Sea Surface Slope and Variation Along the Egyptian Delta Coast

Prof. A. SHAKER , Prof. D. ALNAGGAR, Prof. A. SAAD , Dr. H. Faisal, Egypt

Abstract

A new modern integrated sea-level monitoring system has been installed at Alexandria. New precise hourly tide, GPS, and metrological observations have been collected, processed, and analyzed for the years 2001, 2002, and 2003. Additionally monthly and annual tide records of a number of tide gauge stations in Egypt have been collected and investigated. Therefore, various analysis procedures have been carried out to draw a clear view concerning the behavior and characteristics of the collected tide data over the last century. Rates of sea level rise over different sites on the Egyptian territories are evaluated. Moreover, slope of the Mediterranean along the Egyptian Delta coast is investigated and documented. This research illustrates the data sources, discusses the followed procedures, and presents the obtained results.

1- Introduction

The issue of sea level rise has attained more concerns, on a global basis, in the last years. From a developmental point of view, the harmful effects of sea rise, especially in coastal areas, raise the attention to carry out detailed studies on this phenomenon. Long-term tidal records may contribute significantly to precise determination of sea rise rate. The sea rise rate on a global scale during the twentieth century has an average of 1.5-2.5 mm/year [IPCC, 2001 and IOC, 2002]. These real estimates are derived from analysis of actual long-term tide gauge data all over the world.

Previous local investigations revealed that the MSL in Egypt has increased by 12 cm from 1906 to 1980, which means a rate of approximately 1.5 mm per year [Nassar et al, 1998]. Also, [Sharaf El-Din et al 1989] have estimated the MSL rise rate by 1.6 mm per year at Alexandria in the period from 1958 to 1988. On the other hand, other studies claim that the rising rate will be much higher in the next few decades and will lead to hazardous economical troubles. Most of these investigations are based on different scenarios and estimates of the air temperature rise due to the global warming phenomena. For example, recent environmental researches, based on business-as-usual scenario of greenhouse gas emission, expect that the sea rise on a global scale would be of 12 cm by the year 2030 and about 50 cm by the year 2100. This

implies that the sea level rising rate would be doubled in the twenty-first century compared to the real rising rate of the twentieth century.

Other expectations lead to a sea level rise of about 2 meters by the year 2100 when taken into account the subsidence because of land movements and removal of ground water. However, it is worth mentioning that many of these estimate has a great deal of uncertainties due to their extrapolation nature and suspected assumptions [Houghton, 1997]. Moreover, the sea level rise would differ from an area to another on the globe due to the different nature and amount of the leading factors such as the human and industrial activities. Therefore, the optimum realistic estimates of sea rise should result from analysis of real data sets, particularly long-term tidal records.

2- Available Data

Several data sets related to MSL have been collected and observed for different locations in Egypt. The data may be subdivided into two categories: data for historical tide gauges in the form of annual average values, and three-year detailed data sets measured by the recent installed sea level observing system.

The collected MSL historical data sets are coming from different sources, mainly from the data holdings of the Permanent Service of Mean Sea Level (PSMSL) from [PSMSL, 1989] :

(http://www.pol.ac.uk/psmsl_individual_stations.html)

along with data sets from other published research studies [e.g. Alam El-Din, 1993, Shalaby, 2000 and Gaweesh, 2004]. These data sets are found to be referenced to different vertical datums such as the ESA datum, the Suez Canal datum, and the Navy datum. Consequently, a crucial primary step was to test the validity of each data set, and then convert all of them to be belonged to the same datum. The Egyptian national MSL datum as defined in 1906 was chosen to be the unique datum to be utilized in all computational stages in this research study.

The final compiled data sets consist of*:*

- Annual tide averages for the old tide gauge station located inside the Alexandria harbor covering the period from 1944 to 1992.
- Annual tide averages for a tide gauge station in Port Said covering the period from 1923 to 1987.
- Annual tide averages for a tide gauge station in Suez covering the period from 1923 to 1937 and from 1980 to 1986.
- Hourly tide records at Alexandria from 1993 to 2000

- Monthly tide records at Burullus from 1990 to 2002 and at Ras El-Bar for the period from 1991 to 1992 and 1997 to 2003.
- Monthly tide records at Alexandria from 1985 to 2000.

The Survey Research Institute has installed the recent state-of-the-art sea level observing system, as presented in details in [Faisel, H., 2005]. inside the headquarter of the Navy in Alexandria. That tide gauge station has been constructed and operated, by the hydrographic survey department, since 1993. The gauge contained an old mechanical float-gauge device and several separated sensors for measuring meteorological conditions. This gauge station is located in the Western harbor, 800 meters north-west of the old tide gauge station operated by the Alexandria harbor authority. It should be mentioned, in current context, that the site of the old gauge was found to be unsuitable for modern pressure devices since the water in this site is extremely polluted with ships waste oil. A precise levelling line has been carried out to connect the gauge staffs in both stations. Consequently, the constant datum shift was obtained and used, in later processing stages, to relate the tide readings of the new station to the old historical one.

The data sets resulted from the new installed system, used in this research, cover the entire years of 2001, 2002, and 2003 and consist of:

- Tide water heights measured at 10-minute intervals with a precision of 0.2 cm, averaged and recorded hourly.
- Hourly meteorological data of air pressure, temperature, relative humidity, wind speed and direction.
- Continuous GPS data at a sample rate of thirty seconds (477 days).

3- MSL at Alexandria

3-1 Characteristics of the Tide at Alexandria

The modern installed sea level observing system produces a detailed data set of tidal heights covering the entire year of 2001, 2002, and 2003. Although the original observations have been measured every ten minutes, hourly averages are computed since a one-hour interval is quite suitable for tidal analysis [IOC, 2002, Caldwell, 2001]. Therefore, a total of 8760 tidal measurements are utilized in the processing stages for each year. It should be mentioned here that the installed modern pressure gauge equipment has been installed so that its zero-level corresponds to the zero-level of the staff gauge fixed in the well of the navy tide gauge station. Additionally, a levelling line has been run to determine the

vertical shift between the zero-level of gauge staffs located in both the navy and the old tide gauge stations. Hence prior to any data treatment, the collected measurements have been converted from the Navy datum to the old ESA datum by subtracting that constant datum shift. Statistics of this data set are given in Table 1. From this table, it can be noticed that the measured sea water heights vary from 24.0 cm to 92.0 cm with an average of 54.7 cm for 2001, while for the year 2002 the measured sea water heights vary from 22.0 cm to 87.0 cm with an average 53.1 cm, on the other hand, the measured sea water heights vary from 27.0 cm to 84.0 cm with an average 52.9 cm for the year 2003.

Table 1: Statistics of observed tides in 2001, 2002, and 2003

Hourly Tide (cm)	2001	2002	2003
Minimum	24.0	22.0	27.0
Maximum	92.0	87.0	84.0
Average	54.7	53.1	52.9

3-2 Sea Level Data over the Period 1993-2000 at Alexandria

The hourly heights of the sea level were taken from the records of the tide gauge at Navy datum (1993-2000) in Alexandria. This tide gauge has been installed since 1993 inside the Navy Survey, the data of this station are corrected by adjusting them to the Survey Department zero level datum. This was carried out by subtracting the constant datum shift. The value of the mean sea level calculated from the eight years of observation (1993-2000) is 49.7 cm above the zero of the tide gauge at Alexandria harbor, Figure 1. **This value is 15.9 cm higher than the one used by the Survey Department of Egypt (defined in 1906) with a rate of 1.7 mm/year.**

3-3 Long-Term Sea Level Rise at Alexandria

The collected annual mean values of tidal heights at Alexandria tide gauges, after unifying their tide datum to be the ESA 1906 vertical datum, have been analyzed. That national datum has been considered as an imaginary zero MSL value, so that all obtained results express the changes of the MSL above that datum. The available data set covers 58 years from 1944 to 2003, except for the data gap in 1948 and 1949. Furthermore, the data set has been divided into three sub-sets, each cover almost 19 years in order to follow the traditional point of view concerning

the lunar-motion cycle. Table 2 presents the statistical information of these data sets.

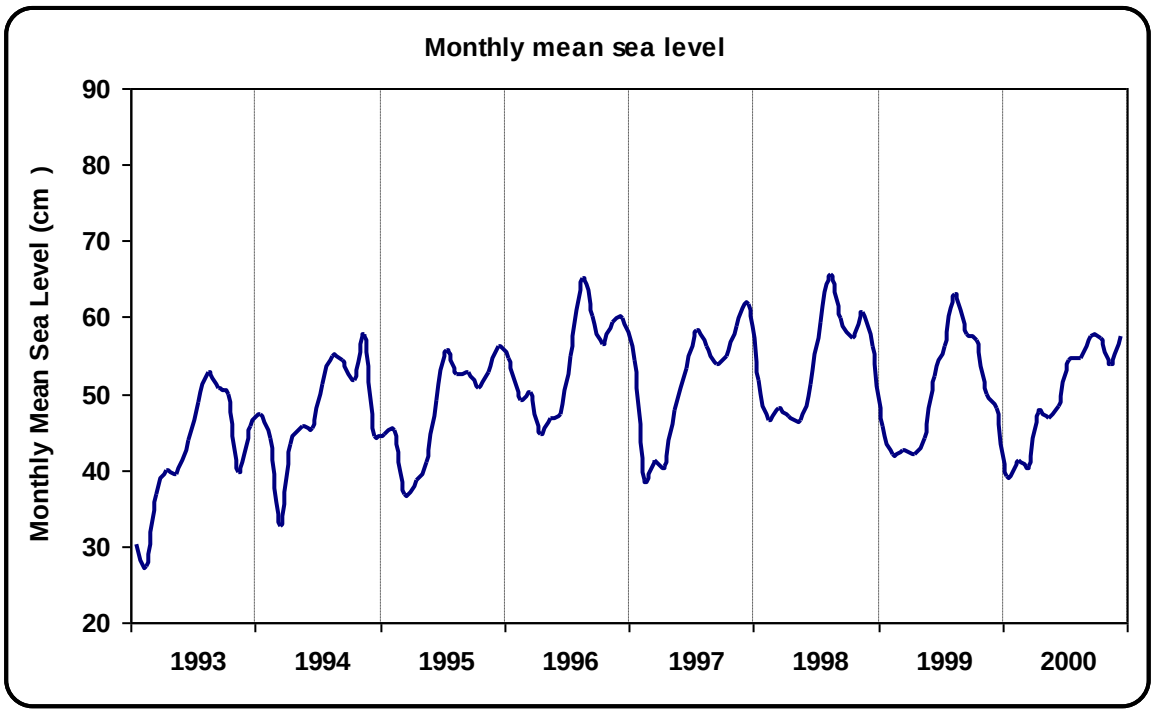

Figure 1: Mean sea level from 1993 to 2000

Table 2: Statistics of MSL variations at Alexandria

Data span	**(1944-1964)**	**(1965-1983)**	**(1984-2003)**	**1944-2003**
Min. (cm)	1.6	7.0	8.3	**1.6**
Max. (cm)	16.0	14.9	20.9	**20.9**
Mean (cm)	8.4	11.2	15.1	**11.6**

From this table, it can be noticed that the first group, from 1944 to 1964, has a minimum of 1.6 cm and a maximum of 16.0 cm with an average of 8.4 cm above the 1906 MSL definition. The second data set, from 1965 to 1983, has a minimum of 7.0 cm and a maximum of 14.9 cm with an average of 11.2 cm. The third data set, from 1984 to 2003, has a minimum of 8.3 cm and a maximum of 20.9 cm with an average of 15.1 cm.

The contribution of these data sub-sets on the sea level rise is depicted in Figure 2 Obviously, it can be noticed from this sketch that a gradual increase of the mean sea level since 1906 with a linear form.

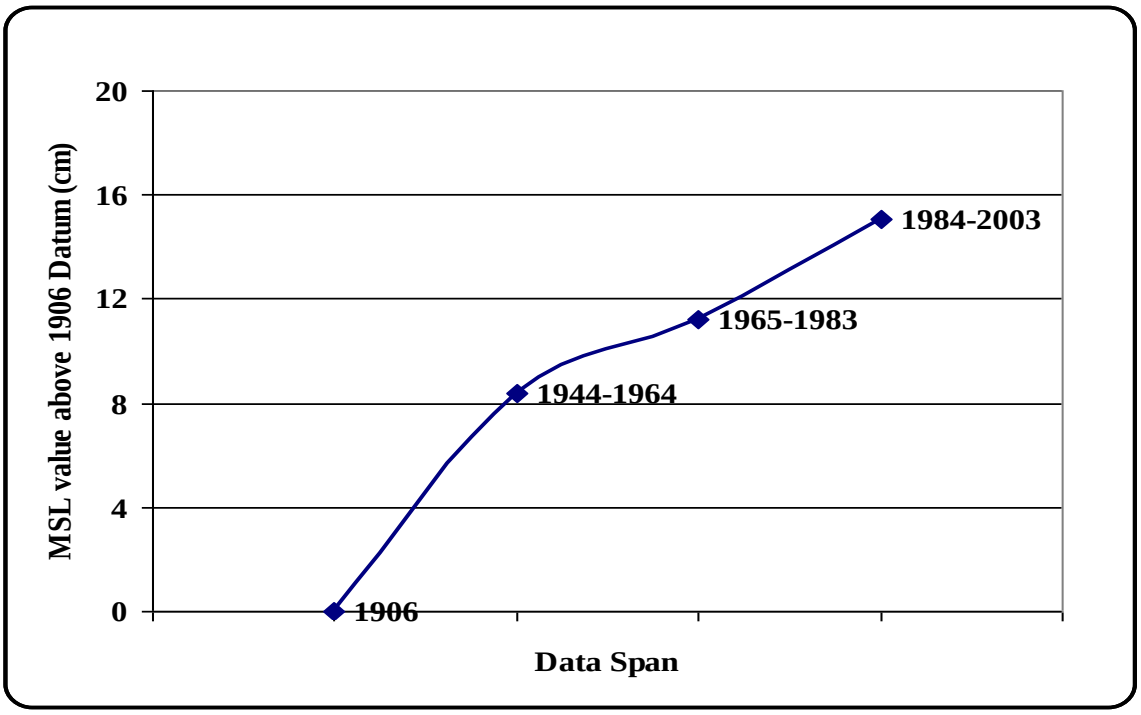

Figure 2: Long-Term MSL rise rate at Alexandria in three Sub-Sets

Considering the whole data set as one piece, the minimum MSL value is 1.6 cm, the maximum is 20.9 cm, and the average MSL amounts to 11.6 cm over the 1906 old definition of MSL.

4- Sea Level Slope and Variation along the Delta Coast in Egypt

Coastal protection and development over the Delta coastlines require a reliable estimate of the level sea rise rate. The Costal Research Institute (CRI) is a government agency, under the umbrella of the National Water Research Center, which collects tidal measurements over the Delta shores. In order to study the lateral variation along the Nile Delta coast, tidal measurements have been obtained and analyzed [Gaweesh, 2004].

The available tidal monthly-averaged gauge records are taken by (CRI) covering the period from 1990 to 2002 at Burullus, and the period from 1990 to 1991 and 1997 to 2003 at Ras El-Bar. The monthly mean sea level values for each station are collected and referred to the Survey department zero level (1906 datum) in Egypt, yearly average, and total average mean sea level were calculated for both stations along the Nile Delta Coast. Figure 3 presents the location of tide gauge stations along the Nile Delta Coast.

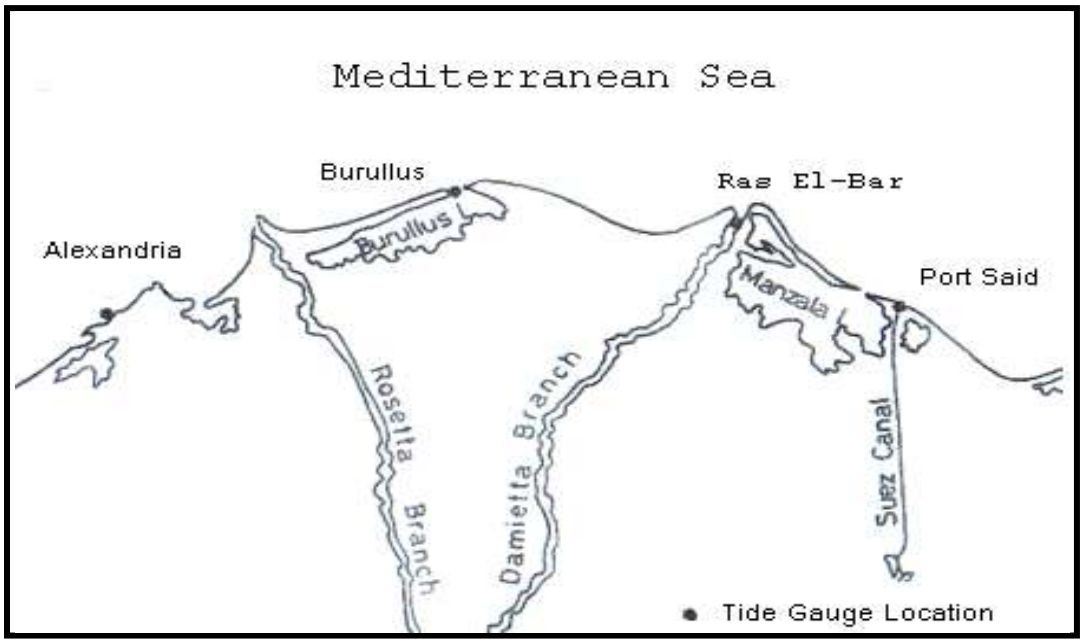

Figure 3: Tide gauge stations over the Delta Coast

The annual mean sea level is determined for each station; statistics of this data set for both Burullus (1990-2002) and Ras El-Bar (1990-1991 and 1997-2003) are summarized in Table 3. From this table, it can be noticed that the minimum value of mean sea level at Burullus is 18.2 cm, the maximum value is 39.0 cm, with a mean value of 29.2 cm referred to the Survey department zero level. Moreover, it has been found that the minimum value of mean sea level at Ras El-Bar is 14.1 cm, the maximum value is 28.9 cm; with a mean value of 22.9 cm referred to the Survey department zero level. Additionally, the monthly mean sea level is represented at both stations Burullus (1990-2002) and Ras El-Bar (1990-1991 and 1997-2003), referred to the Survey department zero level, in Figure 4 and Figure 5 respectively.

Table 3: Annual mean sea level at Burullus and Ras El-Bar (cm)

Station	**Burullus**	**Ras El-Bar**
Data span	**1990-2002**	**1990-1991 & 1997-2003**
Min.	18.2	14.1
Max.	39.0	28.9
Mean	29.2	22.9

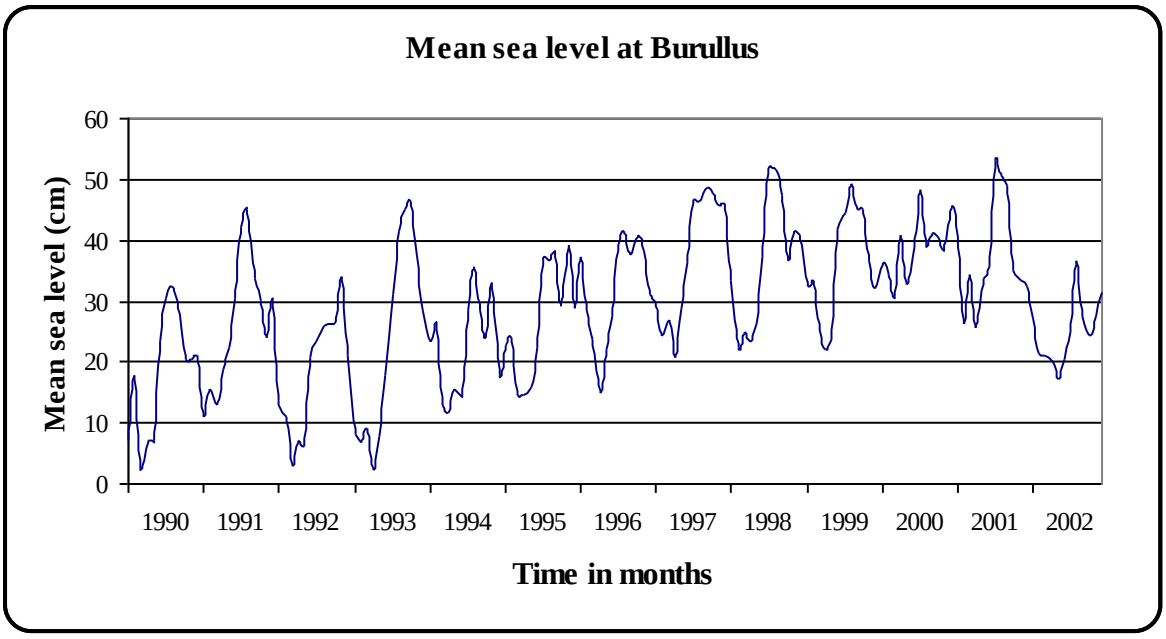

Figure 4: Mean sea level at Burullus (1990-2002)

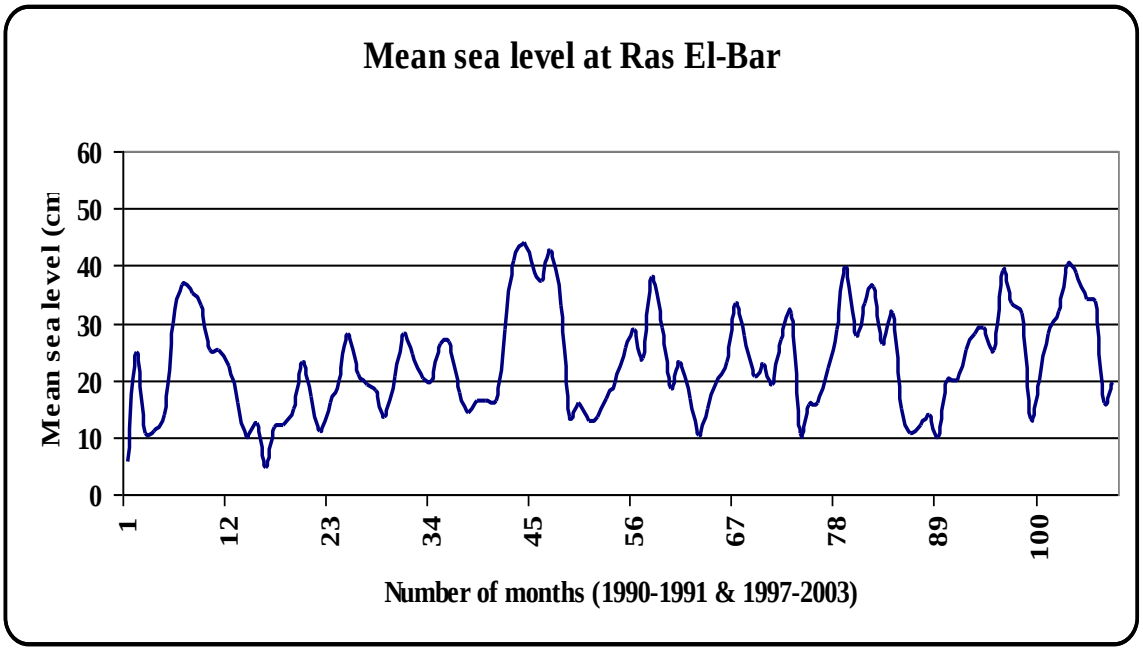

Figure 5: Mean sea level at Ras El-Bar (1990-1991 and 1997-2003)

The seasonal variability of monthly mean sea level at Burullus (1990-2002), as calculated from the whole period of the thirteen-year observations, is depicted in Figure 6. This figure shows the lowest monthly mean sea level occurs in April and the highest value in August.

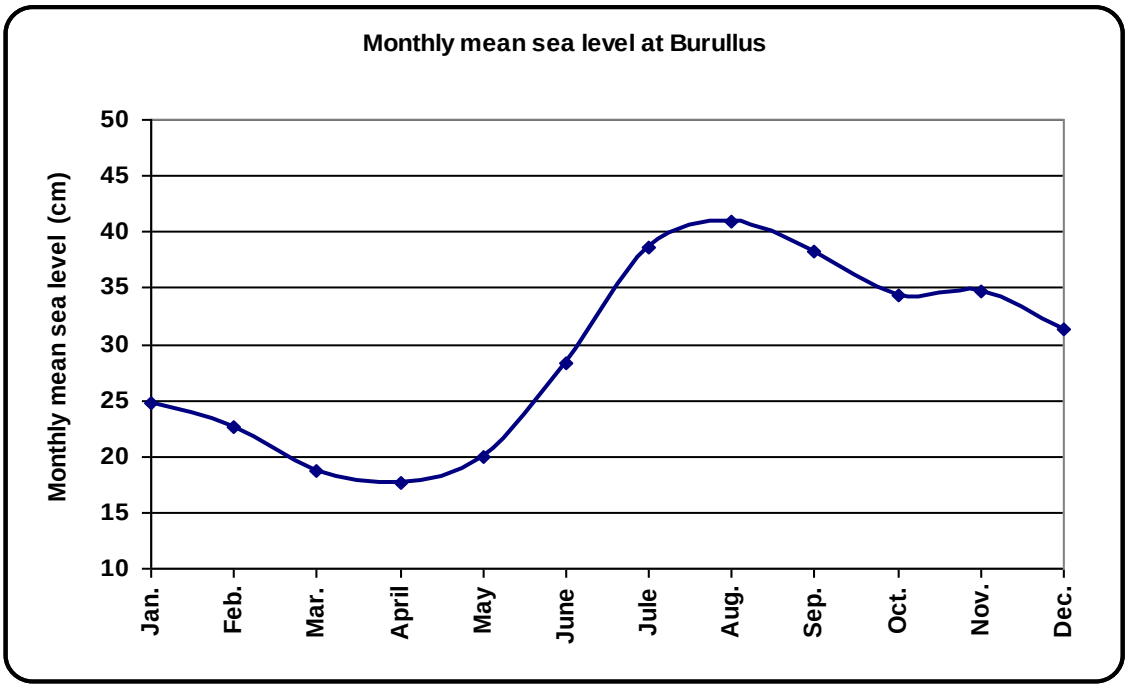

Figure 6: Monthly MSL at Burullus during (1990-2002)

Moreover, the monthly mean sea level at Ras El-Bar (1990-1991 and 1997-2003), as calculated from the whole period of the nine-year observation, is illustrated in Figure 7, with the minimum value in March and the maximum value in July. The seasonal variability in Mediterranean Sea presents its minimum value in spring and the maximum value appears in summer.

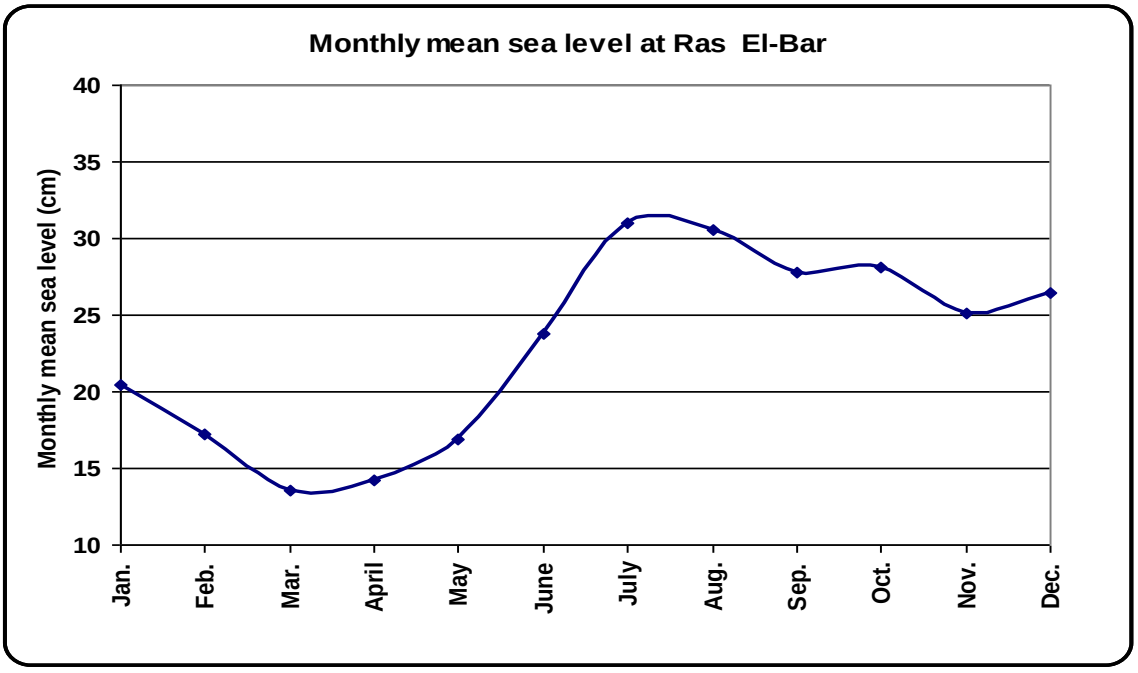

Figure 7: Monthly MSL at Ras El-Bar along (1990-1991& 1997-2003)

In order to compare between the different sea level data and to detect the lateral variation along the Nile Delta Coast, it is important to obtain more uniformity and consistency of data sets. Common data sets for Alexandria, Burullus and Ras El-Bar tide gauges are found to cover the period from 1990 to 1991 and from 1997 to 2002, as presented in Table 4. From this table, it can be noticed that the mean sea level value varies between 11.9 cm and 20.9 cm with a mean value 17.3 cm at Alexandria, while, the minimum value of mean sea level is 18.3 cm, the maximum value is 39.0 cm, with a mean value of 32.0 cm at Burullus. Moreover, it has been found that the minimum value of mean sea level at Ras El-Bar is 14.1 cm, and the maximum value is 28.9 cm, with a mean value of 22.2 cm. The total average of mean sea level at each station is determined and referred to the Survey department zero level.

Table 4: The Mean sea level along the Nile Delta Coast (cm)

Stations	**Alexandria**	**Burullus**	**Ras El Bar**
Min	11.9	18.3	14.1
Max	20.9	39.0	28.9
average	17.3	32.0	22.2

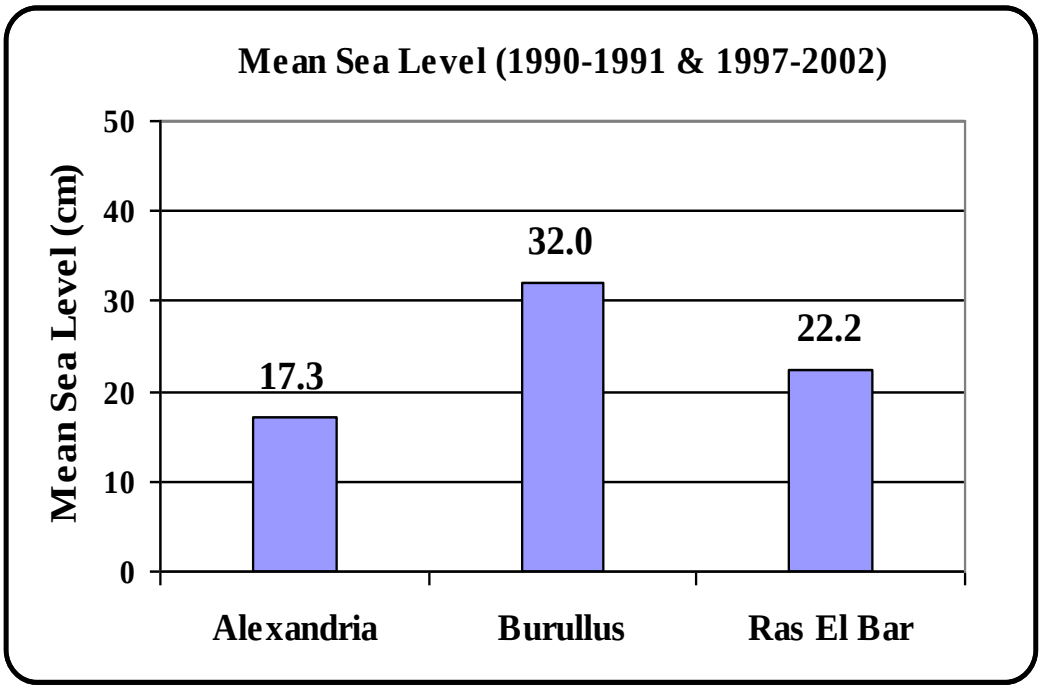

Figure 8: Variation of mean sea level along the Nile Delta Coast

Figure 8 illustrates the total average mean sea level at each station. From this figure, it can be noticed that the mean sea level displays a significant

lateral change along the Nile Delta Coast and there is a general increase from Alexandria to Burullus and then it decreases toward Ras El-Bar. The difference in mean sea level between Alexandria and Burullus is 14.7 cm, while, it is 9.8 cm between Burullus and Ras El-Bar.

Other common data sets for both Alexandria and Port Said tide gauges are found to cover the period from 1944 to 1986, as presented in Table 5. From this table, it can be seen that the mean sea level value varies between 1.6 cm and 16.0 cm with a mean value 9.6 cm at Alexandria, while, the minimum value of mean sea level is 3.0 cm, the maximum value is 24.0 cm, with a mean value of 11.6 cm at Port Said. Moreover, it can be noticed that the mean sea level displays the difference in mean sea level between Alexandria and Port Said is 2 cm. Figure 9 illustrates the mean sea level at both stations.

Table 5: The Mean sea level at Alexandria and Port Said (cm)

Stations	Alexandria	Port Said
Min	1.6	3.0
Max	16.0	24.0
Mean	9.6	11.6

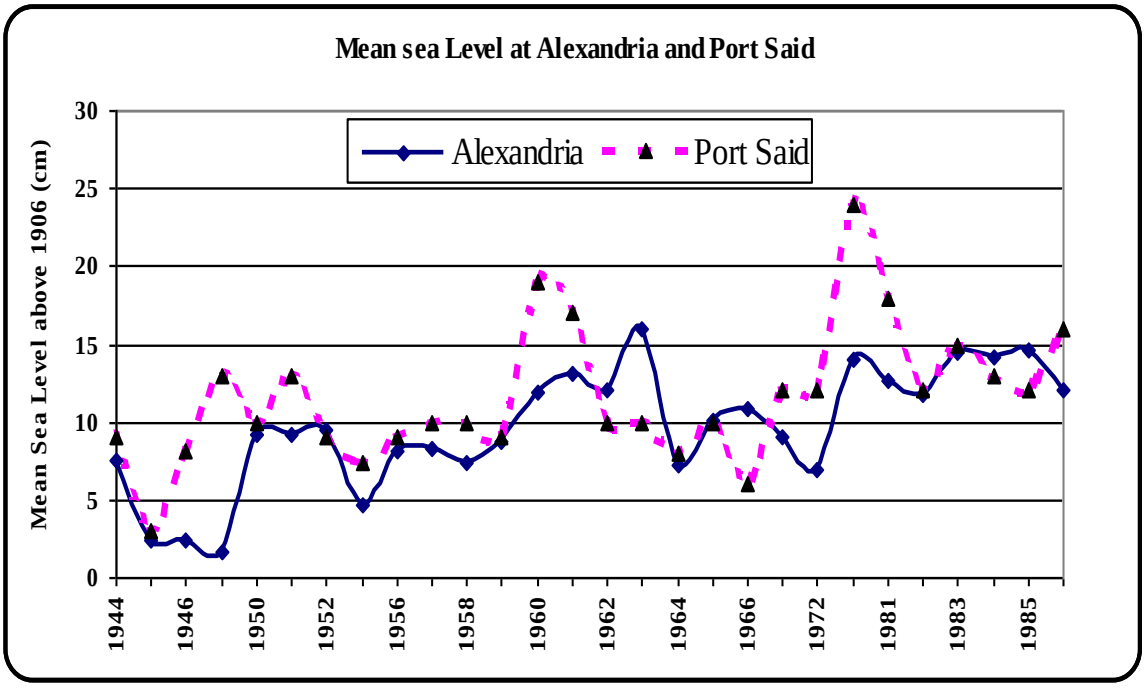

Figure 9: MSL at Alexandria and Port Said (1944-1986)

Next, The available observations, referred to the Survey department zero level in Egypt, have been utilized to investigate the lateral variations along the Nile Delta coast as presented in Table 4 and Table 5. From these tables, it can be concluded that the mean sea level generally increases from Alexandria to Burullus and then decreases from Ras El-Bar to Port Said.

Similar results have been reached by other researchers. [El Fishawi, et al, 1991] studied the sea level characteristics along the Nile Delta Coast at Alexandria, Rosetta, Burullus, Damietta, and Port Said using different data records. It has been concluded that the mean sea level displays a significant lateral change along the coast, and there is a general increase from Alexandria to Burullus, and then a marked decrease from Damietta to Port Said. Again, these results emphasis the crucial demand for modernizing the equipments installed at the existing tide gauge stations and the establishment of new stations along the Mediterranean Sea in order to get reliable measures of the sea slope in an accurate definition of the national vertical geodetic datum of Egypt.

5- Conclusion and Recommendations

Based on the obtained results, the following could be concluded:

- The tide in Alexandria is almost a semidiurnal (mixed) in nature with two high and two low of the water level tide but inequality in water height.

- On a seasonal basis at Alexandria, it can be concluded that the highest mean sea levels occur in August and the lowest mean sea levels in March.

- Considering the whole tidal dataset from 1944 to 2003 as one piece, it has been concluded that the mean sea level at Alexandria MSL is 11.6 cm over the 1906 old definition of MSL with a rate of 1.7 mm/year

- At other tide gauge stations along the Mediterranean coast, it has been found that the annual mean sea level at Burullus (1990-2002) has a minimum value of 18.2 cm; a maximum value of 39.0 cm, with a mean value of 29.2 cm referred to the Survey department zero level. At Ras El-Bar (1990-1991 and 1997-2003), it has been found that the minimum value of mean sea level is 14.1 cm, the maximum value is 28.9 cm, with a mean value of 22.9 cm referred to the Survey department zero level.

- Analysis of the seasonal variability of monthly mean sea level at Burullus shows the lowest monthly mean sea level occurs in April and the highest value in August. Additionally, at Ras El-Bar the minimum value occurs in March and the maximum value in July.

- During the period 1926-1987, the mean sea level of Mediterranean Sea at Port Said has been found to have a minimum value of -1.7 cm, a maximum value of 24.0 cm, with an average of 9.0 cm above the 1906 datum with a rate of 2.4 mm/year. Additionally, the mean sea level of the Red Sea at Suez has been found to have a minimum value of 18.0 cm, a maximum value of 45.3 cm, and an average of 24.0 cm with a rate of 0.5 mm/year.

- Furthermore, it has been concluded that there exist lateral changes of MSL of the Mediterranean Sea over the Egyptian coasts. It has been found that the MSL is general increase from Alexandria to Burullus and then decrease from Ras El-Bar to Port Said.

Based on the attained results and the achieved conclusions, the following recommendations are proposed:

- It is recommended to modernize the equipments installed at the existing tide gauge stations in Egypt with a sea level observing system, a device for monitoring tide gauge, an instrument for collecting different types of meteorological data and a geodetic monitoring technique (GPS), as that installed recently at Alexandria.

- It is recommended to establish new stations along the Mediterranean and the Red Seas in order to get reliable measures of the sea slope in any accurate definition of the national vertical geodetic datum of Egypt.

- It is recommended to continue collecting continuous GPS measurements at the Alexandria tide gauge station and performing further analysis in order to be able to estimate a precise land movement measure and, then, be capable of determining the absolute sea level rise in Egypt.

- The issues of global warming and the rapid changes of the metrological effects need more investigations as it became a dominant concern in the last decade because of its harmful impacts on the development planes on a global basis, and especially their influences on the rise of sea level.

References

Alam El-Din, K., 1993, Sea level fluctuations along the Suez Canal, M.Sc. Thesis, Faculty of Science, Alexandria University, Egypt.

Caldwell, P., 2001, Sea level data processing on IBM-PC compatible computers version 3.0 (Year 200 compliant), JIMAR contribution No. 98-319.

El-Fishawi, N., Khafagy, A., 1991, Sea level characteristics along the Nile delta coast, MBSS Newsletter, No. 13, pp. 29-37.

Faisel, H., 2005, Realization and Redefinition of the Egyptian Vertical Datum based on Recent Heterogeneous Observations, PhD thesis, Shoubra Faculty of Eng., Cairo Egypt.

Gaweesh, M., 2004, Personal communications.

Houghton, J., 1997, Global warming: The complete briefing, Cambridge university press.

IOC, 2002, Manual on sea level measurement and interpretation, Volume 3: Reappraisals and recommendations as of the year 2000, UNESCO.

IPCC (Intergovernmental Panel on Climate Change), 2001, Climate change 2001: The scientific basis, UN Technical report.

Nassar, M., Baraka, M., and El-Shazly, A., 1998, Modeling local sea surface topography in Egypt based on zero frequency response analysis, Scientific Bulletin of Faculty of Engineering, Ain Shams University, V. 33, No. 1.

PSMSL, 1989, Data holdings of the Permanent Service for Mean Sea Level, Bidston Observatory, United Kingdom.

Shalaby, M., 2000, Wave and Surge forecasting along the Egyptian Coast of the Mediterranean Sea, M.Sc. Thesis, Arab academy for science and technology and maritime transport, Faculty of Maritime Transport and Technology, Alexandria, Egypt.

Sharaf El-Din, S., Ahmed, K., Khafagy, A., Fanos., A., and Ibrahim, A., 1989, Extreme sea level values on the Egyptian Medetteranean

coast for the next 50 years, Proceedings of the International Seminar on Climate Fluctuations and Water Management, December 11-14, Cairo, Paper No. II-6.