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Seasonal Changes of Water Properties and Current in the Northernmost Gulf of Aqaba, Red Sea

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Abstract – Seasonal changes of tide signal(s), temperature, salinity and current were studied during the years 2004-2005 in the northernmost Gulf of Aqaba, which is under developmental activities, to obtain scientific bases for best management and sustainability. Spectrum analysis revealed permanent signals of tide measurements during all seasons, which represented semidiurnal and diurnal barotropic tides. The other signal periods of 8.13, 6.10-6.32, 4.16 and 1.02-1.05 h were not detected in all seasons, which were related to shallow water compound and overtides of principle solar and lunar constituent and to seiches generated in the Red Sea and the Gulf of Aqaba. Spatial and temporal distribution of temperature, salinity and density showed significant differences between months in the coastal and offshore region and no significant differences among the coastal sites, between the surface and bottom waters and between coastal and offshore waters. Therefore, the temporal and spatial variation of water properties in the northernmost Gulf of Aqaba behave similarly compared to other parts. The coastal current below 12 m depth was weak (3-6 cms^{-1}) and fluctuated from east-northeastward to west-southwestward (parallel to the shoreline), which may be related to the effect of bottom topography and/or current density due to differential cooling between eastern and western parts in the study area, and wind-induced upwelling and downwelling in the eastern and western side, respectively. The prevailing northerly winds and stratification conditions during summer were the main causes of the southward current at 6 and 12 m depths with average speed of 28 and 12 cms^{-1}, respectively.

Key words – coastal currents, water properties, semi-enclosed seas, Gulf of Aqaba

1. Introduction

The Gulf of Aqaba is a narrow, long and deep semi enclosed basin attached to semi enclosed Red Sea through the narrow and shallow Strait of Tiran (maximum depth 252 m, length ~5 km and width ~2 km; Murray *et al.* 1984), (Fig. 1a). The physical properties of the Gulf of Aqaba were investigated by several authors in order to demonstrate water masses characteristic, current pattern and water exchange regime between the Red Sea and the Gulf of Aqaba through the Strait of Tiran. Most of these studies explained that circulation in the Gulf of Aqaba is affected mainly by the external forces, such as water levels, winds, topography of shoreline and thermocline depth (Berman *et al.* 2000; Berman *et al.* 2002; Monismith and Genin 2004; Manasrah *et al.* 2006a). The current direction is affected by the bottom topography. Unlike the thermocline depth and wind stress, the density change across the thermocline dose not seem to have an effect on the circulation (Berman *et al.* 2000). Moreover, the tidal current and water levels in the northern Gulf show strongly the effects of remote forcing (Monismith and Genin 2004). Water exchange through the Strait of Tiran is limited and represented as two layers and three layers water exchange systems in winter and summer seasons, respectively (Manasrah *et al.* 2004; Klinker *et al.* 1976). Water mass characteristics in the Gulf of Aqaba are governed by the seasonal cycle of winter mixing and summer stratification which is driven by sea-surface cooling or net heat flux (Manasrah *et al.* 2004; Manasrah

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2002; Genin 1995).

Seasonally consistent flow pattern were found along the west coast of the northern tip of the Gulf during 1988-1991 (Genin and Paldor 1998). A southward current along the west coast was observed most of the year, with a short period (November-January) of northward flow and an abrupt reversal in early February. The circulation in the Gulf is made up of a series of permanent gyres oriented along its axis (Manasrah *et al.* 2004; Berman *et al.* 2000). The topography and depth of the thermocline (~250 m) are the main factors of the circulation pattern in the northern Gulf of Aqaba. As the depth of the thermocline becomes large enough a transition from summer to winter circulation is triggered which, in turn, causes a change in the location of the center of the gyres as well as their diameter.

The study area in the northernmost Gulf of Aqaba is actually close to the center of two towns (Aqaba and Eilat) that was selected due to its significant importance for the surrounding countries because it is substantially under various active developments. The current rapid development at the northern end of the Gulf of Aqaba is expected to cause ocean pollutions at this area (Badran *et al.* 2006). Therefore, this study focuses to achieve a detailed description of seasonal changes of water properties (seawater temperature and salinity) and current pattern in the northernmost Gulf of Aqaba in order to obtain scientific bases for management and sustainable use.

2. Materials and Methods

The study was conducted during one year (April 2004-April 2005) within the area that exists between the western border and hotels along the Jordanian northernmost Gulf of Aqaba (Fig. 1). Meteorological conditions, tide, temperature, salinity, density and currents were measured and analyzed in the entire of the study area (Fig. 1b; Table 1).

Meteorological conditions

The meteorological conditions during the study period were measured by a local weather station (Delta-t Weather Station). These conditions were analyzed in order to understand and evaluate the effect of meteorological

Table 1. The geographical coordinates (longitude and latitude) and bottom depth of the coastal and offshore stations in the northernmost Gulf of Aqaba.

Station	Longitude (E) 34° dd.mmm	Latitude (N) 29° dd.mmm	Depth (m)
Coastal sites			
A_1	58.688	32.397	15
B_1	58.625	32.308	30
C_1	58.523	32.103	45
A_2	58.887	32.250	15
B_2	58.836	32.163	30
C_2	58.732	31.981	45
A_3	59.170	32.073	15
B_3	59.130	31.997	30
C_3	59.038	31.843	45
Offshore station			
REF	58.555	31.768	100

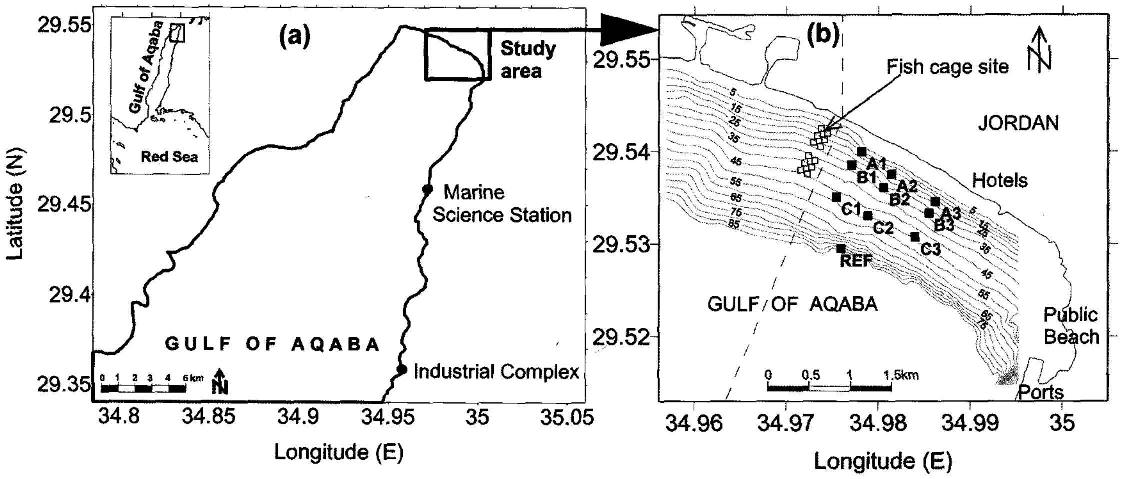

Fig. 1. Map of the a) northern Gulf of Aqaba showing the b) bathymetry chart and sites of sample collection in the study area.

forcing in surface and subsurface physical characteristics at the northernmost Gulf of Aqaba.

Tide

Tide measurements during the months of August 2004, October 2004, January 2005 and March 2005 were used in order to analyze tide signals in the northern Gulf of Aqaba. Tide records were measured using tide gauge (Hydrotide Automatic Tide Gauge) with one average record per 10 min. The spectrum and statistical analysis of currents and tide were performed using MATLAB 5.3 software.

Water properties

Temperature, salinity and density were measured monthly using a self contained Conductivity, Temperature and Depth meter (CTD Ocean Seven 316/319 Probes) at all coastal and offshore stations (Fig. 1b). The CTD measuring resolution and precision were about 0.03% to 0.05% bar for pressure, 0.001 to 0.003 for salinity and 0.003 to 0.005°C for temperature. The instrument was set to record the three parameters simultaneously at 2 seconds interval.

Current measurements

Current measurements were recorded using a moored Acoustic Doppler Current Profiler (ADCP) Workhorse 300 kHz (RD Instrument) at B_2 site (Fig. 1b) during August 2004, September-October 2004, February 2005 and March-April 2005 that represent summer, autumn, winter and spring season, respectively. The records represent 10 minutes interval in 15 layers (depth cells) of the coastal water column (4-30 m) at B_2 site. The ADCP was designed to measure the horizontal and vertical current components at different layers in the water column which depend on the transmitting frequency.

3. Results

Meteorological condition

The meteorological measurements demonstrate that the wind speed fluctuated within the range of 0-9 ms^{-1} during all the seasons (Fig. 2a). Moreover, a harmonic change of wind speed appeared during summer (Fig. 2a1) causing a diurnal cycle that was represented by the strong winds during daytime and relatively weaker winds during nighttime. Meanwhile, northerly winds dominated over the study area and represented more than 90% of total measurements (Fig. 2b). A typical daily cycle of air temperature variation was noticed during all seasons with mean values of 34 ± 4.5 °C, 29 ± 3.8 °C, 19 ± 4.2 °C and 21±4.9 °C for summer, autumn, winter and spring, respectively (Fig. 2c). In general, winds and air temperature had obvious effect on humidity, where the minimum value reached 8% recorded in summer and the maximum value reached 84% recorded in spring (Fig. 2d). Therefore, relative humidity showed a periodic variation following the daily cycle of air temperature and wind speed (Fig. 2d). The seasonal solar heat flux in the northern Gulf of Aqaba ranged between -2 to 846, -2 to 664, -1 to 766 and -1 to 832 Wm^{-2}, respectively. The maximum value was recorded at noon and the minimum values were oserved between sunset and sunrise (Fig. 2e).

Tide and tidal current

Spectrum analysis of the tide measurements during different intervals of the study period revealed six distinguishable periodic signals (T_1-T_6) with different time scales (Fig. 3). T_1 and T_2 represent the diurnal and semidiurnal barotropic tides, respectively. The shorter periods (T_3-T_6) were not related to the principle tidal constituents.

Current

Water movement was observed in the study area in the northernmost Gulf of Aqaba during summer, autumn, winter and spring seasons as follows; August 4th-11th, 2004, September 30th-October 22nd, 2004, January 11th-28th, 2005 and March 6th-April 4th, 2005, respectively (Figs. 4-7).

Two current regimes were observed during the summer trial (August 4th-11th, 2004) at depths between 6-34 m of coastal water column. One regime was observed at depth layers of 6 and 12 m and showed a constant south-southwestward current of 202 ± 39.2°. In addition, it was parallel to the prevailing winds with relatively strong averaged magnitudes of 28.1 ± 13.01 cms^{-1} at 6 m and 12.9 ± 11.33 cms^{-1} at 12 m. Moreover, the average value of daily displacement of water movement was 20.5 km day^{-1} at 6 m and 6.2 km day^{-1} at 12 m (Fig. 4; Table 2). The second current regime was detected below 12 m (18, 24, 30 and 34 m depth layers). Weak currents with vertically anticlockwise rotation in direction were observed from northwestward (321°) at 18 m depth to westward (277°) at 34 m (Fig. 4; Table 2). The average values of current

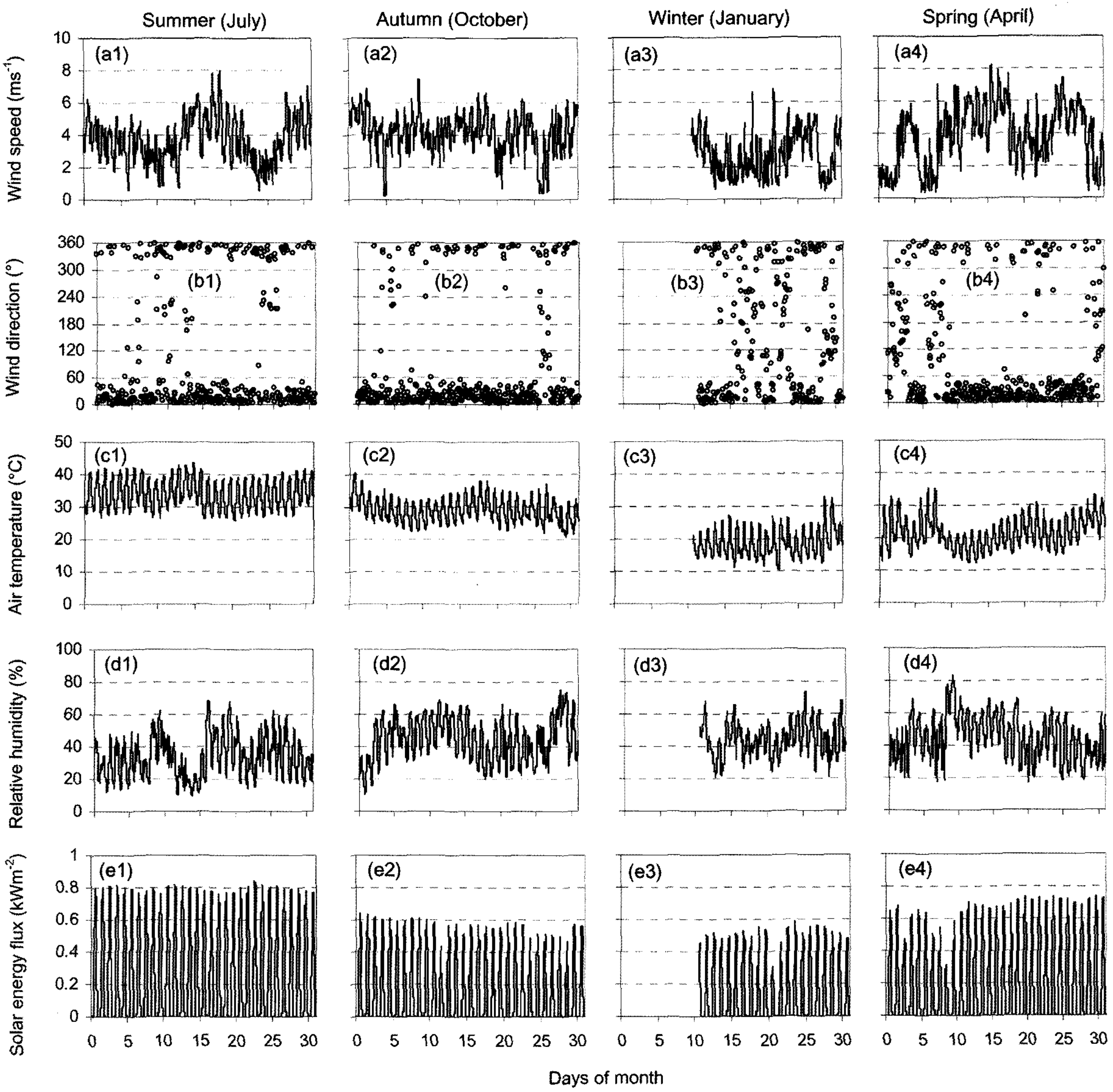

Fig. 2. Time series records of a) wind speed (ms^{-1}), b) wind direction (°), c) air temperature (°C), d) relative humidity (%) and e) solar energy flux (kWm^{-2}) during summer, autumn, winter and spring seasons of the years 2004-2005 in the northern Gulf of Aqaba.

speed and displacement rate of water movement below 12 m depth were 3.3 ± 1.88 cms^{-1} and 1.4 ± 0.17 km day^{-1}, respectively. During autumn (September 30th-October 22nd, 2004), which was at the time of stratification-mixing transition condition, a south-southwestward (210°) current dominated at 6 m with average value of 7.0 ± 3.69 cms^{-1} and displacement rate of 3.0 km day^{-1} and was parallel to the foremost wind direction (Fig. 5; Table 2). Below 6 m (12, 18, 24 and 26 m), the current direction was varying with depth, where anticlockwise rotation in direction was detected from northwestward (338°) at 12 m depth to westward (279°) at 26 m (Fig. 5; Table 2). At each layer below 12 m a multi-reverse current direction was noticed between southeastward and northwestward, i.e. parallel to the shoreline of the study area (Fig. 5). The average value of current speed and displacement rate of water movement for all depth levels below 12 m were 3.8 ± 2.44 cms^{-1} and 1.2 ± 0.06 km day^{-1}, respectively (Table 2). During mixing condition period (January 11th-28th, 2005), current measurements revealed similar current pattern to that detected during summer and autumn, except the anticlockwise rotation of current direction from the upper to the lower layer: the current direction changed gradually from north-northwestward (340°) at 6 m to west-southwestward

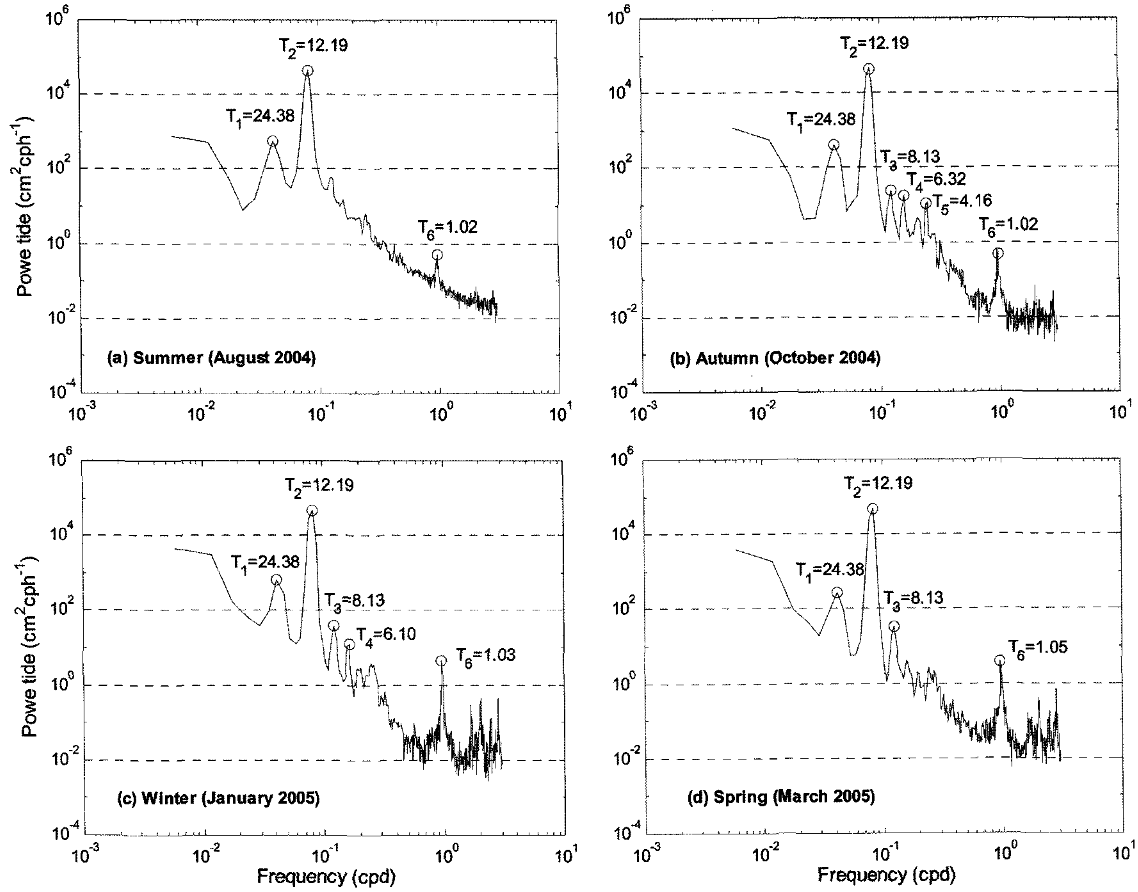

Fig. 3. Power spectrum analysis of tide (cm) records during different months in all seasons of the study period in the northern Gulf of Aqaba.

(245°) at 34 m (Fig. 6). Moreover, a fluctuation in current direction was observed at each selected depth with larger time scale compared to that observed during autumn (Fig. 5). The average value of current speed and displacement rate of water movement for all selected depth levels were 5.4 ± 3.20 cms^{-1} and 2.2 ± 0.62 km day^{-1}, respectively (Table 2).

The spring season of current measurements manifested abrupt changes in current direction from southeast to northwest at each selected depth layer except that at 24 m where the change in direction was from southeast to west (Fig. 7). The average values of current speed, current direction and displacement rate of water movement for all selected depth levels (6, 12, 18 and 24 m) were 4.8±3.78 cms^{-1}, 302° ± 66.1°, 0.9 ± 0.19 km day^{-1}, respectively (Table 2).

Water properties

Temperature

The monthly variation of surface and bottom water temperature (C°) at offshore and coastal stations during the study period revealed the existence of the seasonal cycle (Fig. 8a, b). In April, mean temperature at the coastal and offshore station was 21.56 ± 0.08 °C. Temperature began to increase rapidly during early summer and reached the average maximum value of 25.46 °C in July. On the other hand, the offshore bottom waters reached a maximum temperature of 24.82 °C in November. During autumn, the temperature cooled gradually and reached an average value of 24.83 °C. The lowest temperature in the coastal and offshore water column reached 21.36 °C during winter (February). The statistical comparison (one way ANOVA test) showed significant differences of temperature records between months in the coastal and offshore water column following the seasonal cycle of temperature variation (Fig. 8a, b; Table 3). On the other hand, no significant differences were detected for temperature among the coastal sites and between the surface and bottom waters during the study period (Figs. 8 and 8; Table 4).

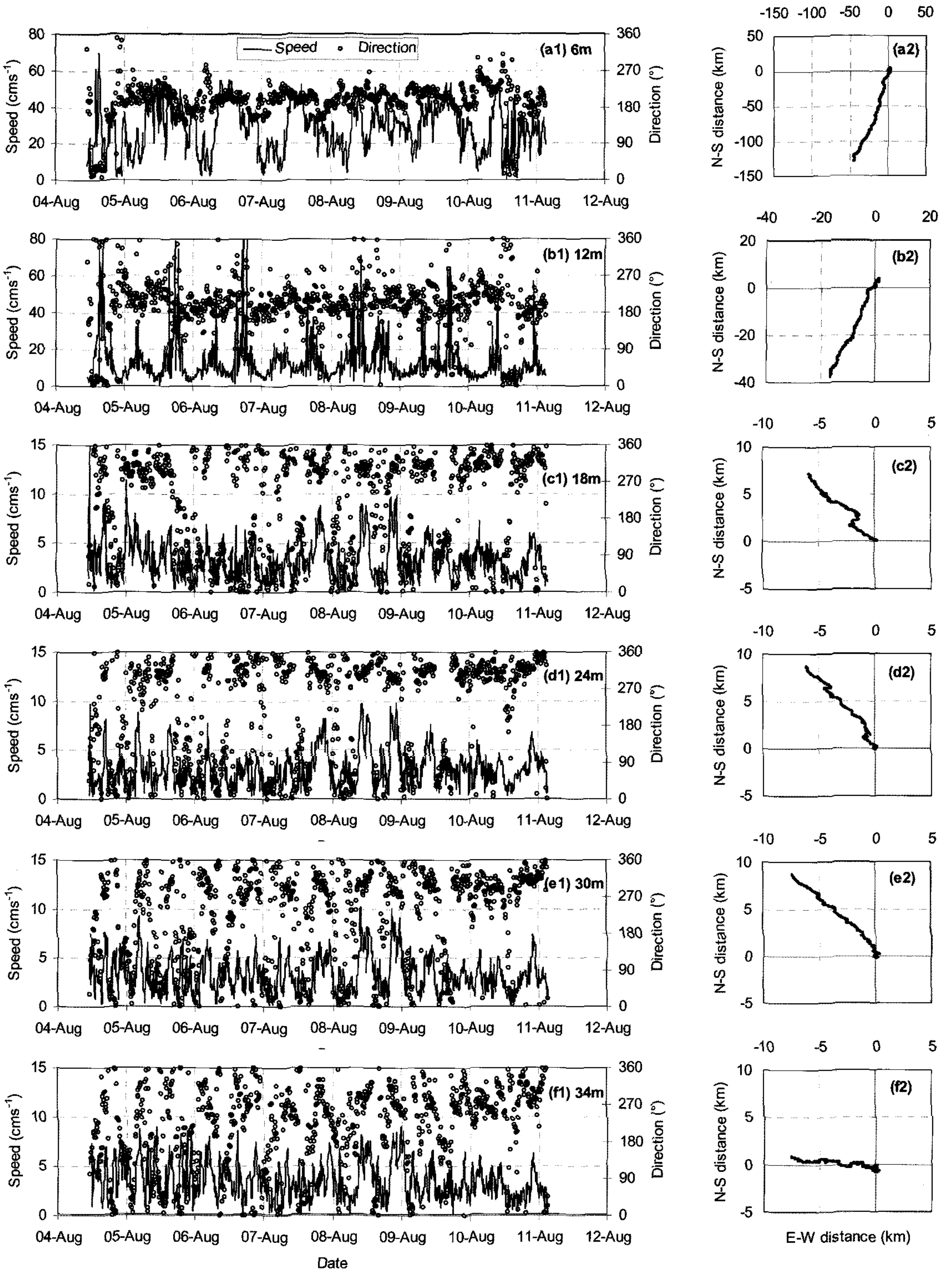

Fig. 4. Raw data set of current speed (cms^{-1}) and direction (°) and progressive vector diagram at selected depth levels during summer season (August 4th-11th, 2004) in the study area in the northernmost Gulf of Aqaba.

Salinity

The temporal variation of average values of salinity in the coastal and offshore water column revealed a fairly stable variation during spring and summer seasons with the mean value of 40.73. Salinity reached a maximum value of 40.91 during autumn (November) and a minimum

Table 2. Statistical summary of current speed (cms^{-1}), current direction (°) and displacement rate (km day^{-1}) of water movement at selected depth levels during the four seasons in the study area in the northernmost Gulf of Aqaba.

	Speed (cms^{-1})		Direction (°)		count	Dis. rate (km day^{-1})
Depth	Mean	SD	Mean	SD		
August 4th-11th, 2004 (summer)						
6	28.1	13.01	199	38.7	961	20.5
12	12.9	11.33	204	39.6	961	6.2
18	3.2	1.94	321	52.9	961	1.4
24	3.1	1.91	325	53.7	961	1.6
30	3.2	1.82	310	50.2	961	1.5
34	3.5	1.86	277	45.9	961	1.2
September 30th-October 22nd, 2004 (autumn)						
6	7.0	3.69	210	36.4	3227	3.0
12	3.8	2.51	338	62.4	3227	1.1
18	4.1	2.60	322	60.0	3227	1.2
24	3.7	2.43	291	60.1	3227	1.2
26	3.6	2.19	279	60.4	3227	1.1
January 11th-28th, 2005 (winter)						
6	5.6	3.06	340	59.1	2400	1.1
12	6.2	3.67	317	62.1	2400	2.4
18	5.6	3.41	306	62.7	2400	2.2
24	5.1	3.33	289	61.9	2400	2.1
30	4.8	2.91	265	60.9	2400	2.4
34	5.1	2.66	244	57.2	2400	3.0
March 6th-April 4th, 2005 (spring)						
6	5.2	3.94	321	66.0	4135	0.6
12	5.1	3.90	336	67.6	4135	1.0
18	4.6	3.87	310	67.8	4135	0.8
24	4.2	3.41	241	63.1	4135	1.1

SD – standard deviation, Dis. rate – displacement rate

mean value of 40.68 at the bottom layer in early summer (May) and 40.72 at the surface layer in late summer (September) (Fig. 8c, d). Therefore, water salinity variation mostly followed a seasonal cycle trend, as indicated statistically (one way ANOVA test). Significant differences of salinity between months were observed in the coastal and offshore water column (Fig. 8c, d; Table 3). As for temperature, no significant differences were detected for salinity among the coastal sites and between the surface and bottom waters during the study period (Figs. 8 and 9; Table 4).

Density (σ_t)

Basically, density is calculated based on temperature and salinity values (Millero and Poisson, 1981). Therefore, the annual variation of density in the coastal and offshore water column revealed a gradual decrease that started in spring (28.72 ± 0.04 σ_t) until summer (27.72 ± 0.04 σ_t), which represented the annual minimum. After that, density increased through autumn to reach the annual maximum value of 28.87 ± 0.01 σ_t in winter (Fig. 8e, f). Similar for temperature and salinity, significant differences of density values were observed between months in the coastal and offshore water column (Fig. 8e, f; Table 3). In contrast, no significant differences for density among the coastal sites and between the surface and bottom waters were found during the study period (Figs. 8 and 9; Table 4).

4. Discussion

Tide and tidal current

The tide signals in the present study agreed well with those revealed by Manasarh *et al.* (2006a). The diurnal signal T_1 might comprise the luni-solar diurnal component

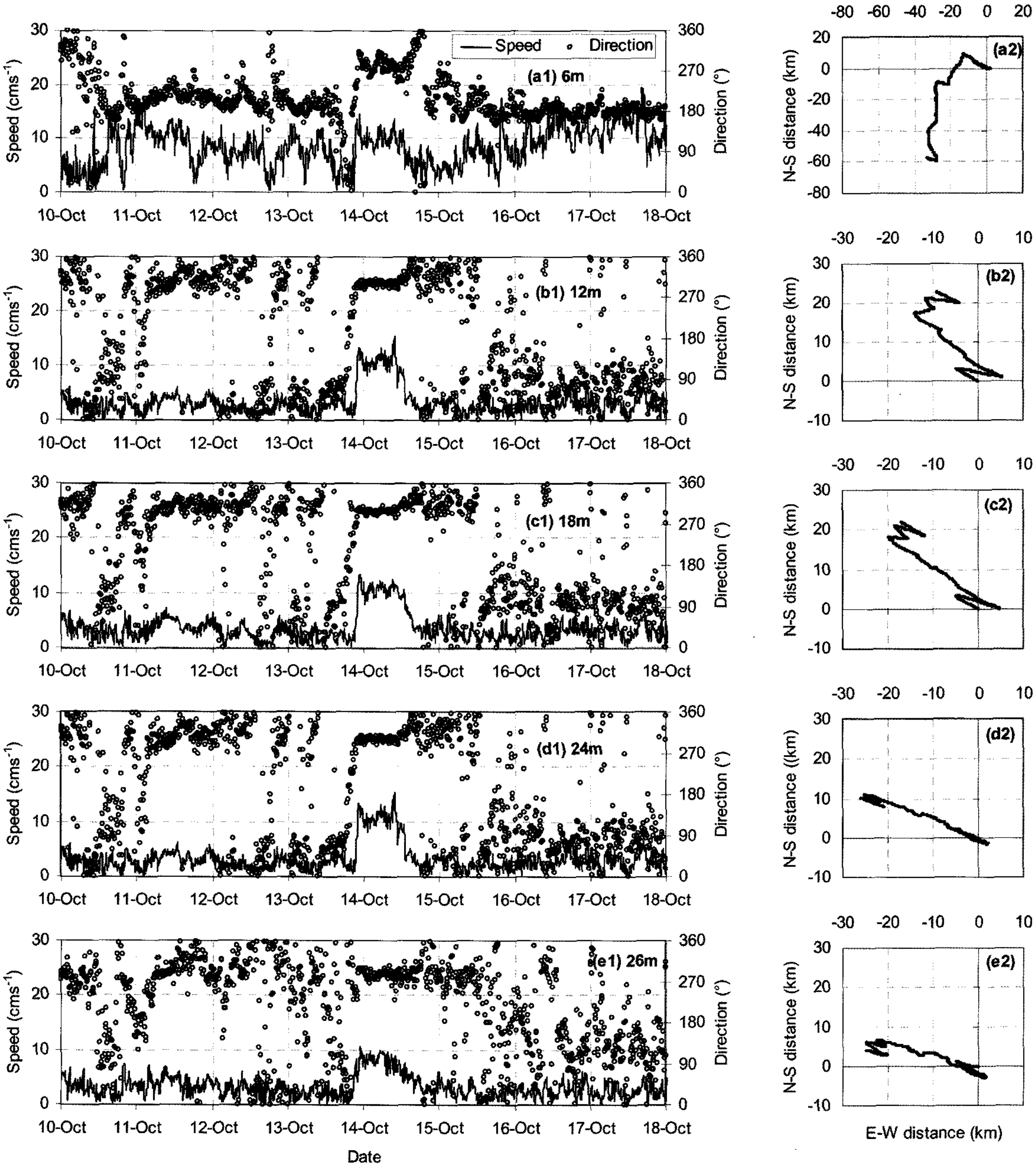

Fig. 5. Partial raw data set of current speed (cms^{-1}) and direction (°) and progressive vector diagram at selected depth levels during autumn season (September 30th-October 22nd, 2004) in the study area in the northernmost Gulf of Aqaba.

(K_1), whereas the semidiurnal signal T_2 might be constituted of the principle lunar component (M_2), which both signals were detected in all seasons. Moreover, the periodic signals T_3-T_5 represent shallow water compound and overtides of the principal solar and lunar constituent. The signal T_3 might comprise the lunar terdiurnal constituent (M_3), T_4 might comprise the lunar and/or solar quarter-diurnal harmonics (M_4; S_4; MS_4), and T_5 might comprise the lunar and solar sixth diurnal harmonics ($2MS_6$; $2SM_6$). Notably, the signal T_3 was not found during summer and T_4 was not found during spring and summer seasons. The shortest period T_6 (1.02-1.05), which was detected in all seasons, is related to seiches of first mode that are generated in the Gulf of Aqaba. Moreover, the first, second and third mode of seiches that are generated in the Red Sea affected the tidal signals T_2, T_4 and T_5, respectively (Fig. 3). Therefore, the tidal currents could be observed in the Gulf of Aqaba, which result from internal tides generated at the Strait of

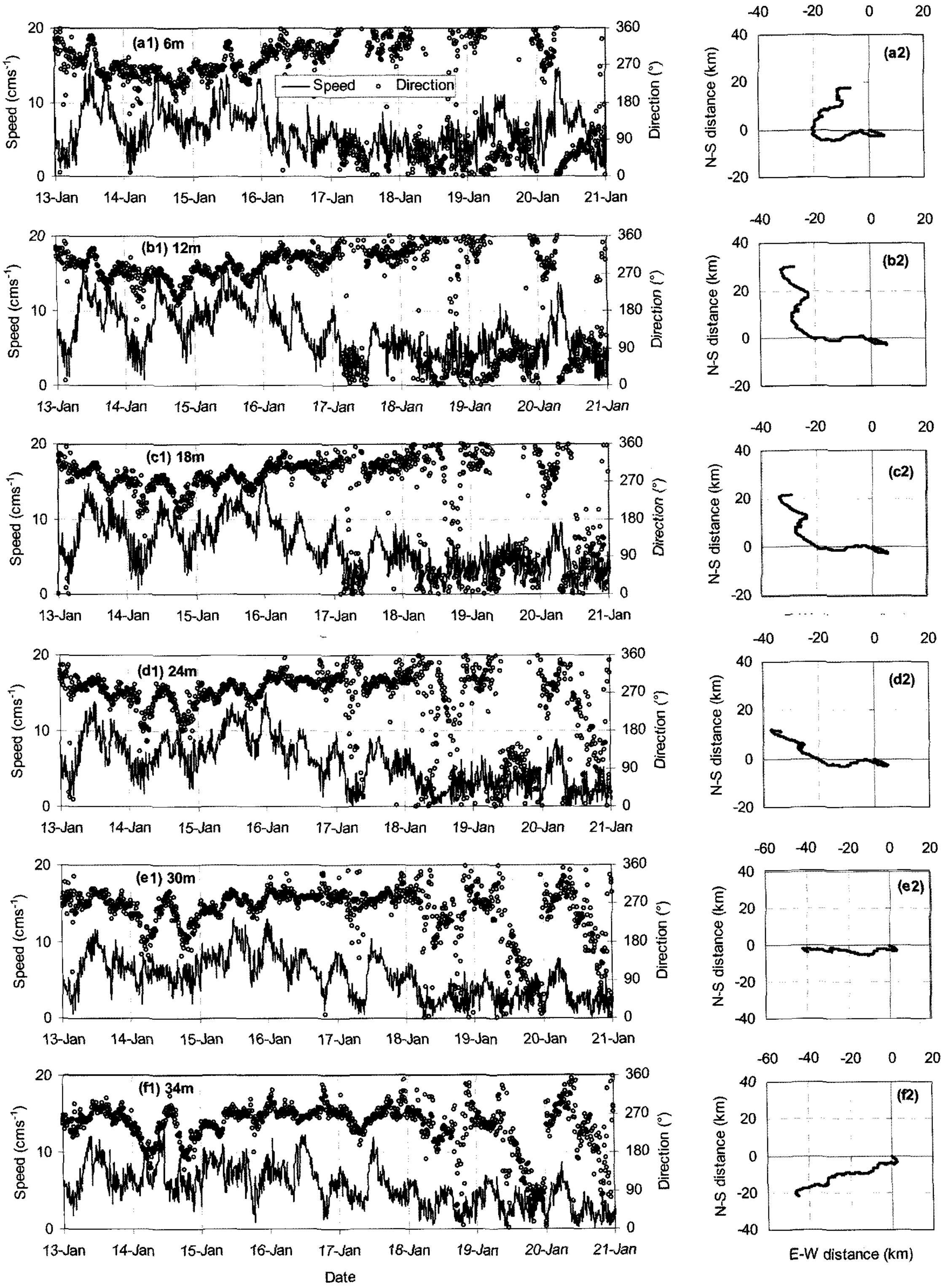

Fig. 6. Partial raw data set of current speed (cms^{-1}) and direction (°) and progressive vector diagram at selected depth levels during winter season (January 11th-28th, 2005) in the study area in the northernmost Gulf of Aqaba.

Tiran. Monismith and Genin (2004) found that when the Gulf of Aqaba is strongly stratified in summer, tidal currents are strong, and when stratification is weak, tidal currents are weak.

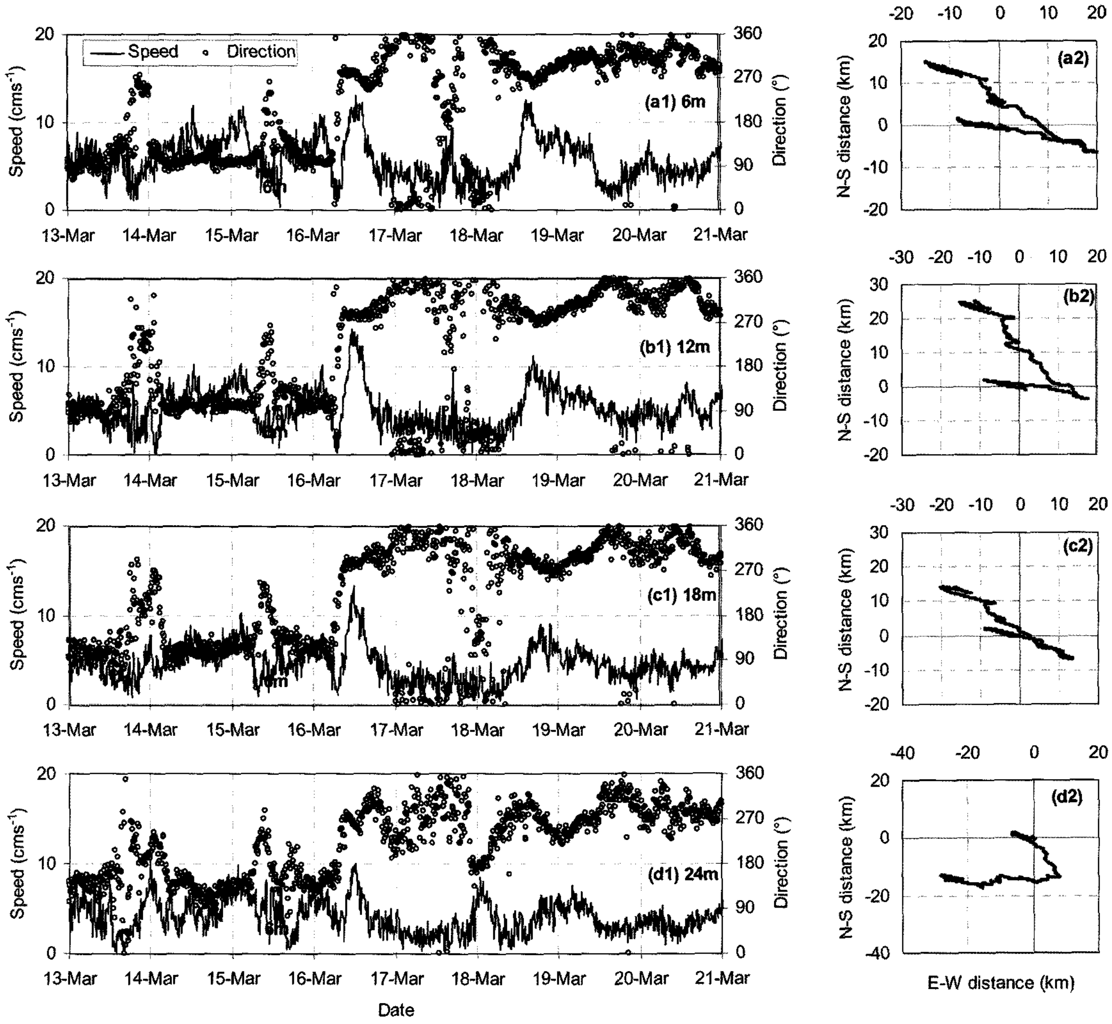

Fig. 7. Partial raw data set of current speed (cms^{-1}) and direction (°) and progressive vector diagram at selected depth levels during spring season (March 6th-April 4th, 2005) in the study area in the northernmost Gulf of Aqaba.

Current

In general, west to northwestward current was dominant in coastal waters of the study area during all seasons for the period of August 2004- April 2005. In summer, water movement at the upper 12 m depth flowed parallel to winds (southwestward) and below 12 m depth it directed northwestward-westward. Wind effect on the upper waters dwindled during autumn to be only on the upper 6 m depth, where the current directed southwestward. In the lower depths (12-34 m) the current direction was northwestward to westward. Current during winter season was northwestward to westward indicating the relative disappearance of wind influence. In spring, the current direction at 6, 12 and 18 m depth was firstly northwestward and then east-southeastward and then northwestward again, which revealed a mix of external forces dominated during spring on water movement. This current pattern might be related to the effect of bottom topography that directed currents to flow parallel to its shape, i.e. parallel to the shoreline. The main feature of current in the study area during autumn, winter and spring seasons was the existence of multi temporal reverses of current direction from northwestward to southeastward, which may be related to the direction reflection of current density due to differential cooling between eastern and western parts in the study area. Previous studies (Brenner *et al.* 1988, 1989, 1991) reported that wind events in the northern Gulf of Aqaba drive upwelling in the eastern side and downwelling in the western side, therefore westward current dominates there. Besides, Nieumann *et al.* (2004) concluded that

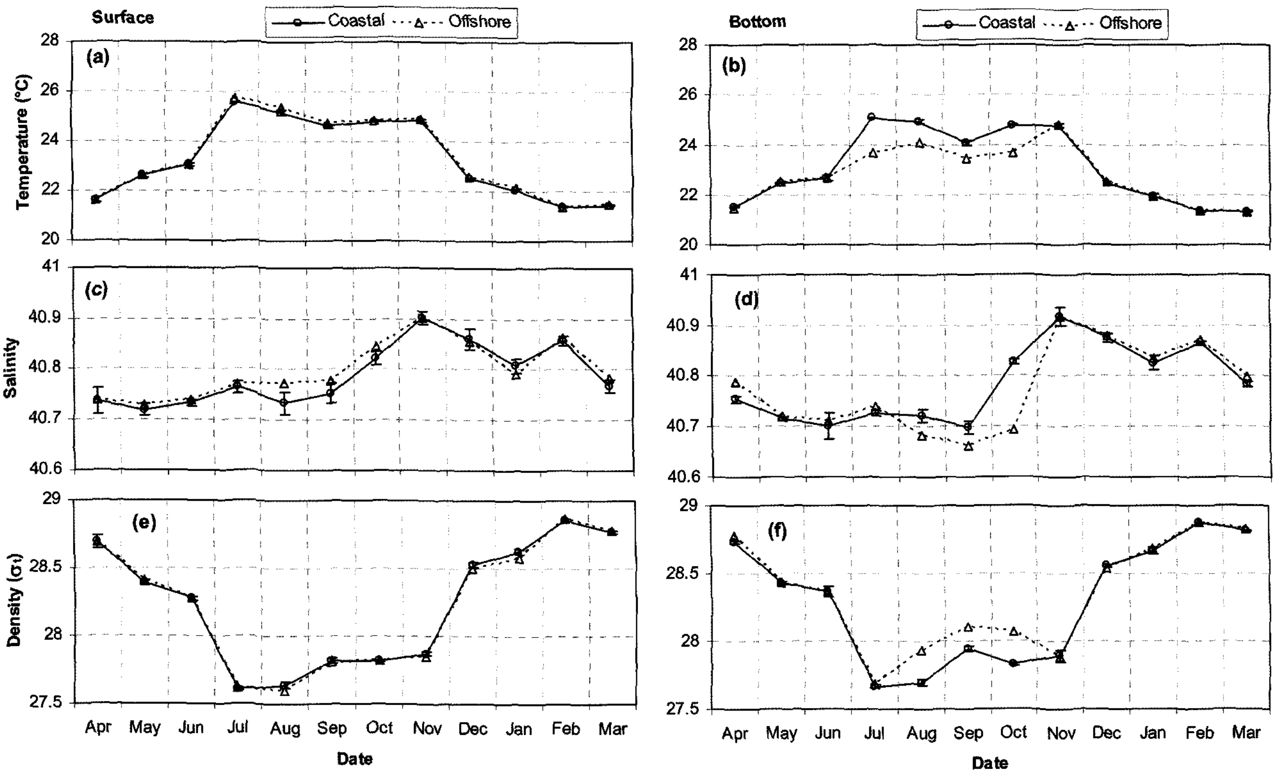

Fig. 8. Monthly variation of a,b) temperature (°C), c,d) salinity and e,f) density (σ_t) for surface and bottom waters at coastal sites and offshore station during the period April 2004 to March 2005.

Table 3. Statistical comparison (One way ANOVA test; P-values, significance level 5%) between months (April 2004-March 2005) at all coastal sites and between coastal sites vs. offshore station for temperature (°C), salinity and density (σ_t) at surface and bottom waters in the northernmost Gulf of Aqaba.

Parameter	Between months (coastal sites)		Coastal sites vs. offshore station	
	Surface*	Bottom†	Surface‡	Bottom§
Temperature (°C)	<0.0001	<0.0001	0.6305	0.4639
Salinity	<0.0001	<0.0001	0.6864	0.8912
Density (σ_t)	<0.0001	<0.0001	0.7101	0.4751

*: Degree of freedom = 11, number of measurements = 102.
†: Degree of freedom = 11, number of measurements = 103.
‡: Degree of freedom = 1, number of measurements = 114.
§: Degree of freedom = 1, number of measurements = 115.

differential cooling of near – and offshore surface water during cold winter nights results in cross-shore gradient of density (σ_t) triggering gravity (density) currents. During summer, the prevailing northern winds and stratification conditions governed significantly the currents at upper 12 m depth, which mostly directed to the south. Several studies showed that winds are effective external forces that govern surface and subsurface currents (Monismith and Genin 2004; Manasrah *et al.* 2004; Berman *et al.* 2000, Brenner *et al.* 1988, 1989). On the other hand, a vertical anticlockwise rotation in current direction from top to bottom was observed specifically during summer and autumn seasons, which may be related to the Ekman wind drift in the coastal region with vertical wall (Price *et al.* 1987; Krauss 1993), which predicts that a steady wind stress acting together with the Coriolis force will produce a transport of water to the right of the wind.

Temperature

Seasonality of water temperature was reported in several previous works along the Jordanian coast of Aqaba Gulf and showed an agreement with the present study (e.g.

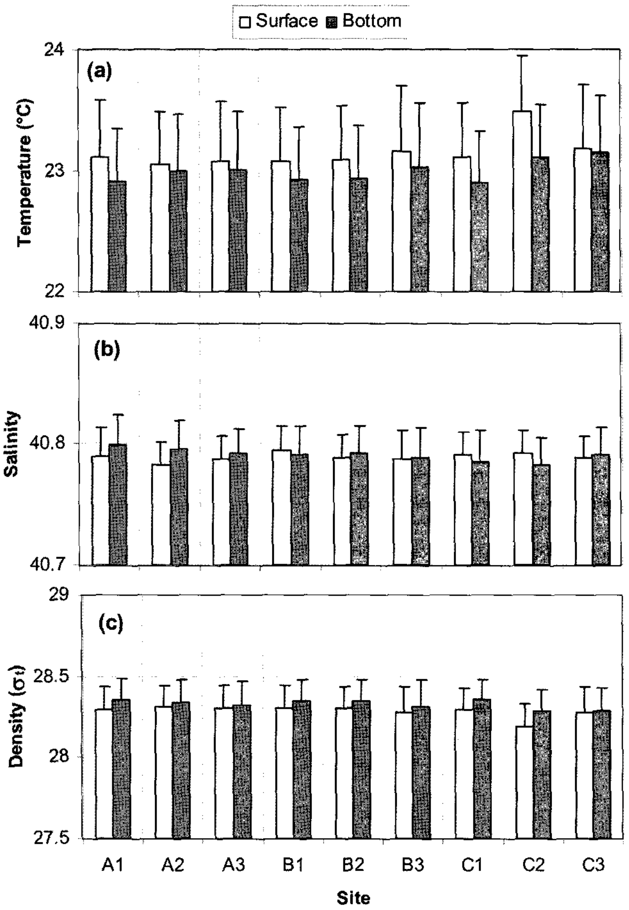

Fig. 9. Annual average of a) temperature (°C), b) salinity and c) density (σ_t) for surface and bottom waters at each site in the study area for the period April 2004 to March 2005.

Badran 1996, 2001; Badran and Foster 1998; Rasheed 1998; Manasrah 1998, 2002; Al-Najjar 2000; Al-Sokhny 2001; Manasrah *et al.* 2004, 2006a, b, c; Badran *et al.* 2005). It showed a maximum surface water temperature during mid summer with maximum value in July (25.75 °C), while a minimum in February (21.34 °C). All previous works have shown that the temperature range mostly fluctuates between 20.5-27.5 °C, which is typical to the prevailing conditions in the Gulf of Aqaba and that certainly follows the mixing and stratification rhythm of water body in winter and summer, respectively. In spite of different bottom depth of the coastal and offshore stations, there were insignificant differences for bottom temperature among these stations. Offshore temperature measured at 100 m depth however showed a slight decrease in summer (July-October) which is attributed to stratification condition in the water column. This is in agreement with that reported by Levanon-Spaneir *et al.* (1979), Badran (1998), Rasheed (1998), Manasrah (2002) and Manasrah *et al.* (2004) who all showed an effect of stratification on bottom water temperature.

Salinity

In general, no distinct variation of salinity with time and depth was observed in the northern Gulf of Aqaba (e.g. Al-Najjar 2000; Manasrah 2002). Klinker *et al.* (1978) reported a salinity range of 40.20-40.80 along the entire coastal water of the Gulf. Rasheed (1998) reported a range of 40.33-40.78, Manasrah (1998, 2002) found that the maximum range of salinity was 40.3-40.7 during the years 1997-2001, Al-Najjar (2000) reported that surface salinity varied between 40.58 in July and 40.33 in April, whereas Al-Sokhny (2001) reported salinity range of 40.57-40.6. This study suggested also the salinity range of 40.66 at offshore bottom waters in September and 40.92 at coastal bottom waters in November. The major factors that control the salinity variation in the Gulf of Aqaba are the high evaporation during summer, the low inflow of saline water from the Red Sea and the mixing condition during winter. Manasrah (2002) suggested that the most of annual difference of salinity in the northern Gulf of Aqaba is due to the high evaporation.

Table 4. Statistical comparison (One way ANOVA test; P-values, significance level 5%) among the coastal sites at surface and bottom waters and between surface vs. bottom waters of the entire the coastal sites for temperature (°C), salinity and density (σ_t) in the northernmost Gulf of Aqaba.

Parameter	Among coastal sites		Between surface vs. bottom
	surface*	Bottom†	Entire coastal sites‡
Temperature (°C)	0.9996	>0.9999	0.4639
Salinity	>0.9999	>0.9999	0.8912
Density (σ_t)	0.9998	>0.9999	0.4751

*: Degree of freedom = 8, number of measurements = 102.
†: Degree of freedom = 8, number of measurements = 103.
‡: Degree of freedom = 1, number of measurements = 205.

Density (σ_t)

Density values are mainly affected by temperature variations. Therefore, it is considered to have an opposite profile to the temperature unless salinity varies significantly. Manasrah (1998) showed a variation in density between 27.2-28.63 σ_t in surface water, while Al-Najjar (2000) reported a range of 26.87-28.51 σ_t. In the present work the observed maximum and minimum density were 28.88 and 27.62 σ_t, respectively.

In conclusion, the coastal stations in the northernmost Gulf of Aqaba showed almost similar properties in term of temporal variation of temperature, salinity and density compared to other areas along the Gulf. Moreover, the current regime in the study area was mainly parallel to the shoreline and fluctuated in direction between east and west. These findings are highly important and useful that should be employed and taken into consideration for monitoring, managing and protecting the environment of the area.

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