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THE MAGNITUDE AND SIGNIFICANCE OF LONG-TERM SEA LEVEL RISE IN EGYPT FROM A GEODETIC PERSPECTIVE

By

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ABSTRACT

On a global scale, the sea level exhibits a relatively rapid rise from 20,000 years ago until present levels were reached some 4,000 years ago. Since that time, the changes have consisted of oscillations of small amplitude. From a geodetic point of view, the significance of sea level is based on the reality that the Mean Sea Level (MSL) is conventionally taken as the vertical datum of the precise levelling (heights) network.

This research study aims to evaluate the variations occurred in MSL over the twentieth century. Long-term tide observations have been collected for two tide gauges at Alexandria, and one tide gauge at Port Said. The obtained results show that the MSL at Alexandria varies from 1.6 cm to 23.5 cm above the current national vertical geodetic datum, with a mean value of 11.1 cm. At Port Said, MSL changes between –1.7 cm to 24.0 cm, with an average of 9.0 cm. Furthermore, it has been concluded that the sea level is rising by a rate of 1.7 mm/year at Alexandria, and 2.4 mm/year at Port Said, which indicates the existence of sea level slop as well.

The sea level rise is one of the main factors that cause shoreline retreat, coastal erosion, lowlands overflow, and increase the salinity of lakes and aquifers. Consequently, there exists a critical demand to explore, on geodetic and environmental basis, the consequences of sea level changes in Egypt. Moreover, an accurate multi-purpose monitoring system has to be established, over the Egyptian shores, to measure precisely the sea level rise.

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1. Introduction

Mean Sea Level (MSL) is the average level of the sea, usually based on hourly values taken over a period of at least a year. Long-term changes of measured sea level are called secular changes, where the global changes are called eustatic changes. The combination of sea level changes measured by several techniques shows a relatively rapid rise of sea level from 20,000 years ago, gradually slowing down 8,000 years ago when levels were some 15 meters below those of today. The increase then proceeded more gradually until present levels were reached some 4,000 years ago [8]. Since that time, the changes have consisted of oscillations of small amplitude. The major effective causes for long-periodic sea level oscillations are [11]:

- Changes due to atmospheric pressure that may, under special conditions, reach up to several decimeters.
- Changes due to wind stress, that are much smaller over long periods, but could reach a few decimeters in some places.
- Thermohaline (thermal and solution) structure of sea water is among the most important causes of long periodic changes in sea level. However, it is generally stable with superimposed seasonal variations of thermal origin in the uppermost layers.
- The time variations of sea current are little known and could be treated among the higher-order factors that could not be modeled.
- River discharge fluctuations can contribute significantly to long-term variations depending on location.
- Glacial melt and the yield of the earth to the melt load are the main constitutes of the secular water rise. Some estimates of this effect vary between 6 and 10 cm per century.
- The magnitude of long-periodic tidal contstituents is so small as to be of little practical consequence. There are two cycles of lunar motion, namely the lunar perigee every 8.85 years and the lunar node every 18.6 years. It was originally thought that it is necessary to have at least 18.6 years of sea level data available to eliminate the influence of the nodal cycle. Recently, it appears that this assumption is no longer justified since recent investigations show that both lunar cycles produce variations of the order of 1 cm only.
- Vertical crustal movements of a local and regional nature affect the tide gauge readings. Their effect should be eliminated if at all possible.

Recent long-period sea level measurements at several stations show that there is a general increase of MSL of about 0.10-0.20 meter per century [8]. However, there are considerable variations from this average value. Table 1 presents estimates of sea level rise at some tide gauges with long records of measured data. The annual rates of sea level rise vary from –2.5 mm/year to 3.8 mm/year [4]. Moreover, analysis of MSL data for several stations in the United States has revealed MSL rise ranging from –2.4 mm/year to 7.9 mm/year in the period from 1930 to 1993 [7].

Table 1
Estimates of Sea Level Change at Some Global Sites

Site	Data Span	MSL Rate (mm/year)
Alaska (57^{o} 03’ N)	1939 – 1979	-2.5
Newlyn (50^{o} 06’ N)	1916 – 1980	1.7
Brest (48^{o} 23’ N)	1807 – 1981	0.9
Halifax (44^{o} 40’ N)	1897 – 1980	3.7
San Francisco (37^{o} 48’ N)	1854 – 1979	3.8
Honolulu (21^{o} 19’ N)	1905 – 1980	1.6
Bombay (18^{o} 55’ N)	1878 – 1978	1.0
Sydney (33^{o} 51’ S)	1897 – 1981	0.7
CBBT (37^{o} 00’ N)	1930 – 1993	6.7
Cambridge (38^{o} 34’ N)	1930 – 1993	7.9

2. Sea Level Rise in Egypt

The vertical datum of the precise levelling network Egypt has been set as the Mean Sea Level (MSL) at Alexandria harbor. It was taken as the mean between the daily readings of high and low water level during the years 1898 to 1906. These were the only available recorded observations when the survey department undertook the levelling in 1906 [3]. It has been found that this imaginary surface is 33.8 cm above the zero of the installed tide gauge.

In the late sixty, an investigation has been carried out to study the variation of MSL at Alexandria in relation to the meteorological elements, namely wind speed and pressure. That study used real data of monthly average water level from 1962 to 1966. From these results, it can be concluded that the new MSL, as calculated from this five-year data set, is 45.0 cm above the gauge zero. Consequently, an increase of 11.2 cm was detected in the definition of the vertical datum of Egypt [10]. A recent study has utilized hourly-recorded data of water level from 1995 to 1998 for the tide station installed in the Western (military) Harbor of Alexandria [9]. The obtained results show that the new MSL, as calculated from this four-year data set, is 51.5 cm above the Egyptian defined zero value. Hence, an increase of 17.7 cm was detected in the definition of the vertical datum of Egypt.

3. Sea Level Slop in Egypt

Many investigations have revealed that in addition to the MSL rise, there is slop in the sea level. For example, In the western coast of the United States, an apparent northward slope of 26 cm was reported [12]. Similar studies in the United Kingdom, based on an analysis of monthly MSL between 1960 and 1975, show that there exist a latitudinal slope of MSL of 5.3 ± 0.4 cm per degree of latitude [2].

In Egypt, the Suez Canal Company (SCC) had established two Mareographs at both Port Said and Suez in 1925. The recorded observations in the period 1923-1937 concluded that the MSL of the Mediterranean Sea at Port Said is 3.9 cm below the MSL at Alexandria, and the MSL of the Red Sea at Suez is 22.2 cm above the MSL of the Mediterranean Sea at Port Said [3]. Nassar et al [6] has concluded that the MSL at Port Said is 5.4 cm below that at Alexandria.

Alam El-Din [1] has analyzed daily records of MSL data at Port Said and Suez in the period 1980-1986. He has found that the rate of increase of the Mediterranean MSL at Port Said is 2.78 mm/year, while it is 0.61 mm/year for the Red Sea at Suez. Hence, the MSL of the Red Sea is 11.9 higher than that of the Mediterranean. Also, he has concluded based on results of several investigations that this difference decreases with time.

4. Available Data

Tide observations, from different sources, have been collected for two tide gauges at Alexandria, and one tide gauge at Port Said. The available measurements span from 1944 to 1999 for Alexandria, and from 1926 to 1987 for Port Said. The first step was to reference all data sets to a common datum. The MSL defined in 1906 as the national Egyptian vertical datum has been used to unify all measurements. Monthly averages of measured tide are applied in the analysis herein. These average values have been computed from hourly tide observations, and then utilized to compute annual MSL for the specific time periods.

5. Results and Analysis

The obtained data sets are utilized to investigate the characteristics of the MSL of the Mediterranean in terms of behaving patterns, magnitude of rising, and the rate of its change in the last century. Environmental and geodetic impacts of MSL rise are discussed in view of the obtained results.

5.1 Pattern of the Seasonal Mediterranean Sea Level

The average monthly tide measurements depict the seasonal variations of the sea level. The data of the last five years, from 1994 to 1999, have been averaged for Alexandria and presented in Table 2, and depicted in Figure 1. From these figure and table, it is obviously seen that the tide has small variation and is semi-diurnal in nature. The tide range over these five years varies from 18.6 cm to 22.9 cm, with a mean of 20.5 cm. Figure 1 shows that the maximum tide value occurs in August, while the minimum exists in April. Also, it can be noticed that the sea level in the winter (February to April) is lower compared with its values in the summer (July to September). This may be due to the differences in the barometric pressure and temperature between the summer and winter seasons.

5.2 Long-Term Rise of Mediterranean Sea Level

The annual averages of sea level at Alexandria and Port Said have been analyzed using the available data sets. The results are summarized in Table 3. The annual change of sea level at Alexandria varies from –11.7 cm to 11.5 cm, while it ranges from –7 cm to 12 cm at Port Said. Considering the zero-value for MSL defined in 1906 as a datum, it has been found that the MSL at Alexandria varies from 1.6 cm (in 1947) to 23.5 cm (in 1987) above that datum, with a mean value of 11.1 cm. At Port Said, MSL changes between –1.7 cm (in 1929) to 24.0 cm (in 1980), with an average of 9.0 cm. Figures 2 and 3 depict the MSL annual changes for Alexandria and Port Said respectively, while figures 4 and 5 present the MSL values, above the selected datum, for both tide gauges.

Table 2
Average Monthly Sea Level at Alexandria (1995-1999)

Month	Ave. Sea Level (cm)
January	49.9
February	43.7
March	43.4
April	41.8
May	45.6
June	50.8
July	57.1
August	59.6
September	55.3
October	55.8
November	55.6
December	55.2

Regression analysis has been performed to compute the rising rates of sea level at Alexandria and Port Said over the last decades. The least-squares estimation technique has been utilized to solve the linear over-determined equations since there exist degrees of freedom. The obtained results are:

For Alexandria:

$$H = 6.09 + 0.1718 * YN_1 \qquad (1)$$

For Port Said:

$$H = 2.29 + 0.2390 * YN_2 \qquad (2)$$

where,

H is the height of the sea level, in cm, above the chosen datum.
YN_1 = Year – 1943, i.e., the number of years from the start of the data series at Alexandria.
YN_2 = Year – 1925, i.e., the number of years from the start of the data series at Port Said.

Table 3
Long-Term MSL Rise

	Alexandria	Port Said
Data Span	1944-1999	1926-1987
Minimum Annual Change	-11.7	-7.0
Maximum Annual Change	11.5	12.0
Minimum MSL Value	1.6	-1.7
Maximum MSL Value	23.5	24.0
Average MSL Value	11.1	9.0

Based on these findings, it can be concluded that the Mediterranean sea level is rising by a rate of 1.7 mm/year at Alexandria, and 2.4 mm/year at Port Said. These estimates are close to results of similar previous studies [e.g. 1 and 5]. However, it worth mentioning that the data utilized in the present study cover longer time span, and hence could be considered more reliable for long-term MSL rise determination.

6. Conclusions

On a global scale, recent long-period sea level measurements at several stations show that there is a general increase of MSL of about 0.10-0.20 meter per century. Data of tide gauges have been utilized, in this research, to study the behavior of the Mediterranean Sea rise. The utilized data sets span the period 1944-1999 for Alexandria, and the period 1926-1987 for Port Said. It has been found that the annual change of sea level at Alexandria varies from –11.7 cm to 11.5 cm, while it ranges from –7 cm to 12 cm at Port Said. Considering the zero-value for MSL defined in 1906 as a datum, it has been concluded that the MSL at Alexandria varies from 1.6 cm to 23.5 cm above that datum, with a mean value of 11.1 cm. At Port Said, MSL changes between –1.7 cm to 24.0 cm, with an average of 9.0 cm. Furthermore, the obtained results prove that the sea level is rising by a rate of 1.7 mm/year at Alexandria, and 2.4 mm/year at Port Said.

The sea level rise is one of the main factors that cause shoreline retreat. Additionally, the sea level rise, combined with other factors, could accelerate coastal erosion, overflow lowlands, and increase the salinity of lakes and aquifers. Consequently, sea level behavior should be taken into consideration in the development planning for the coastal areas in Egypt. From a geodetic point of view, the concept of time-varying geoid definition should be studied in details and its consequent results on vertical datum, levelling networks, and mapping activities should be considered. Moreover, an accurate multi-purpose monitoring system has to be established, over the Egyptian shores, to measure precisely the sea level rise.

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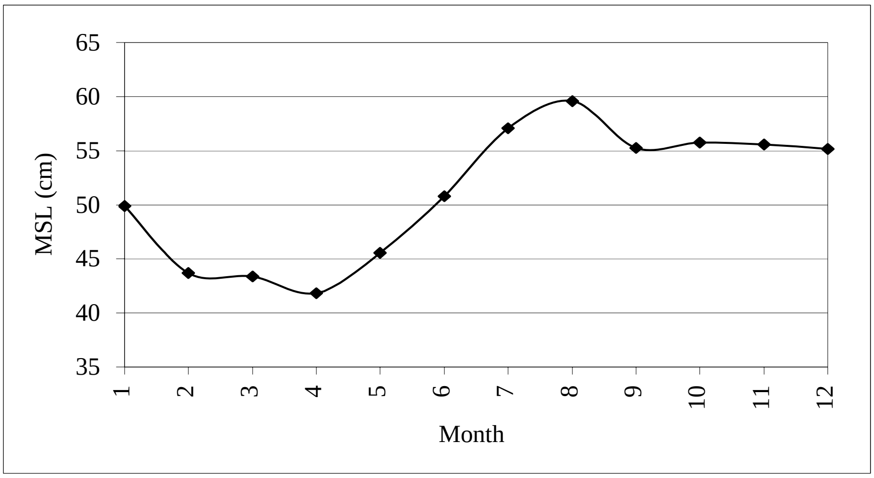

Figure 1: Seasonal Variations of Sea Level at Alexandria (1995-1999)

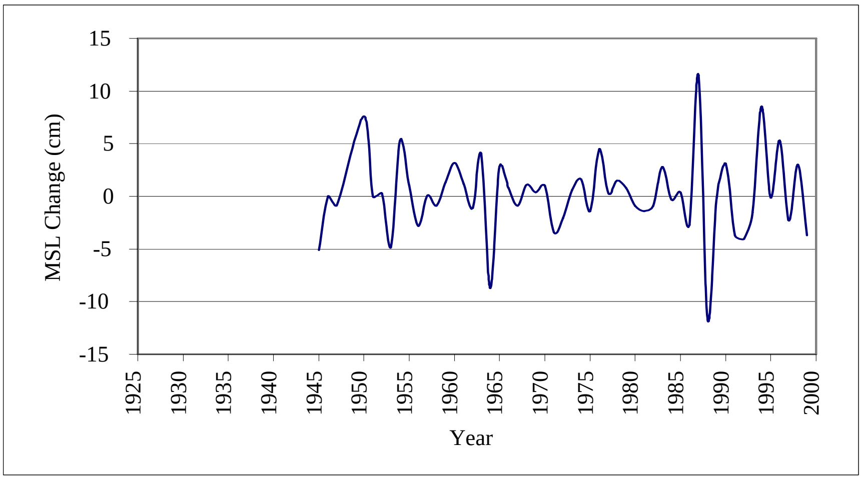

Figure 2: Annual Variations of Sea Level at Alexandria

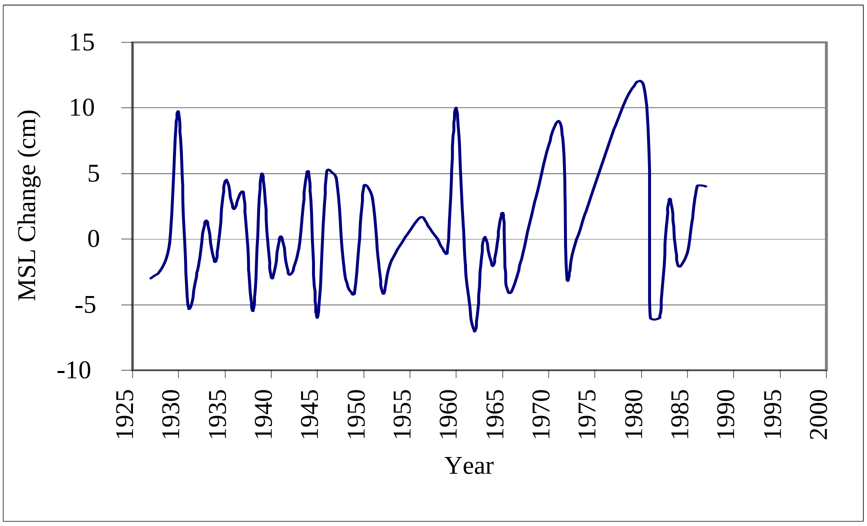

Figure 3: Annual Variations of Sea Level at Port Said

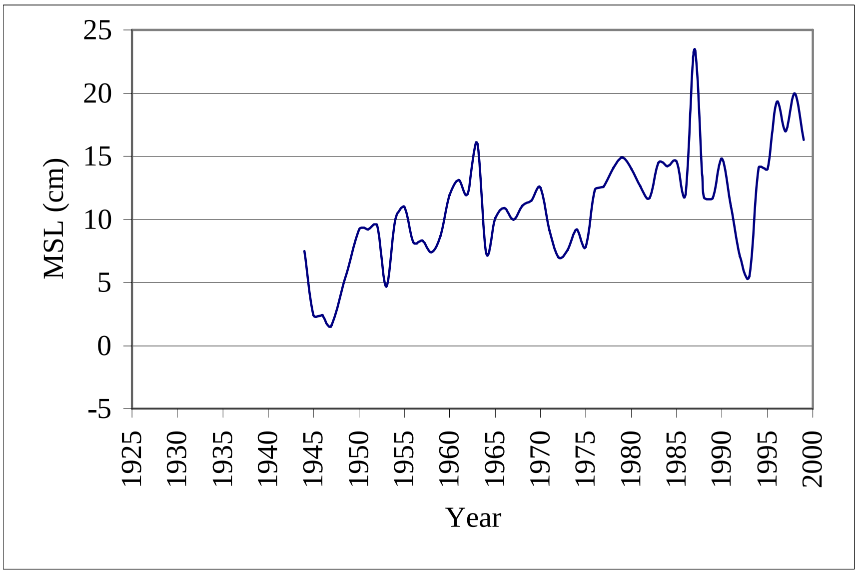

Figure 4: Long-Term Changes of MSL Values at Alexandria
(Relative to the 1906 national datum)

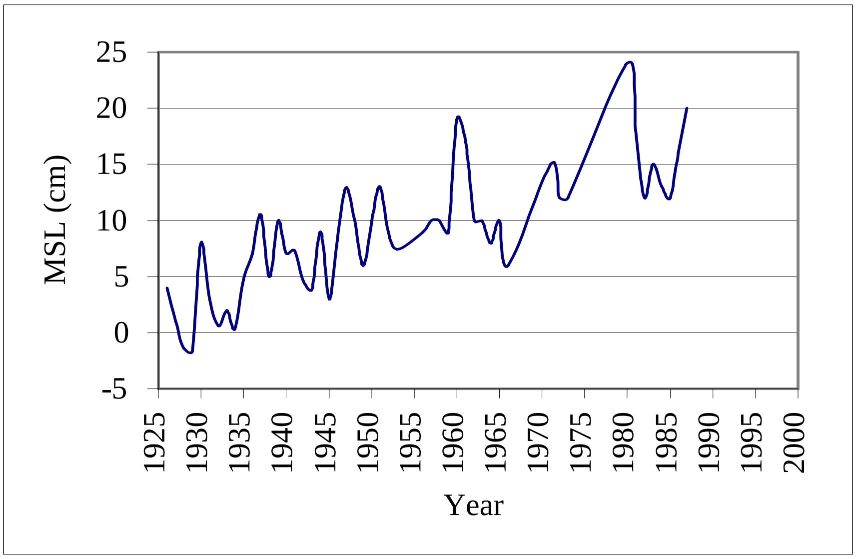

Figure 5: Long-Term Changes of MSL Values at Port Said
(Relative to the 1906 national datum)