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Seasonal Variations in Surface Water Quality Index of the Mainstream Running through Riyadh, Saudi Arabia

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ABSTRACT

The present study, was carried out during June 2009 till March of 2010, involved the monitoring of some surface water quality indices related of water stream running through Riyadh, Saudi Arabia. Water samples were collected from 10 different locations along the course of the stream. The samples were analyzed for dissolved oxygen, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Oxygen Content (TOC), total petroleum hydrocarbon, oil and grease, total viable counts measured at 22°C, 72 h and 37°C, 24 h, total coliforms and feacal coliforms. The results indicated that the water quality varied depending on the time of sampling (month) and the specific location. Poor quality was also recorded at some of the locations owing to the contamination by mixing of industrial effluents. The present study emphasizes on the need for continuous monitoring of the water quality to control the water pollution level of the main stream. The results reported in this study are also deemed to serve as baseline studies on the surface water pollution status of the main stream in Saudi Arabia.

Key words: Water quality, seasonal variations, arid environment

INTRODUCTION

The Kingdom of Saudi Arabia is located within an extremely arid region, where the average rainfall is very less with few surface water bodies (Lin, 1984). This surface water comes from the rainfall that floods and flows in the main stream running for a short duration through Riyadh (ADA., 1991). This available surface water provides an important resource for the Kingdom due to its good quality (Al-Motairi, 2000). However, due to the discharge of domestic and industrial wastewaters into surface waters, its quality is deteriorating rapidly. In addition, non-point sources of wastewater play an important role in polluting the mainstream (Chang *et al.*, 2005, 2007).

The main stream in Riyadh, runs for a length of about 120 km from north to south, cutting through Riyadh, the capital of Saudi Arabia. Several towns and villages are situated along the stream (Al-Homaidan *et al.*, 2011). This then extends to from north of Al Uyaynah to the south of Al-Hair cities. Industrial effluents, as well as domestic sewage/wastes are disposed off into the stream, either with partial or without treatment. Consequently, these are posing a great risk of pollution to this water stream and to the people living in the area (Abdel-Baki *et al.*, 2011).

The water source in this main stream is derived from the seasonal rainfall. During the last two decades, considerable urban and agricultural development has occurred in the catchment area, leading to a considerable disposal of sewage effluent and agricultural drainage into the stream (Siddiqui and Al-Harbi, 1995). Historically, the stream was used as a water source and presently provides a convenient mean for disposing of the city's wastewater. In the future, this water source has the potential to make significant volumes of good quality water available for recycling (Morton and Wu, 1975; Alhamid *et al*., 2007). The groundwater around the stream is polluted by high volumes of sewage water percolation into the ground (Fnais, 2011). Evaluation of water quantity and quality is essential for the development of civilization and to establish a database for planning future water resources development strategies (Al-Harbi *et al*., 2006). Water quality is a term used to describe the chemical, physical and biological characteristics of water with respect to its suitability for a particular use (Khalil *et al*., 2011). It is considered as a main factor for the sustenance of agriculture in the Kingdom (Al-Omran *et al*., 2005). Typically, water quality is determined by comparing the physical and chemical characteristics of a water sample with water quality guidelines or standards. It is variable in both time and space and requires routine monitoring to detect spatial patterns and changes that occur over time. A number of chemical, physical and biological components affect water quality and hundreds of indicators commonly examined and measured in actual practice. Some of these provide a general indication of water pollution. As a result, the assessment of water resources requires knowledge of water quality (Harmanciogammalu *et al*., 1999; Ghani *et al*., 2009) and in Saudi Arabia, the quality of water is currently receiving some attention from environmentalist and water scientists like and has been reported (Al-Hawas, 2002; Al-Redhaiman and Magid, 2002; Al-Turki and Magid, 2003; Al-Zarah, 2008; Al-Turki, 2009). While, Olajide (2010) studied the microbiological status of surface and groundwater in Akungba-Akoko, Ondo state.

Keeping in view the importance of water for a water scarce region and the future's water demand, the present investigations were carried out to investigate seasonal variations of important water quality indices from main stream running through Riyadh city and these data sets may be used for further research and planning and water-treatment.

MATERIALS AND METHODS

Study area: The main stream that runs through Riyadh, Saudi Arabia is one of the principal streams draining the eastern slope of the Tuwaig Mountains (Abdel-Baki *et al*., 2011). The stream is one of the most important natural landmarks in the central region of Saudi Arabia and a discharge of 400,000-600,000 cm^3 of ground water, rainwater and industrial waste and domestic sewage water reaches the valley every day (Al-Homaidan *et al*., 2011). The sampling was done at different locations along the main stream. The details about samples, area code and the description is given in Table 1 (northing and easting of the locations is also given).

Sampling procedure: Water samples from the specified locations were collected (monthly bases) during the months of June (2009) until March (2010). The samples were taken according to standard methods (AOAC., 2003; ASTM D3921-96, 2003). These were then transferred to the laboratory of Saudi Berkefeled Filters Co., Riyadh for the purpose of chemical analyses. Sample temperatures in the laboratory were measured and the mean, standard deviations, maximum and minimum are shown in Table 2. All chemical analyses were performed according to standard methods (AOAC., 2003). No marked variation in the temperature of the samples was observed and the overall mean temperature was recorded to be 23.3°C.

Statistical analysis: Excel spread sheets ware used to calculate and record the mean and standard deviations in addition to the minimum and the maximum of all concentrations. The water quality indicators were selected as 28 water quality variables. A correlation matrix was prepared

Table 1: Description of samples (area code, sampling area, description of area) with the corresponding spatial data (northing and easting of sampling area)

Area code	Sampling area	Description of area	Northing	Easting
SW1C	Arriyadh	North diversion channel-down stream of confluence of proposed channel and DNC	2724103.251	669451.238
SW 12a	Arriyadh	Underneath king fahad expressway, bridge upstream of bio remediation	2721476.628	672518.914
SW 8 A	Al Masane	Manfuh acomplex	2720071.397	675685.708
SW 8 C	Al Masane	Below STP discharge near bridge	2718369.409	675859.770
SW 23	Al Masane	Batha channel before meeting the main stream	2716538.376	676839.277
SW 14	Al Masane	At inlet of culvert Batha channel in stream 100 m downstream of culvert immediately	2716278.544	676631.335
SW 20	Al Masane	Downstream of confluence of existing channel and tributary from Batha channel	2716194.470	676823.123
SW 8 g	Al Masoriyah	150 m downstream of Tannery	2713161.808	6786648.795
SW 10b	Al Hair	Al Hair bridge	2697973.000	685465.000
SW 11b	Near Al Hair Lake	Al Hair lake	2696646.000	693373.000

Table 2: Correlation matrix for different water quality parameters

Parameters	DO	BOD	COD	TOC	TPH	Oil and grease	Total viable count (22°C, 72 h)	Total viable count (37°C, 24 h)	Total coliforms	Fecal coliforms
DO	1									
BOD	-0.894	1								
COD	-0.900	0.998	1							
TOC	-0.027	0.291	0.287	1						
TPH	-0.112	0.329	0.330	0.941	1					
Oil and grease	-0.078	0.294	0.293	0.940	0.998	1				
Total viable count, 22°C, 72 h	-0.053	0.278	0.274	0.963	0.858	0.859	1			
Total viable count, 37°C, 24 h	-0.019	0.236	0.229	0.918	0.806	0.816	0.864	1		
Total coliforms	-0.401	0.718	0.694	0.768	0.715	0.702	0.786	0.673	1	
Fecal coliforms	-0.130	0.307	0.299	0.924	0.891	0.887	0.809	0.908	0.696	1

DO: Dissolved oxygen, BOD: Biological oxygen demand, COD: Chemical oxygen demand, TPH: Total petroleum hydrocarbon

using Excel and the statistical correlation matrices are multivariate analyses used to correlate the relationships between variables. A correlation matrix is always a symmetric matrix to locate the correlation for any pair of variables and find the value in the intersection for those two variables as reported by Gawad *et al*. (2010) and Constable and McBean (1979).

RESULTS AND DISCUSSION

Water quality can be assessed by the study of correlation coefficient among the quality variables of studied sites. The results of coefficient of determination (r^2) are shown in Fig. 1-8 where, the Dissolved Oxygen (DO) is shown to correlate with a number of parameters, especially with the BOD and COD. Data in Fig. 2 shows a very strong correlation between DO and COD ($R^2 = 0.935$). Similarly, a good correlation of TOC with total petroleum hydrocarbon ($R^2 = 0.886$), oil and grease ($R^2 = 0.995$), total viable counts measured at 22°C, 27 h ($R^2 = 0.806$) and 37°C, 24 h ($R^2 = 0.918$) and fecal coliforms ($R^2 = 0.924$) was also found. Negative (inverse) correlations can be seen in 8 cases, while positive correlations are found in 37 cases. A strong relationship (Fig. 1) was observed between mean Dissolved Oxygen (DO) and mean BOD ($R^2 = 0.945$) in water

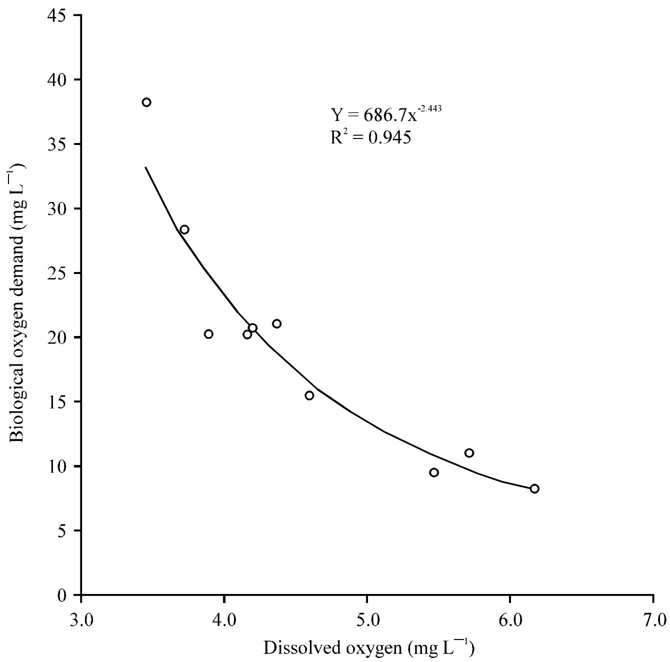

Fig. 1: Relationship between mean Dissolved Oxygen (DO) and mean Biological Oxygen Demand (BOD) levels for water samples taken from ten different locations

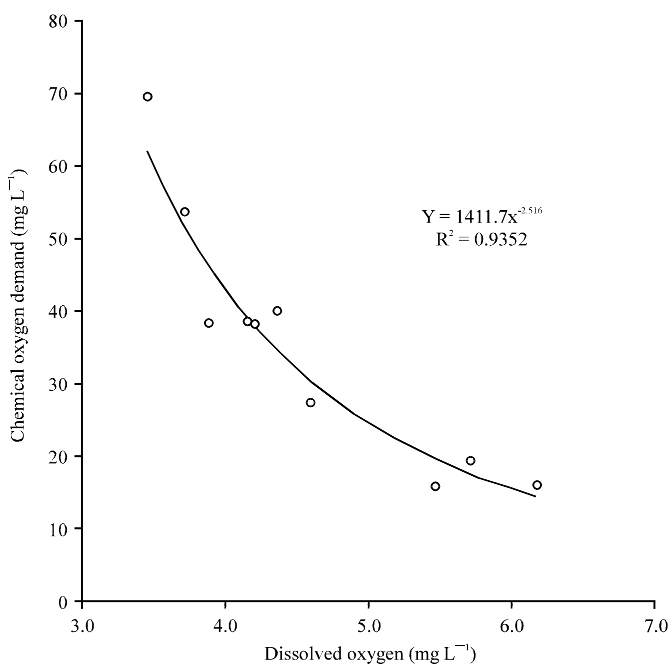

Fig. 2: Relationship between mean dissolved oxygen and mean Chemical Oxygen Demand (COD) levels for water samples taken from ten different sites

samples obtained from the main stream running through Riyadh. It is quite obvious that when BOD levels are high, dissolved oxygen levels decreases due to the bacterial activities that consume

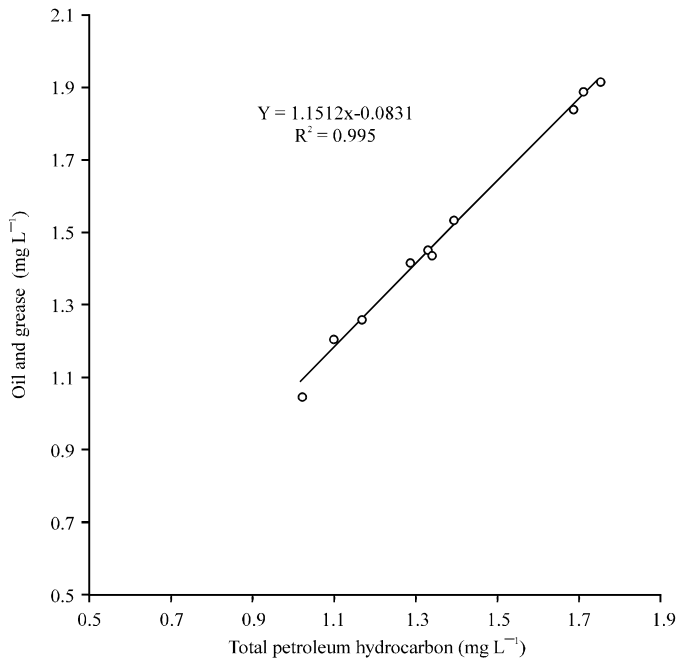

Fig. 3: Relationship between mean total petroleum hydrocarbon and mean oil and grease for water samples taken from ten different sites

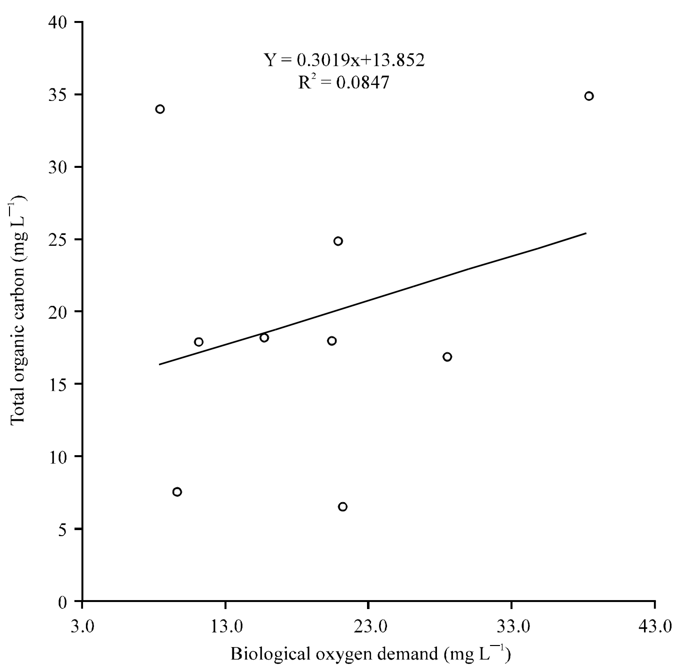

Fig. 4: Relationship between mean biological oxygen demand and total organic carbon for water samples taken from ten different sites

oxygen (Chang *et al*., 2005). This in turn would affect the sustenance and survival of fish and other aquatic organisms. Figure 2 shows the relationship between mean dissolved oxygen and

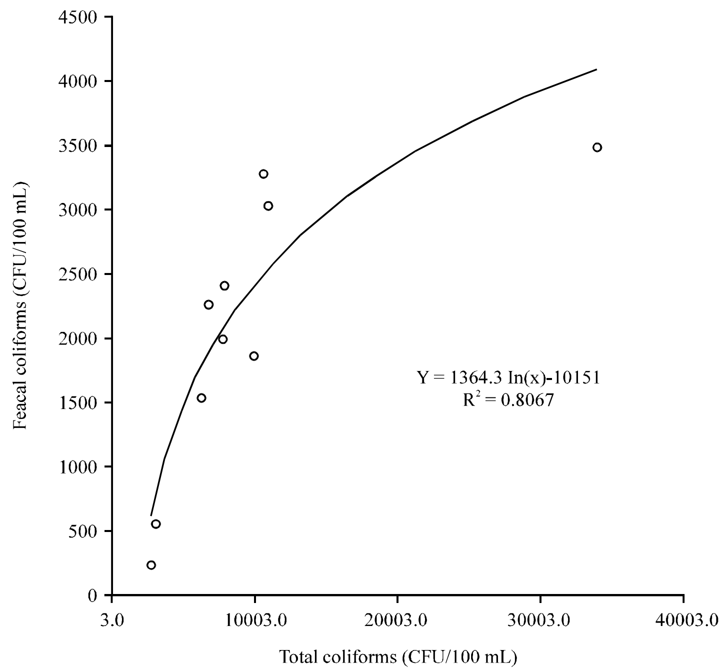

Fig. 5: Relationship between mean total coliforms and feacal coliforms for water samples taken from ten different sites

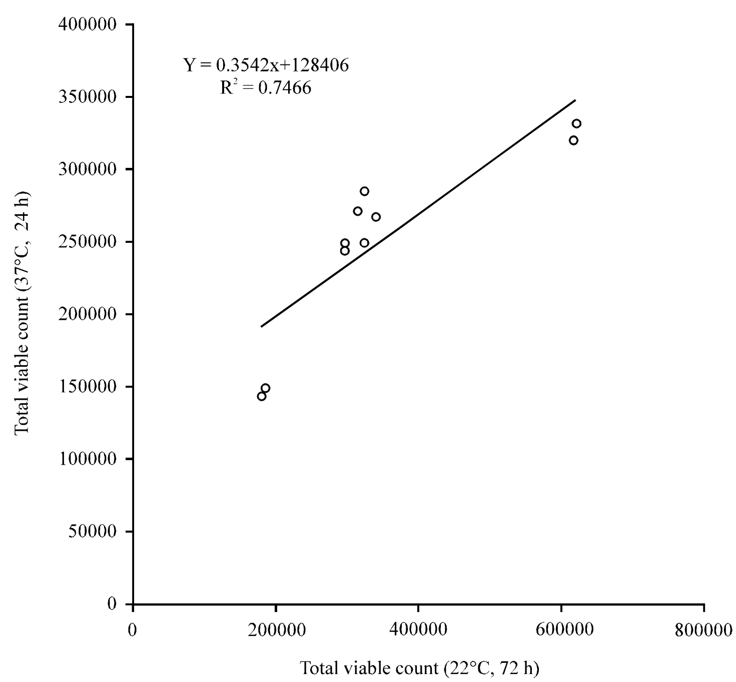

Fig. 6: Relationship between mean total viable count measured at 22°C, 27 h and 37°C, 24 h for water samples taken from ten different sites

mean COD level in water sampled from the ten different sites. A strong correlation can also be seen in this case that reflects the oxygen consumption due to chemical degradation occurring in the main

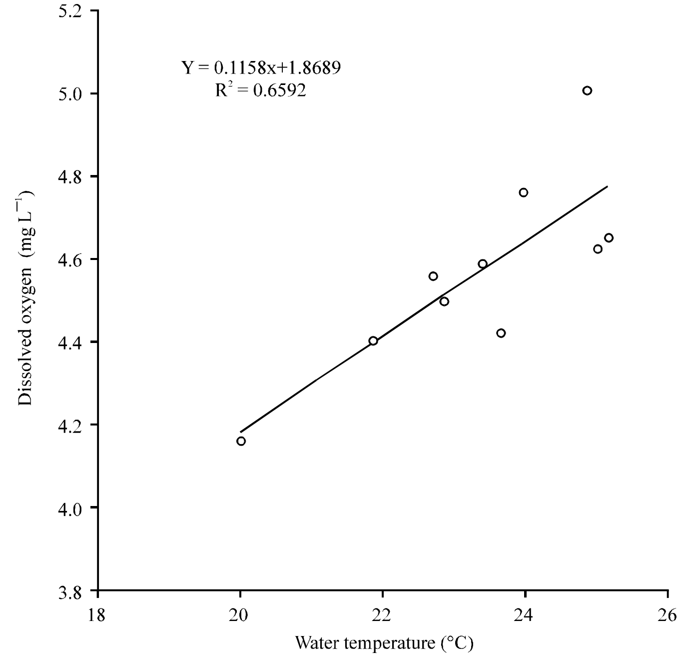

Fig. 7: Relationship between monthly mean water temperature and mean DO

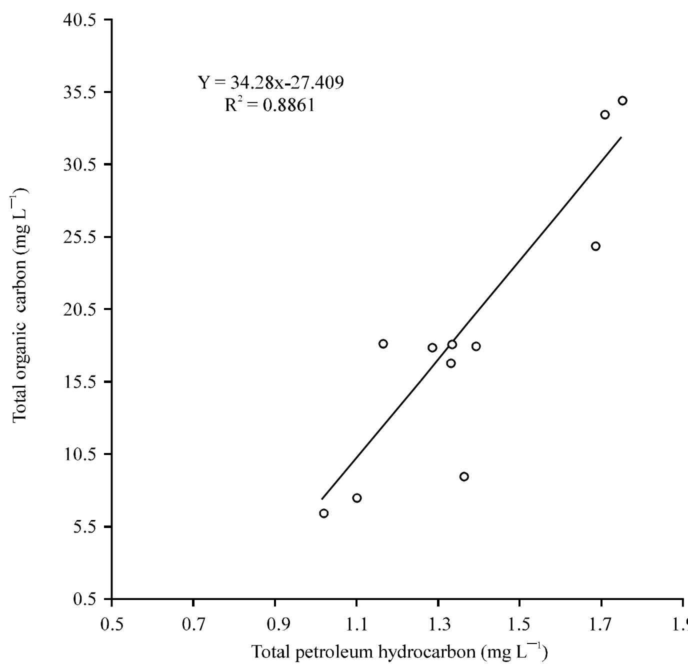

Fig. 8: Relationship between mean total petroleum hydrocarbon and mean TOC at the studied sites

stream water. Among other parameters, Fig. 3 shows the relationship between mean total petroleum hydrocarbon and mean oil and grease for water samples taken from ten different sites, where a linear relationship was observed with R^2 value~0.995. In the case of mean BOD and TOC,

Table 3: Average log of the viable count of the total bacterial load as well as classical bacterial indicators in the tested surface water samples during June 2009 till may 2010 around main stream running through Riyadh

	Log number of colony forming unit (CFU/100 mL)			
	Total bacterial count		Bacterial indicators	
Site of water samples	Total viable count (22°C after 72 h)	Total viable count (37°C after 24 h)	Total coliforms	Feacal coliforms
SW1C	5.56	5.48	4.53	3.33
SW 12a	5.43	5.34	3.91	3.02
SW 8 A	5.35	5.28	3.63	2.79
SW 8 C	5.49	5.43	3.83	3.35
SW 23	5.51	5.46	3.89	3.30
SW 14	5.26	5.17	3.48	2.75
SW 20	5.47	5.39	3.90	3.38
SW 8 g	5.53	5.43	4.02	3.52
SW 10b	5.79	5.51	4.04	3.48
SW 11b	5.47	5.40	3.79	3.19

no such correlation could be established as shown by a R^2 value~0.0847 (Fig. 4). However, a reasonable correlation was found between the mean total coliforms and feacal coliforms (R^2 = 0.8067) for these water samples.

Figure 5, finally, a linear relationship (R^2 = 0.7466) between the mean total viable count measured at 22°C, 27 h and 37°C, 24 h was found for these water samples (Fig. 6).

Bacteriological quality: The results of the variables describing water quality of surface water from studied sites are presented in Table 3. The data show a consider variation among months and sites. The bacteriological quality of the collected water samples was evaluated by monitoring of the total bacterial counts and fecal bacteria indicators in the studied sites around main stream running through Riyadh. The results presented in Table 3 showed the mean maximum log counts 5.79 CFU at 22°C at in site SW 10b, the lowest log mean was 5.18 CFU at 37°C/100 mL at site SW 14, a finding which may be due to the effect organic substances, biological activity and sedimentation (Olayemi, 1993). No site had a zero count at 22°C and the counts at 37°C. Table 4 shows variations in log total viable count, 22°C and 72 h in surface water samples with months and mean, standard deviation, maximum and minimum values for different studied sites. Table 5 shows variations of log total viable count, 37°C, 24 h in the surface water samples with months for different studied sites. Inspection of these values (Table 4, 5) reveals that all water samples exhibited counts. The high log total viable count, 22°C, 72 h is 6.43 CFU/100 mL in site SW10b occurred during July, while the minimum log total viable count, 22°C, 72 h is 5.15 CFU/100 mL in site SW8C during July. The log total viable counts at 22°C were: 72 h (CFU/100 mL) June (5.28-5.58), July (5.15-6.43), August (5.26-5.59), September (5.28-5.60), October (5.28-5.59), November (5.27-5.59), December (5.26-5.58), January (5.23-5.60), February (5.23-5.54) and March (5.25-5.60). The log total viable count, 37°C, 24 h (CFU/100 mL) were: June (5.20-5.49), July (5.06-5.46), August (5.19-5.53), September (5.19-5.51), October (5.03-5.51), November (5.18-5.53), December (5.16-5.55), January (5.16-5.56), February (5.16-5.49) and March (5.20-5.52). Total coliforms and feacal counts were recorded in water samples (Table 3). This may be due to nutrients being available for the growth of the bacteria. Niemi and Niemi (1991) and

Table 4: Variations of log total viable count, 22°C, 72 h (CFU/100 mL) in surface water samples with months and mean for different studied sites

	2009							2010						
Location	June	July	August	September	October	November	December	January	February	March	Overall mean	SD	Max.	Min.
SW1C	5.57	5.59	5.49	5.56	5.54	5.57	5.55	5.60	5.54	5.59	5.56	0.06	5.60	5.49
SW12a	5.37	5.41	5.34	5.32	5.51	5.45	5.43	5.47	5.45	5.46	5.42	0.06	5.51	5.32
SW8a	5.40	5.42	5.29	5.38	5.30	5.32	5.30	5.30	5.28	5.42	5.34	0.12	5.42	5.28
SW8C	5.55	5.15	5.47	5.47	5.54	5.52	5.50	5.56	5.48	5.58	5.48	0.09	5.58	5.15
SW23	5.53	5.26	5.53	5.51	5.54	5.52	5.51	5.51	5.50	5.60	5.50	0.02	5.60	5.26
SW14	5.28	5.23	5.26	5.28	5.28	5.27	5.26	5.23	5.23	5.27	5.26	0.10	5.28	5.23
SW20	5.33	5.26	5.45	5.41	5.53	5.52	5.49	5.54	5.49	5.56	5.46	0.08	5.56	5.26
SW8g	5.51	5.30	5.58	5.52	5.59	5.54	5.56	5.53	5.49	5.59	5.52	0.27	5.59	5.30
SW10b	5.58	6.43	5.59	5.60	5.59	5.59	5.58	5.59	5.54	5.56	5.67	0.11	6.43	5.54
SW11b	5.34	5.28	5.41	5.32	5.52	5.54	5.54	5.53	5.52	5.57	5.46	0.03	5.57	5.28
Mean	5.54	5.43	5.44	5.44	5.49	5.48	5.47	5.49	5.45	5.52				
Max	5.58	6.43	5.59	5.60	5.59	5.59	5.58	5.60	5.54	5.60				
Min	5.28	5.15	5.26	5.28	5.28	5.27	5.26	5.23	5.23	5.27				

SD: Standard deviation, Max: Maximum and Min: Minimum concentration values

Table 5: Variations of log total viable count, 37°C, 24 h (CFU/100 mL) in surface water samples with months and mean for different studied sites

	2009							2010						
Location	June	July	August	September	October	November	December	January	February	March	Overall mean	SD	Max.	Min.
SW1C	5.45	5.46	5.40	5.45	5.43	5.50	5.51	5.56	5.49	5.53	5.48	0.06	5.56	5.40
SW12a	5.28	5.30	5.27	5.27	5.41	5.38	5.37	5.41	5.35	5.34	5.34	0.06	5.41	5.27
SW8a	5.32	5.34	5.23	5.31	5.22	5.26	5.24	5.23	5.22	5.36	5.27	0.07	5.36	5.22
SW8C	5.47	5.32	5.38	5.32	5.49	5.45	5.46	5.48	5.41	5.51	5.43	0.05	5.51	5.32
SW23	5.45	5.34	5.45	5.41	5.51	5.47	5.46	5.46	5.45	5.53	5.45	0.04	5.52	5.34
SW14	5.45	5.06	5.19	5.19	5.20	5.18	5.16	5.16	5.16	5.20	5.17	0.11	5.20	5.06
SW20	5.20	5.15	5.38	5.29	5.45	5.44	5.41	5.48	5.43	5.49	5.38	0.16	5.49	5.15
SW8g	5.43	5.18	5.52	5.43	5.03	5.50	5.51	5.48	5.45	5.52	5.40	0.07	5.52	5.03
SW10b	5.49	5.32	5.53	5.51	5.54	5.53	5.55	5.55	5.49	5.49	5.50	0.15	6.55	5.32
SW11b	5.26	5.06	5.32	5.24	5.47	5.48	5.49	5.49	5.47	5.48	5.38	0.06	5.49	5.06
Mean	5.36	5.25	5.37	5.34	5.38	5.42	5.42	5.43	5.39	5.44				
Max	5.49	5.46	5.53	5.51	5.54	5.53	5.55	5.56	5.49	5.53				
Min	5.20	5.06	5.19	5.19	5.03	5.18	5.16	5.16	5.16	5.20				

SD: Standard deviation, Max: Maximum and Min: Minimum concentration values

Putheti and Leburu (2009) reported that domestic and industrial wastewater, agriculture waste environment are nutrient sources for fecal bacterial to rivers. The results in Table 3 show the highest log mean counts of total coliforms was recorded 4.53 CFU/100 mL in site SW1C, while the lowest log mean was 3.48 CFU/100 mL occurred at SW14. No site had a zero counts of total coliforms. The results in Table 3 also show the highest log mean counts of fecal coliforms recorded 4.53 CFU/100 mL was in site SW1C and the lowest log mean was 2.75 CFU/100 mL in site SW14. No site exhibited a zero counts of fecal coliforms. Table 6 shows the monthly variations of log total coliforms in surface water samples with the mean, standard deviation, maximum and minimum values for the sites studied. Finally, Table 7 shows the monthly variation of log feacal coliforms in surface water samples for the sites studied.

The establishment of water quality objectives is not only a scientific problem but also a political process that requires a critical assessment of national priorities. Such an assessment is based on economic considerations, present and future water uses, forecasts for industrial progress and for

Table 6: Variations of log total coliforms (CFU/100 mL) in surface water samples with months and mean for different studied sites

	2009							2010						
Location	June	July	August	September	October	November	December	January	February	March	Overall mean	SD	Max.	Min.
SW1C	4.20	4.21	4.14	4.21	4.12	4.25	4.23	5.28	4.17	4.28	4.31	0.11	5.28	4.12
SW12a	3.86	3.91	3.86	3.84	4.10	3.94	3.96	3.97	3.84	3.69	3.90	0.16	4.10	3.69
SW8a	3.72	3.30	3.61	3.68	3.45	3.48	3.45	3.42	3.51	3.83	3.60	0.27	3.83	3.42
SW8C	3.56	3.36	3.33	3.63	3.90	3.88	3.91	3.96	3.91	4.14	3.76	0.17	4.14	3.33
SW23	3.76	3.54	3.69	3.78	3.98	3.91	3.92	3.90	3.95	4.16	3.86	0.09	4.16	3.54
SW14	3.53	3.69	3.45	3.42	3.43	3.40	3.43	3.41	3.45	3.48	3.47	0.19	3.69	3.40
SW20	3.63	3.53	3.67	3.91	3.92	3.95	3.92	4.04	3.92	4.13	3.86	5.28	4.13	3.53
SW8g	3.87	3.74	4.19	3.91	4.03	4.05	4.10	4.01	3.98	4.15	4.00	0.13	4.19	3.74
SW10b	3.94	3.75	4.24	3.99	3.99	4.01	4.11	4.04	4.07	4.07	4.02	0.18	4.24	3.75
SW11b	3.58	3.45	3.69	3.56	3.88	3.85	3.91	3.92	3.84	3.92	3.76	0.09	3.92	3.45
Mean	3.76	3.70	3.79	3.79	3.88	3.87	3.89	4.00	3.86	3.98				
Max	4.20	4.21	4.24	4.21	4.12	4.25	4.23	5.28	4.17	4.28				
Min	3.53	3.36	3.33	3.42	3.43	3.40	3.43	3.41	3.45	3.48				

SD: Standard deviation, Max: Maximum and Min: Minimum concentration values

Table 7: Variations of log feacal coliforms (CFU/100 mL) in surface water samples with months and mean for different studied sites

	2009							2010						
Location	June	July	August	September	October	November	December	January	February	March	Overall mean	SD	Max.	Min.
SW1C	3.17	3.28	3.08	3.30	3.11	3.40	3.38	3.49	3.29	3.56	3.31	0.09	3.56	3.08
SW12a	2.91	3.06	2.83	2.98	3.08	3.03	3.07	3.11	3.05	2.98	3.01	0.47	3.11	2.83
SW8a	2.95	3.03	2.88	2.91	2.11	2.16	2.11	2.11	2.26	3.28	2.58	0.34	3.28	2.11
SW8C	Nil	Nil	3.33	2.45	3.36	3.35	3.50	3.39	3.36	3.50	3.25	0.53	3.50	2.45
SW23	2.20	2.23	2.72	3.14	3.49	3.45	3.51	3.40	3.43	3.53	3.11	0.12	3.53	2.20
SW14	2.79	2.91	2.75	2.48	2.84	2.67	2.72	2.69	2.72	2.78	2.73	0.42	2.91	2.48
SW20	2.75	2.56	2.69	3.20	3.46	3.49	3.57	3.57	3.45	3.68	3.24	0.22	3.68	2.56
SW8g	3.11	3.15	3.46	3.29	3.57	3.60	3.71	3.56	3.57	3.71	3.47	0.22	3.71	3.11
SW10b	3.19	2.95	3.57	3.32	3.52	3.49	3.63	3.54	3.59	3.60	3.44	0.38	3.63	2.95
SW11b	2.66	2.49	2.71	2.64	3.32	3.26	3.38	3.32	3.32	3.51	3.06	0.18	3.51	2.49
Mean	2.86	2.85	3.00	2.97	3.19	3.19	3.26	3.22	3.20	3.41				
Max	3.19	3.28	3.57	3.32	3.57	3.60	3.71	3.57	3.59	3.71				
Min	2.20	2.23	2.69	2.45	2.11	2.16	2.11	2.11	2.26	2.78				

SD: Standard deviation, Max: Maximum and Min: Minimum concentration values

the development of agriculture as well as many other socio-economic factors (UNESCO/WHO., 1978; UNECE., 1993, 1995). Total coliform count, total organic carbon and Chemical Oxygen Demand (COD) have been selected as the major parameters for monitoring water quality (Chang *et al*., 2005). Indicators like pH, BOD, suspended solids, DO and coliform counts have also been chosen to classify the rivers and lakes water quality in Japan in relation to water purification treatment approaches (Sato, 2002).

Coliform counts give an indication of extent of water quality degradation (Bhardwaj, 2005). In the present studies, the water at all of the sites showed such counts (Table 6, 7). The log total coliforms (CFU/100 mL) were as follows: June (3.53-4.20), July (3.36-4.21), August (3.33-4.24), September (3.42-4.21), October (3.43-4.12), November (3.40-4.25), December (3.43-4.23), January (3.41-5.28), February (3.45-4.17) and March (3.48-4.28). The log total feacal counts (CFU/100 mL) were: June (2.20-3.19), July (2.23-3.28), August (2.69-3.57), September (2.45-3.32), October (2.11-3.57), November (2.16-3.60), December (2.11-3.71), January (2.11-3.57),

Table 8: Interpretation of BOD levels

BOD level (mg L^{-1})	Status
1-2	Clean water with little organic wastes
3-5	Moderately clean water with some organic waste
6-9	Large amounts of organic material and many bacteria
>10	Very poor water quality. Large amounts of organic material in the water

Source: http://www.ualberta.ca/~edtechpd/documents/activity_probes_procedurebiooxygenproduction_boora_v1.pdf

Table 9: Variations of BOD (mg L^{-1}) in surface water samples with months and mean for different studied sites

	2009							2010						
Location	June	July	August	September	October	November	December	January	February	March	Overall mean	SD	Max.	Min.
SW1C	18.0	18.0	15.9	20.5	11.6	16.9	13.6	18.2	12.1	10.8	15.6	3.3	20.5	10.8
SW12a	12.0	16.0	11.2	16.9	13.6	8.9	8.5	10.8	7.6	5.3	11.1	3.7	16.9	5.3
SW8a	11.0	11.0	12.0	13.1	10.2	6.9	5.5	13.0	6.6	5.3	9.6	2.9	13.1	5.3
SW8C	24.0	18.0	27.5	27.6	35.7	15.4	14.9	15.7	11.5	12.1	20.2	8.0	35.7	11.5
SW23	24.0	22.0	29.1	29.5	34.1	15.0	13.8	14.9	12.1	13.2	20.8	8.1	34.1	12.1
SW14	7.0	7.0	8.0	13.9	11.3	8.2	7.5	8.0	6.1	5.7	8.3	2.5	13.9	5.7
SW20	15.0	14.0	27.1	36.4	27.0	19.5	16.5	20.6	13.2	13.9	20.3	7.6	36.4	13.2
SW8g	34.0	26.0	54.0	35.3	34.2	25.6	24.1	24.0	14.6	14.7	28.4	10.8	51.0	14.6
SW10b	60.0	64.0	77.0	33.4	27.9	26.2	28.1	25.8	20.9	18.7	38.2	20.7	77.0	18.7
SW11b	14.0	21.0	15.0	32.4	24.6	23.1	22.5	22.5	18.6	17.2	21.2	5.3	32.4	14.0
Mean	21.9	21.7	27.5	25.9	23.0	16.6	15.6	17.4	12.3	11.7				
Max	60.0	64.0	77.0	36.4	35.7	26.2	28.1	25.8	20.9	18.7				
Min	7.0	7.0	8.0	13.1	10.2	6.9	6.5	8.0	6.1	5.3				

SD: Standard deviation, Max: Maximum and Min: Minimum concentration values

February (2.26-3.59) and March (2.78-3.71). These variations may be due to human activity, sun intensity and sedimentation which, together with biological activity, all play role on the bacterial distribution (Ali and Osman, 2010).

Biological oxygen demand: The Biological Oxygen Demand (BOD) is the amount of oxygen consumed by bacteria in the decomposition of organic material (http://www.dnr.mo.gov/env/esp/waterquality-parameters.htm). Unpolluted, natural waters should have a BOD of 5 mg L^{-1} or less. Raw sewage may have BOD levels ranging from 150-300 mg L^{-1}. Table 8 shows the expected BOD values for various water qualities; water having BOD below 3 mg L^{-1} indicates there is a gradual improvement in water quality with respect to organic pollution (Bhardwaj, 2005). Table 9 shows the monthly variation of BOD (mg L^{-1}) in surface water studied here with means, standard deviation, maximum and minimum values for different studied sites. Table 9 shows that all of the water samples exhibited very poor quality and contained large amounts of organic material. The monthly BOD values were as follows: (mg L^{-1}) June (7-60), July (7-64), August (8-77), September (13.1-36.4), October (10.2-35.7), November (6.9-26.2), December (6.5-28.1), January (8-25.8), February (6.1-20.9) and March (5.3-18.7). Ghani *et al.* (2009) commented that the monitoring of BOD as indicator of pollution of water is essential to assist decision makers to take desirable action to control the BOD pollution.

Dissolved oxygen: The amount of Dissolved Oxygen (DO) in water is expressed as a concentration (http://www.dnr.mo.gov/env/esp/waterquality-parameters.htm), i.e., the weight of a particular substance per a given volume of liquid. The concentration of dissolved oxygen in a

Table 10: Variations of DO (mg L^{-1}) in surface water samples with months and mean for different studied sites

	2009							2010						
Location	June	July	August	September	October	November	December	January	February	March	Overall mean	SD	Max.	Min.
SW1C	4.4	4.6	4.5	4.3	4.8	4.5	4.9	4.3	4.8	4.8	4.6	0.2	4.9	4.3
SW12a	6.0	5.1	6.0	5.9	5.6	5.7	5.6	5.1	6.0	6.1	5.7	0.4	6.1	5.1
SW8a	5.5	5.6	5.3	5.4	5.2	5.3	5.3	5.3	5.8	5.9	5.5	0.2	5.9	5.2
SW8C	3.9	4.1	4.0	4.0	3.1	4.2	4.5	4.1	5.2	4.4	4.2	0.5	5.2	3.1
SW23	4.0	4.2	3.8	3.9	3.4	4.4	4.8	4.6	4.8	4.1	4.2	0.5	4.8	3.4
SW14	7.6	7.4	7.1	7.4	5.1	5.1	5.2	5.2	5.7	5.8	6.2	1.1	7.6	5.1
SW20	4.1	4.2	3.4	3.9	3.6	3.8	4.1	3.7	4.1	4.0	3.9	0.3	4.2	3.4
SW8g	3.3	4.0	3.2	3.4	3.4	3.5	3.8	4.0	4.9	4.0	3.7	0.5	4.9	3.2
SW10b	3.0	3.0	2.8	3.8	3.5	3.6	3.4	3.7	4.0	3.9	3.5	0.4	4.0	2.8
SW11b	4.9	4.1	5.0	4.0	3.9	4.0	4.1	4.2	4.9	4.6	4.4	0.4	5.0	3.9
Mean	4.7	4.6	4.5	4.6	4.2	4.4	4.6	4.4	5.0	4.8				
Max	7.6	7.4	7.1	7.4	5.6	5.7	5.6	5.3	6.0	6.1				
Min	3.0	3.0	2.8	3.4	3.1	3.5	3.4	3.7	4.0	3.9				

SD: Standard deviation, Max: Maximum and Min: Minimum concentration values

stream is affected by organic wastes and other nutrient inputs from sewage, industrial discharge as well as agricultural and urban runoff, all of which can lead to a decrease in oxygen levels (http://www.dnr.mo.gov/env/esp/waterquality-parameters.htm). Concentrations of DO in unpolluted waters are usually about 8-10 mg L^{-1} (Joseph and Jacob, 2010) and streams with a high dissolved oxygen concentration (greater than 8 mg L^{-1}) are considered healthy and are able to support a significant diversity of aquatic organisms. The summer months are usually the most critical time for dissolved oxygen levels because stream flows tend to lessen and water temperatures tend to increase. In general, DO levels of less than 3 mg L^{-1} are stressful to most aquatic organisms (http://www.dnr.mo.gov/env/esp/waterquality-parameters.htm). The allowable effluent level in treated wastewater for COD is 150 mg L^{-1} (Al-Motairi, 2000). Table 10, describes the seasonal variations of DO (mg L^{-1}) in surface water samples means, standard deviation, maximum and minimum values for different studied sites. This tables shows that all of the water samples exhibited DO values greater than 3 mg L^{-1}. As a result, the water at these sites will maintain most aquatic organisms. The monthly BOD (mg L^{-1}) values were as follows: June (3.0-7.6), July (3.0-7.4), August (2.8-7.1), September (3.4-7.4), October (3.1-5.6), November (3.5-5.7), December (3.4-5.6), January (3.7-5.3), February (4.0-6.0) and March (3.9-6.1). The relationship between mean water temperature during these months and the mean DO is given in Fig. 7; a moderate linear relationship is observed with a R^2 of 0.6592.

Chemical oxygen demand: The Chemical Oxygen Demand (COD) measures the oxygen equivalent of the organic matter content of a water sample that is susceptible to oxidation by a strong chemical oxidant. The COD is usually less than 20 mg L^{-1} in unpolluted waters; higher values may indicate pollution from domestic sewage and industrial effluents (Joseph and Jacob, 2010). In the present study the COD varied from 6.52-130.07 mg L^{-1} (Table 11), showing that some of the water samples are polluted. The values for COD are greater than BOD values at all sites. The data in Table 11 shows that all water samples had values of DO greater than 20 mg L^{-1} or less than 20 mg L^{-1}. The monthly COD values (mg L^{-1}) were as follows: June (12-96), July (14.8-115), August (13-130), September (22-59.2), October (18.9-74.9), November (13.4-56.4),

Table 11: Variations of COD (mg L^{-1}) in surface water samples with months and mean for different studied sites

	2009							2010						
Location	June	July	August	September	October	November	December	January	February	March	Overall mean	SD	Max.	Min.
SW1C	29.8	28.7	26.3	32.4	22.8	30.6	24.3	33.5	24.4	23.1	27.6	3.9	33.5	22.8
SW12a	20.0	21.0	18.0	26.7	26.6	17.2	16.8	19.6	17.0	12.0	19.5	4.5	26.7	12.0
SW8a	19.0	187.0	20.0	22.0	18.9	13.4	13.9	6.5	15.2	12.0	16.0	4.7	22.0	6.50
SW8C	41.0	23.9	52.0	45.8	74.9	32.3	31.8	33.7	26.2	26.5	38.8	15.6	74.9	2.90
SW23	39.0	35.2	47.5	49.7	67.2	30.4	28.4	30.1	27.2	28.3	38.3	13.0	67.2	27.2
SW14	12.0	14.8	13.0	23.1	21.7	16.8	15.9	16.7	15.2	12.5	16.2	3.7	23.1	12.0
SW20	26.0	28.9	45.9	59.2	54.8	40.1	33.8	39.2	28.6	29.1	38.6	11.6	59.2	26.0
SW8g	59.0	42.5	85.3	57.2	69.9	56.4	52.8	53.8	30.2	30.8	53.8	16.7	85.3	30.2
SW10b	96.0	115.0	130.0	54.5	54.8	53.0	54.2	51.8	46.0	42.6	69.8	31.6	130.0	42.6
SW11b	23.0	32.8	24.0	53.0	49.2	47.5	46.8	56.3	40.9	37.9	40.2	10.0	53.0	23.0
Mean	36.5	36.2	46.2	42.4	46.1	33.8	31.9	33.1	27.1	25.5				
Max	96.0	115.0	130.0	59.2	74.9	56.4	54.2	53.8	46.0	42.6				
Min	12.0	14.8	13.0	22.0	18.9	13.4	13.9	6.5	15.2	12.0				

SD: Standard deviation, Max: Maximum and Min: Minimum concentration values

December (13.9-54.2), January (6.52-53.8), February (15.2-45.98) and March (11.96-42.57). The average values of total coliforms, TOC and COD are below 10,000 CFU/100 mL, 2 and 15 mg L^{-1} in the un-contaminated source water, respectively (Chiang *et al*., 2001).

Total organic carbon: Total Organic Carbon (TOC) is the amount of carbon bound in an organic compound and is often used as a non-specific indicator of water quality (http://en.wikipedia.org/wiki/Total_organic_carbon). Total organic carbon can be used as a general indicator of contamination by organics or sewage with changes in its concentration leading to investigations of potential pollution sources (WHO., 2007). Total organic carbon can be found in most city waters in the form of naturally occurring microorganisms, other organic matter and man-made organic-based chemicals (http://www.cal-water.com/pdf/TOC_Info.pdf). Changes in the naturally occurring TOC are frequently found to be a seasonal phenomenon depending on the time of year. The average values of total coliforms, TOC and COD are below 10,000 CFU/100 mL, 2 and 15 mg L^{-1} in uncontaminated source water, respectively (Chiang *et al*., 2001); the allowable level in treated wastewater for TOC is 50 mg L^{-1} (Al-Motairi, 2000).

The TOC in the waters of the United Arab Emirates (UAE) and Qatar of the Arabian Gulf during 1986 showed values ranging from 0.8-3.9 and from 0.5-3.6 mg L^{-1}, respectively (Emara, 1998), with concentrations being higher in surface and bottom waters of the UAE as compared with the Qatari water. Total carbon levels showed similar values in surface and bottom waters for both areas (~25.2 mg L^{-1}). Concentrations of TOC showed significant positive correlation ($r = 0.67$, $p = 0.05$) with petroleum hydrocarbons in the surface waters of the UAE, which may suggest that organic carbon concentration can be considered an indicator of petroleum pollution in this area (Emara, 1998).

The average concentrations of Total Organic Carbon (TOC) in chlorinated sea water and from Jeddah seawater reverse osmosis brine reject were found to be 3.7 and 4.0 mg L^{-1} (Kutty *et al*., 1991). The high TOC in seawater may be attributed to the presence of organics such as humic acids, fulvic acids, high phyto-planktons or zooplankton growth, industrial pollution, urban runoff or oil pollution. The total organic carbon contents in Jeddah seawater are significantly higher than

Table 12: Variations of TOC (mg L^{-1}) in surface water samples with months and mean for different studied sites

	2009							2010						
Location	June	July	August	September	October	November	December	January	February	March	Overall mean	SD	Max.	Min.
SW1C	15.5	15.8	13.8	17.2	10.5	15.5	12.2	16.4	10.2	10.0	18.2	8.2	31.1	9.1
SW12a	10.3	10.8	9.6	13.9	12.0	7.7	7.2	9.8	6.6	4.8	17.9	6.7	26.7	9.9
SW8a	9.7	10.4	10.9	10.6	8.6	5.3	5.3	5.1	5.4	4.8	7.6	2.3	12.7	5.1
SW8C	21.6	13.1	31.1	24.8	30.6	13.7	13.7	14.1	9.1	10.2	18.1	6.0	28.6	11.3
SW23	22.0	19.0	26.7	25.2	26.0	13.2	12.6	13.0	9.9	11.2	24.9	9.9	47.9	13.1
SW14	6.2	8.0	6.3	12.7	9.9	7.6	7.1	7.5	5.3	5.1	34.0	20.0	72.1	17.0
SW20	13.9	15.6	25.8	28.6	23.9	17.1	15.2	17.2	11.3	12.1	18.0	3.8	23.9	12.1
SW8g	31.1	22.9	47.9	27.8	26.2	22.8	23.0	20.9	13.1	13.5	16.9	4.9	25.6	10.4
SW10b	52.5	60.9	72.1	26.7	23.3	22.4	24.7	22.7	17.2	17.0	34.9	19.6	72.1	17.0
SW11b	12.4	17.9	12.1	23.9	21.9	19.8	20.4	19.4	16.3	16.0	6.6	1.9	10.6	4.8
Mean	19.5	19.5	25.6	21.1	19.3	14.5	14.1	14.6	10.4	10.5				
Max	52.5	60.9	72.1	28.6	30.6	22.8	24.7	22.7	17.2	17.0				
Min	6.2	8.0	6.3	10.6	8.6	5.3	5.3	5.1	5.3	4.8				

SD: Standard deviation, Max: Maximum and Min: Minimum concentration values

those from the Arabian Gulf water at Al-Khafji, Al-Jubail and AI-Khobar (Kutty *et al.*, 1989). The determination of total organic carbon concentration in the water system is the first step in assessing water quality. A wide variety of organics in different forms are present in open water.

In the present study, monthly TOC varied from 4.8-72.1 mg L^{-1} (Table 12), showing that the water in all of the sites studied was polluted. By reference to the TOC values (Table 12) it will be seen that all water samples had values of TOC greater than 2 mg L^{-1}. The monthly TOC values (mg L^{-1}) were: June (6.2-52.5), July (8-60.9), August (6.3-72.1), September (10.6-28.6), October (8.6-30.6), November (5.3-22.8), December (15.3-24.7), January (5.1-22.7), February (5.3-17.2) and March (4.8-17.0). In this study, TOC values showed a positive correlation (R^2 = 0.8861) with petroleum hydrocarbons (Fig. 8) present in the surface waters of the sites studied sites, a finding which agrees with those of Emara (1998).

Total petroleum hydrocarbon: Total petroleum hydrocarbons are organic chemicals composed of fused benzene rings formed during the incomplete combustion of coal, oil, petrol and wood (Laflamme and Hites, 1978; NRC., 1989). In one study, the total petroleum hydrocarbons (THC) concentrations ranged between 2.17 and 72.89 with an average of 20.76 µg L^{-1} and from 5.67-87.56 with an average of 26.0 µg L^{-1} during winter and summer, respectively (Said and Hamed, 2006). The total petroleum hydrocarbons concentration in seawater which can produce a harmful effect on the aquatic organisms is in the range of 50 µg L^{-1} in sea water. Higher concentrations of THC are often recorded during summer season which reflects increasing anthropogenic activity in the winter season in the area studied (Said and Hamed, 2006). Total petroleum hydrocarbons in surface water samples collected from the Red Sea coast off Jeddah (Saudi Arabia) ranged from between 1.79 and 17.9 µg L^{-1}. A mean value of 230.41 µg L^{-1} has been reported for the level of total petroleum hydrocarbon in some water wells in Jazan, Saudi Arabia; this value is optimal and means that water is not polluted (Alshikh, 2011).

In water samples studied here, the amount of total petroleum hydrocarbon varied from 1.0-2.20 mg L^{-1} (Table 13). The data is Fig. 9, shows the monthly mean values of total petroleum hydrocarbons and show that all sites were polluted with these products. The observed values for total monthly petroleum hydrocarbon (mg L^{-1}) show that August exhibited the maximum value

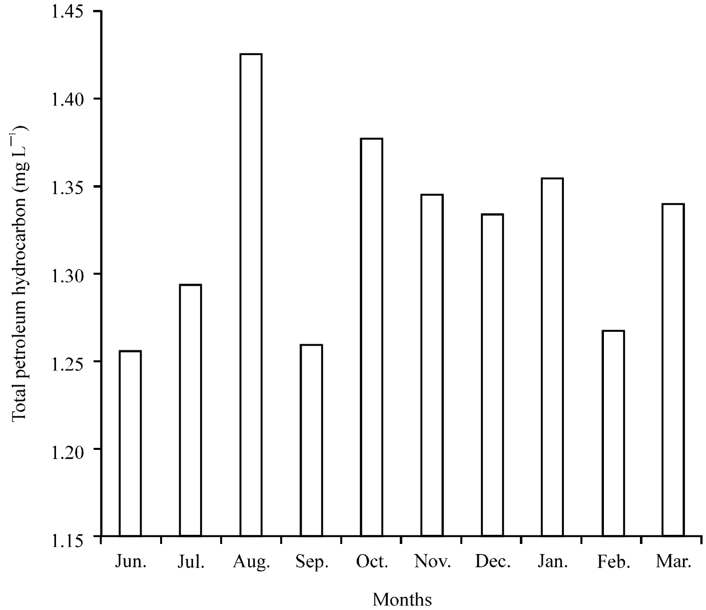

Fig. 9: Monthly variation of mean values of total petroleum hydrocarbon

Table 13: Variations of total petroleum hydrocarbon (mg L^{-1}) in surface water samples with months and mean for different studied sites

	2009							2010						
Location	June	July	August	September	October	November	December	January	February	March	Overall mean	SD	Max.	Min.
SW1C	1.25	1.31	1.03	1.23	1.13	1.62	1.57	1.75	1.39	1.29	1.16	0.13	1.43	1.00
SW12a	1.28	1.29	1.26	1.20	1.43	1.02	1.17	1.28	1.04	1.02	1.28	0.14	1.53	1.10
SW8a	1.14	1.20	1.05	1.06	1.08	1.00	1.00	1.00	1.00	1.00	1.10	0.06	1.19	1.03
SW8C	1.00	1.00	1.30	1.10	1.09	1.16	1.13	1.24	1.19	1.43	1.33	0.11	1.50	1.20
SW23	1.10	1.21	1.47	1.28	1.38	1.21	1.19	1.20	1.25	1.53	1.68	0.19	2.20	1.52
SW14	1.19	1.18	1.15	1.07	1.14	1.08	1.03	1.03	1.03	1.06	1.71	0.17	2.10	1.53
SW20	1.22	1.31	1.50	1.20	1.40	1.32	1.24	1.35	1.28	1.50	1.39	0.20	1.65	1.12
SW8g	1.58	1.64	2.20	1.64	1.73	1.70	1.60	1.58	1.52	1.62	1.33	0.06	1.43	1.26
SW10b	1.65	1.55	2.10	1.70	1.75	1.75	1.80	1.62	1.60	1.53	1.75	0.17	2.20	1.60
SW11b	1.16	1.26	1.20	1.12	1.60	1.60	1.62	1.50	1.38	1.42	1.02	0.03	1.08	1.00
Mean	1.26	1.30	1.43	1.26	1.35	1.35	1.34	1.36	1.27	1.34				
Max	1.65	1.64	2.20	1.70	1.75	1.75	1.80	1.75	1.60	1.62				
Min	1.00	1.00	1.03	1.06	1.00	1.00	1.00	1.00	1.00	1.00				

SD: Standard deviation, Max: Maximum, Min: Minimum concentration values. The statistical data in this table was generously provided by ADA (1991)

(Fig. 9); the other monthly values (mg L^{-1}) were, June, (1.0-1.65), July (1.0-1.64), August (1.03-2.20), September (1.06-1.70), October (1.08-1.75), November (1.0-1.75), December (1.0-1.80), January (1.0-1.75), February (1.0-1.60) and March (1.0-1.62).

Oil and grease: The concentration of dispersed oil and grease (OG) (ASTM D3921-96, 2003) is an important parameter for the determination of water quality and safety. The presence of oil and grease in water can cause surface films and shoreline deposits leading to environmental degradation and can also induce human health risks when discharged in surface or ground waters. Additionally, OG may interfere with aerobic and anaerobic biological processes and lead to

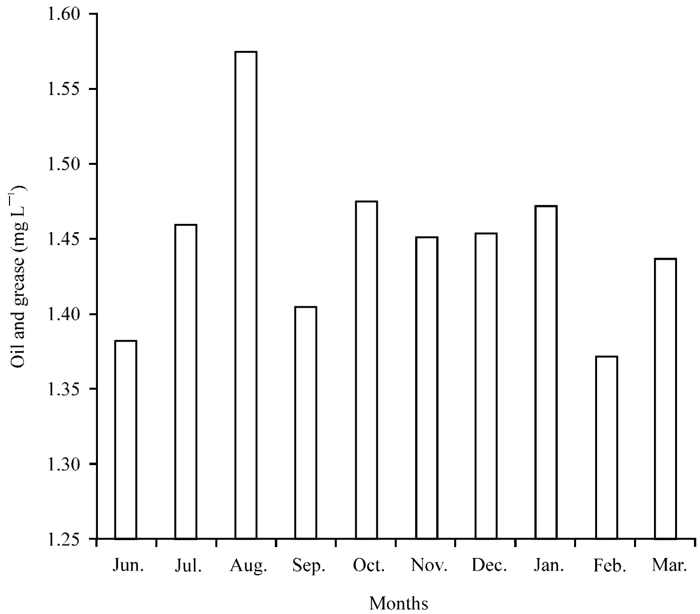

Fig. 10: Monthly variation of mean values of oil and grease

Table 14: Variations of oil and grease (mg L^{-1}) in surface water samples with months and mean for different studied sites

	2009							2010						
Location	June	July	August	September	October	November	December	January	February	March	Overall mean	SD	Max.	Min.
SW1C	1.80	1.40	1.16	1.35	1.20	1.80	1.73	1.90	1.58	1.43	1.26	0.19	1.62	1.00
SW12a	1.42	1.35	1.39	1.36	1.50	1.13	1.25	1.47	1.12	1.08	1.42	0.17	1.69	1.22
SW8a	1.26	1.34	1.24	1.17	1.15	1.00	1.00	1.00	1.00	1.00	1.21	0.09	1.38	1.13
SW8C	1.00	1.00	1.38	1.22	1.14	1.25	1.28	1.38	1.30	1.62	1.44	0.09	1.61	1.36
SW23	1.22	1.36	1.68	1.50	1.46	1.30	1.28	1.28	1.38	1.69	1.84	0.20	2.35	1.63
SW14	1.32	1.38	1.26	1.16	1.20	1.17	1.16	1.13	1.15	1.13	1.89	0.19	2.38	1.69
SW20	1.36	1.61	1.57	1.37	1.48	1.40	1.36	1.46	1.39	1.38	1.53	0.22	1.82	1.25
SW8g	1.76	1.90	2.35	1.80	1.90	1.82	1.74	1.70	1.63	1.78	1.45	0.06	1.58	1.37
SW10b	1.83	1.86	2.38	1.89	1.92	1.87	1.95	1.79	1.72	1.69	1.90	0.18	2.38	1.72
SW11b	1.29	1.40	1.35	1.25	1.82	1.78	1.80	1.62	1.45	1.57	1.05	0.07	1.16	1.00
Mean	1.38	1.46	1.58	1.41	1.48	1.45	1.46	1.47	1.37	1.44				
Max	1.83	1.90	2.38	1.89	1.92	1.87	1.95	1.90	1.72	1.78				
Min	1.00	1.00	1.16	1.16	1.14	1.00	1.00	1.00	1.00	1.00				

SD: Standard deviation, Max: Maximum and Min: Minimum concentration values

decreased wastewater treatment efficiency (Pisal, 2009). Frederick (2005) stated that oil and grease is virtually absent from domestic water and its concentration in water used for agricultural purposes is often around 10 mg L^{-1}. When oil and grease particles reach water courses they form a thick layer on the water surface causing the temperature of water to increase, decrease levels of dissolved oxygen and result in a high BOD. High concentrations of oil and grease also decrease oxygen concentrations by increasing bacterial growth (Ashraf *et al*., 2010). The allowable level in treated wastewater for OG is 8 mg L^{-1} (not to exceed 15 mg L^{-1} in any individual discharge) as reported by Al-Motairi (2000).

In the present study, monthly OG varied from 1.0-2.38 mg L^{-1} (Table 14). The values for total monthly OG (mg L^{-1}) were as follows: August had maximum value (Fig. 10), June, (1.0-1.65), July

(1.0-1.64), August (1.03-2.20), September (1.06-1.70), in October (1.08-1.75), November (1.0-1.75), December (1.0-1.80), January (1.0-1.75), February (1.0-1.60) and March (1.0-1.62).

CONCLUSION

The results of this study show that surface water samples at some sites from the main stream running through Riyadh are contaminated and may be not be safe for agriculture purposes without prior treatment. The sites are subjected to natural contamination and by human activities. As a result awareness of the need to protect the waters at these sites and the consequences of pollution must be made clear and strict legal action should be taken against those who individuals or organizations which contaminate the water. Hopefully, the data reported here will form part of the baseline data which can be used in future studies. The present work may also hopefully assist mangers and planners to establish certain preventive measures and to suggest methods of treatment of the water course studies here.

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