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SEA LEVEL CHANGES AT ROSETTA PROMONTORY, EGYPT

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ABSTRACT

The time series of the available hourly sea level data collected during the periods 1982 – 1983 & 2000 - 2001 at two locations at Rosetta promontory (Sea and Estuary stations) were used to study the main features of sea level, tides and surge variations in this region. The annual ranges of hourly sea level heights at the Sea and Estuary stations have nearly the same value of about 90 cm. The water level at the Estuary station is higher than that at the Sea station and the annual MSL at the Estuary station is about 30.0 cm, while at the Sea station it is 12 cm above the zero level of the Survey Authority. The tides at Rosetta promontory are mixed but are mainly of semi-diurnal type and the tidal ranges are less than 26 cm .The tidal range in the estuary is relatively larger and the times of high and low water are slightly later than at the sea. The annual mean surge levels at both stations are close to zero. At the Estuary station, the monthly mean sea and surge levels are generally below the corresponding annual mean levels in February and during the period from April to June, while at the Sea station they are lower during the period from April – August.

1. INTRODUCTION

Rosetta promontory is located on the eastern part of Abu Quir Bay at about 60 km eastward of Alexandria (Fig. 1). This region is considered as one of the most important areas of trade, agriculture and fishing activity in Egypt. The promontory was formed by sediment delivered to the Mediterranean coast of Egypt by Rosetta branch of the River Nile. During the 20th century and particularly after the construction of the High Dam in 1964 there have been dramatic changes in the shore line instability of the Nile Delta coastal zone in terms of erosion, accretion and sea level rise. Rosetta promontory is subjected to erosion processes, the rate of shore line retreat at the tip of the promontory reached about 106 m/yr (Frihy and Komar, 1993). El-Fishawi and Badr (1995) indicated that the local estimates of relative sea level rise along the Nile Delta coast could be ranged between 24 cm and 69 cm by the year 2100. The loss of coastal lands was about 17 km^2 at Rosetta during the period 1909 – 1994. The expected sea level extreme calculated from the long term maximum annual water level showed that the 50-year recurrence to be 115 cm, while the 20-year recurrence to be 107 cm (Fanos, 2001). These previously mentioned problems attract the attention to study coastal processes including sea level changes along the Nile Delta coast. The present work focuses on studying the spatial and the temporal variations of sea level and surges at Rosetta promontory as well as determination of tidal constants using the available sea level data collected during the periods 1982 - 1983 & and 2000 - 2001.

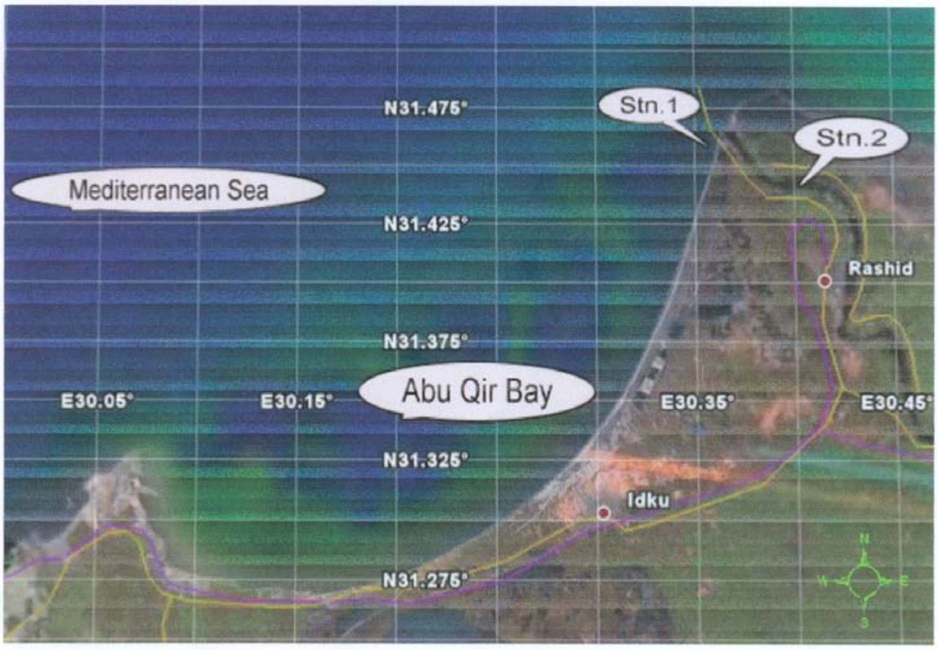

Fig. (1): Locations of tide gauges at Rosetta promontory.

2. MATERIALS AND METHODS

The hourly sea level data used in the present work were collected by the Coastal Research Institute, Alexandria, Egypt (Debes, 2002). Two tide gauges were used to record sea level at Rosetta promontory during the periods 1982 - 1983 & and 2000 -2001. The first gauge is permanently fixed at the sea (Sea station) at latitude 31° 27.89` N and longitude 30° 21.81` E and the other one (Estuary station) is fixed at Rosetta branch of the River Nile at latitude 31° 26.66` N and longitude 30° 22.90` E (Fig. 1). The zero level of these tide gauges is adjusted to the zero level of the Survey Authority. During the period of investigation (1982- 1983 & 2000 - 2001), the periods with available sea level observations at the Sea station include: January to December, 1982, January -June, 1983 and February - June, 2001. At the Estuary station these periods are: January to December, 1982, all months in 1983 except June, August - December, 2000 and January to May, 2001. The graphical records of the tide gauges were first smoothed out by hand to eliminate seiches and short wave effect. The hourly heights of sea level were then tabulated from the smoothed records. These hourly heights were used to study the sea level variations and to calculate the harmonic constants (amplitude&phase) of the major tidal constituents, they are also used to determine tidal and surge heights at Rosetta promontory.

Spectral and tidal analyses have been applied to the hourly sea level time series of 1982 months (The year that has complete hourly sea level records at both stations). The spectral analysis of sea level time series was done using Statistica 5 software package. The harmonic constants (amplitude&phase) of the major tidal constituents have been computed using the IOS software package (Foreman, 1977). The values of the harmonic constants of each computed tidal constituent were then averaged over the whole period of analysis (12 months) to give the mean values of amplitude and phase of this constituent. The type of tide at Rosetta promontory was determined using the ratio factor F which is the ratio of the sum of the amplitudes of diurnal components (K1+O1) to the sum of the amplitudes of the semi-diurnal components (M2+S2).

The tide at any locality is of semi-diurnal type when F lies in the range 0.0 to < 0.25, and it is mixed and mainly semi-diurnal when F is in the range 0.25 to < 1.5, while it is mixed and mainly diurnal when F in the range 1.5 to < 3.0. When the F factor is ≥ 3.0 the tide is of diurnal type (Pugh, 1987).

The mean values of the harmonic constants of the major tidal constituents (M2, S2, K1, N2, MSF, K2, O1, MU2, OO1, M4, Ms4, and 2SM2) have been used to compute the predicted hourly tidal level using IOS software package (Foreman, 1977). The hourly surge levels S (t) have been computed according to the following equation (Pugh, 1987):

$$S(t) = H(t) - T(t) - Z_0(t)$$

Where H (t) is the observed sea level, T (t) is the predicted tidal level, Z_0 (t) is the mean sea level and t is the time.

3. RESULTS AND DISCUSSION

3.1. Sea level variations

The sea level at Rosetta promontory generally shows relatively remarkable spatial and temporal variations. The hourly sea level heights at the Estuary station are greater than those observed at the Sea station (Fig. 2). During 1982, 1983 and 2001 the hourly sea level heights at the Sea station varied between -27 cm (recorded in April, 1982) and +62 cm (in February, 1982). At the Estuary station the hourly sea level heights during 1982, 1983, 2000 and 2001 varied between -14 cm (observed in February, 1982) and +85 cm (in February, 1983).Analysis of hourly sea level data collected during 1982 (The year that has at both stations complete hourly sea level records) indicates that about 90% of the recorded data exist within the limits of -7.5 cm to +27.5 cm (Fig. 3.a), while those at the Estuary station are within the limits of +2.5 cm to +52.5 cm (Fig. 3.b). The histograms (Figs. 3.a and 3.b) indicate that percentage frequency distributions of hourly sea level heights at both stations are approximately symmetrical around their corresponding means. The annual ranges of hourly sea level heights at these two stations have approximately the same value of about 90 cm. This value is larger by about 20 cm than that observed by Debes (2002) at Abu Quir (35 km westward of Rosetta) and that indicated by El-Gindy and Moursy (1996) at Burulus, which lies at about 60 km eastward.

Generally, during 1982 the values of the monthly mean sea level (MSL), low low water level (LLWL), high high water level (HHWL) and the monthly range at the Estuary station are larger than those at the Sea station (Table 1) . The annual MSL at the Estuary station is about 30 cm, while at the Sea station it is of about 12 cm above the zero Survey Authority. The monthly MSL at the Sea station was below the annual level (12.4 cm) during the period from April to August, while during the rest of the year it is above the annual MSL. At the Estuary station, the monthly MSL is below the annual mean (29.8 cm) in February and during the period from April to June, while it is above the annual MSL during the rest of the year (Table 1). The observed seasonal variation in water level at the Sea station may be significantly attributed to the seasonal variability in weather conditions, which will be latter. At the Estuary station, the seasonal fluctuations in water level may be mainly attributed to the significant seasonal fluctuations in the rates of fresh water discharged into the Mediterranean through Rosetta branch of the River Nile. According to the Ministry of water resources and irrigation in Egypt, the rate of fresh water discharged into the sea via Rosetta branch of the River Nile is high in winter (67x 10^6 m^3 / day) and low in summer (5x 10^6 m^3 / day).

3.2. Tidal variations

During 1982, the monthly power spectral analysis of hourly sea level heights at the Sea and Estuary stations showed two relatively significant peaks at 12 hr and at 24 hr (Fig. 4). The peak at 12 hr is the most significant at these two locations and can be attributed to the semi-diurnal tidal constituents (M2&S2). The second peak at 24 hr is less significant or it is completely absent as in the case corresponding to the monthly power spectral curves of February (Fig. 4.a).This less significant peak can also be attributed to the diurnal tidal constituents (K1&O1). The existence of semi-diurnal and diurnal tidal oscillations of sea level at the Estuary station as concluded from the spectral analysis of hourly sea level heights at this station (Fig. 4b) indicates that the tidal waves can penetrate Rosetta estuary and affect the water level in the down stream reaches of Rosetta branch of the River Nile.

Generally, the tides at Rosetta promontory are mixed but are mainly of semi-diurnal type (Table 2). The tidal ranges in Rosetta estuary are relatively larger and the times of high and low water were slightly later than in the sea just outside. This can be attributed to the funneling and the retarding effects of the estuary and also to the convergence and divergence of tidal currents within the estuary during the tidal cycle. At the Estuary station, the mean spring [2(M2+S2)], mean neap [2(M2-S2)] and the largest spring [2(M2+S2+K1+O1)] ranges are 20.8 cm, 5.2 cm and 26.2 cm, respectively. At the Sea station, these ranges are 14.0 cm, 2.0 cm and 17.6 cm, respectively (Table 2). At Rosetta promontory, the most significant tidal constituents are the principal semi-diurnal lunar (M2) and solar (S2) constituents (Table 2), which have periods of about 12 hours. Table 3 shows that at Rosetta Sea station, the amplitudes of M2 and S2 are of the same order of magnitude as those computed at Abu Quir and at Burulus, while the phases of these constituents at Rosetta Sea station are later than at Abu Quir and Burulus. Also it is clear from table 3 that the amplitudes of M2 and S2 at Rosetta Sea station are smaller than those found at Alexandria and Port Said. The phase of M2 at Rosetta is later than that at Alexandria and Port Said. Also at Rosetta, the phase S2 is later than that at Alexandria but it is approximately similar to that computed at Port Said (Table 3). These differences in amplitudes and phases that were noticed between the previously mentioned tidal stations are attributed to the tidal dynamics, which take into consideration, beside the astronomical forces, the effect of: earth's rotation, bottom topography, shape of the shoreline and bottom friction.

3.3. Surge level variations

Surges are weather-induced sea level variations. The weather elements that affect these changes in sea level are: atmospheric pressure and winds. Atmospheric pressure affects sea level through the "inverted barometer effect" by amount equal to 1 cm per mbar of pressure variation. Wind effects arise mainly by the across shore components of wind stress. According to Hamed (1996), the sea level raises along the Mediterranean coast of Egypt when the prevailing winds blow from NW-N directions (i.e. winds with onshore component), whereas winds blowing from SW-SE directions (i.e. winds with offshore component) cause lowering in sea level.

Along the Mediterranean coast of Egypt low values of atmospheric pressure, generally, occur in summer while higher values occur in winter (Moursy, 1976). In summer the mean daily atmospheric pressure is about 1010 mb, whereas in winter it amounts 1015 mb (El-Meligy, 1999). Hamed (1983) indicated that during winter and spring seasons the distribution of atmospheric pressure over the Eastern Mediterranean generate over the Egyptian Mediterranean coast a wind system that exhibits relatively large fluctuation in both speed and direction.

During these two seasons winds from SW-SE directions have a higher percentage of occurrences than in summer and fall seasons. Relatively weak but less variable winds from NW-N quadrants generally prevail during summer and fall seasons. Shereet (2004) showed that the wind at Rosetta coast is predominantly blowing from the north (with high frequency of occurrence) and north-west (Fig. 5). Winds from all other directions occurred but with significantly low frequency of occurrence. The winter season was characterized by wind coming from all directions but northerly and northwesterly winds were still more predominant than those coming from the other directions. During the summer season, northerly winds prevailed while during the spring season, the predominant direction of wind ranged between N and NW with some minor percentage from northeasterly direction.

During 1982, the hourly surge heights at Rosetta promontory were significantly varying from one month to another. The surge levels at the Sea and at the Estuary stations were not similar in height as well as in their patterns of fluctuations. Generally about 90% of the hourly surge heights at the two tide gauges have values between -17.5 cm and +17.5 cm (Figs. 3.c and 3d). The hourly surge levels are referenced relative to the corresponding MSL at the Sea station (+12 cm above the zero level of the Survey Authority) and at the Estuary station (+29.8 cm above the zero level). At the Sea station, the values of hourly surge level were between about -46 cm and +44 cm with an annual range of about 90 cm. This value is larger by about 25.0 cm than that observed at Abu Quir during the period 1993 – 1999 (Debes, 2002). At this station the minimum level was recorded in April, while the maximum one was in February. It is to be mentioned that the rate of fresh water discharged into the sea via Rosetta branch of the River Nile is high in winter (67x 10^6 m^3 / day) and low in summer (5x 10^6 m^3 / day) and this may be the cause of the differences in surge levels between Abu Quir And Rosetta Sea stations. At the Estuary station, the hourly surge levels ranged between about -33 cm and 45.0 cm with an annual range of about 78 cm. The maximum and the minimum hourly surge levels occurred at this station during February and March, respectively (Table 4) and can be related to the seasonal variations in flow rates of fresh water through the Rosetta branch.

The monthly mean surge ranges at both the Sea and at the Estuary stations during 1982 were approximately equal (about 46 cm) and the annual mean surge heights at these two stations were close to zero (table 4). The seasonal variations of monthly mean surge height is more regular at the Sea station than at the other one. This is because the surge level at the sea station is more affected by the quasi-regular seasonal cycles of wind and pressure regimes of the Egyptian Mediterranean coast. At the Estuary station, which is far inland, the surge level is more related to the fluctuations in the amounts of fresh water discharged into the sea through Rosetta outlet. Generally, negative surge is prevailing at the Sea station during the period from April to August, while at the Estuary station the negative surge is observed during February, April -June and November. At both stations positive surge occurs during the other months of the year.

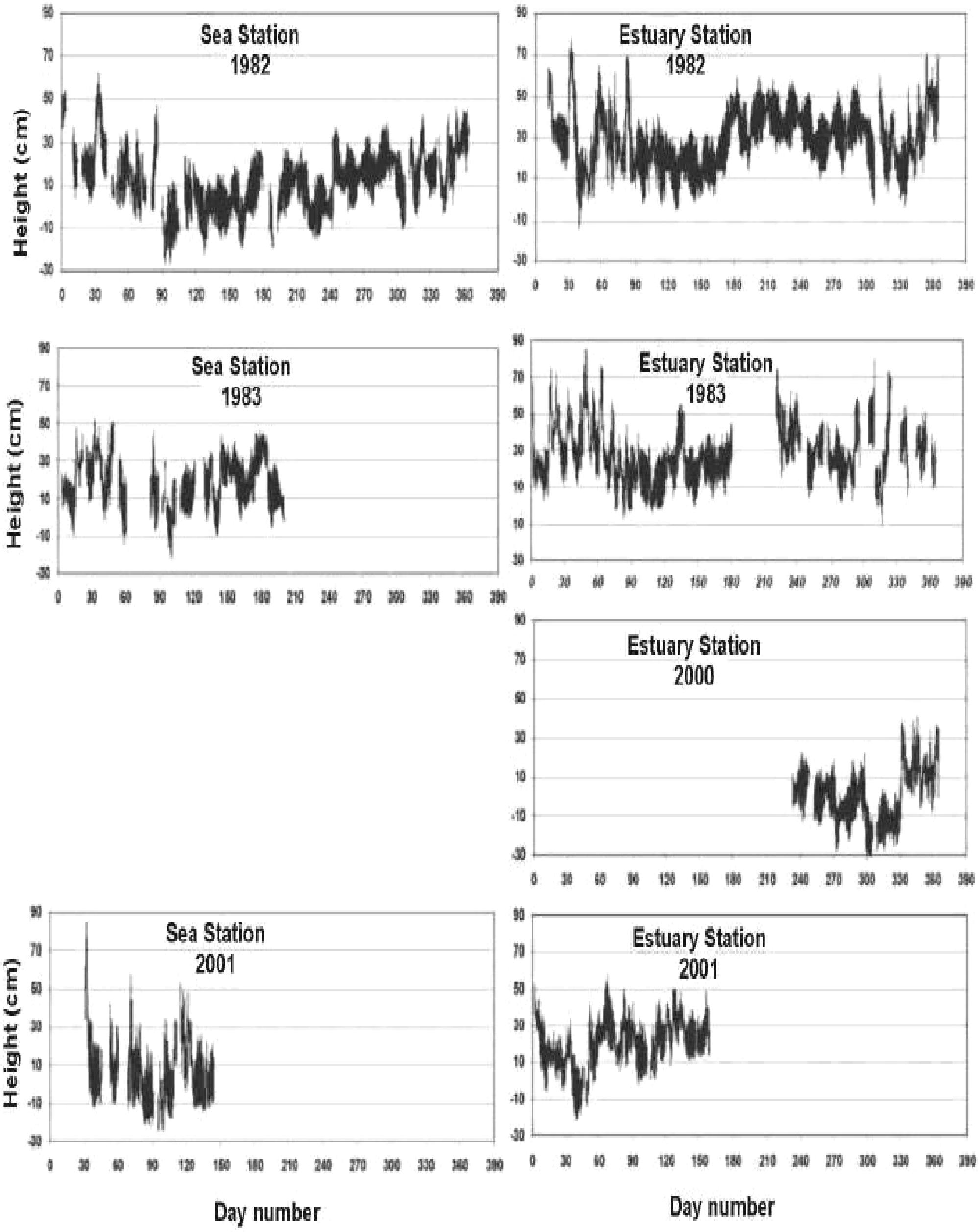

Fig. (2): The variations of the hourly sea level at Rosetta Sea and Estuary stations.

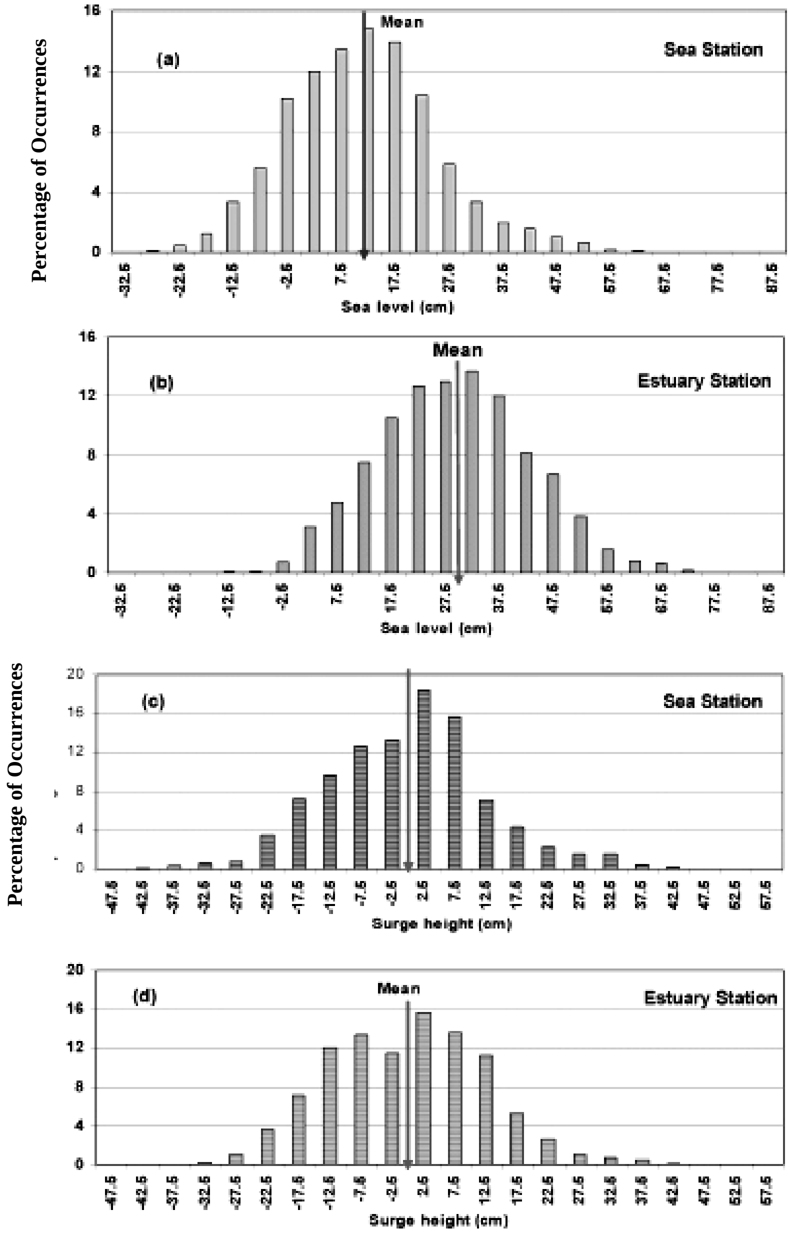

Fig. (3): Frequency distribution of the hourly sea and surge levels at Rosetta Sea (a, c) and Rosetta Estuary (b, d) stations during 1982.

Table (1): Monthly mean sea (MSL), low low water (LLWL), high high water (HHWL) levels and monthly range (cm) at Rosetta Sea (stn.1) and Estuary (stn.2) stations during 1982.

	Monthly MSL		LLWL		HHWL		Monthly range	
Month	**Stn.1**	**Stn.2**	**Stn.1**	**Stn.2**	**Stn.1**	**Stn.2**	**Stn.1**	**Stn.2**
January	24.6	36.8	2	15	54	73	52	58
February	23.3	26.8	-1.5	-14	62	77	63.5	91
March	12.6	31.1	-7	4	47	69	54	65
April	-2.6	21.1	-27	-2	23	41	50	43
May	-0.1	15.1	-23	-5	15	34	38	39
June	5.8	24.9	-18.5	2	27	51	45.5	49
July	8.2	38.5	-19	15	27	59	46	44
August	3.1	39.2	-15	23	32	58	47	35
September	16.2	30.9	-2	10	37	52	39	42
October	18.9	34.2	-6	10	39	57	45	47
November	16.3	23.9	-11	-2	43	60	54	62
December	22.8	35.6	-4	-3	46	70	50	73
Mean	12.4	29.8	-11	4.4	37.7	58.4	48.7	54

4. SUMMARY AND CONCLUSIONS

The time series of the available hourly sea level data collected during 1982 - 2001 at two locations at Rosetta promontory (Estuary and Sea stations) were used to study the main characteristics of sea level, tides and surge variations in this region. During 1982, 1983 and 2001 the hourly sea level heights at the Sea station ranged between -27 cm and +62 cm. At the Estuary station the hourly sea level heights during 1982, 1983, 2000 and 2001 were varying between -14 cm and +85 cm. The water level at the Estuary station is higher than that at the Sea station and the annual MSL at the Estuary station is about 30.0 cm, while at the Sea station it is 12 cm above the zero level of the Survey Authority. The annual ranges of hourly sea level heights at the Sea and Estuary stations have nearly the same values of about 90 cm. During 1982 (The year that has complete hourly sea level records at both stations), spectral analysis of hourly sea level data at the Estuary and Sea stations showed two significant peaks. The peak at the period of 12 hours is the most significant and is attributed to the semi-diurnal tidal constituents (M2&S2). The less significant second peak at the period of about 24 hours is attributed to the diurnal tidal constituents (K1&O1). Generally, the tides at Rosetta promontory are mixed but are mainly of semi-diurnal type and the tidal ranges are less than 26 cm. The tidal range in the estuary is relatively larger and the times of high and low water are slightly later than at the sea. The annual mean surge levels at both stations are close to zero. At the Estuary station, the monthly mean sea and surge levels are generally below the corresponding annual mean levels in February and during the period from April to June, while at the Sea station they are lower during the period from April – August.

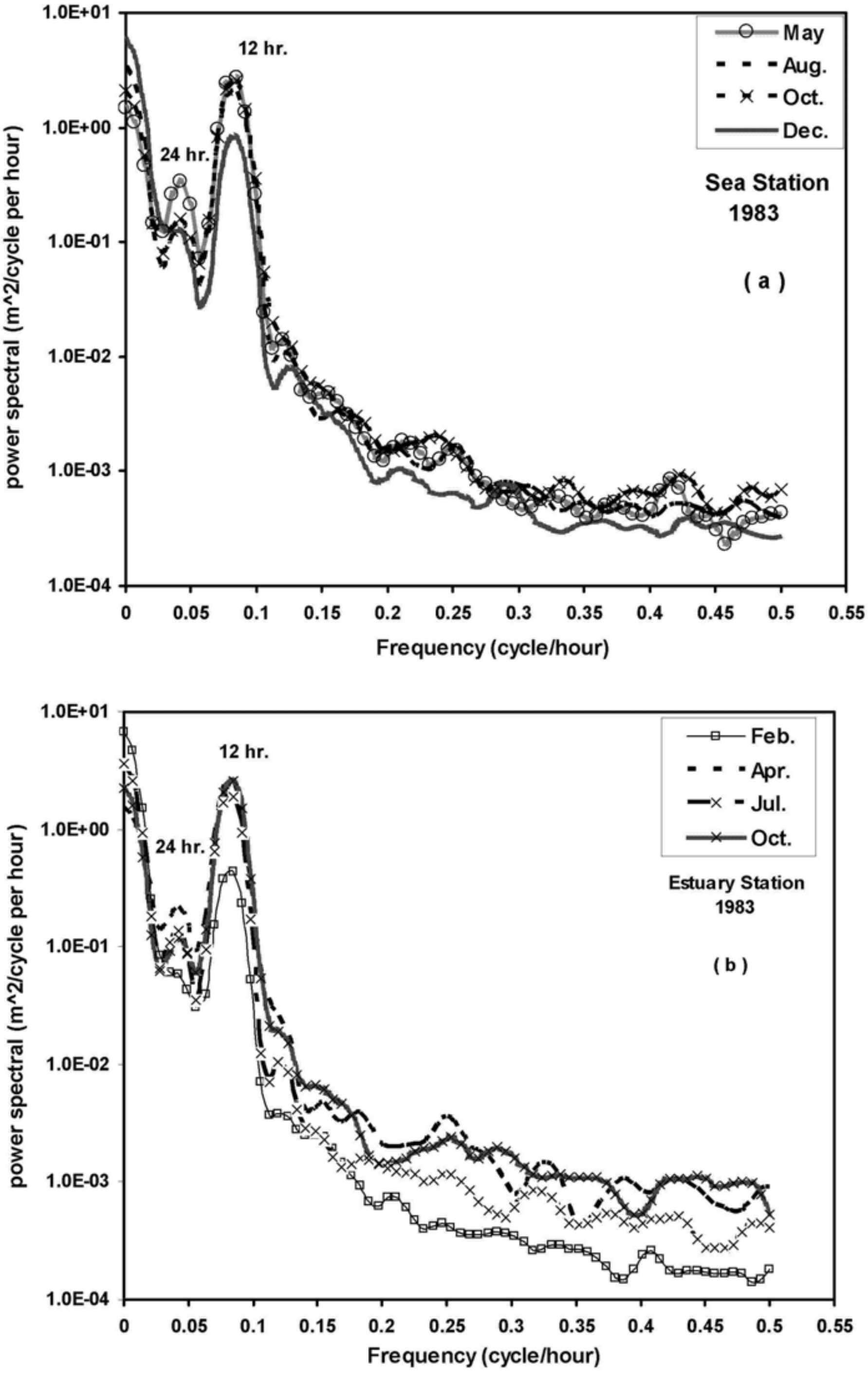

Fig. (4): Spectral analysis of hourly sea level data at Rosetta Sea (a) and Estuary (b) stations during 1982.

Table (2):The F factor and the annual mean sea level (S_0), harmonic constants of major tidal constituents at Rosetta Sea (Stn.1) and Estuary (Stn.2) stations during 1982.

Constituent	Harmonic Constants (amplitude (H) and phase (G))			
	Stn.1		Stn.2	
	F=0.28		F=0.25	
	H (cm)	G (degree)	H (cm)	G (degree)
S_0	12.4	*	29.8	*
M2	4.7	316	6.8	316
S2	2.9	317	4.2	329
K2	2.1	304	1.2	5
K1	1.2	248	1.5	208
MM	1.5	295	1.8	313
N2	1	314	1.6	324
O1	0.9	279	1.2	273
MSF	0.9	298	1.4	325
OO1	0.6	112	0.2	121
MU2	0.4	271	0.4	240
MS4	0.1	277	0.02	227
M4	0.1	34	0.1	58
2SM2	0.01	356	0.1	8

Table (3): Harmonic constants (amplitude (H) & phase (G)) of the most significant tidal Constituents (M2&S2) computed by different authors at some cites along the Mediterranean coast of Egypt.

Location	Constituents			
	M2		S2	
	H (cm)	G (degree)	H (cm)	G (degree)
Alexandria (Rady, 11979)	7.1	256	5.2	255
Abu Qir (Debes, 2002)	5.6	272	3.3	235
Rosetta Sea (Present authors)	4.7	316	2.9	317
Burulus (El-Gindy, 1996)	3.7	214	1.9	297
Ras El-Bar (El-Gindy and Moursy, 1996)	7.1	300	4.1	285
Port Said (Defant, 1961)	11.7	304	6.9	319
Port Said (Alam El-Din, 1993)	10.6	304	6.2	317

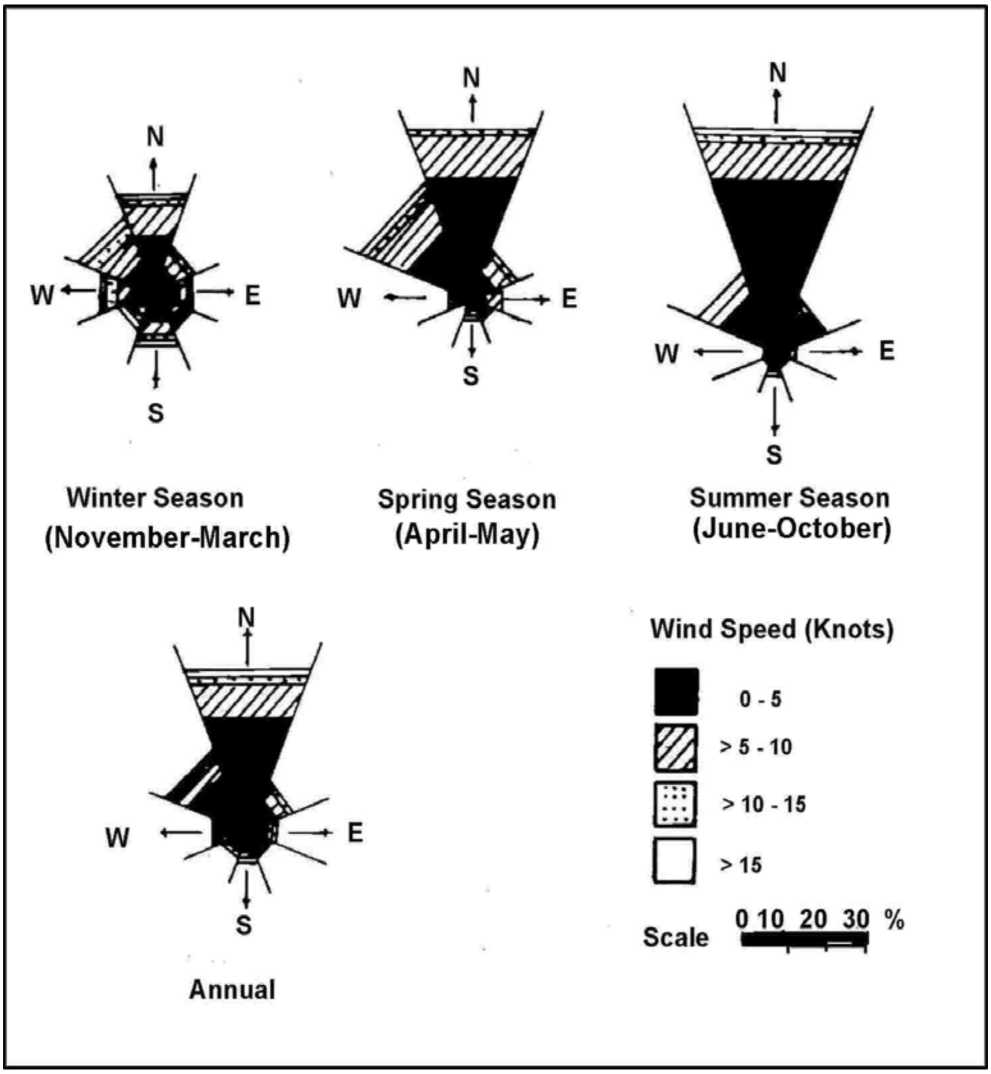

Fig. (5): Wind Rose at Rosetta promontory.

Table (4): Monthly mean surge height, minimum, maximum and monthly range of surge height (cm) at Rosetta Sea (stn.1) and Estuary (stn.2) stations during 1982.

Month	mean		minimum		maximum		range	
	Stn.1	St.2	Stn.1	St.2	Stn.1	St.2	Stn.1	St.2
January	12.2	7.4	-4.7	-8.1	37	38	41.8	46.1
February	10.5	-3	-12.6	-33.2	44.4	39.9	57	73.1
March	0.6	1	-21.3	-25.2	41.3	44.6	62.6	69.8
April	-14.2	-8.9	-45.9	-31.6	9.3	10.9	55.1	42.5
May	-12.3	-14.9	-28	-31.7	3	1.8	31	33.5
June	-6.2	-4.9	-25	-31	14	16.8	39.4	47.7
July	-3.8	8.7	-33.3	-12.2	8.9	23.8	42.2	36
August	-8.9	9.5	-25.8	-0.2	14.9	24.8	40.7	25
September	4.1	1.2	-9	-15	20.8	17.1	29.8	32.2
October	6.8	4.4	-18	-11	23.7	20.8	41.6	31.8
November	4.1	-5.9	-23	-23.8	30.1	28.4	53.2	52.4
December	10.6	5.7	-11.9	-21.4	30.8	36	42.8	57.4
Mean	0.3	0.03	-21.5	-20.4	23.2	25.2	44.8	45.6

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