The Relationship between Mean Sea Levels of the Mediterranean and the Red Sea through Port Said and Sues

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

Abstract

Monthly and annual tide records at Port Said and Suez have been collected and investigated. Accordingly, the differences in MSL between the Mediterranean and the Red Sea over almost the twentieth century have been explored. This research illustrates the data sources, explains the followed procedures, and presents the obtained findings.

1- Introduction

Measurements of sea level have a long history in several places all over the world, and have been utilized in a wide variety of scientific applications. In the nineteen century, there were studies related to vertical land movements in the belief that average level of the sea was constant over long periods of time, and hence, changes of the mean sea level was attributed to land movements. Now, it is a common fact that neither the land nor the sea levels are permanent. Changes in the mean sea level are related to the changes in the volume of water in the oceans and to variations in the ocean currents. Sea level studies, in nowadays, concern with coastal erosion and protection, geological processes, and climate changes. Glacial melting, expansion of water due to heating, and changes in sea surface gradients are some factors leading to sea level change.

The major effective causes for long-periodic sea level oscillations are [Vanicek and Krakiwsky, 1986]:

- Changes due to atmospheric pressure that may, under special conditions, reach up to several decimeters. The larger the pressure, the larger the depression with an average coefficient of proportionality around 1 cm per millibar (inverted barometer effect).

- Changes due to wind stress, which are much smaller over long periods, 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. For example, this effect is from 1 and 3 cm per degree Celsius in the United States.

- 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 constituents 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 [Vanicek and Krakiwsky, 1986, pp. 425].

- Vertical crustal movements of a local and regional nature affect the tide gauge readings. Their effect should be eliminated if it is possible.

An instantaneous measurement of sea level may be considered as the sum of three components:

Observed sea level ≈ mean sea level + tide + meteorological residuals

Tides may be defined as the periodic movements of the seas, which have coherent amplitude and phase relationship to some periodic geophysical force [IOC, 1985 and The Open University, 1994]. The dominant force is the variation in the gravitational field on the surface of the earth due to the regular movements of the earth-moon and the earth-sun systems. This type of tides is called gravitational tides. Meteorological tides are weak tides generated by periodic variations of atmospheric pressure and on-shore off-shore winds.

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 [IOC, 1985 and IAG,

2000]. The simplest way is to take the arithmetic average, but more elaborate methods should be used such as the use of low-pass filters to eliminate tides and surges before tacking the average. Monthly and annual mean sea level series for a global network are collected and published by the Permanent Service for Mean Sea Level (PSMSL). Data is held for over one thousand stations, of them 112 have recorded data from before 1900.

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. Since that time, the changes have consisted of oscillations of small amplitude. Recent long-period sea level measurements at several stations show that there is a general increase of MSL of about 0.15-0.25 meter per century. However, there are considerable variations from this average value [IOC, 2002].

2- Available Data

The collected MSL historical data sets are coming from different sources, mainly from the data holdings of the data holdings of the Permanent Service of Mean Sea Level (PSMSL) 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 and the Suez Canal datum. Consequently, a primary step was to test the validity of each data set, and then convert them to be belonged to the same datum, [Faisel, H., 2005]. 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 used data set consists of:

- 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.
- Annual tide averages for a tide gauge station in Suez covering the period from 1980 to 1986.

3- Variation of Mean Sea Level between the Mediterranean Sea and Red Sea

The following analysis procedure has been performed to investigate the difference in sea levels between the Mediterranean Sea and the Red Sea. Common data sets for both Port Said (at the Mediterranean) and Suez (at the Red Sea) tide gauges are found to cover the period from 1923 to 1937 and from 1980 to 1986. The statistics of mean sea level are given in Table 1 and depicted in Figure 1 for both locations. During the period 1923-1937, the sea level of the Mediterranean Sea at Port Said has been found to have a minimum value of -5.2 cm, a maximum value of 9.8 cm, with an average of -0.2 cm above the 1906 datum. Additionally, the level of the Red Sea at Suez has been found to have a minimum value of 17.9 cm, a maximum value of 28.1 cm, with an average of 22.7 cm. Moreover, the difference in annual mean sea level value between the Suez and Port Said is 22.9 cm.

Table 1: Annual MSL variations over the Mediterranean and Red Sea (1923-1937)

	Port Said (cm)	**Suez (cm)**
Min.	-5.2	17.9
Max.	9.8	28.1
Average	-0.2	22.7
Diff.	**22.9**	

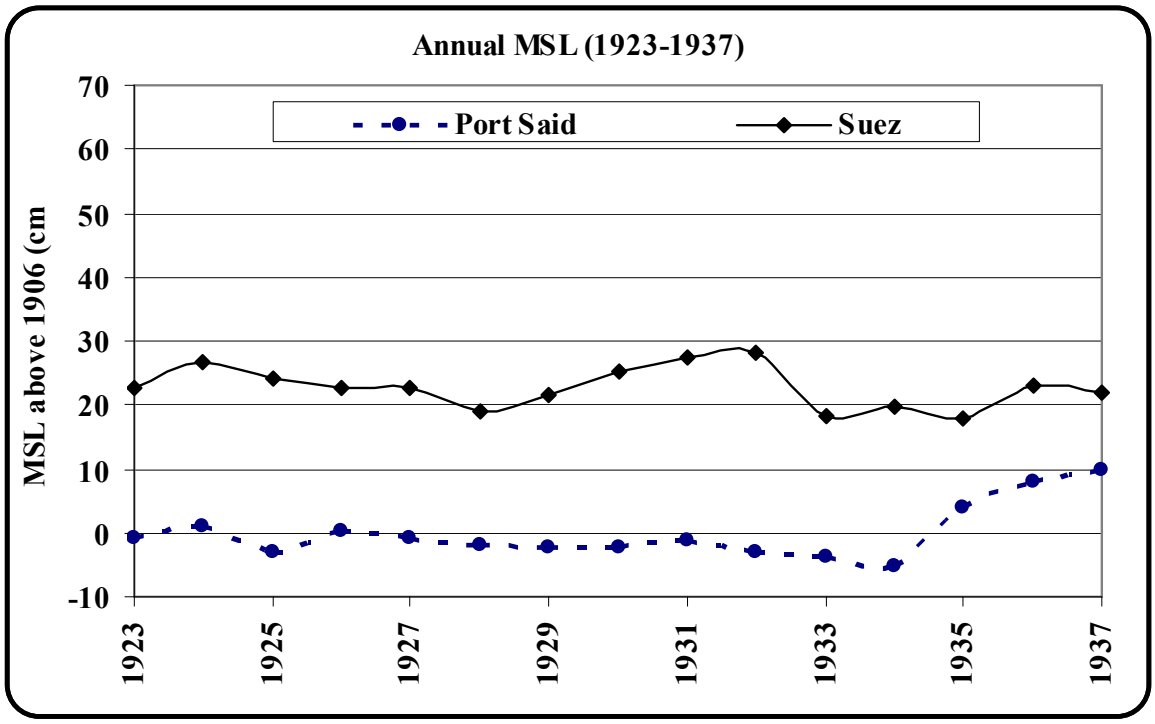

Figure1: MSL variations over the Mediterranean and Red Seas (1923-1937)

The collected data sets cover the period 1980-1986, except for the year 1981, are summarized in Table 2 and presented in Figure 2 for both locations. From the above, it has been found that the sea level of the Mediterranean Sea at Port Said has a minimum value of 12.0 cm, a maximum value of 24.0 cm, with an average of 15.3 cm above the 1906 datum. Also, the level of the Red Sea at Suez has been found to have a minimum value of 18.4 cm, a maximum value of 45.3 cm, with an average of 25.9 cm. Additionally, the annual mean sea level difference value between the Suez and Port Said is 10.6 cm.

Consequently, it can be concluded that, in a mean sense, the Red Sea level at Suez is higher than the Mediterranean Sea level at Port Said by 22.9 cm in the period 1923-1937 and 10.6 cm in the period 1980-1986. In the all period from 1923 to 1937 and from 1980 to 1986, the Red Sea level at Suez is higher than the Mediterranean Sea level at Port Said by 16.7 cm.

Table 2: Annual MSL variations over the Mediterranean and Red Seas (1980-1986)

	Port Said (cm)	**Suez (cm)**
Min.	12.0	18.4
Max.	24.0	45.3
Average	15.3	25.9
Difference	**10.6**	

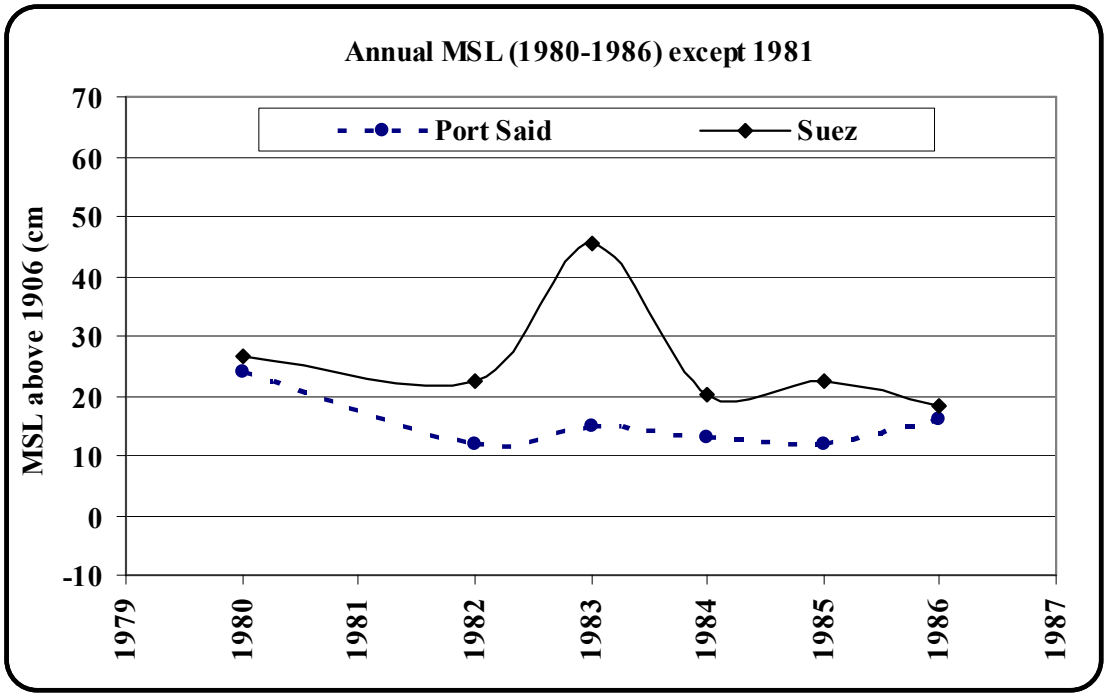

Figure 2: MSL variations over the Mediterranean and Red Seas (1980-1986)

4- Seasonal Variations of Mean Sea Level along the Mediterranean Sea and Red Sea

Seasonal changes of monthly mean sea level at Port Said and Suez in the period from 1924 to 1937 are depicted in Figure 3, while Table 3 presents the statistical summary of the utilized data at both locations. From figure 3 and table 3, it has been found that the higher value of the monthly mean sea level at Port Said occurred usually in August, while the lowest ones are usually occurred in March. The general trend is inverted at Suez with higher value of monthly mean sea level occurred in December, while the lower ones occurred in September.

The seasonal variability in Mediterranean Sea at Port Said presents its minimum value in spring and the maximum value appears in summer, whereas the seasonal variability in Red Sea at Suez presents its minimum value in autumn and the maximum value occurred in winter. Therefore, in this period, the Red Sea level at Suez is higher than the Mediterranean Sea level at Port Said by 22.6 cm.

Table 3: The monthly mean sea level (average 1924-1937)

Month	Suez	Port Said	Diff. (m)
Jan.	18.355	18.013	0.342
Feb.	18.351	17.993	0.358

Mar.	18.313	17.952	0.361
April	18.319	17.956	0.363
May	18.309	17.979	0.330
June	18.211	18.036	0.175
July	18.169	18.115	0.054
Aug.	18.144	18.146	-0.002
Sep.	18.097	18.120	-0.023
Oct.	18.197	18.085	0.112
Nov.	18.391	18.086	0.305
Dec.	18.407	18.076	0.331
Annual mean	**18.272**	**18.046**	**0.226**

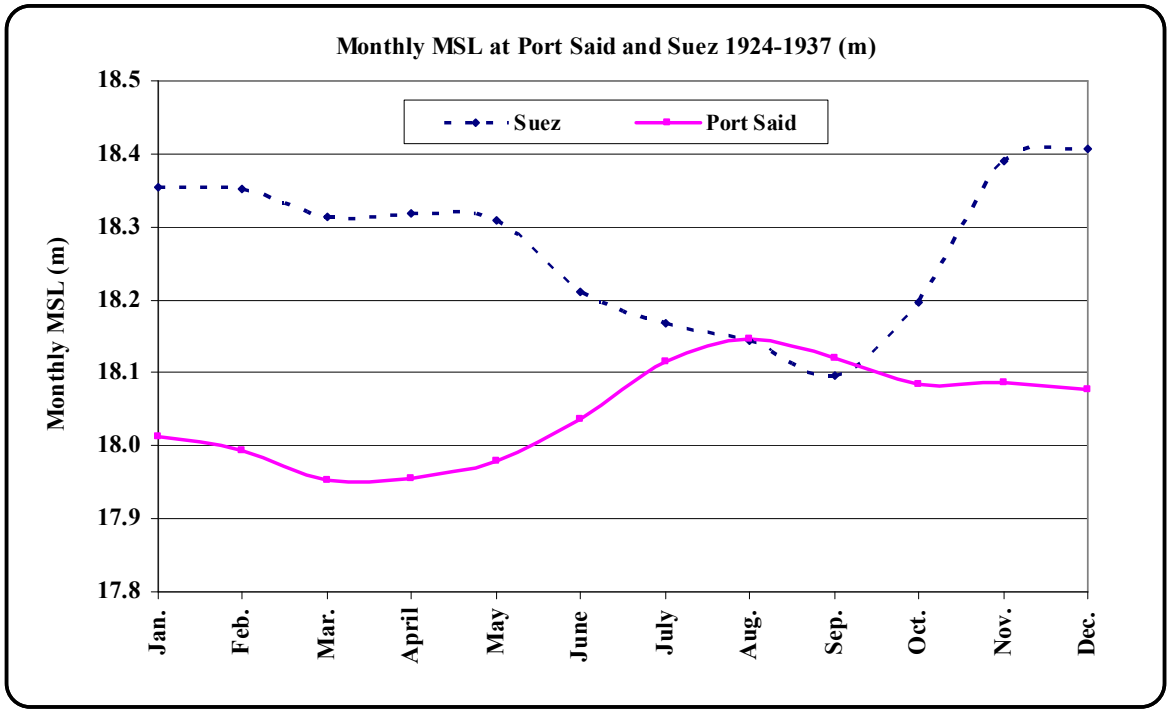

Figure 3: Monthly MSL at Port Said & Suez during (1924-1937)

Moreover, Figure 4 presents the difference between monthly mean sea level at Port Said and Suez along 1924-1937. From this figure, it can be seen that in September the mean sea level of Port Said is higher than Suez with maximum difference of 2.3 cm, while in April the mean sea level is higher at Suez than Port Said with the maximum difference is 36.6 cm.

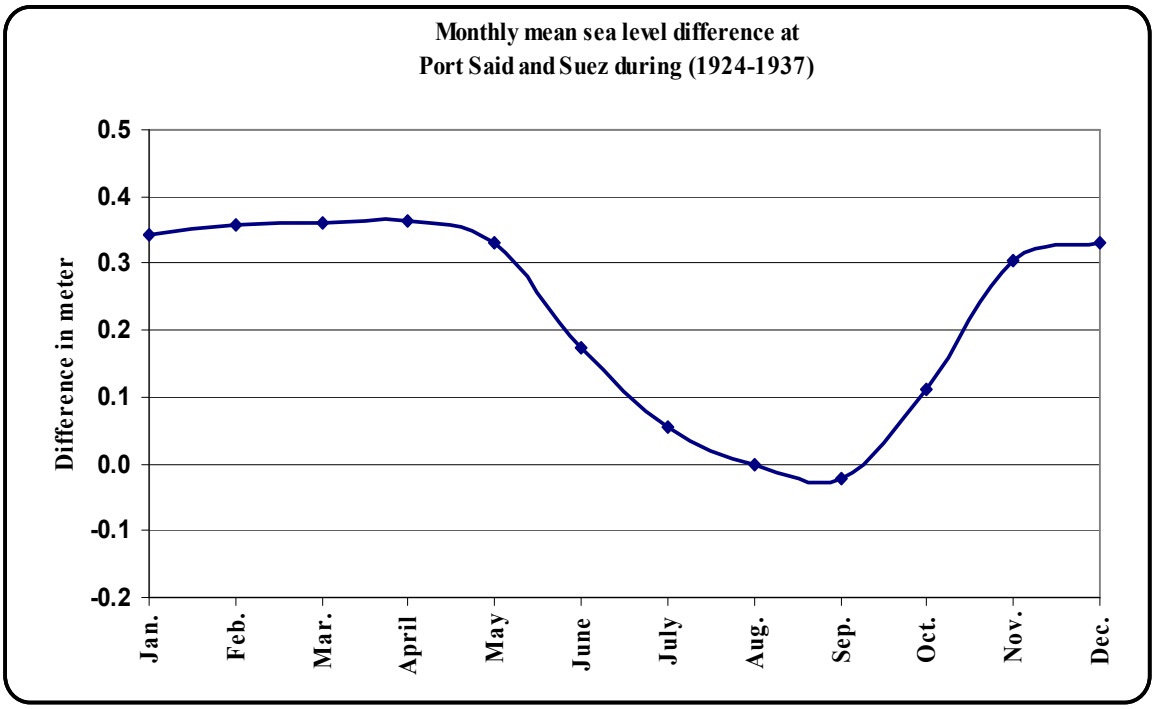

Figure 4: Monthly MSL difference at Port Said & Suez during (1924-1937)

Utilizing the available tide gauge data at Port Said (1926-1987), as illustrated in Figure 5 and tabulated in Table 4, the minimum MSL value is -1.7 cm, the maximum is 24.0 cm, and the average MSL amounts to 9.0 cm over the 1906 old definition of MSL, produces the following trend formula:

MSL at Port Said in cm = 0.2389 * YD - 2.2543 (1)

Where, MSL is the value of MSL height in centimeter above the 1906 definition, and YD is the year difference or number of years since 1906 (the year of which annual mean sea level is calculated in cm - the year 1906).

Therefore, a trend analysis of the mean sea level is illustrated in Figure 5. This trend indicates that the sea level rising rate of the Mediterranean Sea at Port Said is 2.4 mm/year.

Table 4: Annual MSL variations over Port Said (1926-1987)

Station	Port Said
Min. (cm)	-1.7
Max. (cm)	24.0

Average (cm)	9.0

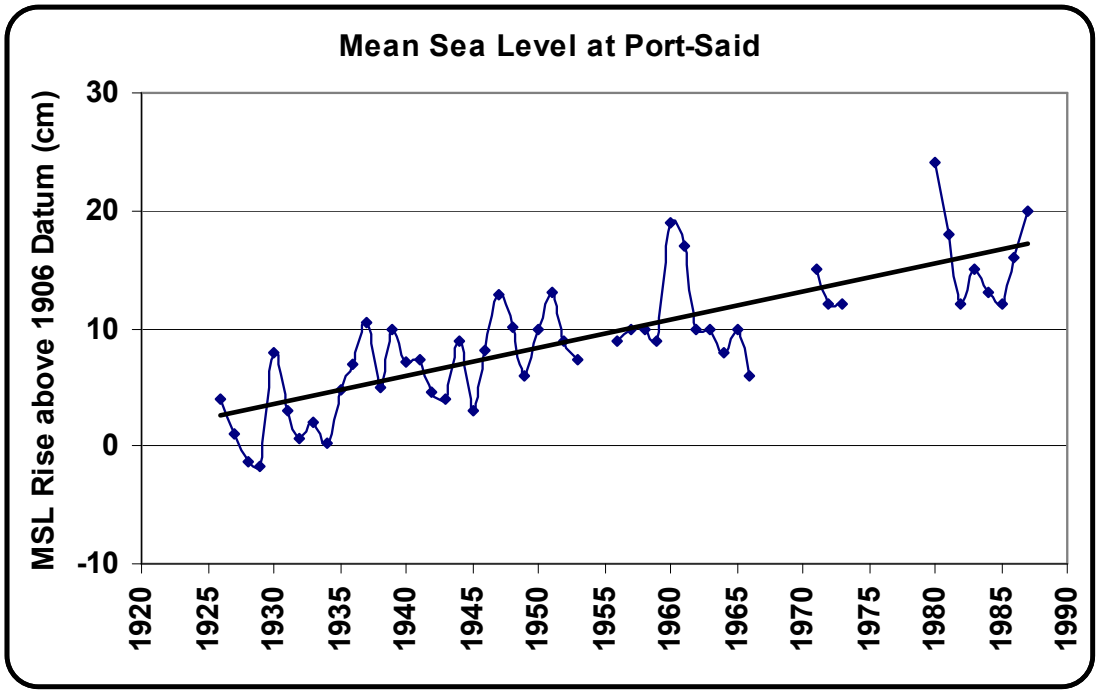

Figure 5: Long-Term MSL variations at Port Said

Employing the third available tide gauge data set at Suez (1923-1986), which is depicted in Figure 6 and presented in Table 5, the minimum MSL value is 18.0 cm, the maximum is 45.3 cm, and the average MSL amounts to 24.0 cm over the 1906 old definition of MSL. The following trend formula is:

MSL at Suez in cm = 0.0462 * YD + 22.1963 (2)

Where, MSL is the value of MSL height in centimeter above the 1906 definition, and YD is the year difference or number of years since 1906.

Hence, the sea level rising rate of the Red Sea at Suez is 0.5 mm/year. A trend analysis of the mean sea level at Suez is presented in Figure 6.

Table 5: Annual MSL variations over Suez (1923-1986)

Station	Suez
Min. (cm)	18.0
Max. (cm)	45.3
Average (cm)	24.0

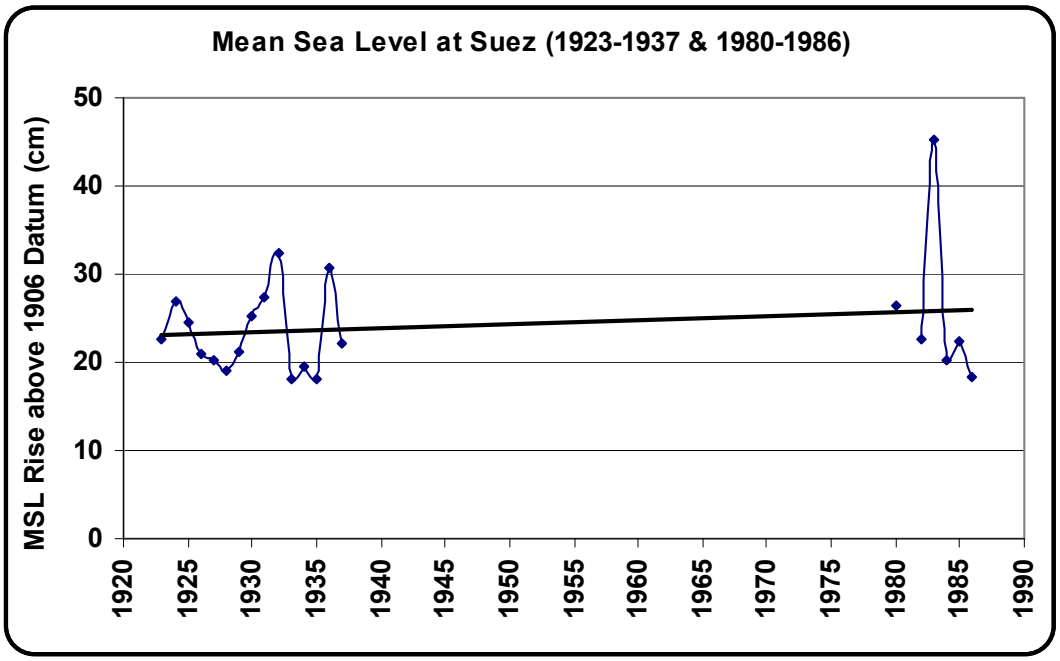

Figure 6: Long-Term MSL variations at Suez

Figures 5 and 6 are showing the long period variation in annual mean sea level and the trend of variation at Port Said and Suez respectively. From the above results, the slope of the trend line at Port Said indicates an increase of sea level by 2.4 mm/year at Port Said but only 0.5 mm/year at Suez.

It is worth mentioning that other researchers have investigated the issue of the sea level slope in Egypt. Although the used data sets may be different in each study, their obtained estimates of the difference in annual mean sea level between Suez and Port Said have been collected and analyzed. Table 6 presents those estimates of the difference between sea level at Suez and Port Said decrease with time. Those figures, generally, agree with the computed values as presented in Table 1, Table 2 and Table 3. Based on these results, it can be concluded that more modern sea level observing system should be installed on the Red Sea in order to take into account the different sea levels in any accurate definition of the national vertical geodetic datum of Egypt.

Table 6: The difference in annual MSL between Suez and Port Said

Author	Period	Difference (cm)
Lisitzen, 1963	1923-1925	24.0

Cole, 1939	1923-1937	22.9
Current Study	1924-1937	22.6
Sharaf El Din, 1975	1956-1966	15.3
Abdel Aziz, K.,1993	1980-1986	11.9
Current Study	1980-1986 except 1981	10.6

Furthermore, a linear regression has been carried out based on this data set in order to figure out the time at which that MSL difference will be zero. The obtained results are represented in Figure 7, and the achieved formula is given by:

Annual MSL difference between Suez and Port Said =

$$443.2331 - 0.2179 * \text{Year} \quad (3)$$

Hence, it has been found that the value of the difference in annual MSL between Suez and Port Said tends to zero in the year 2034 according to the Equation (3).

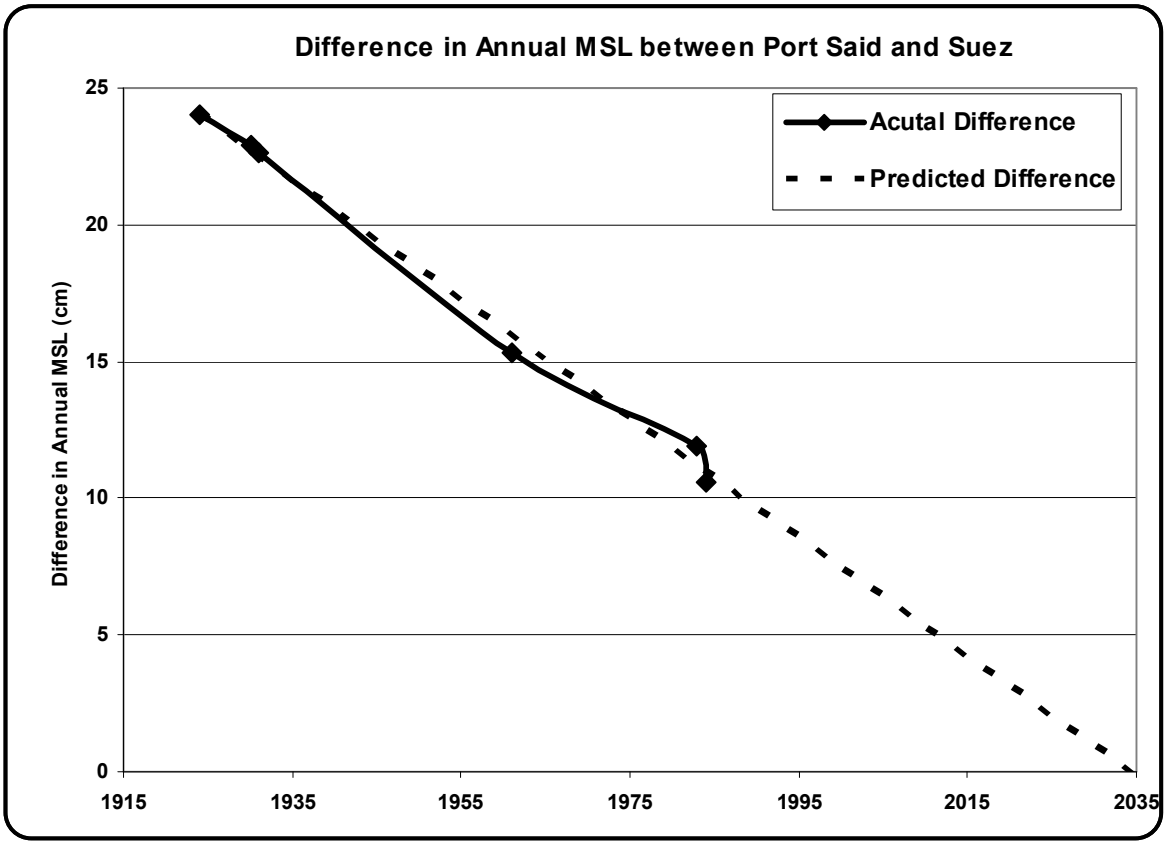

Figure 7: The difference in annual MSL between Suez and Port Said

5- Conclusions and Recommendations

The following can be concluded from the obtained results:

- 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.

- Also, it can be realized that, in a mean sense, the Red Sea level at Suez is higher than the Mediterranean Sea level at Port Said by 16.7 cm. Hence, it has been found that the value of the difference in annual MSL between Suez and Port Said decreases with time.

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

- 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.

- 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.

- It is recommended that the geodetic community in Egypt should participate in the undergoing international research studies and projects that investigate the establishment of a global vertical datum.

References

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

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.

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.