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Full Length Research Paper

Water heights and weather regimes at Alexandria Harbor

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The response of water level variations to the changes in local meteorological elements (atmospheric pressure, air temperature and wind force) has been investigated for Alexandria harbor over 11 years period (1995 to 2005). The study has shown clearly a close connection between them. The coherence is noted and the linear effect is discussed. The result of the regression technique indicated an increase of water level by 1.4 cm for each decrease of 1 mb of atmospheric pressure, and the water rises by 1.1 cm for each increase of air temperature by 1°, while it changes by 0.5 cm for each 1 knot of NW wind. The general pattern of water levels is illustrated and a marked seasonal trend is appeared. The most pronounced frequency of monthly water level distributions is concentrated in the level of 55 cm, and a sea level rise has occurred at a mean rate of 0.03 cm/year during the study period. Estimation of the generalized correlation indicated that the wind force induce 17% of the total variations on water levels, while air temperature have contribution to about 45% and the local atmospheric pressure are responsible for 16%.

Key words: Meteorological elements, water levels, atmospheric pressure, air temperature, wind force.

INTRODUCTION

In the central Mediterranean area the astronomical tide is quite limited (generally less than ±20 cm), but sea level may be increased several decimeters by meteorological factors producing sea surges. The main meteorological surge-related factor is, indeed, strong wind, atmospheric depressions, air temperature. It is therefore important to improve our understanding of the possible trends of change for surge-related to weather regimes. A wide variety of studies on climate variability in the Mediterranean is available, especially for regional temperature and precipitation reconstruction (Bolle, 2003; Lionello et al., 2006) the quantification and variability of surges remains much less studied.

Weather regimes and sea surge variations over the Gulf of Lions during the 20th century are studied by Ullmann and Moron (2008), they conclude that the relationships between monthly/ seasonal frequency of weather regime and 75th percentile of sea surge at Grau-de-la-Dent located in the Rhône Delta tend to strengthen during the 20th century. Ullmann et al. (2008) analyses sea surge variations measured at four tide-gauge stations almost evenly located around the Gulf of Lions (North Western corner of Mediterranean Sea) and their relationships with local-scale winds and regional-scale atmospheric patterns. They obtained that the frequency of southerly winds significantly increases since 1950, while the frequency of northerly winds decreases consistent with the increase of sea surges in the Gulf of Lions. A two-dimensional, hydrodynamic tide-surge model for the Mediterranean Sea is used by Wakelin and Proctor (2002) to model two storm surge events in the Adriatic Sea. Also, Tsimplis et al. (2005) have compared the recent sea-level evolution in the Mediterranean with the output of a barotropic model forced by atmospheric pressure and wind, finding that meteorological forcing has contributed to large residual trends in mean sea level; Gomis et al. (2008) have studied the contribution to low frequency sea-level variability obtained from simulations of air pressure and wind values deduced from reanalysis.

Alexandria western harbor (Figure 1), is located at the west of Alexandria city (29°52ˋ E and 31°11N) along the

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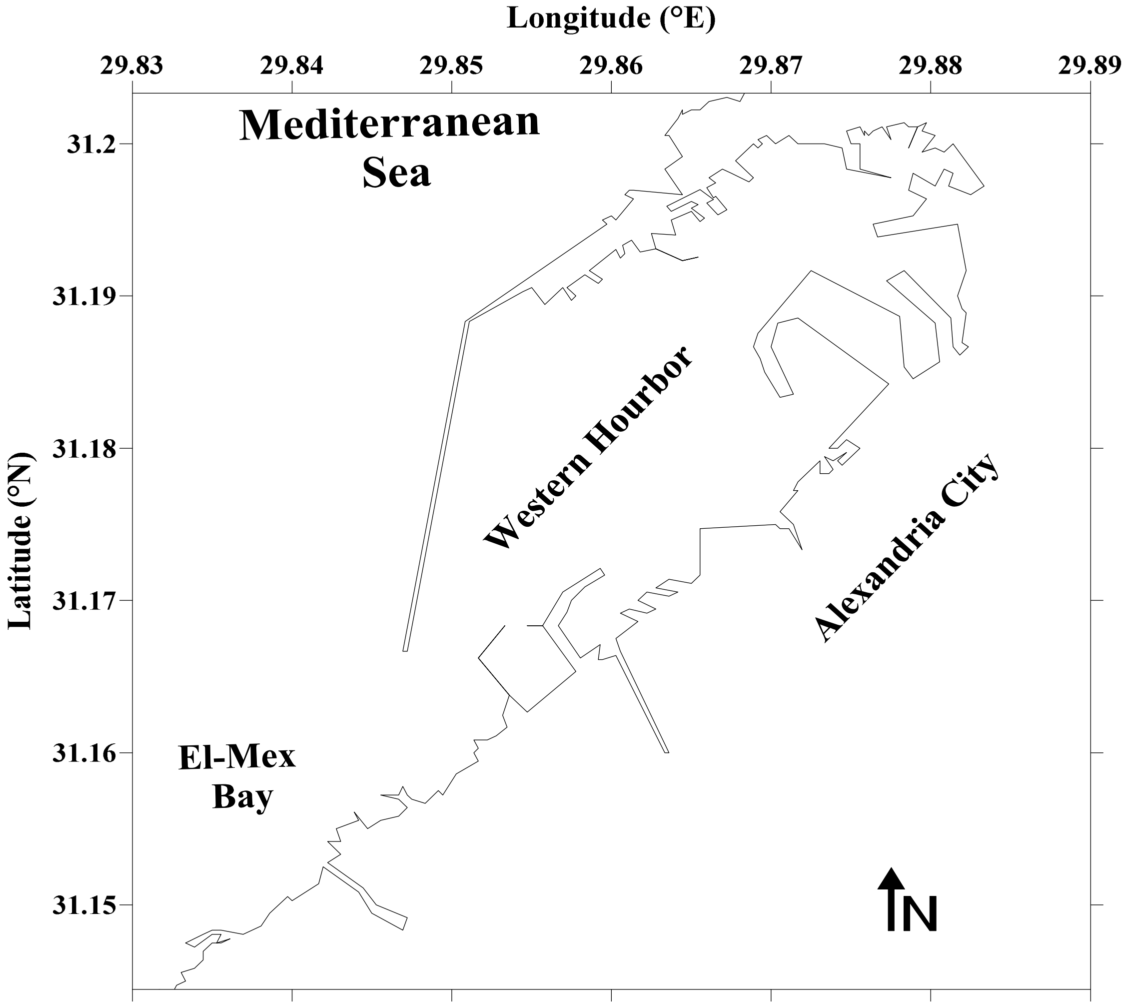

Figure 1. Alexandria western harbor.

Mediterranean coast of Egypt. Its area is about 31 km^2 and is an almost enclosed basin with restricted water exchange with the Mediterranean through a narrow strait. The water harbor can be considered tideless or of weak tide where M 2 is 6.9 cm (Tayel, 2008). The mean tide level over the 11 years (1995 to 2005) was obtained as 45 cm, above the zero level of the tide gauge. The mean high tide determined was 57.4 cm, while the mean of low tide was 32.8 cm, where it leads to tide range of 24.6 cm, which is relatively small. The frequent passage of atmospheric pressure system over the nearly tideless harbor of Alexandria generates considerable water level fluctuations. The combination of barometric pressure, wind force and air temperature can cause several different effects, from the general lowering of water level due to high pressure and low temperature to the creation of surges which forcing water on shore for several days during winter season.

The present discussion is concerned with the interactive relationship between the water level changes and the meteorological conditions (wind force, atmospheric pressure and air temperature). It is also concerned with the variability in the seasonal occurrence of water levels as well as their frequency distributions.

DATA

Sea level data of Western Harbor of Alexandria are analyzed over monthly scale for 11 years period (1995 to 2005). Analysis are conducting bearing in mind the determination of the probabilistic nature of meteorological action on sea level, and to get an estimation of that part of water level variations which is associated with the variation in each of the meteorological factors. Regression analysis is applied to the monthly mean of both water levels and the meteorological contribution (wind force, atmospheric pressure and air temperature). In attempting to examine the significance of the correlation between water level variations and the atmospheric forces, the formula of Spiegel (1982) is used for the generalized correlation coefficient (r^2) where:

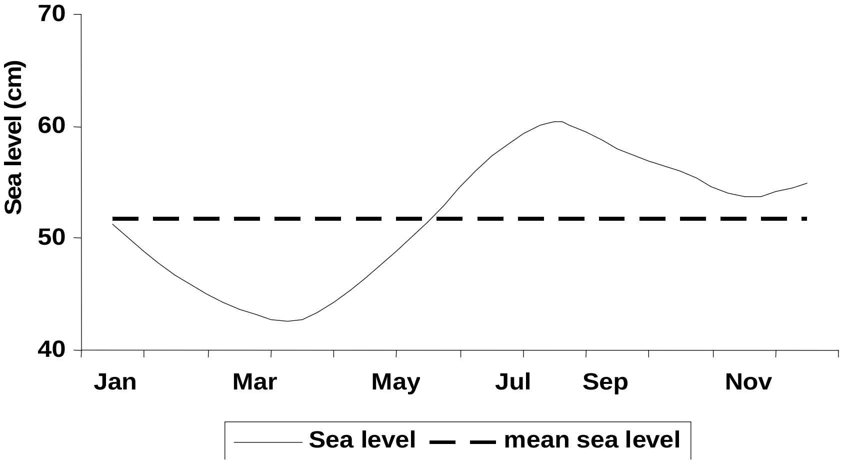

Figure 2. Seasonal variation of water level at Alexandria (1995 to 2005).

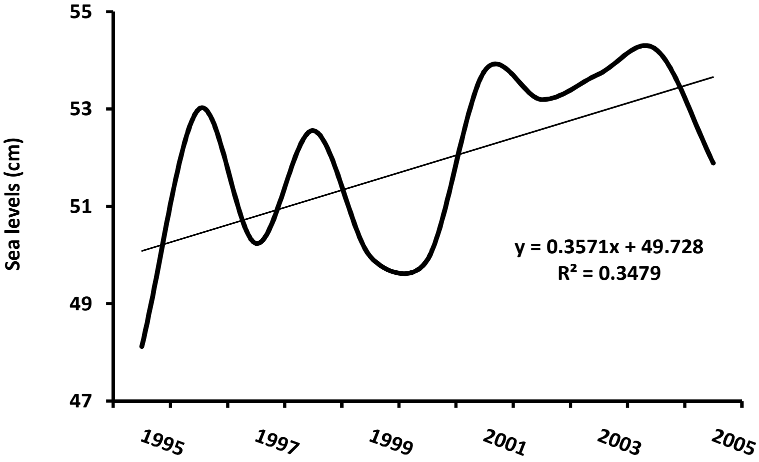

Figure 3. Annual mean water level at Alexandria (1995 to 2005).

$$r^2 = \frac{\text{Explained variations}}{\text{Total variations}} = \frac{\sum (y_{est} - \hat{y})^2}{\sum (y - \hat{y})^2}$$

Which reflect the form of the regression line. The terminology in the formula arises because the deviations ($y_{est} - \hat{y}$) are explained by the least square regression line and so tend to follow a definite pattern. In our case, y is the monthly mean water level while $\hat{y}$ is its mean value and y_{est} is the estimated water level due to meteorological elements by using the linear regression equations.

RESULTS

On basis of the 11 years period of monthly mean water levels at Alexandria harbor, the analysis have shown that the mean sea level is 51.8 cm, over the zero level of the tide gauge. The mean sea level was obtained as 50.6 cm for the period (1997 to 2004) by Maged (2010). The seasonal variations are characterized by a fairly pronounced regularity with high level during summer months (July and August), and low level in spring months (March and April). These fluctuations are shown in Figure 2, where the highest level is observed in August (60.0 cm) and the lowest are in April (42.6 cm). This fact agrees with the one obtained by Hamed (1983) and Moursy (1989). It is also noticed that the mean monthly water levels are below their average during the first half of the year and above during the second half. Annual mean levels are presented in Figure 3, where the heights are ranging between 48.2 (1995) to 53.8 cm (2003). It is also noticed an upward trend of 0.03 cm/year. This trend appeared to indicate an enormous of sea level rise. The general pattern of the monthly mean levels distribution is

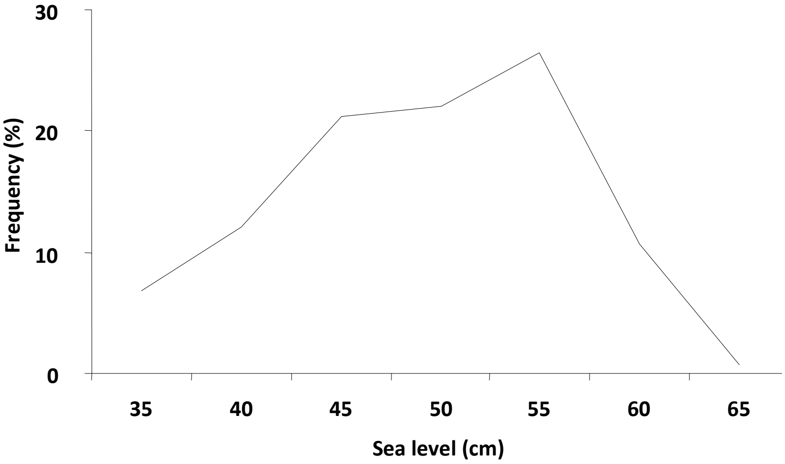

Figure 4. Frequency distribution of water level at Alexandria (1995 to 2005).

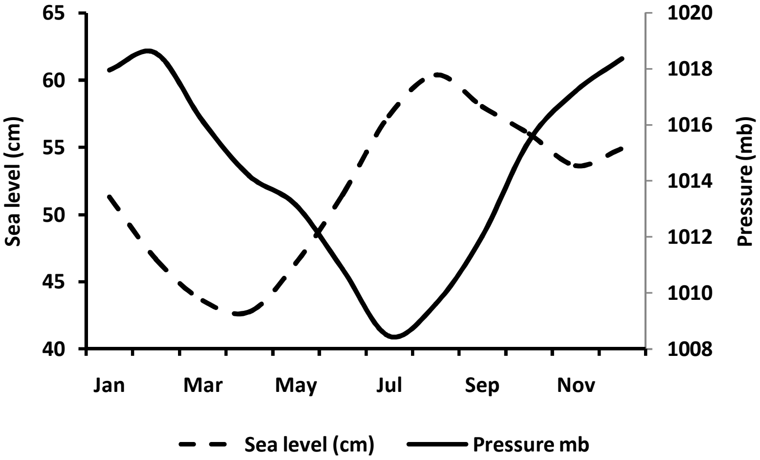

Figure 5. Seasonal variation of water level and local atmospheric pressure at Alexandria harbor (1995 to 2005).

appeared from their frequency.

Figure 4 illustrates these distribution, where the most pronounced frequency are concentrated in the level of 55 cm and represent 26.5% of the total frequencies.

Water heights and weather regimes

Water levels of Alexandria harbor fluctuates in relation to weather conditions (Sharaf El Din, 1975; Hamed, 1983; Moursy, 1994). These variations in water levels are generally the result of a very large scale meteorological disturbance generated over the water surface. For this reason the monthly water levels are analyzed in parallel with the variable meteorological data of atmospheric pressure, wind force and air temperature, with the aim of studying the general feature of the water heights and their dependency on meteorological conditions.

Atmospheric pressure impact

The response of sea level to atmospheric pressure changes is usually stated as a sea level rises by about 1 cm for each millibar fall. In reality however, this is not the case, science variation in atmospheric pressure is associated with changes in other meteorological factors which contributing to the fluctuation in water levels. The seasonal pattern of atmospheric pressure and water levels at Alexandria harbor are shown in Figure 5, where the highest pressure is found during winter months (December, January and February) while the lowest are in summer months (July and August). A fairly interactive inverse relationship between water level and atmospheric pressure are appeared. The close inverse relationship between water level and the local atmospheric pressure are appeared in Figure 6 for their annual mean value. Regression analysis is applied to the monthly mean of

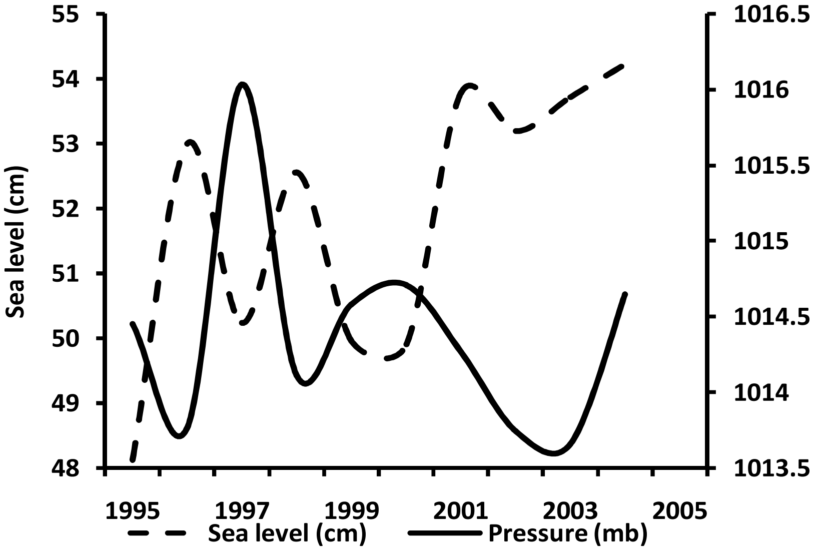

Figure 6. Annual variation of water level and local atmospheric pressure at Alexandria harbor (1995 to 2005).

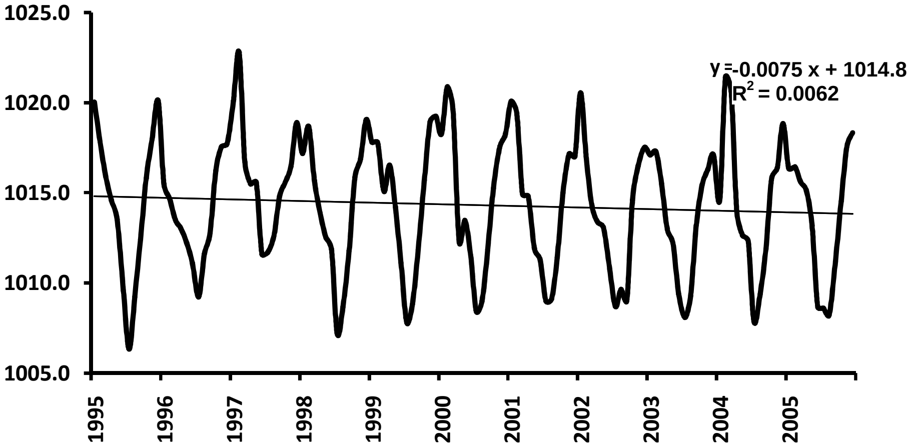

Figure 7. General changes in local atmospheric pressure at Alexandria harbor (1995 to 2005).

water levels and their corresponding monthly of atmospheric pressure. The result is the least square line:

W. L. (cm) = - 0.68 P (mb)

This relation shows that the water level is depressed about 1.4 cm for each millibar of increased atmospheric pressure. The direct comparison of the two elements gave a correlation coefficient of -0.40 which is relatively not very high. Detailed investigation of the monthly atmospheric pressure and their corresponding monthly water levels has been obtained from the generalized correlation coefficient (r^2) which is found to be 0.16. The natural consequence is that the value (1 - r^2) to be 0.84 which means that about 16% of the total variations in the water heights are attributed to the changes in the local atmospheric pressure and still about 84% remain unexplained, this could be due to other additional variables which have not been considered. The general variations of atmospheric pressure during the study period are appeared in Figure 7, which shows a very slight decreasing trend.

Air temperature impact

Changes in air temperature influence the sea surface, at least its effect is one of the numerous elements which

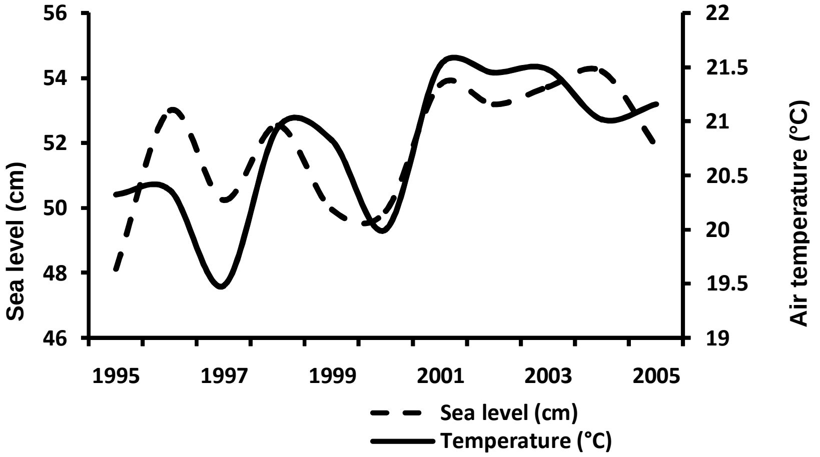

Figure 8. Annual variation of water level and air temperature at Alexandria harbor (1995 to 2005).

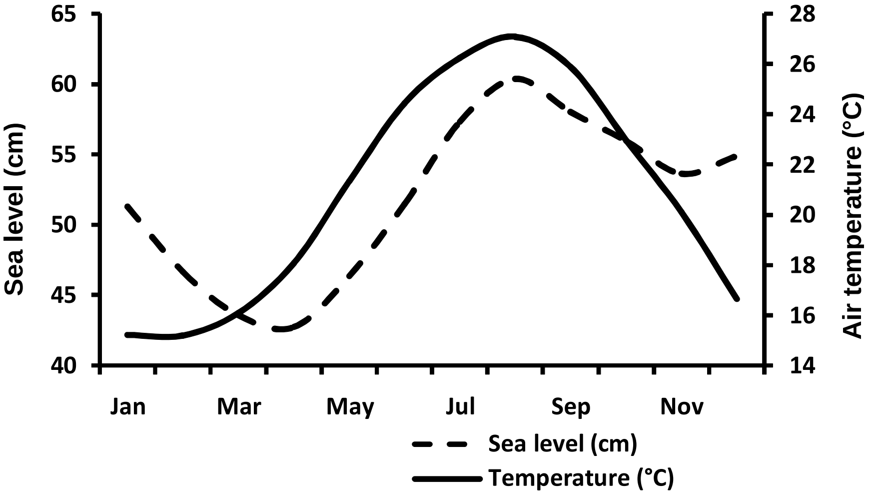

Figure 9. Seasonal variation of water level and air temperature at Alexandria harbor (1995 to 2005).

may contribute to the sea level variations. Water expands as its temperature increases. As climate change increases water temperature initially at the surface, the water will expand contributing to sea level rise due to thermal expansion. The response of the annual water level variations to the changes in the corresponding air temperature at Alexandria are appeared in Figure 8, which shows a close connection between the two elements. It also shows water level as rising and their upward curve agrees with the temperature trend. Similar pattern are found for the seasonal fluctuations in both air temperature and water level (Figure 9). The agreement between the two curves reveals the highly coherent and the close connection between them. To identify the influence of air temperature causes water level variations, the following linear relationship has been obtained:

S. L. (cm) = 0.888 T°

With correlation coefficient of r = 0.673.

The linear relationship indicates a rising in water level by 1.1 cm for each increase of 1°of air temperature, and the relatively high coefficient shows that the air temperature may consider one of the main causes affecting the water level at Alexandria harbor. The generalized correlation (r^2) gave a value of 0.45 which reveals a fairly pronounced relationship between them and about 45% of the water level variations are due to the changes in air temperature and still about 55% of the variations are

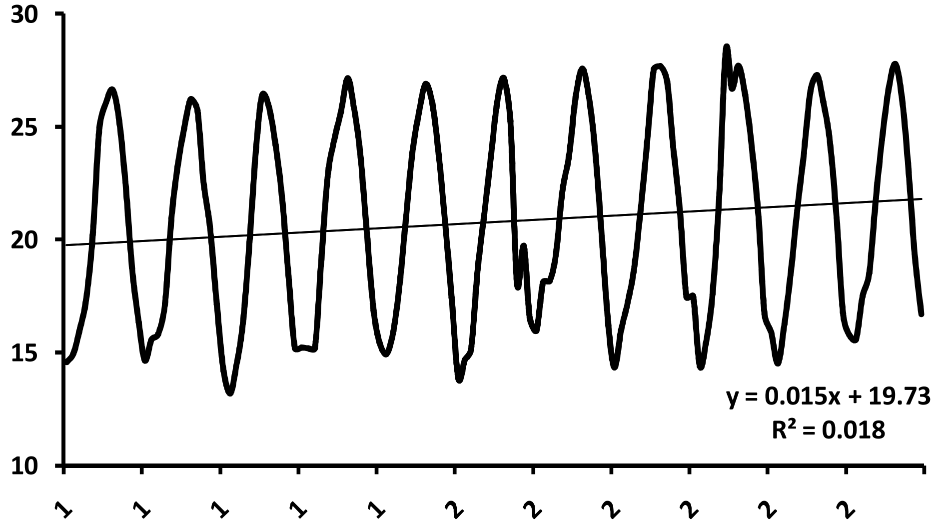

Figure 10. General changes in air temperature at Alexandria harbor (1995 to 2005).

unexplained which could be due to other additional variables which are not considered. The general fluctuation in air temperature during the study period appeared in Figure 10, where it gave an upward trend.

Wind force impact

One of the most basic ways in which the atmosphere drives the ocean is through wind stress applied to the ocean surface, where the attractive force of the wind acts to drag the water in the direction of the wind. The wind forces induce seasonal variations on mean sea level. It is also blowing over the water surface, exerts a horizontal force that induce a surface current. Hamed (1983) has shown that the predominant component of wind at Alexandria are between Southwest and Northwest during winter, and it is Northwest in summer while it changes between Southwest and Northeast during spring and autumn. The same pattern is found for the prevailing wind at Alexandria harbor during the study period. The mean monthly wind speed was ranging between 4 to 14 knots with high intensive Southwesterly wind during winter and spring seasons. The general pattern of wind forces at Alexandria harbor are illustrated in Figures 11 and 12. The interaction between wind speed with the water levels during the study period have been applied statistically using the monthly mean of wind speed and water levels. Because the SW wind is the most effective wind on sea level at the Alexandria harbor during the study period, the contribution of this wind to the water level change is evident in the linear regression equation:

S. L (cm) = -1.96 W (knot) + 2.49

With a correlation coefficient of 0.44 and generalized correlation of 0.17 which reveals that about 17% of the water level variations are due to the North West wind and the sea level rises by about 0.53 cm for each increase in North Westerly wind by 1 knot (0.5 m/s). An attempt was also made to determine the effect of wind stress upon water heights. A formula which has been widely used, giving the wind stress vector (τ) in terms of the wind velocity (W), measured at about 10 m above the sea surface is:

$\tau = k \rho_a W^2$ (Welander, 1961)

Where W is the wind speed, ρ_a the density of the air (1.3 kg/m^3) and k a constant with a value around 2.5×10^{-3}. Welander (1961) pointed out that the sea surface elevation (ξ) can be estimated by the formula:

$\xi \approx k (\tau F/g \rho h)$

Where τ is the wind stress, F the fetch (the distance over which the wind is acting), g the acceleration of gravity, ρ the density of the water, and h the height. Here k is a constant of the order of 1, its value depends on the assumed bottom stress. If the bottom stress is zero, the coefficient is 1. Taking into consideration that the mean wind speed at Alexandria is 10 knots (5 m/s), with $\rho = 1.4 \times 10^3$ kg/m^3 , $g = 10$ m/s^2 , $F = 2 \times 10^5$ m and h = 10 m, then $\xi \approx 46.4$ cm which is the elevation in the sea surface due to the influence of the stationary wind stress.

CONCLUSION

On basis of 11 years period (1995 to 2005), water level of Alexandria harbor has a mean value of 51.8 cm over the zero level of the tide gauge. It has a seasonal cycle which

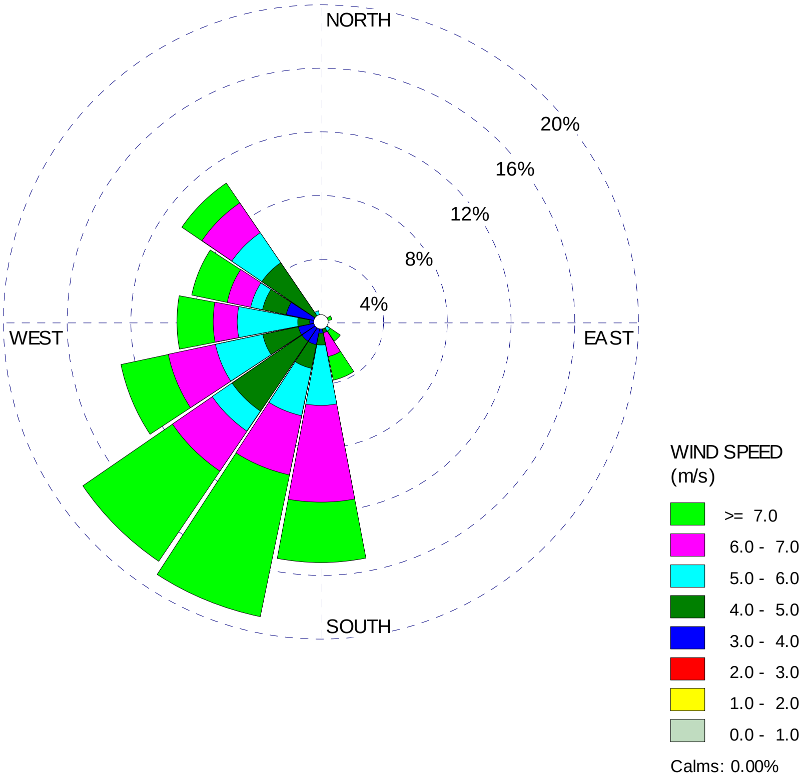

Figure 11. The general pattern of wind speed and direction at Alexandria harbor (1995 to 2005).

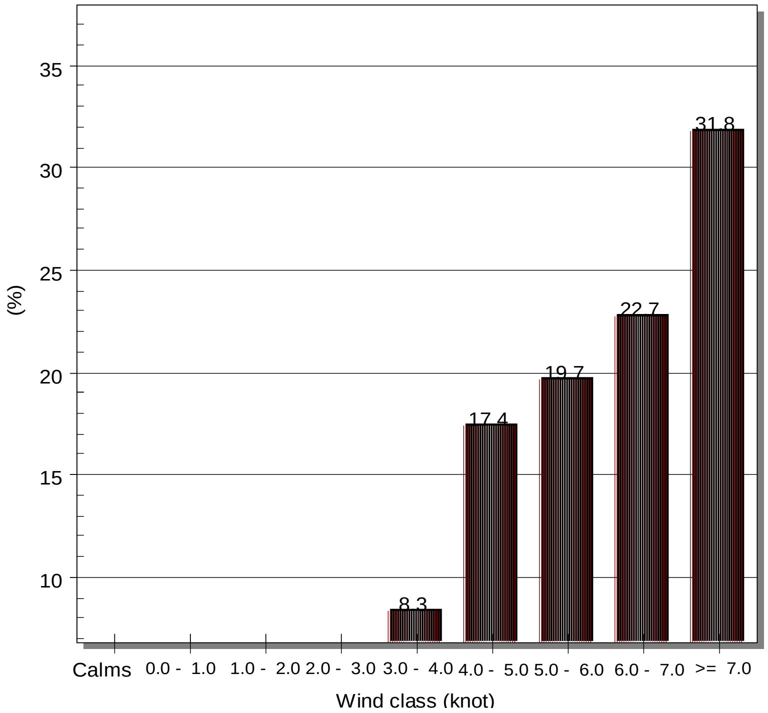

Figure 12. Wind class frequency distribution at Alexandria harbor (1995 to 2005).

apparently reflecting a regional trend of high levels in summer and low ones in spring. The most pronounced frequency is concentrated in the level 55 cm. The water height demonstrated moderately sea level rise with a rate of 0.3 cm/year. The water level increases by 1.4 cm for each decrease of 1 mb of atmospheric pressure, and it rises by 1.1 cm for each increase of 1° of air temp erature, while it changes by 0.5 cm for each 1 knot of North West wind. The seasonal variations of water heights are in line with their corresponding changes in local atmospheric pressure, wind force and air temperature. Most perturbbations in water heights are the result of these three factors. Wind exert a stress on water surface leading to 17% of the total variations, while inverse barometric effect responsible for 16% and air temperature have contribution to about 45%. The other variations in the water levels could be due to other disturbing factors which have not been considered. However, it is important to have large-scale view to understand regional and local changes in future.

The deviations in the general phenomena of water level have to be taken into consideration and may not be neglected. Even a seemingly small increase in sea level can have a dramatic impact on coastal environments.

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