VARIATION OF SEA LEVEL ON THE EGYPTIAN MEDITERRANEAN AND RED SEA COASTS

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ABSTRACT

Records for an 11-year period (1956-1966) from tide gauges at Alexandria and Port Said (Mediterranean), and Port Teufik (Red Sea) have been analysed and the relation between the mean monthly sea level and the meteorological factors examined. The seasonal and annual variations of sea level at these three ports were studied. At Alexandria and Port Said significant coherence was found between the monthly mean sea level and the atmospheric pressure. At Port Teufik the fluctuation of sea level can be mainly attributed to the wind and current regimes. The non-tidal pattern of water circulation in the Suez Canal is chiefly affected by the wind regime at the two ends of the canal.

INTRODUCTION

Sea level variations can be attributed to various causes such as atmospheric pressure, wind, evaporation, precipitation, river discharge, steric and astronomical factors. Each of these parameters has its effect on the sea levels around the world, and the effect varies from one area to another. Along the Mediterranean coast of Egypt the main factors affecting variations in sea level are atmospheric pressure, wind, and steric effects. On Egypt's Red Sea coast the sea level is affected by the wind regime rather more than by the atmospheric pressure system (Patzert, 1972). Information on the variations of sea level on the Mediterranean coast of Egypt (Alexandria and Port Said) is relatively scarce. For Alexan-

dria the first value for mean sea level was calculated by STERNECK (1927) from the harmonic constants of a one-year record. SHARAF EL DIN and RIFAT (1968) studied the seasonal fluctuation of sea level at Alexandria over the five years 1962-1966 using the hourly values of the tidal records. At Port Said and Port Teufik — the two ends of the Suez Canal — the determination of mean sea level goes back to 1762 (SHUKRY 1968) when different engineers carried out various studies based on tidal records (J.-M. LE PERE 1799, LIEUSSOU 1856, and C. NIEBUHR 1943).

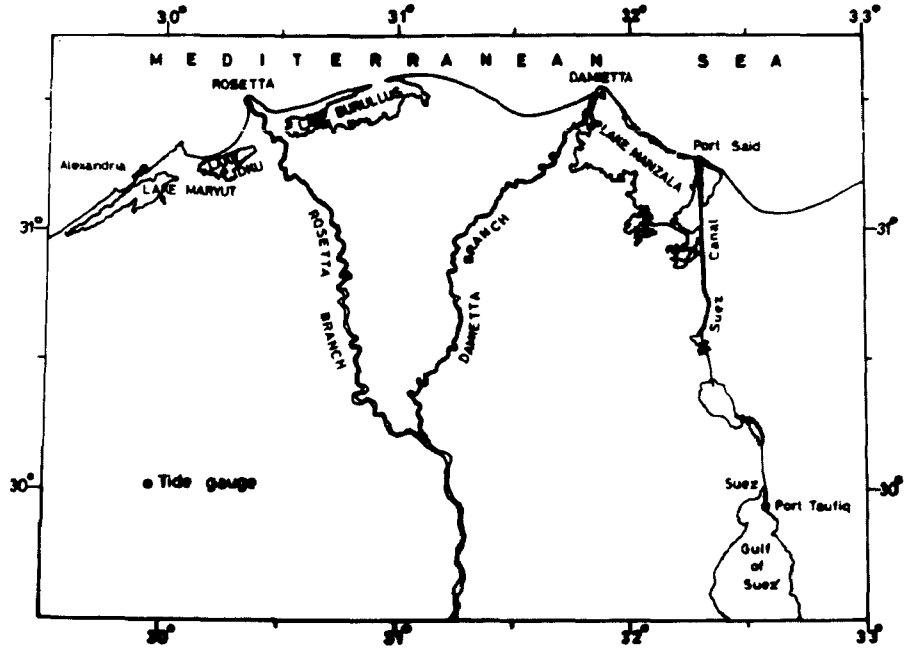

FIG. 1

An important contribution is the analysis made by Ferdinand de LESSEPS during the construction of the Suez Canal (SHUKRY 1968). The first continuous tidal records were obtained from the tide gauge constructed by the Suez Canal Company at the time the canal was inaugurated.

The tidal records at Port Said for the period 1931-1949 were analyzed by GOBY (SHUKRY 1968) who listed the minimum, mean and maximum for both highest and lowest levels. VERCELLI (1931) listed the monthly mean sea levels at Port Suez for the years 1923 through 1926. PATTULLO *et al.* (1955) listed also the mean sea levels at Port Suez for the years 1923-1929 and 1931 through 1946.

The object of this paper is to give a general picture of the variations of the monthly mean sea level at Alexandria, Port Said and Port Teufik and their relation to wind speed and direction and to atmospheric pressure. The seasonal fluctuations of the monthly and annual mean sea level at these three locations during the period 1956-1966 are discussed.

TIDAL AND METEOROLOGICAL OBSERVATIONS

Tidal records for the 11-year period 1956-1966 at Alexandria, Port Said and Port Teufik were used in the analysis. Two different methods were used for obtaining the daily mean sea levels at Alexandria. From 1956 to 1961 the daily averages of high and low water heights were used. From 1962 to 1966 the daily mean sea levels were obtained as the direct average of 8 heights per day (SHARAF EL DIN and RIFAT 1968). A comparison was made between the results of the two methods of calculation, and the difference found to be insignificant. At both Port Said and Port Teufik (Suez) the daily mean sea levels were obtained by averaging the hourly heights per day. From these daily values the monthly and the annual means were both calculated.

During the period 1956 to 1966 wind speed and atmospheric pressure reduced to sea level were measured at Alexandria, Suez and Port Said meteorological stations at 3-hourly intervals, and from the daily averages the mean monthly values were calculated.

MONTHLY AND ANNUAL MEAN SEA LEVEL AND THEIR RELATION TO METEOROLOGICAL CONDITIONS

(a) *Mediterranean coast* (Alexandria and Port Said).

Mean sea level calculated from the 11-year observational period is 44.1 cm above the zero of the Alexandria Harbour tide gauge. This value is 0.9 cm lower than the one previously obtained (SHARAF EL DIN and RIFAT 1968).

At Port Said the annual mean sea level calculated for the same period is 50.5 cm above the Survey Department's zero level which is 17.633 m above the zero level of the Suez Canal at Port Said; this annual mean sea level is lower than that previously obtained (MORCOS 1960).

Seasonal variations of the monthly mean sea level at Alexandria and Port Said show similar fluctuations :

At Alexandria the graph of the monthly mean sea level variations (figure 2) exhibits a seasonal trend with low values in winter and higher ones during summer. From table 1 giving monthly and annual mean sea levels it is seen that the higher values usually occur in summer and autumn, the exception being 1963 which was an unusual year.

At Port Said the monthly sea level variations show the same trend as at Alexandria (figure 3 and table 2).

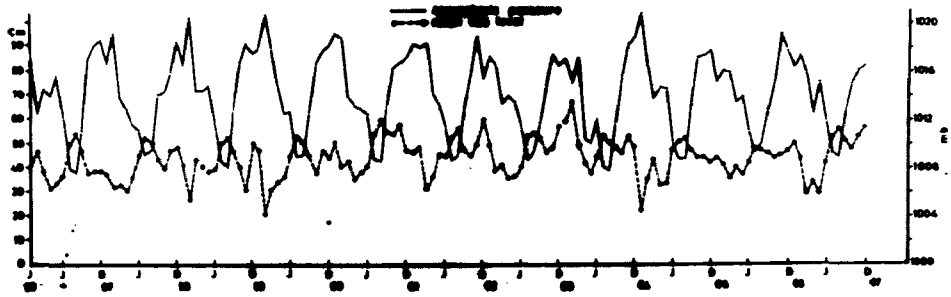

FIG. 2. — Monthly mean sea level and monthly atmospheric pressure at Alexandria : 1956-1966.

TABLE 1

Variation in monthly and annual mean sea levels at Alexandria : 1956-1966 (in cm)

Month	Year											Annual Mean
	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	
January	42	38	41	47	50	46	49	59	22	44	50	44
February	48	32	27	21	40	48	38	67	35	41	44	40
March	39	33	44	31	42	31	41	49	43	35	29	38
April	32	31	41	34	35	36	35	42	32	40	34	36
May	34	37	38	36	38	45	36	37	33	37	29	36
June	37	46	40	45	40	45	40	44	47	42	42	42
July	51	53	50	53	53	52	53	53	51	48	53	52
August	55	51	52	51	60	56	54	50	52	47	56	53
September	47	44	46	45	54	47	52	58	57	46	51	48
October	38	40	40	37	53	45	46	46	44	44	48	44
November	39	48	31	47	57	49	48	53	44	45	53	47
December	39	49	51	43	47	60	57	48	42	47	57	49

Comparing the average mean sea levels for Haifa and Ashdod (STRIEM and ROSENAN 1972) with those at Alexandria and Port Said it can be concluded that the general trend of monthly mean sea level fluctuations is very similar along the whole of the south eastern coast of the Mediterranean.

The graphs of the monthly mean sea level and the monthly atmospheric pressure at Alexandria and Port Said (figures 2 and 3) both show a close inverse correspondence between the variation in mean sea level and the atmospheric pressure (except for 1963). STRIEM and ROSENAN (1972) have postulated that the variation in the mean sea level in the south eastern sector of the Mediterranean can be attributed to the difference in the barometric pressure between the central and eastern sectors of the Mediterranean.

From the values of the mean monthly sea level and mean monthly atmospheric pressure it has been shown that the highest sea level values have correspondingly lower atmospheric pressure values, and vice versa. The wind has some effect also. From percentages for frequency of wind

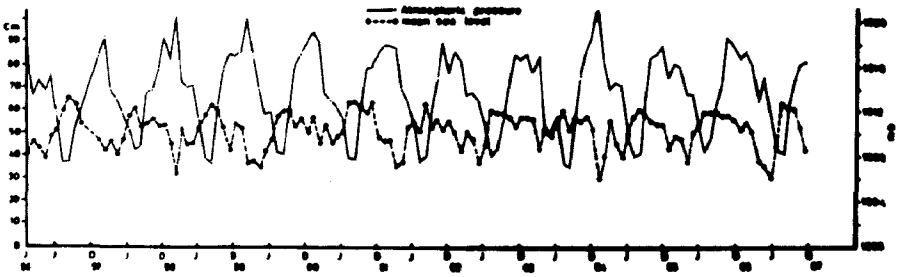

FIG. 3. Monthly mean sea level and monthly atmospheric pressure at Port Said : 1956-1966.

TABLE 2

Variation in monthly and annual mean sea levels at Port Said : 1956-1966 (in cm)

Month	Year											Annual Mean
	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	
January	41	47	45	52	57	47	50	56	29	42	50	47
February	47	43	32	37	45	47	42	55	39	48	53	44
March	44	47	52	37	54	35	50	42	54	46	49	46
April	39	41	45	35	45	36	47	50	44	36	36	41
May	49	47	46	42	48	51	36	48	39	49	34	44
June	51	58	53	47	51	54	44	33	49	51	29	49
July	60	61	58	57	63	50	59	59	56	58	43	57
August	66	53	63	60	67	63	58	51	59	57	62	60
September	63	54	60	60	61	52	58	56	57	57	60	58
October	54	57	53	52	59	55	56	54	54	56	59	55
November	–	53	42	56	64	51	52	56	53	56	51	53
December	–	54	54	50	48	55	56	51	52	55	41	51

direction at Alexandria and Port Said (HAMED 1972) it was shown that the predominant component of the wind is NNW at Alexandria, while at Port Said it is NW and NE during the summer season. This leads to high sea level values at both Alexandria and Port Said during summer indicating that the wind also has a direct effect on sea level variations.

On average, during the winter the wind direction fluctuates from one quarter to another. In summer for 80-85 % of the time the wind blows from one direction only. The average monthly mean sea levels are consequently considerably higher during summer. The constancy of the wind from one quarter and the low barometric pressure thus contribute greatly to the higher mean sea level in summer.

Table 3 gives the percentage frequency of a NNW wind at Alexandria (1946-1965) and for winds in the NW and NE quarter at Port Said (1942-1965).

The steric sea level effect is dependent on the seasonal variations of sea temperature and salinity. Due to a lack of continuous observations of temperature and salinity at both Alexandria and Port Said, the steric sea level cannot be accurately determined. However, as the mean sea tempera-

TABLE 3

Winds : mean monthly speed and percentage frequency

		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Alexandria (1946–1965)	Mean wind speed (in knots)	8.6	8.9	9.4	8.4	7.9	8.0	8.6	7.8	7.1	6.3	6.6	8.0
	Percentage frequency of NNW winds	24.9	36.7	43.8	52.8	58.7	84.4	87.8	87.0	79.4	51.1	36.8	23.6
Port-Said (1942–1965)	Mean wind speed (in knots)	9.7	10.5	11.8	11.1	9.9	9.2	8.7	7.6	7.6	8.3	8.7	8.6
	Percentage frequency of winds between NE and NW	28.4	46.1	51.4	66.4	76.4	72.4	79.9	79.8	87.6	77.0	61.0	38.2
Suez (1931–1965)	Mean wind speed (in knots)	8.5	6.6	7.6	8.2	8.9	10.8	9.8	9.7	9.9	6.1	5.4	5.8
	Percentage frequency of NNW wind	44.2	44.9	57.3	67.4	72.3	83.5	83.5	84.8	88.1	77.3	65.4	50.0

TABLE 4

Monthly mean sea temperatures at Alexandria, Port Said and Ashdod (°C)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Alexandria 31° 12′ N, 29° 52′ E (1948 – 1960)	17.3	16.3	16.3	17.3	19.9	22.7	25.0	26.1	25.8	24.1	21.9	19.3
Port Said 31° 16′ N, 32° 19′ E (1948 – 1960)	16.8	16.1	16.7	18.2	21.1	24.1	25.8	27.0	27.0	25.0	22.1	18.8
Ashdod 31° 45′ N, 34° 35′ E (1948 – 1960)	17.2	16.7	16.7	18.1	20.7	23.3	26.0	27.6	27.1	25.1	22.5	19.4

ture fluctuations at Alexandria and Port Said (table 4) do not vary much from the seasonal sea temperature variations at Ashdod it is possible to give a good picture of the steric sea level for the south east sector of the Mediterranean.

The steric sea level at Ashdod, calculated by STRIEM and ROSENAN (1972), indicates that an increase of 1 °C in sea temperature is accompanied by a 1 cm increase in sea level. This phenomenon can be generalised for the whole of the south east Mediterranean as long as the temperature variation remains the same.

(b) *Egyptian Red Sea Coast* (Port Teufik)

The value of the annual mean sea level at Port Teufik (1956-1966) is 35.2 cm above the Survey Department's zero level which is 17.871 metres

above the zero level of the Suez Canal at Port Teufik. Table 5 shows that lower values of monthly mean sea level occurred during the period July to October. From November to April monthly mean sea levels are usually high. Figure 4 shows the seasonal fluctuations in the monthly mean sea level and monthly atmospheric pressure at this port, and demonstrates that the variations observed in monthly mean sea level are not a consequence of atmospheric pressure changes. VERCELLI (1931) and PATTULLO *et al.* (1955) also demonstrated similar trends in monthly fluctuations of sea level.

TABLE 5

Variation in monthly and annual mean sea levels at Port Teufik : 1956-1966 (in cm)

Month	Year											Annual Mean
	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	
January	53	53	53	59	51	66	35	63	42	28	22	48
February	67	46	42	42	39	51	33	65	38	30	21	43
March	57	55	46	34	43	35	32	49	49	29	21	41
April	45	54	50	45	53	45	32	57	40	27	19	42
May	32	58	39	51	49	44	29	55	30	16	19	38
June	33	42	46	37	36	39	—	40	31	25	16	35
July	30	34	37	35	29	29	20	35	27	22	14	28
August	38	32	34	32	28	29	16	30	23	20	13	27
September	26	29	23	22	25	21	12	30	19	17	14	22
October	29	42	34	17	20	19	15	37	17	19	12	24
November	—	52	58	51	19	34	13	42	23	20	14	33
December	—	56	64	45	48	37	49	44	28	20	15	41

The variation of sea level at Port Teufik is however affected indirectly by atmospheric pressure since changes in the pressure system are accompanied by changes in the wind field.

As the Suez Canal and Gulf of Suez are narrow areas the effect of wind pile-up in the direction of the wind has a greater influence on water level variations than fluctuations of barometric pressure.

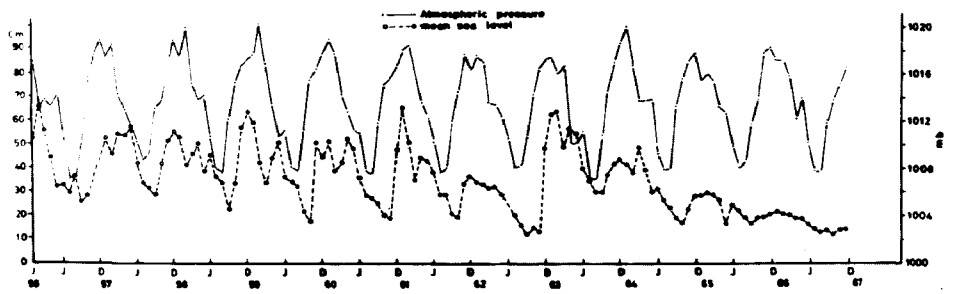

FIG. 4. — Monthly mean sea level and monthly atmospheric pressure at Port Teufik : 1956-1966.

During the winter season the surface water flow from the Red Sea has more effect on sea level variation than wind. In winter the surface flow is to the NNW, against dominant winds, causing the surface flow in these areas to converge (PATZERT 1972). This convergence leads to high values for monthly sea level as illustrated in figure 4. During the summer the prevailing NNW winds blow strongly (table 3) giving a SSE surface flow towards the southern part of the Red Sea. Thus the predominant factors affecting the sea level there are the prevailing wind and the current system of the Gulf of Suez (PATZERT 1972).

(c) *Sea level variation in the Suez Canal*

Sea level fluctuations between the two ends of the Suez Canal vary from one season to another and from year to year. The level at Port Said is thus sometimes higher than that at Port Teufik, and vice versa. Differences in sea level in these ports depend on the tides and on the meteorological conditions over the Suez Canal, principally on the wind regime. The tidal range at the ends of the canal is not the same. At Port Teufik it is about 80 cm at neap tides and 140 cm at spring tides. The tidal range at Port Said is about 30 cm. Studies conducted by the Suez Canal Authority in 1884, 1906, 1919 and 1936 (SHUKRY 1968) showed that the Red Sea mean sea level is higher than the Mediterranean mean level in winter and lower in summer. The pattern of the variations in level at the two ends of the Suez Canal is different and depends on tides and meteorological conditions. The levelling along the Canal calculated from the observations made by LISITZIN in 1923-1925 showed a difference of 24 cm between Port Said and Port Teufik (MORCOS 1970).

This difference is higher than that calculated by MORCOS (1960b) for the period 1924-1927 (17.6 cm) and by MORCOS and GERGES (1968) for the period 1956-1963 (12.3 cm). The difference in mean sea level used in the present analysis between Port Said (50.5 cm) and Port Teufik (35.2 cm) is 15.3 cm.

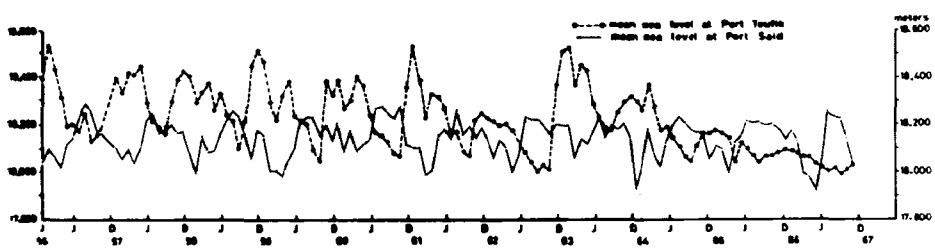

FIG. 5. — Monthly mean sea level at the two ends of the Suez Canal : 1956-1966.

The monthly mean sea levels at Port Said and Port Teufik 1956-1966 (figure 5) show a remarkable seasonal change, with the monthly sea level higher in winter months at Port Teufik than at Port Said. However, during summer (July-September) the monthly mean sea level at Port Said is higher than that at Port Teufik.

During 1965 and 1966 the monthly mean sea level at Port Said was however higher than that at Port Teufik for most of the year. The only interpretation for this phenomenon is that the weather conditions during these two years were anomalous.

TABLE 6

Monthly mean sea levels at ends of the Suez Canal : 1956-1966 averages

Month	Port Teufik (metres)	Port Said (metres)	Difference (Teufik–Said)
January	18.349	18.102	0.247
February	18.303	18.076	0.227
March	18.279	18.096	0.183
April	18.296	18.046	0.250
May	18.255	18.077	0.178
June	18.218	18.123	0.095
July	18.155	18.202	–0.047
August	18.140	18.229	–0.089
September	18.088	18.213	–0.125
October	18.109	18.187	–0.078
November	18.197	18.168	0.029
December	18.277	18.148	0.129
Annual mean	18.222	18.139	0.083

From the monthly mean sea level variations (table 6) it is seen that from July to October the sea level at Port Said is higher than that at Port Teufik. This difference in mean sea level between the Mediterranean and the Red Sea ends of the canal has the effect of generating non-tidal currents. Thus the pattern of Suez Canal currents arising from the sea level difference is not always the same. It is controlled to a certain extent by the wind system blowing over Port Said and Port Teufik.

CURRENTS IN THE SUEZ CANAL

The current regime of the Suez Canal may be divided geographically into two parts: from Port Said to the northern end of the Great Bitter Lakes; and from the southern end of the Great Bitter Lakes to Port Teufik (Suez).

In the northern part the direction of the current is northward for most of the year (October to June), but southward from July to September. This pattern is based on the salinity and temperature observations taken in the Canal (MORCOS 1960b) and confirmed by a year's daily current observations carried out by the Suez Canal Authority (MORCOS 1960b).

The currents in the Great Bitter Lakes themselves are nearly negligible due to the size of the area.

The southern part of the Canal is dominated by strong tidal currents which are subjected to the disturbing influence of non-tidal currents affecting their regularity of occurrence (SHUKRY 1968). The direction of the current in the southern part is similar to that in the northern part.

The current regime in both parts of the Canal is also greatly affected by local meteorological conditions. The non-tidal current induced by the difference of sea level between the Red Sea and the Mediterranean (see table 6) correlates with the observed current pattern.

DISCUSSION AND CONCLUSIONS

Monthly mean sea level values for Alexandria, Port Said and Port Teufik during the eleven years 1956-1966 show seasonal variations. Fluctuations of the monthly mean sea level at Alexandria and Port Said exhibit the same trend as those for the south eastern sector of the Mediterranean. High values are obtained during the summer and low ones during the winter season. At Port Teufik the monthly mean sea level shows high values from November to April and low ones from July to October.

On the basis of sea level and barometric pressure records for Alexandria and Port Said it can be concluded that atmospheric pressure is the main factor contributing to seasonal fluctuations in mean sea level over the south eastern sector of the Mediterranean. However, both wind and steric effects also have an influence on the monthly sea level. At Port Teufik (Suez) the main cause for the mean sea level variation is the wind, and only indirectly the atmospheric pressure. Here the current regime plays also a significant part in sea level fluctuations.

Variation between the monthly sea level at the ends of the Suez Canal is mainly dependent on the meteorological conditions reigning over the south eastern coast of the Mediterranean and over the northern part of the Red Sea.

From the eleven year data of the monthly sea level it is seen that the level at Port Said is higher than at Port Teufik from July to October but that the contrary is the case from November to June. The pattern is, however, not consistent from year to year.

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