). The overall mean of each parameter at different stations were specifically compared using one-way ANOVA and Post hoc testing (ANOVA: d.f. = 4, F= 318.71; *P*<0.01). The Fisher's pair wise comparisons show a significant difference between the following stations (1 and 2, 1 and 4, 2 and 3, 2 and 5, 3 and 5, 4 and 5). The dissolved oxygen of Gaza seawater varies between 4.5 and 7.0 mg/L. The effect of the raw sewage discharge and the runoff are very clear which caused the significant difference between the stations with no source of pollution (1 and 5) and the stations lay at the outfalls of raw sewage discharge (2, 3 and 4) Figure 1.

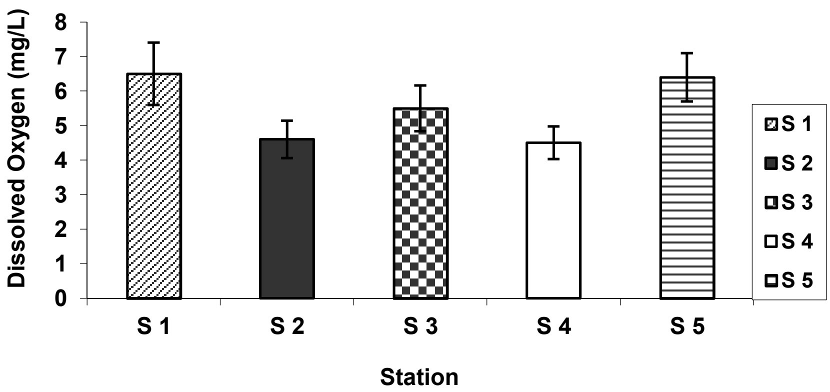

Figure 1: Dissolved oxygen averages at the five stations. For each station, the average ± standard error is calculated.

Inspection of monthly dissolved oxygen profile by using one-way ANOVA and Post hoc testing showed that dissolved oxygen concentration at S1, S2, S3 and S 5 were similar, and no distinct monthly trend was found. On the other hand stations (S4), however, dissolved oxygen exhibited significant monthly variations at P<0.01. Interestingly, dissolved oxygen was lower in rainy winter season in (January, February and March) than in the dry summer season because station 4 lays at the Wadi Gaza mouth and received a lot of runoff during the rainy months (ANOVA: d.f.=6, F=246; P<0.01). The monthly average values of dissolved oxygen presented in (Figure 2).

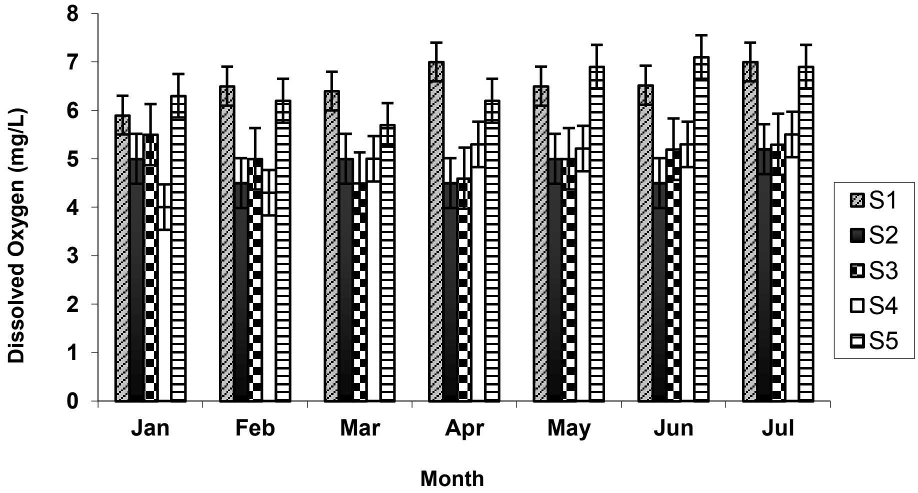

Figure 2: Monthly average of dissolved oxygen values at the five stations. For each month, the average ± standard error is calculated.

Salinity has varied greatly spatially between stations; data indicate that salinity was significantly higher in stations 2, 3 and 4, lower than stations 1 and 5 (ANOVA: d.f. =4, F= 208.71; P<0.01).

The effect of fresh water discharge as a result of raw sewage discharge caused the decrease of salinity in stations 2 and 4 and since station 1 and 5 are situated in clear water their was no significant variation between the two stations and the salinity concentrations was high and similar, therefore (Post hoc testing, the Fisher's pair wise comparisons and one-way ANOVA) shows that the salinity in stations 2,3 and 4 are very different from stations 1 and 5 (ANOVA: d.f. =4, F=998.49; P<0.01). Figure 3 presents the average values of seawater salinity at the different stations. The combined two-factor analyses of variance for salinity revealed non-significant differences between months. The measurements in this study indicate that the salinity values ranges between 15 PSU to 37.5 PSU.

Statistical comparisons and the combined two-way ANOVA analyses of variance for turbidity revealed a high significant difference between stations as well as months (Figure 4). The statistical analysis by using two-way ANOVA shows a spatial variation between the stations (ANOVA: d.f. = 4, F=145.2; P<0.01). The overall turbidity averages at different stations was specifically compared using one-way ANOVA and Post hoc testing (ANOVA: d.f. = 4, F= 52.15; P<0.01). The Fisher's pair wise comparisons show a significant difference between the following stations (1&2, 3, 4), (2& 3, 5), (3&4, 5) and (4&5). The turbidity of Gaza seawater varies between 0.8 and 7.0 (NTU). The effect of the raw sewage discharge and the runoff are very clear which caused the significant difference between the stations with no source of pollution (1 and 5) and the stations lay at the outfalls of raw sewage discharge (2, 3 and 4).

All stations exhibited significant monthly variations (ANOVA: d.f.= 6, F= 4.36; P<0.01), turbidity at all stations was consistently higher in the rainy winter season (January, February, March and April) than the dry summer season (May, June, and July), the turbidity varies from 0.5 to 9.5 NTU. The turbidity gradually decreased after April in the free pollution runoff stations (S1&S5) on the other hand the turbidity was high in the polluted station during summer and winter seasons as a result of raw sewage runoff discharge. Figure 5 shows the monthly average values of seawater turbidity at the different station.

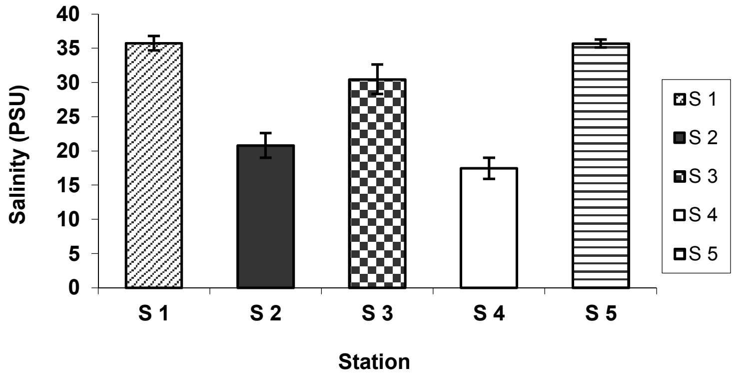

Figure 3: The average of salinity values at the five stations. For each station, the average ± standard error is calculated.

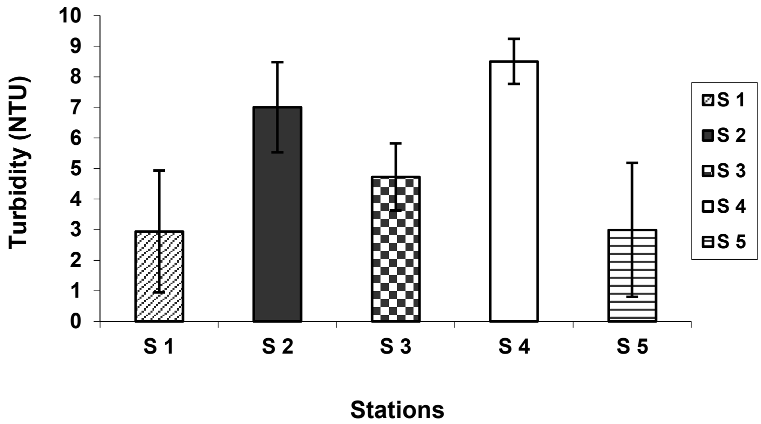

Figure 4: The average of turbidity values at the five stations. For each station, the average ± standard error is calculated

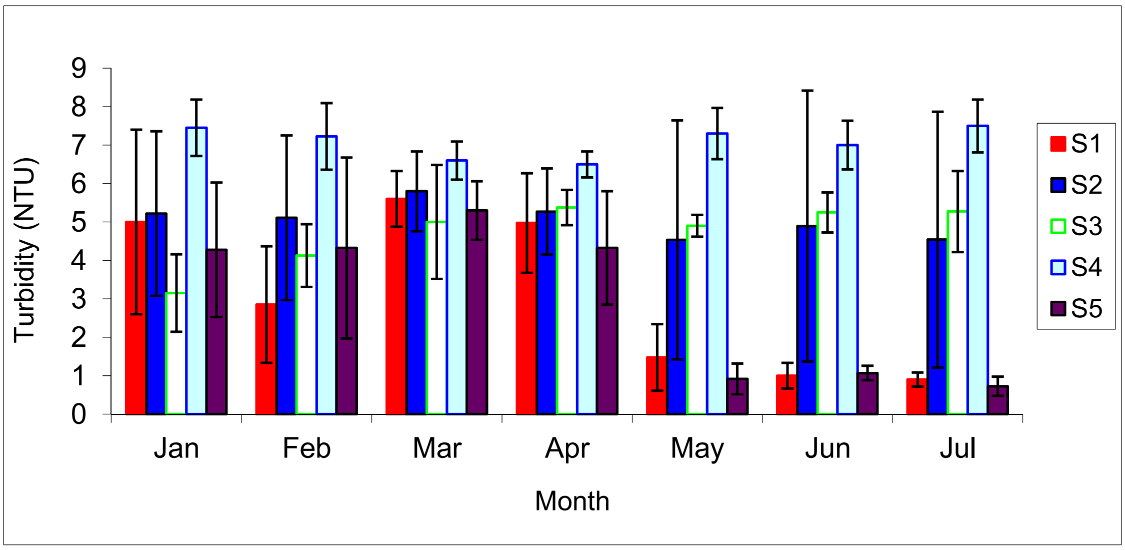

Figure 5: Monthly average of turbidity values at the five stations. For each month, the average ± standard error is

calculated.

3.2 Faecal bacteria

The average, (log cfu/100ml) for the bacterial parameters, faecal coliform (FC) and faecal Entercocci (FE) are given in Table 3. The two bacterial types exhibited marked spatial and temporal variations. The observed variations in bacterial communities among the five stations were statistically analyzed (Table 4) and the averages were compared by using (one-way ANOVA) and Post hoc testing, the Fisher's pair wise comparisons). Significantly inter-locality as well as monthly differences were found for (FC) (ANOVA: d.f. =4, F=13.14; P<0.01) and (ANOVA: d.f. =4, F=7.86; P<0.01) respectively and for (FE) (ANOVA: d.f. =4, F=8.01; P<0.01) and (ANOVA: d.f. =4, F=4.00; P<0.01) respectively.

Table 3: Summary of calculations of the combined (two-factor) ANOVA the two bacterial communities.

Parameter	Variation	d.f.	Sum of squares (ss)	Mean square (ms)	F-ratio	P
Faecal entrococci	Stations	4	50.82	12.70	13.14	<0.01*
	Months	6	45.58	7.59	7.86	<0.01*
	S*M Interaction	24	23.97	0.9991	1.03	0.439
Faecal coliform	Stations	4	42.30	10.57	8.01	<0.01*
	Months	6	31.64	5.27	4.0	<0.01*
	S*M Interaction	24	36.05	1.50	1.14	0.329

Table 4: Variation of bacteria (log mean S.E. cfu/100ml) at the different seawater stations.

Sampling stations	Log FC	Log FE
Station 1	1.696±1.312	1.577±1.03
Station 2	3.224±1.11	2.85±1.42
Station 3	2.150±279	1.927±1.22
Station 4	2.719±1.528	3.298±1.13
Station 5	1.522±1.040	1.598±1.180
ANOVA P	0.001*	0.000*

The overall log average for (FC) and (FE) at the five stations have been specifically compared using one-way ANOVA and Post hoc testing (ANOVA: d.f. = 4, F= 4.85; P<0.01) and (ANOVA: d.f. =4, F=9.69; P<0.01) respectively. The Fisher's pairwise comparisons show a significant difference between the following stations only (1&2, 1&4, 2&3, 2&5) for (FC) and (1&2, 1&4, 2&3, 2&5, 3&4, 3&5) for (FE). The data revealed that (FC) were significantly higher in the stations (S2 and S4) Table 2.4 and Figure 5 show the log average of (FC) and (FE) at the five stations (Figure 6).

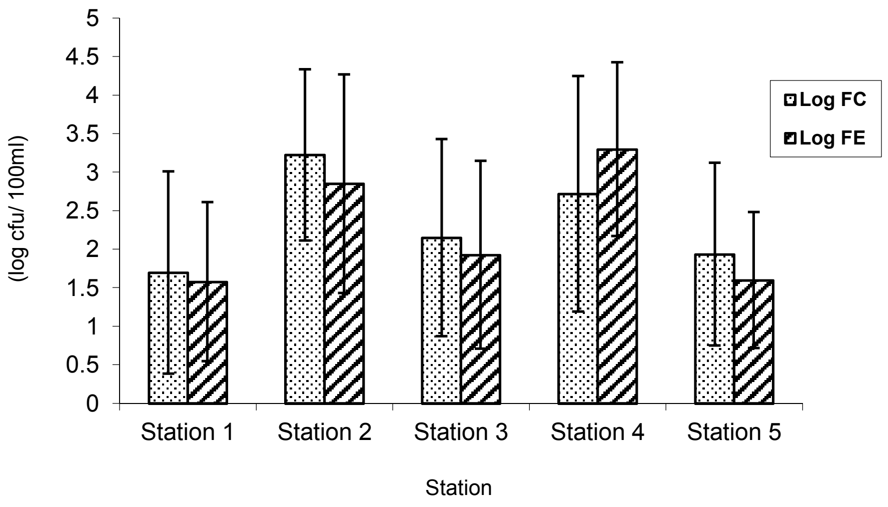

Figure 6: The average of faecal coliform and faecal entrococci for each station, the average ± standard error is calculated.

These two stations (S2 & S4) are receiving large amount of collected raw sewage and runoff during the rainy season from two different areas. Station (S3) also shows a slightly higher (FC) and (FE) concentration comparing with stations (S1) and (S5) because this station lies on a partially treated sewage outfall and also located north of stations 4, however due to dominant current direction which is usually from south to north carrying more pollutants toward station 3 from the large raw sewage discharge outfall in station 4 (Photo 1, Wadi Gaza).

Inspection of seasonal and monthly FC and FE by using one-way ANOVA and Post hoc testing showed that both (FC) and (FE) during January, February, March and April were very high at all of the stations on the other hand during May, June and July (FC) and (FE) was only high at stations S2, S3 and S4, however, (FC) and (FE) were sharply decreased on May, June and July at stations (S1&S5). The monthly log average of (FC) and (FE) from different stations is presented in Figure 6 and Figure 7 respectively (Figure 7) and (Figure 8).

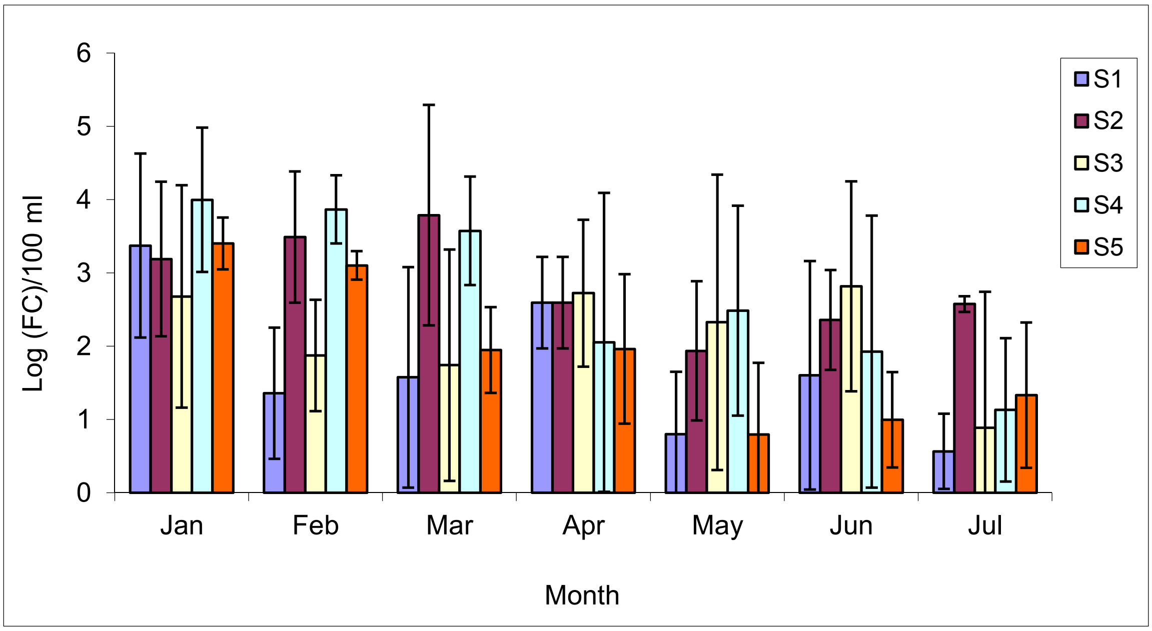

Figure 7: Monthly log average of faecal colifom values at the five stations. For each month, the average ± standard error is calculated

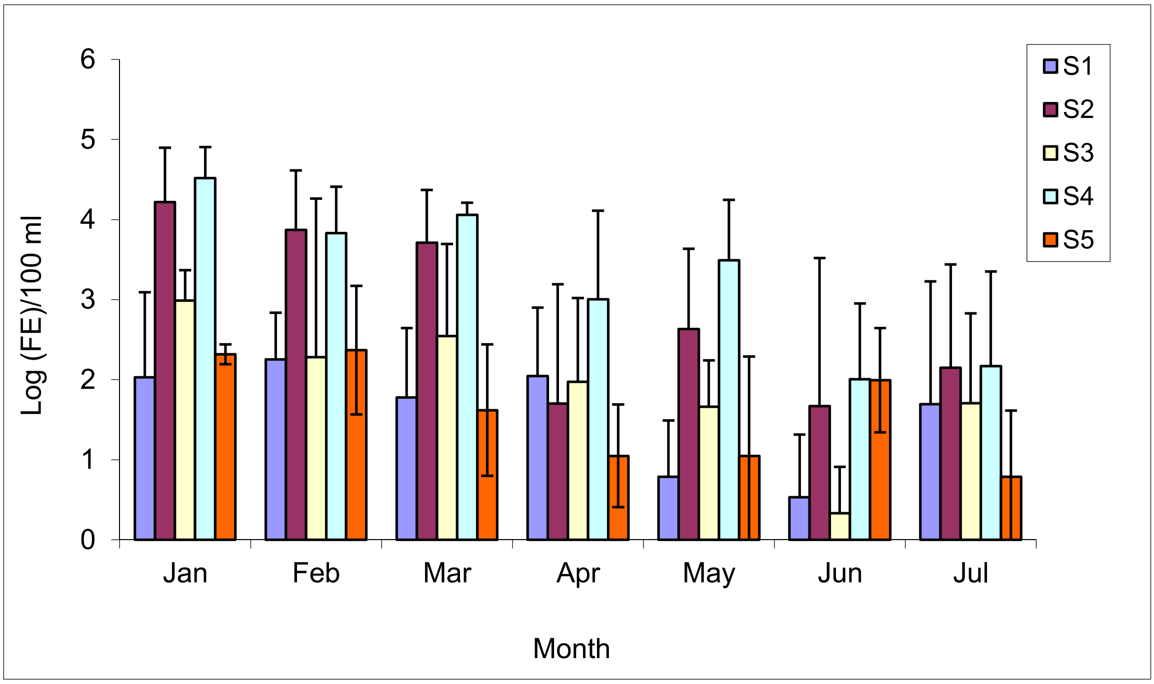

Figure 8: Monthly log average of faecal entrococci values at the five stations. For each month, the average ± standard error is calculated

This study shows that the stations close to the raw sewage discharge have very high faecal coliform and faecal enterococci levels comparing with the free pollution stations. The data indicates a high microbiological contamination of seawater above the international accepted limits especially in stations lie on sewage outfalls. (FC) and (FE) reach average of 4000 and 3000 respectively), which violates the European Countries standards for bathing water (Mandatory=2000/100 ml, Guideline<100/100ml).

The bathing water and water used for recreational purposes should be sufficiently free from any sort of pollution to ensure that there is negligible risk to the health and the safety of the users and the bathers. Swimming in contaminated water by sewage can result in minor illness such as: skin rashes, eye and ear infections and upset stomachs or more sever and potential life threatening disease such as cholera, hepatitis and meningitis. A survey about the health impact of bathing in Gaza seawater has shown that a high percentage of the people suffered adverse symptoms after exposure to seawater. Although a high percentage of the interviewed people were aware of contaminated sites and noticed changes in the seawater color or ordor (IUG, 2001).

During the fieldwork, it has been noticed that some of the sewage drains discharges directly on the sand beach which definitely causing sand beach contamination. Stream sediments and sands in swash zone have shown to contain faecal coliform at concentrations higher than those observed in the water column (Ashbolt et al., 1993; Van Donsel and Geldreich, 1997) have indicated that sediments may contain 100 to 1000 times more than the number of Faecal coliform bacteria contained in the overlaying water.

In Gaza Strip, wastewater treatment has been neglected to a certain extent, with most attention focused on measures to solve water quantity and supply problems. The lack of operational and efficient wastewater treatment plants makes wastewater the main source of pollution of the coastal zone of Gaza Strip. Most of the wastewater is discharged untreated or partially treated along the shoreline, by both the Palestinians as well as the Israeli settlements resulting in pollution of most of the shoreline (ARIJ, 2001). In addition to the treatment plants effluents, there are more than 20 individual sewage drains, ending either on the beach or a short distance away in the surf zone.

Photo 1: Wadi Gaza outlet channel to the beach (Station 4)

The major sources of coastal and marine pollution originating from the land is the lack of operational and efficient wastewater treatment plants makes wastewater the main source of pollution of the coastal zone of Gaza Strip. Most of the wastewater is discharged untreated or partially treated along the shoreline, both by Palestinians as well as Israeli settlements resulting in pollution of most of the shoreline. In addition to treatment plant effluents, there are more than 20 individual sewage drains, ending either on the beach or a short distance away in the surf zone. A high percentage of the wastewater that is generated in Gaza City is currently discharged without treatment into the sea (50,000m3/day). Only about 20% of the sewage generated in the Gaza Strip is properly treated. The percentage of population served by sewerage systems is 70%. The insufficient number of sewage treatment plants in operation, combined with poor operating conditions of available treatment plants, and the present disposal practices are likely to have an adverse effect on the quality of seawater (PWA, 2001).

4. Conclusion

Based on this study, the land-based pollutants by sewage disposal constitute greatest threat to coastal and marine ecosystems and to public health in Gaza Region. The amount of pollutants discharges through sewage disposal may be considered the most significant pollutants threats to the sea water by causes high nutrient levels and even eutrophication near sewage outfalls and also causes long-term adverse impacts on the ecology of the coastal ecosystems. So it is widely acknowledged that the pollution of the sea must be cut back or stopped by increasing the wastewater sewage collection and treatment facilities. On other hand, issuing laws on possible effluents and should prevent future emissions of pollutants by preventing the use of pollutants. The alleviation of the sewage problem and the creation of a long-term viable economy will necessitate a political commitment to develop and enforce legislation relevant to the management of the coastal zone, as well as adherence to planning policies taking into account the potential environmental impacts of development.

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