Currents and Sea Level Variability of Alexandria Coast in Association with Wind Forcing

Ahmed M. Khedr¹, Saad M. Abdelrahman¹ and Khaled A. Alam El-Din²

¹Arab Academy for Science Technology and Maritime Transport, and ²Faculty of science, Oceanography department, Alexandria University, Egypt

Abstract. Data records of wind, current and sea level were arranged and smoothed to hourly data off Alexandria coast, Egypt. The first data records in (1996) was collected at the Eastern Harbor (EH), and the second data set (2008) collected at the Western Harbor (WH) of Alexandria at the monthly duration. Currents speed data were statistically analyzed and showed a variation from 0 to 43.2 cm/sec at (EH), while in the (WH) varied from 0 to 27.2 cm/sec. Based on the frequency occurrence percentage, the long-shore NE current component was found highly dominated under the influence of the alongshore wind component of the prevailing NW. The rotary tidal current strength was elongated close to the shore and found directed either in the NE-SW or in the ENE-WSW directions in (EH). Currents in (WH) were generated by the dominant NW wind, and partially due to the huge amount of polluted water discharged from El-Max Bay via El-Umoum drain. At both Harbors, the average tidal current contribution was estimated as 30 % of the total current energy at both sites. Sea level data were statistically analyzed, and it was found that the range of sea level variation in the (EH) was about (0.53 m), while inside the (WH) was (0.57 m). Harmonic analysis showed a mixed semi-diurnal tidal regime at both sites with significant dominant constituents. Spectral analysis displayed a tidal energy contribution to the sea surface oscillations at both sites (EH) and (WH) of 22% and 13% of the total sea level variability, respectively. While surge energy was estimated as 78% and 87%, respectively at both harbors. In general, the results implied that, tide-generating forces are responsible for generating less than 30% of the total current and total sea level oscillation, while more than 70% of the total energy in both sea level and current data were mainly due to the wind forcing and other non-tidal factors.

Keywords: Current analysis, Sea level, Surge, Tidal harmonic analysis, Wind forcing.

1. Introduction

Alexandria is the second largest city, and the largest harbor in Egypt, which serves about 70% of the Egyptian foreign trade, especially the Western Harbor WH, which is considered the major military and commercial harbor in Egypt. Despite the importance of the WH, there are a shortage in continuous oceanographic studies (sea level – current) and its relation with wind forcing, which is always needed for port innovations, coastal engineering and safe navigation.

Areas of the study in this paper are Eastern Harbor (EH) and Western Harbor (WH) of Alexandria port. The (EH) is a shallow, protected, semi-enclosed circular basin, situated between Longitudes ($029^{\circ} 52.01' E$ and $029^{\circ} 54.4' E$), and between latitudes ($31^{\circ} 12' N$ and $31^{\circ} 12.9' N$), with an average depth between 5 and 6 m, increasing inwards to reach 9 m (El-Geziry and Maiyza 2006). The (WH) lies between longitudes ($029^{\circ} 50.4' E$ and $029^{\circ} 52.5' E$), and between latitudes ($31^{\circ} 9.6' N$ and $31^{\circ} 12' N$) and

depths range from 5.5 m to 16 m (Ismail, 1991).

Existence of Alexandria Naval Base inside the WH impeded the continuity of oceanographic researches, concerning sea current and offshore sea level, besides most of the sea current-meters deployed, covered only the area in front the EH and El-Max area, e.g. Sharaf El-Din, 1999; Hazem, 1999; Alam El-Din, 2001; Sharaf El-Din and Ezzat, 2007, except Farag in (1982), who represented circulation patterns and hydrographic structure of El-Max and Western Harbor areas, by accomplishing 4 cruises for 1 year from June 1980 to June 1981, and recorded the hourly sea current for one day for every month, at a station at the entrance of El Bougaz of Western harbor.

Although, sea level variations in Alexandria, have attracted the attention of many researches, e.g. Eid, 1990; Tsimplis *et al.*, 2005; Gomis *et al.*, 2008; Tayel, 2008, Ullmann and Moron, 2008; Hussein *et al.*, 2010; Saad *et al.*, 2011; their studies were limited only inside the harbors, which needs to be compiled by offshore sea level data.

Due to scarcity of available current and offshore sea level data and limited previous studies, authors got motivated to analyze the available environmental conditions of Alexandria Western Harbor, Egypt. Furthermore, the knowledge of hydrodynamics of the area will be a useful tool in studying dispersion and transportation of pollutants, and their effect on surrounding area, in conjunction with wind effect that mainly affects the coastal environmental conditions. In addition to this, it might be the first time to use sea current data collected from S4 buoy electromagnetic sea current and sea level meter in Egypt. This present paper aims at investigating the overall pattern of current and sea level oscillations

along Alexandria coast, in association with dominating wind forcing.

In general, it is essential to have a thorough understanding of meteorological and oceanographic parameters, to establish a sound coastal management for coastal environment development. In addition, to know what is the relationship between tidal components of current and sea tidal level, phase and oscillation motion patterns, correlation between non-tidal (residuals) components of current and wind components, and finally, the correlation between (surge) and wind components.

2. Data Collection

Two data sets of wind, current and sea level records were taken at the same period from 26th of October until 31st of December, at two different years 1996 and 2008, and two different locations. The first data set was collected in front and inside the (EH) by Metcalf & Eddy international Inc. (Alexandria Waste Water Project, 1996). The second data set was collected inside and in front of the (WH) by the Meteorological Department of the Egyptian Navy (ENMD, 2008). Table 1 represents location (lat. & long.) of all devices used in collecting data.

Table 1. The positions (lat. & long.) of instruments used in collecting data.

Harbor Instrument	Eastern Harbor (1996)	Western Harbor (2008)
Wind set	Anfushi wind set (31° 12' 41"N, 29° 52' 55"E)	Ras El-Tin wind set (31° 11' 50.94"N, 29° 51' 49.83"E)
Current-meter	CM-4A 19.4m (31° 16' 15"N, 29° 51' 57.07"E)	S4ADW (31° 12' 01.13"N, 29° 51' 00.19"E) *Sea level was also measured
Tide gauge	TDR-3A (31° 12' 44"N, 29° 53' 3.00"E)	Aqua-tide PS3100 (31° 11' 56.41"N, 29° 52' 21.57"E)

In the (EH), data of hourly wind speed and direction were collected by the onshore Anfushi climate automated weather station, with the wind sensor fixed approximately at 19.38 meters height above the Egyptian mean sea level (EMSL). Offshore current speed and direction was collected in 15-minutes time intervals, utilizing 105 HIF recording current-meter at a distance 5.4 n.m. off the coast, that was deployed at a fixed depth 19.4 m, at a water depth of 39.4 m. Sea level data was measured at 15-minutes time intervals, using TDR-3A tide gauge, deployed at approximately 1 meter water depth, and the tide gauge zero level was referenced to the Egyptian Survey Authority (ESA) control datum '1906'. This datum was first derived based on sea level observations for eight years from 1898 to 1906. Cole (1939) found that this imaginary level (MSL) was (33.8 cm) above the zero of the tide gauge (zero of the tide staff) in Alexandria tide well. This MSL is

considered as Survey Department zero Level Datum or zero of the Egyptian Survey Authority (ESA) datum '1906'.

In the (WH), data of hourly wind speed and direction recorded, utilizing the Dines Coastal Weather Station at approximately 15.01 m above (EMSL). Offshore current speed and direction were logged at 5-minutes time intervals, using S4 Current-Meter buoy, at a distance 1.5 n.m. off the coast (Inter-Ocean system, 1994). The Current-meter was deployed at fixed depth 16.5 m, in about 19 meters' water depth. The time series of sea level data was collected from two sources; the first one at 30-minutes time intervals, from PS3100 Aqua tide gauge, referenced to the vertical control datum of Egyptian Survey Authority (ESA) datum '1906', and the second was logged at the same interval of S4 current-meter buoy (depth sensor). Figure 1 shows the position of measuring devices; sea level, current and wind at both harbors.

Fig. 1. Positions of the measuring devices in both harbors of (EH 96) & (WH 08).

3. Methods of Analysis

MATLAB 7.0, T_TIDE (Pawlowicz *et al.*, 2002) and WRPLOT View programs were utilized, to analyze the two data sets at the two locations. First, the wind data was analyzed (both wind speed and direction), then, sea current data analysis was done by performing; classical harmonic analysis of tidal stream, to estimate tidal current and residuals, then identifying current power spectral density (PSD). After that, sea level data was analyzed using classical harmonic analysis technique also, to get the predicted tidal elevation and estimated surge, in addition to spectral estimates of energy before and after removal of tidal constituents (PSD). Finally, results were cross-correlated and discussed.

The hourly-recorded wind data at both harbors were decomposed, into long-shore and cross-shore components (W_x and W_y) following El-Sherbeny (2006). Descriptive summary of wind statistics, for both data sets were calculated, using the WRPLOT View program (Lake Enviromental, W. V., 2008), and presented on wind rose plots, along with histogram of wind speed classes.

Sea current data records smoothed to hourly values (velocity in cm/sec, direction in degrees), in time series consisting of 67 days. Summary statistics of current velocity for both data sets, were computed and presented, to describe basic descriptive characteristics (minimum, maximum, mean and standard deviation), besides, current rose statistics and plot were made, using WRPLOT View program, to demonstrate current frequency distribution of occurrence, in each of specified direction sectors, and speed classes. The current speed components (C_x) and (C_y) for the (EH) and (WH) data sets, were analyzed into both long-shore and cross-shore directions. Then, the time series of the current velocity components were low pass filtered, by

applying 25 hour running means for three times successively to each velocity component (Stacey *et al.*, 1987; Abdelrahman, 2003). Hourly tidal stream values were obtained by subtracting the filtered series (non-tidal) from corresponding original hourly data. Thirty-six hour data (twelve hours in each 25 hours averaging process) were ignored at each end of the original series to match the length of the filtered data. Gaps in time series were interpolated using linear interpolation. In the (EH) data, there was 15 days gap giving 1246 data points, while in the (WH) data, there was 5.5 days gaps that means 1476 data points). Then, the hourly tidal stream values were imported to MATLAB (T_TIDE), as a vector complex numbers $xin(u + i v)$. While current components (C_x) and (C_y) in both long-shore and cross-shore directions, were passed separately as two scalar time series, to perform classical harmonic analysis, to separate tidal current from residuals, based on the assumption that the tidal variations can be represented by a finite number (N) of harmonic terms of the form:

$$W = u + i v \quad (1)$$

$$= a_u \cdot \cos(\omega t - \phi_u) + i a_v \cdot \cos(\omega t - \phi_v) \quad (2)$$

Where, a_u and ϕ_u are the amplitudes and phase lag form the U components and likewise for a_v and ϕ_v , and ω is the tidal angular frequency, and W is the form of a complex tidal current (Zhigang, 2002).

(a_u) is a constituent amplitude, (g_i) is the astronomical phase lag in Equilibrium Tide, relative to the Greenwich meridian at zero time, while (ωi) is an angular speed. Finally, spectral estimates before and after the removal of tidal energy, and it is also used to decompose the time series into different harmonic components, each of it are associated with a particular frequency, in

addition to, current ellipse parameters (major and minor constituent axes length in cm), and ellipses orientation in degrees, besides constituents phase angles in degrees relative to Greenwich and their 95% confidence intervals, calculated by constituent algorithm in (T-tide)

Sea level data sets of (EH) and (WH) were smoothed to hourly time series values in meters. Gaps of the original series were interpolated, using the linear interpolation, then imported to (T_TIDE) in MATLAB to compute classical harmonic analysis using the same mentioned formula. Tidal regime classified using the form factor (F) that relates the main diurnal components ($K1 + O1$) to the main semi-diurnal components ($M2 + S2$) (Pugh, 1996). Then, measure of the power for each frequency expressed, by the value of the spectrum. Highest power peaks are found at the most important frequencies affecting the analyzed time series. Correlation was performed to find out the relationship among the three studied variables (current, sea level in conjunction with wind). In addition, a comparison and a discussion to the results of the two records 1996 & 2008 data was made to find out the degree of association among the results of the considered variables at the two sites.

4. Results

4.1 Wind Analysis

Statistical summary of wind data was shown in Table 2. Wind speed in the (EH) varied from 0 knots to 25.1 knots with a mean 7.6 and standard deviation 3.8 knots. During the recording period, wind speed at the (WH), varied from 0 knots to 34 knots with a mean 10.8 and standard deviation 5.8 knots.

Figures 2 & 3 depict the wind rose, displaying wind regime scattered in a wide range of directions, with a prevailing NW wind at (EH) and (WH), with a percentage of 11.9 % and 12.4 %, respectively. Figures 4 &

5 display histograms of wind speed classes, showing a high percentage of occurrence in the speed ranges between 12 to 23 knots in addition to a dominant percentage that was observed in the year 1996 ranged between 6 to 17 knots. On the other hand, the prevailing directions were from NW and NNW during the period of study.

Table 2. The Statistical summary of wind records at EH and WH.

Wind Data	Min.	Max.	Mean	St. Dev.
Wind speed EH (knots)	0	25.1	7.6	3.8
Wind speed WH (knots)	0	34	10.8	5.8

In the (EH), the maximum wind speed from NW direction was 25 knots, and from SE direction was 22 knots. While in the (WH), maximum wind speed was 34 knots from NW, and 28 knots from SE direction.

4.2 Analysis of Measured Sea Current

Figures 6 & 7 depict frequency distribution of current occurrence at both Harbors via current rose display.

Demonstrating two prevailing current directions in the (EH); in the NE direction with a percentage of 17.7 %, and ENE direction with a percentage of 16.4 % of all directions. In addition, there was a considerable current in SW and WSW directions to the opposite of the prevailing NE current, with a percentage of 8.3 % and 11.3 %, respectively. In the (WH), no progressive vector tracks, and the obvious dominant current was towards East direction, with a percentage of 37.9 % and sometimes towards ENE direction with a percentage of 22.1 % of all directions. The current directions outside the (EH) were mainly parallel to the coast in the NE-SW directions and sometimes in the ENE-WSW directions, which indicated that the major axes of tidal ellipse (flood-ebb)

are oriented in these directions. Outside the (WH), current direction was mainly drifted eastward. Furthermore, from the Histogram of current speed classes shown in Fig. 8 & 9, most of the current speed percentage of occurrence in (EH) ranged between 6-12 cm/sec, while in (WH), a high percentage of

occurrence about 51% of the total speeds ranged between 9-12 cm/sec. Table 3, shows statistical summary of current speed in both (EH) and (WH), and the average values are (10.5 and 7.3 cm/sec), respectively, and the maximum values are (43 and 27 cm/sec), respectively.

Fig. 2. Wind rose for prevailing wind (EH).

Fig. 3. Wind rose for prevailing wind (WH).

Fig. 4. Histogram of the wind speed in (EH).

Fig. 5. Histogram of the wind speed in (WH).

Fig. 6. Prevailing current at (EH).

Fig. 7. Prevailing current at (WH).

Fig. 8. Histogram of the current speed in (EH).

Fig. 9. Histogram of the current speed in (WH).

Table 3. The Statistical summary of current data at EH and WH, Alexandria.

Current Data	Min.	Max.	Mean	St. Dev.
Current speed (EH) (cm/sec)	0	43.2	10.5	8.2
Current speed (WH) (cm/sec)	0	27.9	7.3	2.7

On the spatial scale, averaged energies of current at both stations (EH) and (WH) 5.4 and 1.5 n.m., respectively, showed a general trend of decrease when moving towards the

coast because of frictional bottom drag of the shallow water.

4.3 Harmonic Analysis of Tidal Stream

Line spectra in T_TIDE (MATLAB) with 95% confidence level were employed, and only 18 constituents were judged to be significant, in front of (EH) as shown in Fig. 10. The dominant constituent was the Lunar diurnal second-order constituent (OO1), in addition to some secondary dominant diurnal constituents such as (K1, NO1, J1, O1, UPS1

and O1), along with semidiurnal constituents (M2, S2 and L2). Furthermore, most of the shallow water constituents were significant such as (M4, MN4, SN4 and M8). In front the (WH) as shown in Fig. 11, only 21 constituents were judged to be significant, and the dominant constituent was the principle lunar and solar constituent (K1), in addition to some secondary dominant diurnal constituents such as (NO1, J1, O1, Q1 and OO1), along with major semidiurnal constituents M2 and S2. Furthermore, the shallow water constituents were significant such as M4 (the largest of the shallow water constituents), besides M6, M8, M10, MN4 and MS4.

4.4 Estimated Tidal Current and Residual

Tidal current speed was predicted using the resulted constituents, then was subtracted from the total current speed data to obtain the residuals for each data set, as shown in Fig. 12 & 13. In front of the (EH), the magnitude of total absolute current speed ranged between 0 and 16.4 cm/sec, with an average of 6.6 cm/sec. In addition, the maximum absolute tidal stream speed was about 5.4 cm/sec, with an average of 1.5 cm/sec. While the maximum absolute residual speed was about 15.9 cm/sec, with an average speed of 5.2 cm/sec. Equally, in the (WH), the magnitude of absolute total current speed ranged between 0 and 12 cm/sec, and the average speed was about 2.4 cm/sec. The maximum absolute tidal stream speed was 2.5 cm/sec, with an average speed of about 0.8 cm/sec. Lastly, the maximum absolute residual speed was about 11.8 cm/sec, with an average speed of 1.6 cm/sec.

These results imply that the ratio of absolute tidal stream to the total absolute current speed in (EH) equals 22 %, while the ratio of absolute residual speed to the total absolute current speed equals 78 %. The ratio of the absolute tidal stream to the absolute total current speed in (WH) equals about 33 %, and the ratio of absolute residual speed to the

total absolute current speed equals about 66 %.

4.5 Current Power Spectral Density

Power Spectral Density (PSD) for the total absolute and residual current at both sites were shown in Fig. 14 & 15. The spectra showed that the most significant constituents in the diurnal and semidiurnal bands (≈ 0.04 cph = 25 hr, and ≈ 0.08 cph = 12.5hr, respectively). However, several frequency constituents also appear to be marginally significant, in spite of the large energy in their bands (≈ 0.01799 cph = 55.6 hr, and ≈ 0.108 cph = 9.3 hr respectively) but they are apparently non-significant constituents.

4.6 Sea Level Analysis

The basic summary statistics of sea level is represented in Table 4, the hourly minimum sea level record was (-0.05 m) and the maximum one was (0.48 m) in the (EH), which agreed with Sharaf El-Din and Ezzat (2007). While inside the (WH), the hourly minimum sea level record from the tide gauge was (0.18 m), and the hourly maximum was (0.75 m). Moreover, the hourly minimum sea level record from S4 depth sensor was (0.24 m), and the hourly maximum one was (0.77 m) after datum correction. The range of sea level variation in the (EH) was about (0.53 m), while inside the (WH) was (0.57 m), and outside the WH was (0.53 m). The standard deviation is comparable with the same order of magnitude, which demonstrated equal dispersion and quality for all data sets. These results agree with (Eid, 1998) during the same period with a range of sea level variation in Alexandria of about (0.54 m).

4.7 Tidal Elevation (Predicted)

In performing harmonic analysis of sea level records, program algorithm selected 35 constituents in the (EH), and 38 constituents in the (WH), and only 9 constituents were judged

to be significant inside both harbors, with only 11 constituents from S4 depth sensor outside the (WH). From form factor, tidal regime in the area during the period of study was semidiurnal inside and outside the (WH), and mixed semidiurnal inside the (EH). Table 5 illustrates a comparison between values of the four major tidal harmonics (amplitudes and phase angles) in this paper, and the nearest previous studies, at the same area such as; Rady (1979); Mourcy (1996); F. Mosetti and N. Purga (1990).

Table 4. The Statistical summary of sea level data.

Sea level Data	Min.	Max.	Range	St.Dev.
Sea level TDR-3A EH (m)	-0.05	0.48	0.53	0.09
Sea Level Aquatide WH (m)	0.18	0.75	0.57	0.10
Sea Level S4 outside WH (m)	0.24	0.77	0.53	0.09

Table 5. Shows comparison between harmonic results of present work and previous studies.

	HARMONIC	M2		S2		K1		O1	
	Ref.	H. cm	σ Deg.	H. cm	σ Deg.	H. cm	σ Deg.	H. cm	σ Deg.
Previous	Moursy (96)	7.19	325	4.34	309	1.64	317	1.34	300
	Mosetti, Purga (90)	6.45	306.4	3.93	322.4	1.77	308.6	1.42	278.9
	Rady (79)	7.09	256.1	5.20	225.8	1.66	280.5	1.23	249.8
Current Study	EH (96)	7.4	328	4.4	348	2.00	301	1.4	280
	WH (08)	7.6	327	4.2	347	1.7	310	1.2	277
	Outside WH (08)	6.7	318	4.3	330	1.6	310	1.00	286

4.8 Estimated Surge

Figures 16 & 17 display the separation of tidal from non-tidal components of sea level signals (EH and WH). The graphs show the time series of the original sea level signals, the elevations of synthesized tidal series and the residual elevations (surges). Surge in EH was 78%, while in WH, it was 87% of total sea level elevations, as a result of increased wind speeds

in 2008. This means that meteorological effects are the main influential factor on sea level, and it agrees with El-Geziry and Radwan (2012), who concluded from 10 years of sea level data analysis, that surge contributes about 62.37 % to about 37.63 % of tidal force from total sea level energy.

4.9 Sea Level Power Spectral Density

Figures 18 & 19 demonstrate power spectral density. It displays significant diurnal (K_1 , O_1) and semi-diurnal (M_2 , S_2) constituents. Constituents in semi diurnal bands have larger power density. The maximum tidal range at the two locations is identical, giving about 0.23 m. The surge percentage of total elevation was higher in 2008 than in 1996 due to stronger wind forcing and other factors affecting sea level variations.

4.10 Cross Correlation (Xcorr) Analysis

Cross correlation coefficients and time lag, were investigated for the different components of the adapted three variables (wind, current and sea level). Table 6 summarizes a comparison between the variables with each other at both sites.

Table 6. Correlation coefficients (Xcorr) comparison (EH 96 and WH 08) with time lag in hours.

Correlated factors	EH		WH	
	Xcorr	Lag (hrs)	Xcorr	Lag (hrs)
Wind & Current (speeds)	0.39	1	0.43	1
Wind speed & Residual of current-meter	0.38	0	0.42	0
Wind speed & Surge of tide-gauge	0.25	11	0.26	18
Tide-gauge (Surge) & Residual of current	0.49	24	0.31	0

In (EH), cross correlation coefficients indicated overall moderate correlations between wind speed and current speed, residual of current-meter, surge height as well as surge height with residual current as shown in Fig. 20.

While in (WH), cross correlation coefficients indicated moderate correlations between wind speed and current speed, residual of sea current and surges of the tide-gauge. In addition to the aforementioned, surge and residual of current-meter which showed almost the same time lag as shown in Fig. 21.

Wind and current vectors have been resolved into long-shore and cross-shore components and were checked to enhance the correlation strength, but didn't show any significant improvement. This probably indicates the importance of other parameters other than wind to force the non-tidal components.

Fig. 10. Significant constituents in EH.

Fig. 11. Significant constituents in WH.

Fig. 12. Abs. tidal stream and residuals EH.

Fig. 13. Abs. tidal stream and residuals WH.

Fig. 14. Current Power Spectral Density at EH.

Fig. 15. Current Power Spectral Density at WH.

Fig. 16. Tidal and surge oscillations at EH.

Fig. 17. Tidal and surge oscillations at WH.

Fig. 18. Total sea level and surge spectra at EH.

Fig. 19. Total sea level and surge spectra at WH.

Fig. 20. Xcorr between surge and residual at EH.

Fig. 21. Xcorr between surge and residual at WH.

5. Discussion and Conclusion

From wind analysis in (EH), most wind speeds lie in the range between 6 -11 knots representing a percentage of about 29% of all speeds, while in the (WH), most of the wind speeds lie in range between 12-17 knots, with a percentage equal to 22.2%. This was due to higher wind speeds in the year 2008 than in 1996 as the mean wind speed indicated. The prevailing winds over Alexandria were from NW to NNW directions with percentages equal to 23 % and 29.5% from all directions, which agrees with earlier studies (e.g., Meligy, 2000).

From current analysis in front the (EH); most of the current speeds ranged between 9-12 cm/sec, representing a percentage of 18.1% of all speeds. Furthermore, the average hourly speed was 10.5 cm/sec and the maximum was 43.2 cm/sec, which agrees with Sharaf El-Din and Ezzat (2007). In front of the (WH); most current speeds ranged between 6-9 cm/sec representing 51 % of all the speeds. Moreover, the maximum hourly one was 27.2 cm/sec. The reason for the discrepancy in maximum current speed between EH and WH was probably caused by the differences in bottom drag force affecting both harbor

sensors. The current meter sensor in front the WH is more affected than that of the EH due to its proximity to the seabed. Current directions gave an evidence to the dominant circulation pattern in the (EH), which is directed in the NE direction with a percentage of 17.6 % of all directions under the influence of the NW wind direction. It is occasionally directed SW with a percentage of 8.4 % of all directions, when the wind has an Easterly component. Furthermore, in the (WH) most of the tidal current strength is directed towards the E direction with a percentage of about 37.9 % of all directions, due to the strong and frequent easterly flow, and partially due to the huge amount of polluted water discharged in El-Max Bay via El-Umoum drain as described by Alam El-Din (2007). The current directions outside the (EH) were mainly parallel to the coast in the NE-SW directions and sometimes in the ENE-WSW directions, which indicated that the major axes of tidal ellipse (flood-ebb) are oriented in these directions.

From the current harmonic analysis in (EH), only 18 constituents were judged to be significant. The dominant constituent is the Lunar diurnal second-order constituent (OO1), which had $(2.1 \times 0.9 \text{ cm})$ major and minor

axes, 159° ellipse orientation and 015° phase angle relative to Greenwich, and most of the shallow water constituents were significant. Whereas in the (WH), only 21 constituents were judged to be significant with the dominance of the principle lunar and solar constituent (K1), which had 46.9° ellipse orientation and 200° phase angle, and most of the shallow water constituents such as M4, M6, M8, M10, MS4 and MN4 are significant. Moreover, diurnal constituents are the dominant constituents, in addition to the shallow water constituents, which, contributed to the tidal distortion in the area near the coast, due to bottom friction. From the motion patterns of the tidal stream and the tidal elevation. It was found that motion could be modeled by mostly a standing wave as they have 90° differences in phase. Furthermore, the tidal stream in the (EH), represented around 20% off the total current, while the residual current represented around 80%. Moreover, in the (WH), the tidal stream represented around 30% of the total current, while the residual currents represented around 70% of the total currents.

From the sea level analysis, sea level ranged 0.53 m in (EH), while in (WH) it was 0.57 m at the same period, demonstrating approximately an average annual rate of change 3 mm/year. This agrees with satellite altimetry results which revealed that the Mediterranean sea level rises at a rate of 3 mm/ yr. over the period 1993-2011 (Tsimplis *et al.* 2013), and also agrees with (Alam El-Din *et al.* 2007) indicating a positive MSL trend rate 1.97 mm/yr. The differences in minimum and maximum values in sea level data at both harbors reflect the different reference datums considered for the tide-gauges. Moreover, sea level harmonic analysis showed only 9 significant constituents in both harbors, and only 11 constituents from S4 depth sensor analysis in 2008. The dominant

semidiurnal constituents were (M2 & S2), along with the diurnal constituents (K1 & O1), demonstrating mixed semi-diurnal and semi-diurnal tidal regimes in (EH) and (WH), respectively. Moreover, all the shallow water constituents are insignificant in the (EH) and vice versa in the (WH).

In general, by comparing the correlation coefficients shown in Table 5, a great resemblance was noticed with minor discrepancies. The first is climatic and meteorological changes through the 12 years (period difference between times of data sets collection). In addition to this, bathymetric features, location and level of the instruments fixation and finally the deployment depth of the current-meter sensors and the effect of bottom friction in the shallow water.

References

- Abdelrahman, S. M.** (2003), Rotary spectrum and characteristics of tidal currents in the Arabian gulf, *Arab Academy for science & Technology and Maritime Transport Journal*, **26**(52): 15.
- Alam El-Din, K. A.** (2001), Study of the water circulation and wastewater transport in El-Max bay area, Alexandria, Egypt using numerical modeling and satellite images, *Alexandria, Egyptian J. Remote Sensing & Space Sci.*, **4**: 19-32.
- Alam El-Din, K. A.** (2007), *Hydro-dynamical features and transport processes in Alexandria coastal area proceeding of the 8th international conference on the Mediterranean coastal environment*, Med. coast 07, Alexandria, Egypt, faculty of science, Oceanography Department.
- Alam El-Din, K. M., Abdelrahman, S. M. and El Meligy, M.** (2007), Seasonal and long term variations of sea level and meteorological conditions along the Egyptian coasts, *Proceeding of the 8th international conference on the Mediterranean coastal environment, med. coast 07, Alexandria, Egypt*.
- Alexandria Waste Water Project 2** (1996), *Wastewater project-phase 2*, Mediterranean Sea, ocean surveys Inc., Metcalf and Eddy. Alexandria, Egypt.
- Cole, J.** (1939), *Revision of first order levelling Lower Egypt*, Survey Department Paper No. 44, Egyptian Survey Authority, Giza, Egypt.
- Eid, F.** (1990), Variation of surge heights at Alexandria Port (Egypt), *J. King Abdulaziz Univ., Mar. Sci.* **9**: 3-18.

- Eid, F. M.** (1998), Variation of surge heights at Alexandria Port, Egypt, *J. KAU, Mar. Sci.*, **9**: 1-18.
- El-Geziry, T. and Radwan, A.** (2012), Sea level analysis off Alexandria, Egypt. *Egyptian Journal of Aquatic Research* **38**: 1-5.
- El-Geziry, T. M. and Maiyza, I. A.** (2006), The hydrographic structure of Alexandria Eastern Harbor, *International Conference on Aquatic Resources, Alexandria, NIOF*.
- El-Sherbeny, A.** (2006), Weather characteristics in the South East sector in the Mediterranean Sea during 15 years (1982-1996), Faculty of Science, University of Alexandria. *M.Sc. Thesis*, p. 221.
- ENMD** (2008), *The Egyptian Navy Meteorological Department*, Monthly Report, Alexandria, Egypt.
- Farag, M. M.** (1982), Circulation patterns and hydrographic structure of El-Mex and the western harbor areas, Faculty of Science, University of Alexandria. *M. Sc. Thesis*: 103 p.
- Gomis, D., Ruiz, S., Sotillo, M., Alvarez-Fanjul, E. and Terradas, J.**, (2008), Low frequency Mediterranean Sea level variability, the contribution of atmospheric pressure and wind, *Global Planet Change*, **63**: 215-229.
- Hazem, M. M.** (1999), Wave and Surge forecasting along the Egyptian Coast of the Mediterranean, *M. Sc. Thesis*, Faculty of Science, Alexandria, Egypt.
- Hussein, M., Moursy, Z. and Tayel, M.**, (2010), General pattern of Alexandria western harbor sea level change, J. King Abdulaziz Univ., *Mar. Sci.*, **21** (2): 47-61.
- Inter-Ocean System**, (1994), *S4 Current Meter user's manual*, U.S.A.
- Ismail, G.** (1991), Environmental assessment of Alexandria Western Harbor, Institute of Public Health, *M. Sc. Thesis*, Alexandria University, p.156.
- Lakes Environmental, W. V.** (2008), *Lakes Environmental Software Windows program*, C. L. Jesse L., Michael A., Johnson Oleg Shatalov, Lakes Environmental, Wind/current Rose plots for meteorological data.
- Meligy, M. M.** (2000), Wave and Surge forecasting along the Egyptian Coast of the Mediterranean, *M. Sc. Thesis*, Oceanography, Arab Academy for Science and Technology and Maritime Transport, Alexandria, Egypt.
- Mosetti, F. and Purga, N.** (1990), Tides and Sea Level Evolution at Alexandria (Egypt), *Nuovo Cimento*, **13** (C(3)): 647-651.
- Moursy, Z.A.** (1996), Sea temperature contribution to sea level at the south east sector of the Mediterranean, *Oebalia*, **XXII**: 131-137.
- Pawlowicz, R., Beardsley, B. and Lentz, S.** (2002), *Classical tidal Harmonic analysis including error estimates in Matlab using T_TIDE*, Computer & Geosciences, Department of Earth and Ocean Science, University of British Columbia, 28 pp. 929-937.
- Pugh, D. T.** (1996), *Tides, Surges, and Mean Sea Level*, Great Britain, Antony Rowe Ltd, Chippenham, Wiltshire.
- Rady, M. A.** (1979), Variation of sea level at Alexandria and its relation to the meteorological conditions, *M.Sc. Thesis*, Faculty of science, Alexandria, Egypt.
- Saad, N., Moursy, Z. and Sharaf El-Din, S.** (2011), Water heights and weather regimes at Alexandria Harbor, *Int. J. Phys. Sci.* **6** (30), 7035-7043.
- Sharaf El-Din, S. H.** (1999), *The Oceanography of the Coastal Zones of Alexandria and Eastern Harbors*, Technical report submitted to UNICCO for Pilot Project for the Sustainable Development of the Submarine Archeological Sites at Qayet bey citadel and eastern harbor.
- Sharaf El-Din, S. H. and Ezzat, A.A.** (2007), Marine Impact of extension of coastal road on the transformation of materials of the near shore marine environment, *International Conference of urbanization rabid organization and land use conflict in coastal cities*, 30 October – 1 November 2007, Aqaba, Jordan.
- Stacey, M. W., Pond, S., Le Blond, P.H, Freeland, H.J. and Farmer, D.M.** (1987), An analysis of the low frequency current fluctuations in the Strait of Georgia from June 1984 until January 1985, *J. Physical Oceanography*, **17**: 326-342.
- Tayel, M.** (2008), Using Artificial Intelligence (AI) Techniques for Tidal Level Forecasting at Alexandria Western Harbor, *M. Sc. Thesis*, Alexandria University, Egypt.
- Tsimplis, M., Alvarez-Fanjul, E., Gomis, D., Fenoglio-Marc, L. and Pe'rez, B.** (2005), Mediterranean Sea level trends atmospheric pressure and wind contribution, *Geophys. Res. Lett.* **32** (20): 20602.
- Tsimplis, M.N., Calafat, M.F., Marcos, M., Jordà, G., Gomis, D., Fenoglio-Marc, L., Struglia, V.M., Josey, A.S. and Chambers, P.D.** (2013), The effect of the NAO on sea level and on mass changes in the Mediterranean Sea, *J. Geophys. Res.*, **118**: 1-9.
- Ullmann, A. and Moron, V.** (2008), Weather regimes and sea surge variations over the Gulf of Lions (French Mediterranean coast) during the 20th century, *Int. J. Climatol.* **28** 2: 159-171.
- Zhigang, Xu.** (2002), *Ellipse Parameters Conversion and Velocity Profiles for tidal Currents in Matlab*, Maurice-Lamontagne Institute, ocean science division, fisheries and ocean Canada.

التغير في التيارات البحرية ومنسوب سطح البحر أمام سواحل مدينة الإسكندرية بتأثير قوة الرياح

أحمد خضر^١، و سعد عبدالرحمن^١، و خالد علم الدين^٢

^١ الأكاديمية العربية للعلوم والتكنولوجيا والنقل البحري، و^٢ كلية العلوم، قسم علوم البحار، جامعة الإسكندرية،

مصر

المستخلص. تم استخدام بيانات ساعية لمنسوب سطح البحر والتيارات البحرية والرياح عند موقعين مختلفين أمام شاطئ مدينة الإسكندرية: الموقع الأول أمام الميناء الشرقي، عام ١٩٩٦م، والموقع الثاني أمام الميناء الغربي في نفس الفترة الزمنية من عام ٢٠٠٨. تم جمع البيانات وترتيبها وتحليل متجهات الرياح والتيارات المائية بمحاذاة الساحل والعمودي عليه، كما تم حساب التوزيعات التكرارية ووردة الرياح لاتجاهات وسرعات التيار على وردة البوصلة للاتجاهات الحقيقية بواسطة برنامج (WRPLOT)، وتم استخدام استخدام برنامج (MATLAB T-tide) لتحليل البيانات الخاصة بالتيارات المائية ومستوى سطح البحر. وأظهرت دراسة التوزيعات التكرارية الثنائية (سرعة واتجاه) للتيارات المائية لعام ١٩٩٦م أن سرعة التيار المائي أمام الميناء الشرقي عند عمق ١٩ مترًا (في عمق كلي ٣٩,٥ متر) في فترة الدراسة، تراوحت ما بين صفر إلى ٤٣,٢ سم/ث، كما أظهرت أن سرعة التيارات المائية لعام ٢٠٠٨م أمام الميناء الغربي عند عمق ١٦ مترًا (في عمق كلي ١٧,٥ متر) في فترة الدراسة تغيرت ما بين صفر إلى ٢٧,٢ سم/ث. ووجد أيضًا أن أعلى نسبة تردد تكراري يكون للتيار السائد بالمنطقة في هذه الفترة، وغالبًا ما يكون في اتجاه الشمال الشرقي عندما تكون الرياح قادمة من الشمال الغربي، أي أن اتجاه المحور الرئيس للشكل البيضاوي الممثل لشدة التيار المدي (Flood/Ebb) يكون في اتجاه (شمال شرق/جنوب غرب)، وفي بعض الأحيان يكون في اتجاه (شرق شمال شرق/غرب جنوب غرب) في الميناء الشرقي. وقد وجد أيضًا من التحليل الطيفي لكلا الموقعين أن متوسط طاقة التيارات المديّة تمثل حوالي ٣٠٪ من إجمالي الطاقة في التيار المائي، بينما يمثل التيار المتبقي حوالي ٧٠٪ أو أكثر من إجمالي طاقة التيار عند كل منطقة. كما تبين من التحليل الإحصائي لبيانات منسوب سطح البحر أن مدى الاختلاف في منسوب سطح البحر كان ٠,٥٣ في الميناء الشرقي و ٠,٥٧ متر في الميناء الغربي. ومن تحليل المركبات التوافقية للمد وجد أن أقصى مدى مدي للعامين ١٩٩٦ & ٢٠٠٨م كان (٠,٣٠) متر في الميناء الشرقي و (٠,٢٩) متر في الميناء الغربي، بينما كان أقصى مدى للمركبات غير المديّة خلال العامين يساوي (٠,٣٧) متر للميناء الشرقي و (٠,٢٩) متر للميناء الغربي بالترتيب. وقد أظهر التحليل التوافقي لبيانات المد

والجزر أن نوعه من النوع نصف اليومي الخليط في الموقعين، مع وجود تأثير قوي للمركبات الرئيسية الأربعة. كما أوضحت حسابات التحليل الطيفي لطاقة التغيرات في منسوب سطح البحر أن طاقة تذبذبات المد والجزر بمفردها تمثل فقط ٢٢٪ و ١٣٪ من الطاقة الكلية للتغير في منسوب سطح البحر في كل من الميناء الشرقي والغربي على الترتيب. وبالتالي تكون نسبة الطاقة للتغيرات الناتجة عن العوامل الجوية والأخرى ٧٨٪، ٨٧٪ للموقعين. وبصورة عامة أثبتت مناقشة النتائج أن أكثر من ٧٠٪ من طاقة تغيرات منسوب سطح البحر والتيارات البحرية في المتوسط أمام الأسكندرية ترجع بصورة أساسية إلى تأثير قوة الرياح والعوامل غير المدية.

كلمات مفتاحية: التيارات البحرية، مستوى سطح البحر، الارتفاع، التحليل التوافقي المدي، تأثير الرياح.