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Vulnerability Assessment of the Coastal Area in the Southern Part of the Suez Canal due to Global Warming and Accelerated Sea Level Rise

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Abstract. The impact of CO_2 and temperature increase will be of great concern particularly if they are combined with the rapid increase of population in the Suez Canal region. The population is expected to increase from about 700,000 in 1996 to 1,170,000 in 2020 and 3,800,000 in 2090 in Ismailia Governorate with an expected gradual decrease in growth rate from 2.4% in 1996 to 1.9% in 2020 and to 1.0% in 2090. The growth of population in the case study area will increase the enroachment of urban areas on agricultural lands and hence the crop production will be reduced. Erosion and sedimentation may not have significant influence on the area, but inundation with a 1.0 m ASLR is one of the major factors that may deteriorate the environment. In addition, the expected change of groundwater character in the lowland areas may also affect the crop production. Accelerated sea level rise will threaten also the shoreline, the coastal communities, the infrastructures, and tourism activities. With the increase of temperature, few species may get benefits as algae and sea grasses, the primary production will increase, which may assist in reappearing of the coral reefs.

By dividing the vulnerable area into segments, land and capital values (for agriculture, industry, housing, public facilities and tourism) for each segment were estimated to help in assessing the land areas which may be lost by flooding or may be changed from one activity to another and their capital values for the different scenarios (30, 50, and 100 cm ASLR).

The protection cost for local and full measure through soft and hard solutions were evaluated. The vulnerability profiles were established. In case when sand nourishment be applied, no harm will be gained particularly when marine organisms accommodate themselves with the new environmental conditions, or by converting the inundated areas to fish farms.

Introduction

Since long time ago, the coastal zones have attracted many people to settle down there. The richness of the marine environment and the reliability of transport between different countries were the motivating factors for inhabiting these coastal areas. Although most of these areas are threatened by natural phenomena such as floods, storms, and surges, life still continues. Sustainable progressive developments of these areas threaten the integrity of the environment leading to serious changes in the socio-economic structures. The Accelerated Sea Level Rise (ASLR) resulting from climate changes may add further complications to the environment.

It is proposed that the release of more CO_2 and some other gasses as methane, ozone, carbon tetrachloride and chloroflourocarbons may warm the earth by a mechanism known as the "Greenhouse Effect". Such warming will facilitate the melting of ice sheets accumulated at the Poles and on the peaks of the mountains and hence accelerate the sea level rise. Therefore, it is important to assess the most vulnerable areas in the world by considering all the information about the atmosphere, hydrosphere and the earth mantle to evaluate and estimate the degree of risk that population, property, natural system, social and economic system may face. Moreover, it is also important to emphasize the strong negative impacts caused by the unlimited explosion of the population, which may be worse than the impacts due to climatic changes.

The United Nations Environment Program (UNEP) established a task team for the Red Sea and Gulf of Aden Region to review the proposed terms of references, which are:

Short-Term Objectives

i. To analyse the possible impact of expected climate change on the coastal and marine ecological systems, as well as on the socio-economic structures and activities.

ii. To prepare overviews as well as to select case studies relevant to specific regions.

Long-Term Objectives

i. To assess the potential impact of climate change on the coastal and marine environment as well as on socio-economic structures and activities.

ii. To assist Governments in the identification and implementation of suitable policy options and response measures which may mitigate the negative consequences of the impact.

The meeting was held in February 25-27, 1992 from 12 experts from the region (Egypt, Kingdom of Saudi Arabia, Sudan and Yemen) at Suez Canal University, Ismailia. In the second meeting of December 9-12,1992 in Sinai, the participants discussed the prepared overview and the proposed case studies. The southern part of the Suez Canal Region and its associated lakes was selected as one of the vulnerable case study areas. The objectives of the present work are:

i. Identification of problems that the study area will have to face.

ii. The assessment of physical changes, natural system responses and the corresponding impacts due to global warming and accelerated sea level rise.

iii. Types of assistance which are most needed to overcome these problems.

Historical Background of the Suez Canal

The Suez Canal (Fig. 1) extends from 29º55′N at Suez to 31º15′N at Port Said, and stretches between 32º17′E and 32º35′E. The Canal opened for the first time for navigation in 17 November 1869. At that time the canal was only 8 m deep. It passes on its way through a number of lakes: Lake Timsah (LT), Great Bitter Lake (GBL), and Little Bitter Lake (LBL). In the past, the lakes were low depressions in the eastern desert. Lake Timsah depression was used as a reservoir receiving fresh water during the high Nile flood (Soliman & Morcos, 1990). During Queen Hatchipsot erament, a canal was dug to connect Suez with the Bitter Lakes, known as Sizoustrees Canal. Due to natural hazards including sand dunes, the canal was buried and the Bitter Lakes were separated from Lake Timsah and converted later to salty lakes. Through evaporation, the lake was completely isolated and left behind layers of salt deposits of about 13 m thick, as estimated by Lesseps (1876). The waterway between the Nile and Suez was renewed for the first time after the Arabs arrival to Egypt. The canal and its lakes were dredged and widened several times. As a result, the water in the Canal showed a wide variety in its salinity.

The Mediterranean and the Red seas had a common history and once formed a continuous basin (Stoffers and Khun, 1974). According to Coleman (1974), the Miocene invasion of Red Sea came from the Mediterranean. In middle Miocene times, the northern part of the Nile Delta formed a shallow embayment in the Mediterranean, which was connected to the Gulf of Suez.

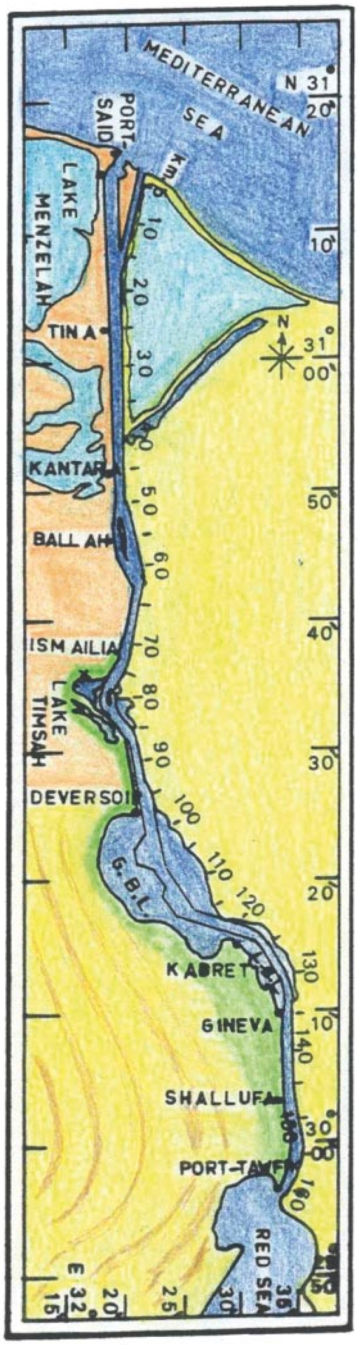


Fig. 1. The Suez Canal map.

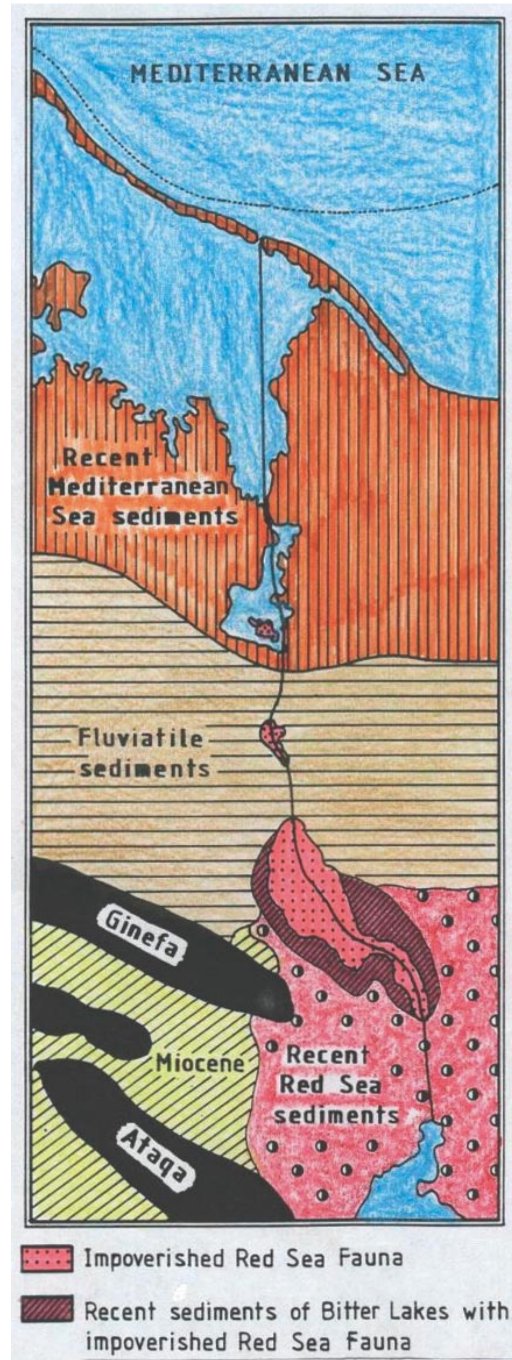


Fig. 2. Geological map of the Isthmus of Suez (after Fuchs, 1978).

Earlier studies of the Pleistocene sediments of the Suez Isthmus before the flooding of the Suez Canal (Por, 1978) show that the sediments of the northern 65 km are of Mediterranean origin. Those of the central 60 km are either of freshwater or Red Sea origins, also, those of the southern 40 km are of Red Sea origin (Fig. 2).

In the recent past, at the end of Flandrian Transgression (around 4000 years BP) the Gulf of Suez reached Serapeum when the Mediterranean shoreline was 50 km inland encompassing Lake Ballah. By about 2500 BP. the Red Sea still stood at Shallufa and the Mediterranean embayment regressed when the water level in the Mediterranean dropped to –2.5 m.

Lesseps (1876) suggested that the alternation of salt and marl in the Bitter Lake presumes that even after the communication with the Gulf of Suez has been interrupted, the Lake must have received occasional floods from the Red Sea and the Nile.

The Vulnerable Area

The area of study extends from Suez (km 161.8) at the head of the Gulf of Suez to Ismailia (km 76) at the northern boundary of Lake Timsah (Fig. 3). It is bounded from west by Suez fresh water canal, from east by the lakes and the southern part of the Suez Canal. Since the western bank of the Canal is the inhabited area, the vulnerability analyses were applied in particular to that area.

The region is classified into six segments along the Canal: Ismailia (km 76-80), Lake Timsah and central part of the Canal (km 80-97.5), Great Bitter Lake (km 97.5-120), Little Bitter Lake (km 120-134), southern part of the Canal (km 134-154), and Suez segment (km 154-162). In addition, the coastal zone of the vulnerable area is divided laterally into four subdivisions according to the height over mean sea level (zero level):

The Area Extended Between Zero and One Metre Level

This stretch contributes about 11.5% of the case study area. It is located in the coastal plain at two sites, which are considered as one of the great economic importance for Ismailia and Suez Governorates. The first site extends along the western side of the Bitter Lakes, which includes: Tourist villages, Fishermen convention centers, and Cultivated lands. The second site is the cultivated area along the western side of the Suez Canal.

The Area Extended Between 1.0-2.0 m Level

This stretch is classified with the ASLR of 1.0 m as area at change. It contributes about 11.0% of the case study area.

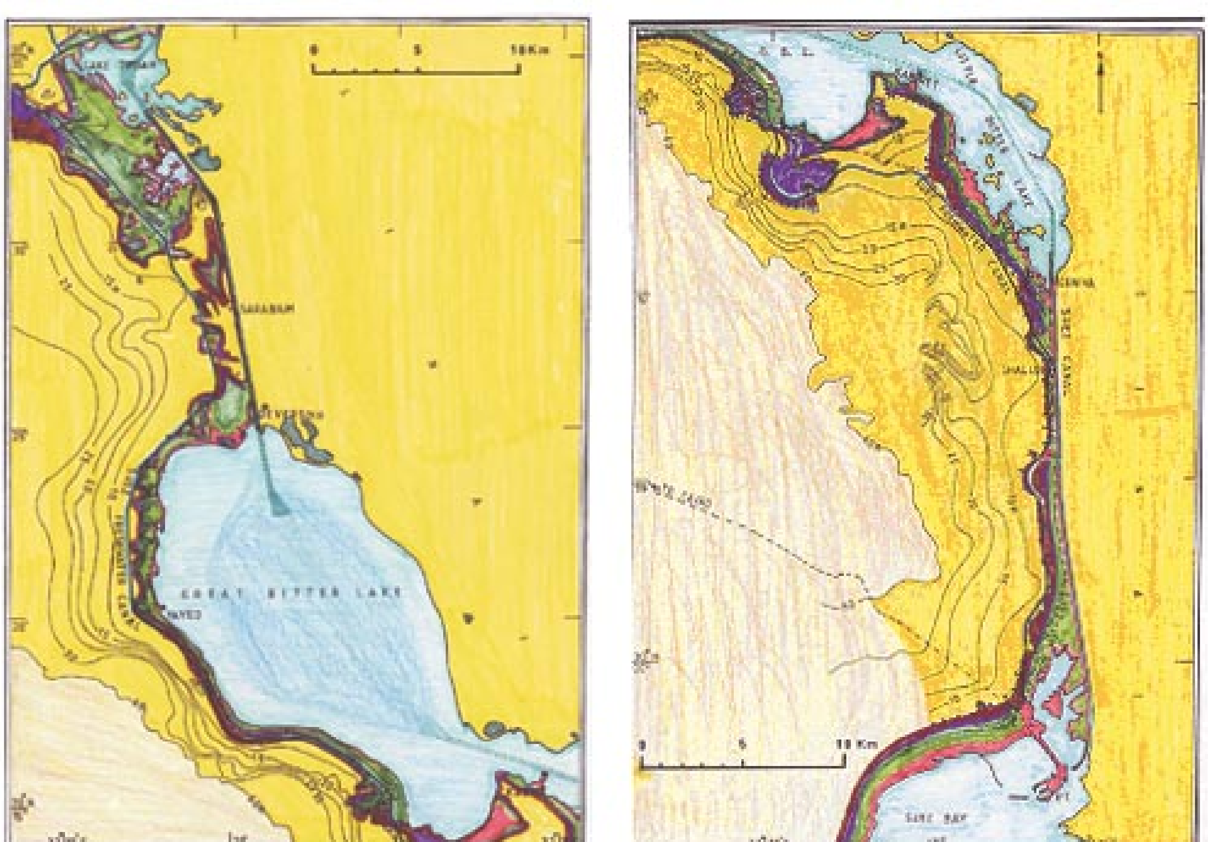


Fig. 3. The coastal zone of the vulnerable area showing the different elevation levels.

The Area Extended Between 2.0-3.0 m Level

This stretch (3989 fed.) contributes about 19% of the case study area. The water table is found at depths of 100-120 cm

The Area Above 3 m Height

This area (11290 fed.) represents the rest of the case study area which contributes more than 53%. It is mostly elongated adjacent to the Suez Fresh Water Canal. Most of the village buildings are allocated in this area, and hence they may be slightly influenced with the ASLR due to the rising in the water table. The soil of this stretch is highly productive. Most of the fruit trees (as Mango) and all kinds of vegetable crops are cultivated there. Table 1 gives the distribution of land and population in the vulnerable area.

The Boundary Conditions

The assumed boundary conditions in the present study were established by IPCC WG-1 (1990) due to ASLR as: a rise of 30 cm, 50 cm and 100 cm for 30, 50 100 years respectively. Different cases according to these conditions were considered.

The Major Impact Categories

The major impact categories due to ASLR are defined as follows:

i. Values at loss (capital and ecological values): due to flooding of land and erosion,

ii. Values at risk (population and capital): due to changes of flood risk, and

iii. Values at change (includes all other impacts as lake ecology and fisheries, agriculture yield and cost): due to increase in soil salinity, drainage conditions, fresh ground-water availability, tourism and socio-economic states.

These aspect are caused by one or more of the following mechanisms:

a. Shoreline retreat: Shoreline retreat is a known phenomenon in coastal zone area. It depends on coastal zone dynamic, such as: **waves, currents, storm surges, wind setup, tides, sea level rise, natural soil subsidence,....etc.** It depends also on coastal morphology, such as: **Frontal shore slope, soil characteristics, nature of soil,....etc.** The two banks of the Canal are constructed to face the sea level changes caused by waves, which are generated mainly by transit ships. If the sea surface rises, due to global warming, to levels higher than the present bank's level over topping will occur and hence the banks must be reconstructed and raised to safety level. The shoreline and the coastal infrastructures along the lakes, particularly their western sides, may be considered as the most pronounced threatened area.

The assessment gives the area lost along the beach of the lakes, the amount of sand lost in cubic meters and the amount of sand required to keep the shoreline at its present state. Also, it gives the cost of artificial nourishment as well as the coastal protection demands.

b. Flooding: If flood happens, the inundated areas are mostly those that of the lake shores. The flooding areas inundated more than once a year are considered at loss, while the others at risk. In both cases the capital values were evaluated and the number of people to be moved were estimated.

c. Direct exposure to the coastal hydraulic environment: All structures constructed along the coasts of the lakes and exposed directly to the water as: harbors, fishing ports and marinas, markets, tourist villages, hotels and housing are considered either at loss or at risk. Their values were evaluated.

The different types of mechanisms assumed in the present study are analyzed and then related to the proposed impacts.

Data Requirements

According to the common methodology (IPCC, 1991), the data required are:

Natural and Physical Characteristics

The following information are required to be known:

i. Geography & topography of the coastal areas.
ii. Geological characteristics of the considered area.
iii. Climatic conditions.
iv. Hydrographic features, waves, water circulation and salinity variations.
v. Water resources and hydraulic conditions.
vi. Coastal processes and sedimentation.
vii. Hydrological conditions.

TABLE 1. Total area (TA), agriculture area (AA) and population in the case study area at different levels and segments in 1992.

			0-1 m				1-2 m				2-3 m				> 3 m			
Segment			TA	AA	AA/TA %	Pop	TA	AA	AA/TA %	Pop	TA	AA	AA/TA %	Pop	TA	AA	AA/TA %	Pop
Ismailla	Seg. 1	km²	1.15	0.76	66.09	944	0.88	0.81	92.05	722	5.53	5.46	98.73	2450	12.59	12.34	98.01	5577
		Fed.	272.7	181.7			208.6	193.6			1316.2	1301.2			2997.8	2937.8		
	Seg. 2	km²	0.87	0.73	83.91	384	0.63	0.61	96.83	279	0.96	0.93	96.88	425	4.37	4.33	99.08	1936
		Fed.	207.8	172.8			151.2	144.2			227.5	220.5			1040	1030		
	Seg. 3	km²	6.32	2.54	40.19	10372	6.35	6.14	96.69	5211	5.78	5.61	97.06	2561	22.64	21.99	97.13	18565
		Fed.	1504.8	604.8			1513	1462.5			1375.6	1335.2			5390.9	5235.9		
	Total	km²	8.34	4.03		11700	7.86	7.56		6212	12.27	12		5436	39.6	38.66		26708
		Fed.	1985.3	959.3			1872.8	1800.3			2919.3	2856.9			9428.7	9203.7		
Suez	Seg. 1	km²	8.05	7.86	97.64	3566	2.4	2.36	98.33	1063	4.14	4.09	98.79	1834	4.78	4.7	98.33	3920
		Fed.	1915.6	1870.4			570.3	562.2			986.5	974.4			1138.5	1118.2		
	Seg. 2	km²	1.4	1.23	87.66	1148	1.71	1.69	98.83	1403	0.92	0.87	94.57	754	4.13	4.07	98.55	3866
		Fed.	332.5	292.3			408.2	402.1			218.2	208.1			983.4	968.3		
	Seg. 3	km²	2	–	–	21200	1.2	–	–	12720	1	–	–	10600	0.8	–	–	8480
		Fed.	476.2	–	–	–	285.71	–	–	–	238.1	–	–	–	190.5	–	–	
	Total	km²	11.45	9.09		25914	5.31	4.05		15186	6.06	4.96		13188	9.71	8.77		16286
		Fed.	2724.3	2162.7			1264.21	964.3			1442.8	1182.5			2312.4	2086.5		
Total		km²	17.79	13.12		37614	13.17	11.61		21390	18.33	16.96		18624	49.31	47.43		
		Fed.	4709.6	3122			3137	2764.5			4362.1	4039.4			11741.1	11290.2		42364

Habitats and Species

i. Sea Grass and Algae

ii. Sabkha

Socio-Economic Information: The socio-economic information, population and population growth rate for the case study area are needed to be collected.

Land Use Activities (Land Use and Land Values)

This item includes the activities, areas and values of the most important economic sectors, which are defined as: The Suez Canal, Agriculture, Industry (minor effect), Fisheries and aquaculture and Tourism.

Study Area Characteristics

Natural and Physical Characteristics

Geomorphological Settings

The landscape of Suez Canal region (Fig. 4) shows characteristic geomorphic features. In the northern part, the canal is bordered on both sides by extended lagoonal and marshy flats. From El-Ballah to the northern parts of the Great Bitter Lake, the western shores of the Canal is bordered by rolling plain (Said, 1981) with its massive sand dunes and gravel tewaces (Abbasia gravels). The western landscape southward to Suez shows very complicated geology and geomorphology. This area is characterized by extensive faulting and its topography is controlled by the geological structure (Said, 1962).

The northern 60 km of the Canal cuts into low-lying deltaic-lagoon deposits. Further south to Kabrit the Canal cuts into extensive sandy zone. The part from Kabrit to the tunnel area cuts into cemented silt-clay. At the immediate south of the tunnel the sediment section presumes recent faulting. A sudden break in lithological continuity is noticed at this point and from there until P.T., the Canal cuts into sandy zone underlain by salty clay (Fig. 5).

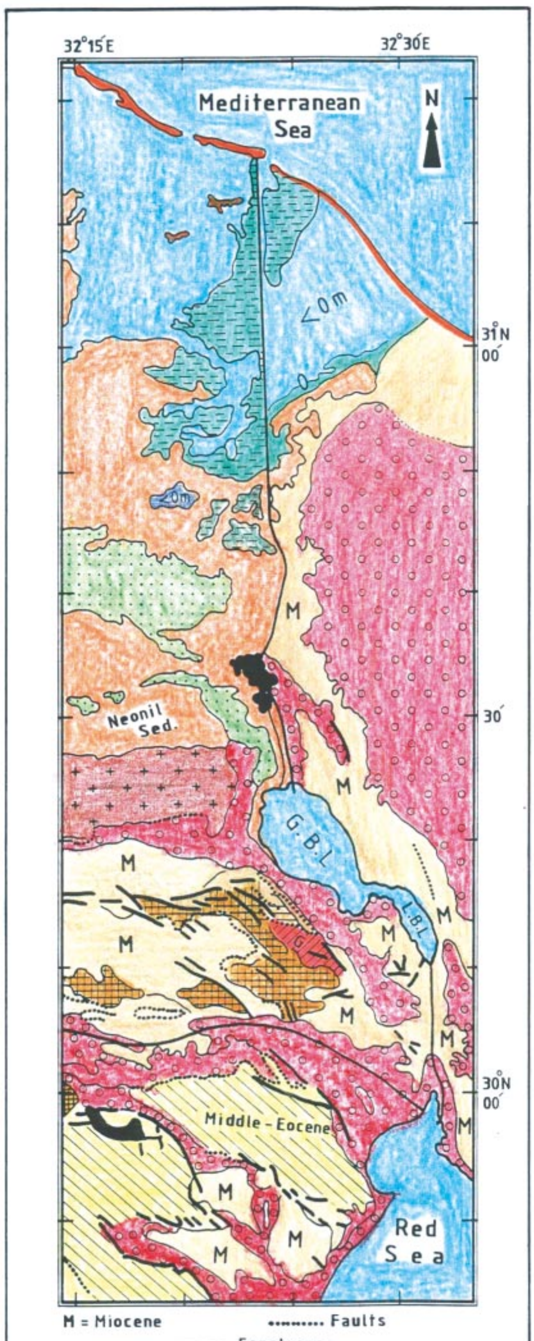
Climatic Conditions

The climate of the region is subtropical, *i.e.*, it is merely arid. It is too hot and dry (more than 35.0ºC) in summer, cool in winter (14.0ºC). Rainfall is scarce in winter (8.0-15.0 mm/day), while evaporation varies between 4.0 mm/day in winter and 4.5 mm/day in summer. Moderate NW-N-NE winds dominate most of the year, which may change to SE for short periods (Table 2). The Khamsin blows in spring and autumn, which is mostly hot. The existence of the Mediterranean in the north and Red Sea in the south may reduce the severity of climatelogical conditions of the surrounding deserts. The change from the Mediterranean climate in winter to the Arabian and southern African depression in summer causes a marked increase in temperature after the cold winter months caused by the cold polar air masses directed to the region

Hydrographic Features

i. Salinity and currents. After the opening of the Suez Canal in November 1869, the Bitter Lakes showed mostly the denser water over the whole Canal. A salt barrier of salinity greater than 65 was established in the Bitter Lakes, which acted as an obstacle for the migration of marine organisms between the Mediterranean and the Red Seas due to the existence of the salt bed at the lakes bottom. As a result of continuous dredging and widening of the Canal and its lakes (Fig. 6), the water salinity showed a rapid decrease with time. Soliman and Morcos (1990) concluded that the salt bed was about to be exhausted and its effect on salinity was insignificant. They added, "The salt barrier which has been dominating for more than hundred and twenty years is going to disappear". El-Sharkawy and Sharf El-Din (1983) showed that the evaporation potential could be considered as the main significant factor in increasing the salinity of the lakes particularly during summer. Therefore, salinity in the lakes is expected to fluctuate within the range of 42.3 ± 1.2. Accordingly, the migration of the marine organisms between the joined seas can occur occasionally at any time without any osmotic problem. In addition, the ecology of the lakes will be developed.

The monthly mean water level rises in winter at P.T. and falls at P.S. In summer, the contrary occurs, *i.e.* it falls at P.T. and rises at P.S. Accordingly the current regime in the Canal is northward in winter and southward in summer. Generally, the wind and the annual gradient of the mean sea level (MSL) are mostly responsible for the current regime in the Canal.



Q_3 : Neonile sediments cover, mainly fanglomerates

Q_w : Sub recent alluvial cover, mainly fanglomerates

Q_d : Sand duness

T_e : Eocene, mainly limestone

M : Oligocene cover Miocene gravel spread

T_p : Paleonile sediments

G : Oligocene and Miocene mainly sand gravels

FIG. 4. Landscape of the Suez Canal region (after Said, 1981).

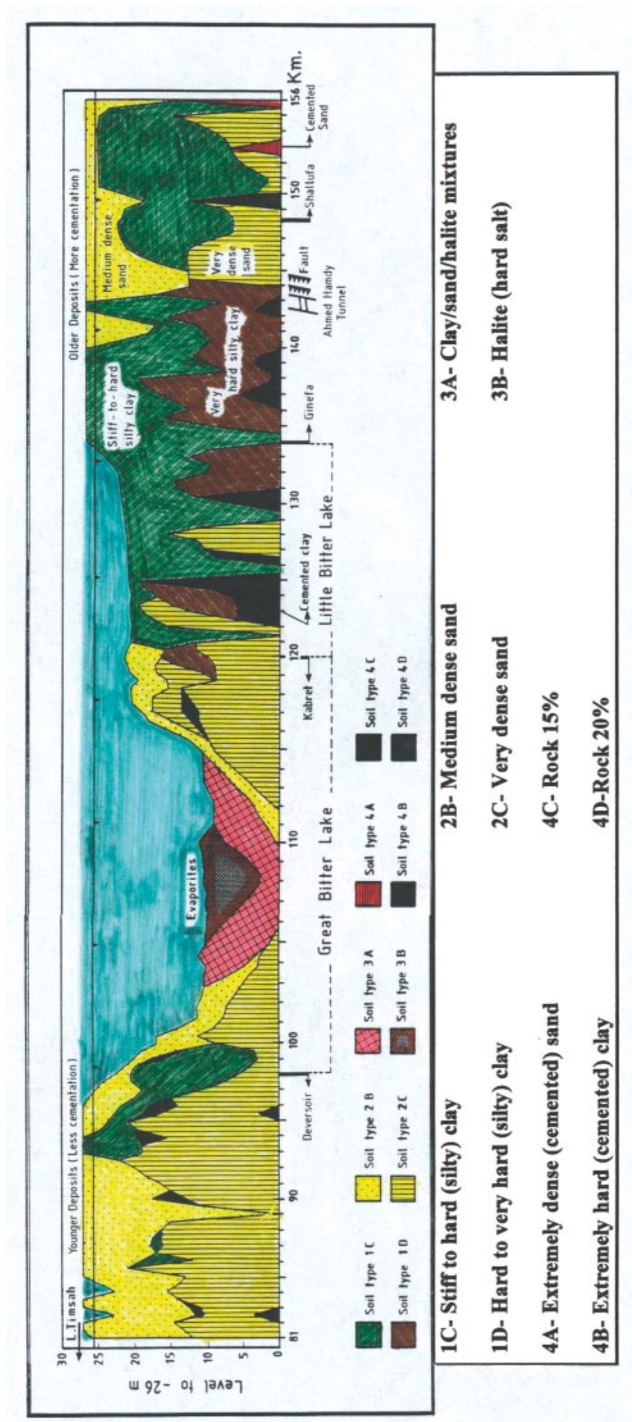


FIG. 5. Sediment-pattern along the Suez Canal (Anon, 1997).

TABLE 2. Wind frequency at Ismailia.

Month		1	2	3	4	5	6	7	8	9	10	11	12
Direction	Velocity (knot)												
	1 ~ 10	7	9	8	13	16	26	25	27	30	22	18	6
345°	11 ~ 21	0	0	0	4	3	7	3	1	1	2	1	0
~ 14°	≥ 22	0	0	0	0	0	0	0	0	0	0	0	0
	Total	7	9	8	17	19	33	28	28	31	24	19	6
	1 ~ 10	9	11	14	16	22	15	15	14	13	15	12	9
150°	11 ~ 21	0	1	1	4	3	4	3	0	0	2	1	0
~ 44°	≥ 22	0	0	0	0	0	0	0	0	0	0	0	0
	Total	9	12	15	20	25	19	18	11	13	17	13	9
	1 ~ 10	5	8	14	10	13	6	4	6	2	6	5	6
45°	11 ~ 21	0	0	1	1	2	0	1	0	0	1	0	0
~ 74°	≥ 22	0	0	0	0	0	0	0	0	0	0	0	0
	Total	5	8	15	11	15	6	5	6	2	7	5	6
	1 ~ 10	3	4	6	2	10	1	1	1	1	2	1	2
75°	11 ~ 21	0	0	0	0	3	0	0	0	0	0	0	0
~ 104°	≥ 22	0	0	0	0	0	0	0	0	0	0	0	0
	Total	3	4	6	2	13	1	1	1	1	2	1	2
	1 ~ 10	2	2	3	4	3	1	0	0	0	3	3	3
105°	11 ~ 21	0	0	0	0	0	0	0	0	0	0	0	0
~ 134°	≥ 22	0	0	0	0	0	0	0	0	0	0	0	0
	Total	2	2	3	4	3	1	0	0	0	3	3	3
	1 ~ 10	6	7	4	7	3	1	0	0	1	3	4	6
135°	11 ~ 21	0	0	0	0	0	0	0	0	0	0	0	0
~ 164°	≥ 22	0	0	0	0	0	0	0	0	0	0	0	0
	Total	6	7	4	7	3	1	0	0	1	3	4	6
	1 ~ 10	14	9	7	4	2	1	0	1	1	4	3	8
165°	11 ~ 21	0	0	1	1	0	0	0	0	0	0	0	0
~ 194°	≥ 22	0	0	0	0	0	0	0	0	0	0	0	0
	Total	14	9	8	5	2	1	0	1	1	4	3	8
	1 ~ 10	7	6	5	2	2	1	1	1	1	2	3	9
195°	11 ~ 21	0	1	0	0	0	0	0	0	0	0	0	1
~ 224°	≥ 22	0	0	0	0	0	0	0	0	0	0	0	0
	Total	7	7	5	2	2	1	1	1	1	2	3	10
	1 ~ 10	8	9	4	3	1	2	3	3	1	5	6	15
225°	11 ~ 21	1	2	0	1	0	0	0	0	0	0	1	2
~ 254°	≥ 22	0	0	0	0	0	0	0	0	0	0	0	0
	Total	9	11	4	4	1	2	3	3	1	5	7	17
	1 ~ 10	15	10	9	4	2	5	6	6	3	7	10	15
255°	11 ~ 21	2	0	2	1	0	0	0	0	0	0	1	2
~ 284°	≥ 22	0	0	0	0	0	0	0	0	0	0	0	0
	Total	17	10	11	5	2	5	6	6	3	7	11	17

Table 2. Contd.

Month		1	2	3	4	5	6	7	8	9	10	11	12
Direction	Velocity (knot												
	1 ~ 10	13	12	13	10	5	13	12	15	11	10	13	11
285º	11 ~ 21	0	0	1	0	0	0	0	0	0	0	0	0
~ 314º	≥ 22	0	0	0	0	0	0	0	0	0	0	0	0
	Total	13	12	14	10	5	13	12	15	11	10	13	11
	1 ~ 10	9	9	6	12	9	15	26	24	34	18	19	8
315º	11 ~ 21	0	0	1	1	0	1	0	0	0	0	0	0
~ 344º	≥ 22	0	0	0	0	0	0	0	0	0	0	0	0
	Total	9	9	7	13	9	16	26	24	34	18	19	8

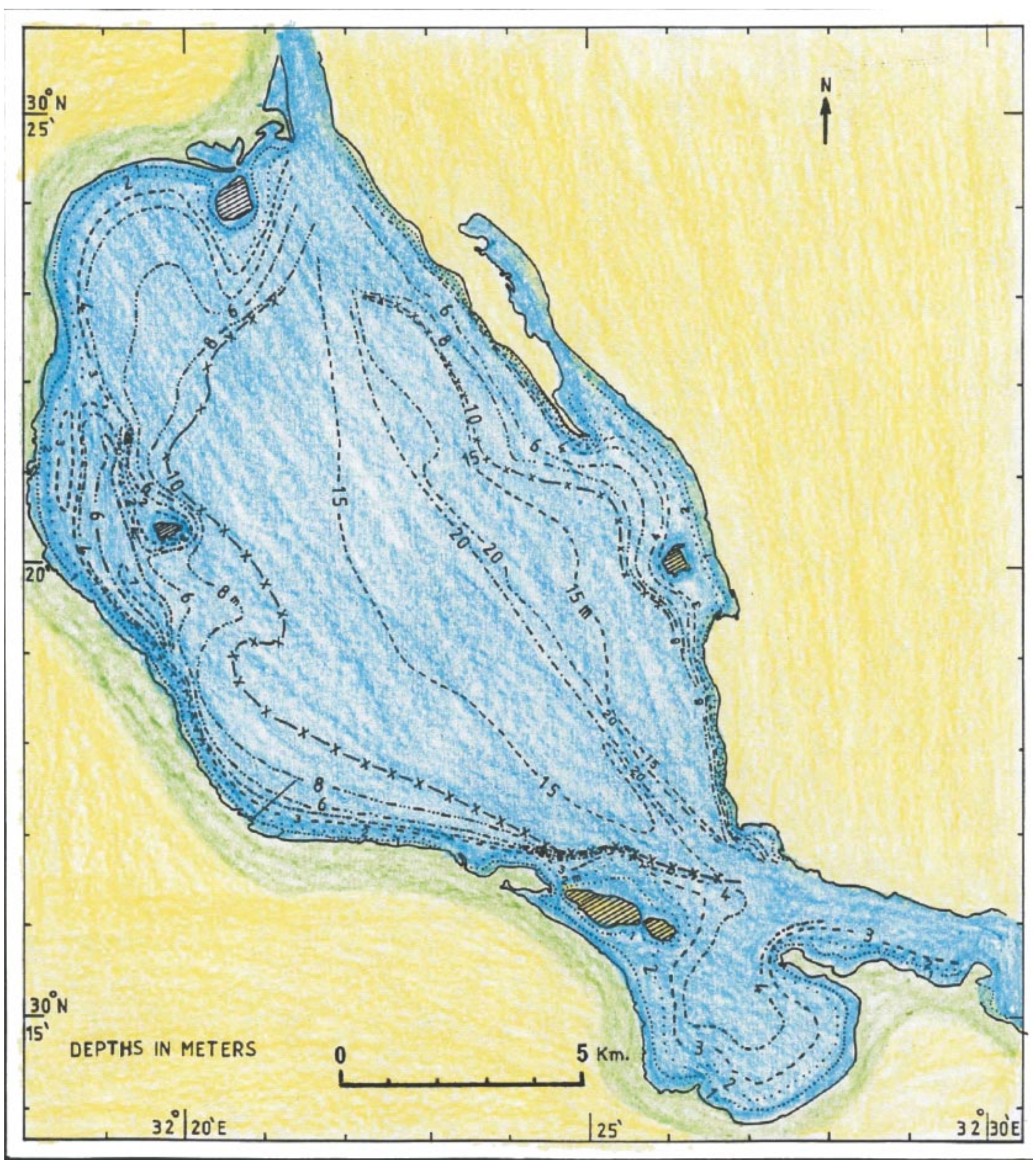


Fig. 6. Recent bathymetric chart of the Great Bitter Lake (1994).

ii. Waves. Waves are generated in the Canal and its associated lakes either by tides or winds & transit ships. The tidal waves are of long wave type, while those due to wind and ship motions are of short wave type.

a. Tides: The Suez Canal is connected with the Red Sea from the south and with the Mediterranean from the north. The tidal motions in the Canal are in co-oscillation with that in the two seas. They showed large ranges at Suez (1.0-1.8 m) and small ones at P.S. (0.4-0.8 m). The vast surface area of the Bitter Lakes converts them to a big reservoir, which damps greatly the vertical movements of the tidal waves that propagate from both ends of the Canal towards the lakes. A numerical model has been investigated to simulate the tidal motion in the Canal and in the associated lakes before and after the last widening and deepening of the Canal (Soliman, 1995). The same model was used to estimate the impact of ASLR on the tidal motion in the Canal. Tables (3-4) give the amplitudes and phases of M2-tide and M2-tidal current (the semi-diurnal lunar component) at different locations along the Canal as well as the observed values.

b. Wind induced waves: Waves generated by wind show values of the order of 20 cm in the normal cases while it may exceed 50 cm in storms. As there is no observational wave data available for Bitter Lakes, the wave conditions are predicted using the following formula (Anon., 1997)

$$\frac{gH_{1/3}}{U^2} = 0.3\left(1 - \frac{1}{\left(1 + 0.004\left(\frac{gF}{U^2}\right)^{1/2}\right)^2}\right) \qquad (1)$$

TABLE 3. Observed and computed M2-tide at different locations along the Suez Canal.

Station	Location (km)	Observation		Computed values							
				Depth of 1967		Depth of 1995		Due to ASLR 1.0 m		Due to ASLR 0.5 m	
	From P.S.	A (cm)	φ (deg)	A (cm)	φ (deg)	A (cm)	φ (deg)	A (cm)	φ (deg)	A (cm)	φ (deg)
Suez (P.T.)	161.5	57.2	343**	56.1	277.4	56.1	277.4	57.1	277.4	56.1	277.4
		58.2	340*								
Shalloufa	146.1	27.3**		29.4	282	34.7	284.2	30.7	283.5	31.8	293.9
Genifa	134	7.1**		7	293.8	16.5	298	12.2	298.8	14.1	298.5
		7.3	4*								
Kabret	120			1.6	9	3.3	21.8	4	14.2	3.8	15.1
Deversoir	97.5			1.5	37.5	3.1	38.6	4.2	26.3	3.8	34.9
Lake Timsah (South)	80.5			1.3	15.8	2	24.7	1.8	4.8	1.9	17.2
Lake Timsah (North)	76.3			1.3	12.2	1.8	24.7	1.7	15	1.9	22.6
El-Ballah	54.6			3.5	291.4	3.3	276.5	3.3	271.3	3.2	273.6
Kantara	45			5	280.9	4.4	263.7	4.9	261.9	4.8	261.9
El-Tina	24.8			8				8.2	251.8	7.9	252.1
Ras El-Esh	14.3			9.5	255.8	9.5	249.3	9.7	248.3	9.7	248.2
Port Said (P.S.)	0			11.7	243.4	11.7	243.4	11.7	243.4	11.7	243.4

Table 4. Observed and computed M2-tidal current at different locations along the Suez Canal.

Station	Location (km)	Observation		Computed values							
				Depth of 1967		Depth of 1995		Due to ASLR 0.5 m		Due to ASLR 1.0 m	
	From P.S.	A (cm/sec)	φ (deg)	A (cm/sec)	φ (deg)	A (cm/sec)	φ (deg)	A (cm/sec)	φ (deg)	A (cm/sec)	φ (deg)
Suez (P.T.)	161.5	92.05 N 98.19 S	Summer	36.3	282.4	45.4	287.3	49.2	289.4	51.5	290.9
Shalloufa	146.1	100.40 N 60.00 S	Winter	37	292.8	46.3	292.8	50.7	295	53.6	296.2
		86.40 N 90.60 S	Summer								
Genifa	134	94.63 N 57.66 S	Winter	37.4	296.9	45.6	296.4	50.5	297.5	53	297.9
Kabret		20.97 N 17.00 S	Winter	5	357	63	358	62	358	6.5	358
	120	15.54 N 12.09 S	Summer								
Deversoir	97.5			0.5	(123.6) 303.6	2.5	85.4	3.1	67.9	4.4	59.9
Lake Timsah (South)	80.5			0.9	(124.8) 304.8	4	83.9	4.8	74.4	5.6	61.5
Lake Timsah (North)	76.3			2.5	(108.6) 288.6	4.5	94.2	4.5	93.1	4.6	92.9
El-Ballah	54.6			3.0	(98.6) 278.6	4.8	90.1	5	90.4	5	89.9
Kantara	45			3.1	(88.5) 268.5	5.2	88.4	5.2	88.1	5.2	88.1
El-Tina	24.8			3.5	(62.6) 242.6	4.9	75.7	5.1	76.4	5.2	77.6
Ras El-Esh	14.3			3.9	(47.8) 227.8	5	69.9	5.1	71	5.1	72.6
Port Said (P.S.)	0			7.8	(29.4) 209.4	5	56.3	5.1	57.3	5.1	58.4

$$\frac{gT_{1/3}}{U} = 1.37\left(1 - \frac{1}{\left(1 + 0.008\left(\frac{gF}{U^2}\right)^{1/3}\right)^5}\right) \qquad (2)$$

where:

$H_{1/3}$: Significant wave height (m)
$T_{1/3}$: Significant wave period (sec).
U : Wind velocity at 10 m above sea level (m/sec)
F : Fetch length (m)
g : Acceleration due to gravity (m/sec^2).

The wind velocity on the lake surface area is assumed to be 20% above the observed velocity on land. The maximum calculated significant wave height is about 1.25 m (for wind speed of 20 m/sec and fetch length of 5 km), and the maximum significant wave period is about 4.0 sec for the same wind conditions. From wave refraction, the wave height in the active coastal zone is about 40 cm.

c. Waves due to transit ships: The maximum wave heights generated by transiting ships through the Suez Canal are estimated to be 10 cm. Their effect is of great importance on the revetment constructions on both sides of the Canal. The effect of hydraulic phenomena is less remarkable in the Little Bitter Lake.

Coastal Processes

The cross-sectional area of the Canal was designed for one-way traffic. It has been increased with a factor of 14 since the Canal opening in 1869. At present it varies from one location to another according to the nature of its surface soil. It changes between 3900 and 4200 squared meters in 1994. The canal depth varies between 19.5 and 25.0 meter. The coastline stretches to about 300 km long, while the threatened areas are nearly 3.0 km wide, and 3-5 m height (Fig. 3).

Generally, the coastal zone in the Bitter Lakes area is mostly stable. Variations are observed in the areas where waves attack the coast and where man-made coastal works had been carried out. The banks of the Canal are protected by bank protection work composed mainly of sheet piling and stone revetments (Fig. 7).

Water Resources

Rainfall in Egypt is generally scarce. However, the cultivated lands in Egypt depend mainly in its irrigation system on one of the following water sources: River Nile, Ground water, wells, and Rain.

i. River Nile. The River Nile is considered as the main source of supplying Egypt with fresh water. It is true that "Egypt is the Gift of the Nile". Due to the rapid progress in land reclamation the amount of water required for irrigation must be well managed. Although the crops yield will increase for a while, the reduction of water may lead either to the increase of salt content in soil or to desertification.

ii. Ground water. Ground-water resources in the western desert were explored by remote sensing and described as a huge reservoir, which contains more than $1.5^{*}10^{9}$ m^{3}. The main groundwater reservoir in the case study area is the Quaternary deposits that consists of sands and gravels with clay lenses. Ground water of the quaternary aquifer is assessed to be fossile water. Recent recharge may take place from Ismailia canal and its branches. Moreover, some recharge may take place by upward leakage of the saline water of the underlying Miocene aquifer according to the prevailing hydrogeologic setting.

Along the western Suez Canal stretch, the relatively shallow fresh ground-water is in close proximity to saline water of the Suez Canal and attached Lakes. A brackish transition zone separates the two fluids and is protected from dispersion by the continuous seaward flow of the fresh-water. Within this transition zone the salinity of the groundwater increases progressively seaward and with depth as well.

If the water level in the Suez Canal and Bitter Lakes is assumed as zero level, the water level in the Suez Fresh Water Canal is at about 5 m above sea level. Consequently, the fresh water canal forms a western recharge boundary front. On the other hand, the Great Bitter Lake acts as a drain for the ground water, which represents a discharge boundary front.

This means that the ground water flows continuously to the east, particularly as the sources are mostly unusable, since the people depend entirely on the surface water resources. The eastward flow, and the continuous recharge of the aquifer, may be proved in the field by a follow up of water salinity between the two boundaries, using existing two holes with about 10 m distance in between and about 20 m from the shoreline. Water salinity varies laterally from west to east between 513 ppm (the Suez fresh water Canal), 12124 and 16020 ppm in the two holes and 44450 ppm (GBL). Moreover, the salinity values of the two holes point to the transition zone always exist due to mixing between the coastal groundwater and sea water.

iii. Rain. Egypt lies within the very arid zone in the world. The heaviest annual precipitation is in the northern coast (about 104 mm at Sallum, 123 mm at Marsa-Matrouh, 185 mm at Baltim, and 250 mm at Rafah). Rainfall turns to traces southwards.

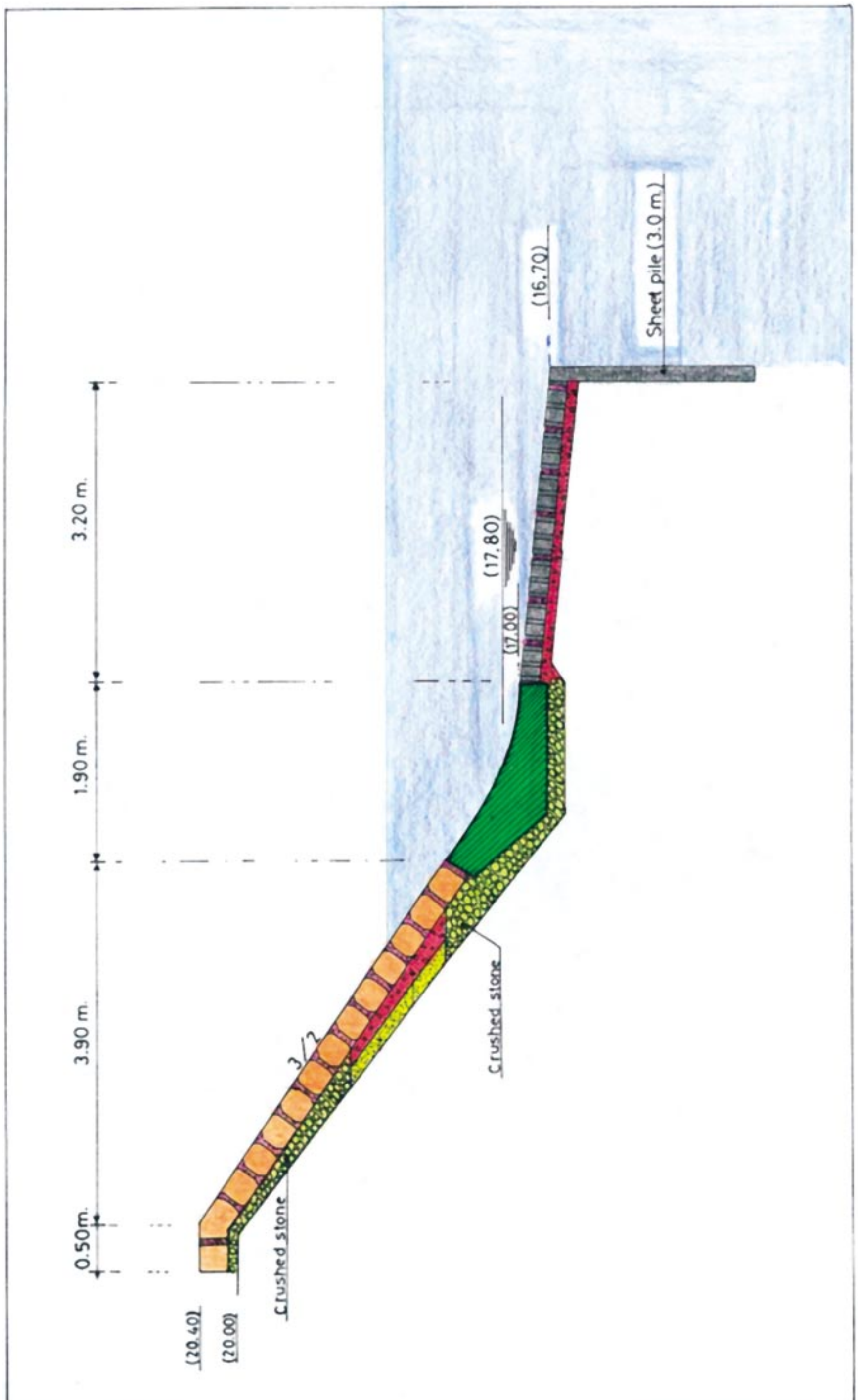


FIG. 7. Revetment used in the southern part of the Canal.

The Suez Canal Habitats

Sea-Grass and Algae

The subsequent taxonomic studies in the Suez Canal revealed the presence of 131 algal taxa and in addition 4 species of sea grass. Several Indo-Pacific immigrants had already been recorded in the western Mediterranean. The distribution of benthic fauna in the Canal is given by Por (1978). The importance of the Canal as a habitat for benthic algae was little known. Littoral algae can be exposed to a wide range of water temperature in the Canal (6.0ºC in winter and 29.0ºC in summer). The high salinity prevailing at the bottom of the Canal for most of the year creates favorable conditions for benthic algae from the Red Sea to colonize any suitable substrata particularly in the lakes.

In the Canal, the water is slightly turbid because of the stirring up of bottom deposits by the ship movements. Oil pollution is also noticed on the banks. The turbidity as well as oil pollutants restrict the vertical distribution of plants on the Canal banks. The bottom sediments of the Canal (muddy sand) are not suitable substrata for alga growth. In the Bitter Lakes, ancient eroded coral patches occur on which there are copious growths of algae and abundant reefs of the bivalve mollusc Brachidontes. This bivalve also forms scattered patches along the shores of the Bitter Lakes. A few living corals are encountered in these lakes. Lake Timsah sustains rich flora. Apart from littoral algae such as blue green algae, a rich red algae community flourished at depths of 0.5-1.0 m below surface. The majority of the flora is typical of the Red Sea and Indo-Pacific region.

Aleem (1984) listed all the algae he had recorded in the Canal. Halim (1969) noted that the high turbidity caused by continuous ship traffic, the lack of suitable substrates, the comparatively higher temperature of the Canal waters, and the hypersalinity of the Bitter Lakes in the past were commutative obstacles to the penetration and settlement of organisms from both ends. He added, an increasingly rich and varied fauna and flora, however, appears to have gradually established itself in the Canal in the following years, evidencing the changes in the Canal conditions and mostly the disappearance of the salt barrier, which is confirmed by Soliman and Morcos (1990).

Lake Timsah is observed inhabited by avifauna such as pelicans, flamingoes, ducks and geese (Anon, 1992). According to Aillaud (1968), the LBL, of about 7 km long and 2 km wide, was found inhabited by a rich fauna of water birds.

Socio-Economic Information

General Economic Information

The main economic sectors in Egypt could be considered as: Agriculture, Industry, Oil, Electricity, Construction, Housing, Suez Canal, Transportation and Communication, Tourism, Trade, Finance and Insurance. The local and national incomes during the period 1982/83-1986/87 are presented in Table 5.

TABLE 5. Local and national incomes (in MLC).

Income \ Year	1982-83	1983-84	1984-85	1985-86	1986-87
Local	24,367.8	28,956.0	34,132.1	39,059.5	40,832.5
National	26,989.0	33,251.2	38.298.6	41,966.0	46,819.7

Population and Population Density

The number of population in the directly threatened region according to the population census of 1986 was around 120 thousand persons. They represent 22.18% of the total population of Ismailia Governorate, while those living in Ganaien region in Suez Governorate represent 10.0% of the total population of the administrative center. The region is not considered highly overpopulated region due to its desert like nature. Meanwhile, its economic activity is limited in volume and variations in spite of its bordering the Suez Canal, which is considered one of the most important sources in the Egyptian National Income. The population density in Ismailia Governorate is 465 person/km^2, and 23 person/km^2 in Suez Governorate (Table 6), but this figure is evasive due to the extension of Suez Governorate into unoccupied desert regions.

In the study area, the growth rate of the population was found as 2.3 %/Y and 2.53%/Y during 1990-1995 in Ismailia and Suez respectively and as 2.26% and 2.48% during 1995-2000; The growth rate is expected to be 2.21% and 2.45% during 2000-2010; and 2.11% and 2.35% during 2010-2020 in Ismailia and Suez (Table 7).

TABLE 6. Population, population density, growth rate and the expected values in Egypt, Ismailia and Suez (1966-2020).

Year / District	1966*			1976*			1986*			1995			2020+			Area km²
	Pop. in thous.	Population density /km²	Growth rate %	Pop. in thous.	Population density /km²	Growth rate %	Pop. in thous.	Population density /km²	Growth rate %	Pop. in thous.	Population density /km²	Growth rate %	Pop. in thous.	Population density /km²	Growth rate %	
Egypt (60,000.00 km²) (1,000,612.4) km²)	30076			36627			48254			59711			100,007			
		30			37			48			60			100		1,000,612
		1003			1221			1608			1990			3334		60,000
									2.43			2.3			1.96	
Ismailia (4,482.74 km²) (1,441.59) km²)	335.471			431.741			550.243			678.776			1,166.63			
		75			96			123			151			260		4,482.7
		(233)			(299)			(377)			(471)			(809)		1,441.6
	1.12%		2.6	1.18%		2.5	1.14%		2.37	1.14%		2.31	1.17%		2.06	
Suez (17,840.42 km²)	271.00			256.00			338.726			425.216			773.08			
		15			14			19			24			43		17,840.4
	0.90%		–	0.50%		–	0.70%		2.48	0.71%		2.55	0.77 %		2.3	

TABLE 7. Estimated population for different growth rates during the period 2000-2090.

7(a). In Egypt

Year	Constant growth rate		Stationary decrease GR of 0.01%		Stationary decrease GR of 0.02%	
	Egypt		Egypt		Egypt	
	GR %	Estimated no.	GR %	Estimated no.	GR %	Estimated no.
1992	2.50	55,659,000				
2000	2.50	67,815,070			2.15	66,581,000
2010	2.50	86,809,000			1.95	81,560,439
2020	2.50	111,122,820	1.95	100,007,000	1.75	97,969,087
2030	2.50	142,246,560	1.85	123,011,590	1.55	115,388,380
2040	2.50	182,087,570	1.75	146,963,720	1.35	136,199,320
2050	2.50	233,087,420	1.65	173,862,460	1.15	154,214,230
2060	2.50	298,371,520	1.55	203,670,870	0.95	171,193,320
2070	2.50	381,940,660	1.45	236,251,810	0.75	186,313,810
2080	2.50	488,916,200	1.35	271,356,530	0.55	198,784,280
2090	2.50	625,853,900	1.25	308,617,200	0.35	207,912,530

7(b). In Ismailia and Suez

Year	Constant growth rate				Stationary decrease GR of 0.01%				Stationary decrease GR of 0.02%			
	Ismailia		Suez		Ismailia		Suez		Ismailia		Suez	
	GR %	Estimated no.	GR %	Estimated no.	GR %	Estimated no.	GR %	Estimated no.	GR %	Estimated no.	GR %	Estimated no.
1992	2.60	633,458	2.65	390,297								
2000	2.60	777,851	2.65	481,135					2.26	760.138	2.50	484,562
2010	2.60	1,005,472	2.65	624,966					2.06	940,319	2.30	613,654
2020	2.60	1,299,702	2.65	811,793	2.06	1,166,631	2.30	773,083	1.86	1,140,635	2.10	762,091
2030	2.60	1,680,031	2.65	1,054,472	1.96	1,452,123	2.20	987,466	1.66	1,356,720	1.90	928,073
2040	2.60	2,171,654	2.65	1,369,696	1.86	1,753,711	2.10	1,220,937	1.46	1,582,299	1.70	1,108,237
2050	2.60	2,807,141	2.65	1,779,154	1.76	2,059,957	2.00	1,494,893	1.26	1,809,361	1.50	1,297,601
2060	2.60	3,628,589	2.65	2,311,016	1.66	2,439,388	1.90	1,812,463	1.06	2,028,539	1.30	1,489,676
2070	2.60	4,690,415	2.65	3,001,874	1.56	2,860,431	1.80	2,176,036	0.86	2,229,697	1.10	1,676,744
2080	2.60	6,062,961	2.65	3,899,257	1.46	3,321,281	1.70	2,587,000	0.66	2,405,063	0.90	1,850,333
2090	2.60	7,837,152	2.65	5,064,904	1.36	3,818,555	1.60	3,045,485	0.46	2,540,569	0.70	2,001,813

Land-Use Activities (Land-use and Land Values)

Suez Canal

Suez Canal could be considered as the main axis of economic activity in the region concerning the investment of its activities, the revenue perception and other activities.

Agriculture

The agriculture sector was heavily influenced by government policy till 1980 through the intervention in production pricing and marketing of major crops and inputs. Private sector processing and marketing of agricultural products were encouraged, and the foreign trade of agricultural crops and products were shifted to the free foreign exchange market. In 1991, the value of exported amount of these commodities attained 1,906 MLC, which represents 16.2% of the total exports.

The study area is generally flat and slopes gently towards the east, *i.e.*, towards the Bitter Lakes and the Suez Canal. This feature plays an important role in its hydraulic properties. The soil of the cultivated area is mostly moderately saline with a moderate to high water table level. The main problems encountered in the area caused by the generalized high water table level resulting from water seepage from the Suez Fresh Water Canal.

The crop area in Ismailia sector was 20732 feddan with intensity factor 1.7. Vegetables and fruit trees (Mango) occupied 50% and the rest was under field crops. In Suez sector, the crop area attained 17095 feddan with intensity factor 1.88. 31% of this area was under vegetables and fruit trees, and the rest (69%) was under field crops.

At eight locations along the southern part of the Suez Canal and Bitter Lakes, transacts have been taken from the shoreline up to the Suez fresh water canal. Soil profiles were dug to the water table, where soil samples were collected at different depths. The samples were then analyzed for salinity, pH, soluble cations and anions (Anon, 1997). It is found that the salinity of the surface soil layer (0-60 cm) decreases sharply from the Suez Canal towards the fresh water canal, *i.e.*, from east to west, whereas it increases from north to south towards Suez. Accordingly, one may conclude that salt-water intrusion can occur in the coastal areas of the Suez Canal and the Bitter Lakes. The location of the salt-water wedge depends on: The extent of the sea level rise, the slope of the area towards the coastal plain, the water level in the fresh water canal, the irrigation activity, the drainage efficiency, and tide.

Industry

The case study area does not contribute any industrial activity except the Suez Canal shipping maintenance center.

Fisheries

Fishing was one of the major activities in Egypt. In 1964, the total catch from the Mediterranean (26,000 ton) and the northern lakes (35,000 ton) was about 61,000 ton; about 18,000 ton from the Red Sea with about 1,500 ton from the Suez Canal and its lakes. The total catch in Egypt was about 79,000 ton. After the completion of the Aswan High Dam in 1966, the yield declined greatly to about 13,700 ton from the Mediterranean, the northern lakes remained nearly at the same level (35,000 ton), 12,000 ton from the Red Sea and about 1,300 ton from the Suez Canal. The total catch was about 62,000 ton. Although, the Canal lakes landings are considered to be relatively small to the total catch, yet they are economically important. It covers part of the needs of the local market in Ismailia Governorate (Ghobashy *et. al.*, 1991). Ghobashy *et.al.* (1991) revealed that the general decline in landings of prawns and overall fish landings may be related to several causes as: overfishing, the type of gear used, the number of boats, the duration of catch season, mortality either naturally or side effect, fishing in the spawning and nursery grounds and pollution due to oil or pesticides. They concluded that stock-assessments essentially required to be carried out to determine the present stocks for the different species in the area, and the possibility to increase the sustainable yield, to decrease the side effect due to the by-catch, and regulating the time fishing. Due to the continuous development of the area particularly that belonging to tourism industry along the lakes coasts, and also due to the continuous deepening of the Canal and its lakes, the total catch in that region showed a drastic decline for a long period.

Tourism

Tourism activities are concentrated mainly on the lakes coasts mostly as internal tourism, which represents 72% of the total tourism activity in the study area. The tourism activity occupies an area of about 740 feddan. There are about 7000 workers involved in tourism activity. The revenue from such activity amounted 4.9 MLC in 1990/91 due to the Gulf war, while it was 6.5 MLC in 1987/88.

Results and Discussions

Vulnerability Assessments

Water Level and Water Level Frequencies of Coastal and Tidal Waters

For each hydraulic condition, there is an exceedance frequency level. The coastal areas are vulnerable to flooding if they lie below a certain level defined by a number of factors such as:

i. Global hydraulic factor, which is defined by the ASLR of 30 cm/30Y or 1.0m/100Y.

ii. Subsidence and uplift of the coastal areas. In the present case study, there is no clear vertical motion and hence this factor is ignored.

iii. Local hydraulic factors as: tides, storm surges and mean sea level.

The influence of the last factor differs from one area to another. The tidal range at the southern entrance of the Canal changes between 90 cm during neap tide and 1.80 during spring tide. It falls to about 20 cm at Genifa and lesser in the Bitter Lakes. Waves generated by wind play certain role in the lakes, while ship's waves have significant influence in the Canal proper.

Generally, the flood level "FL" for the different Suez Canal Impact Zones (SCIS) were determined using the following formula:

$$FL = MHWL + W.S. + SUBS + ASLR \qquad (3)$$

Where:

MHWL = Mean high water level,
W.S. = Wind set-up (With maximum ranges between 20 and 30 cm),
SUBS = Subsidence or tectonic uplift,
ASLR = Accelerated Sea Level Rise, which was assumed as: 30, 50,and 100cm.

The Suez Canal Impact Zones are:

Zone 1 : Lake Timsah and central part of the Suez Canal area
Zone 2 : Bitter-Lakes area,
Zone 31 : Genifa area,
Zone 32 : Shallufa area.

The flood levels "FL" and the maximum rush-up height for the different scenarios, maximum wave run-up due to ships and the present revetment crest level for the different SCIZ are given in Table 8.

Table 8 indicates that the Suez Canal Impact Zones 1 and 2 will be flooded for the different scenarios, while zone 31 will be flooded for scenarios 2 and 3 and the last zone will be only influenced by the third scenario 3.

Loss of Land in the Coastal Zones of the Canal and its Associated Lakes

The coastal morphology shows that the nature of soil in the active coastal zone is mainly sand. The "Bruun rule" (Bruun, 1962) can therefore be used for the analysis of the effect of accelerated sea-level rise.

For a coastal segment with length *L*, with height of morphologically active coast *H*, and with a morphologically active coastal profile in case of ASLR will shift in two directions:

TABLE 8. The flood level and the revetment crest level at the different SCIZ.

SCIZ	Flood level “FL” (m)			Maximum wave run-up due to ships (m)	Maximum rush-up height (m)			Present revetment crest levels (m)
	Scenario 1	Scenario 2	Scenario 3		Scenario 1	Scenario 2	Scenario 3	
1	18.81	19.01	19.51	1.0	19.81	20.01	20.51	19.80
2	18.93	19.13	19.63	1.0	19.93	20.13	20.63	19.80
31	18.82	19.02	19.52	1.0	19.82	20.02	20.52	20.00
32	18.95	19.15	19.65	1.0	19.95	20.15	20.65	20.40

i. Horizontally landward, by recision,
ii. Vertically, by sea level rise.

The rate of change of water column due to horizontal movement is given by:

$$V_h = H * E * L \quad (4)$$

Similarly, the rate of change of water column due to vertical movement is given by:

$$V_v = W * S * L \quad (5)$$

The combination of both expressions, assuming stability of coastal zone under the present coastal dynamics, leads to the simplest form of the "Bruun rule".

$$E = W * S / H \quad (6)$$

where:

E : Rate of horizontal movement (rate of shore line retreat)

S : Rate of vertical Movement (Rate of ASLR).

H/W : Average slope of the morphologically active coastal profile.

The total loss of land area for a coastal segment with length L, and during a time period t is given by

$$A = L \int_0^t E dt$$

Summation of the results over all segments along the Bitter Lakes yields the loss of land area for the entire lakes coast according to the different scenarios as well as the sand nourishment required to recover the shoreline to its present situation (Table 9-a). These values with capital losses due to beach retreat and cost assessment of beach nourishment, coastal wall and revetment constructions in MLC are given in Table (9-b).

Other Damages and Impacts Related to Changes in Water Management or Salinity

Actually, most of the field land in the case study area lies in the low land, which extends nearly parallel to the shore line of the lakes and the Suez Canal. The water-table is high near the soil surface particularly in the coastal plain. With accelerated sea level rise, the following situations could be regarded:

i. Do nothing against sea level rise, which means cultivating the land with usual crop types.

ii. Changing the crop types by selecting crops with higher salt tolerance.

iii. Changing the land use activity.

iv. Changing the irrigation and drainage water rate by:

a. Increasing the irrigation water supply and hence the discharge of the drainage water.
b. Using a new irrigating technologies.

i. Do Nothing Against Sea Level Rise

This means that the present agriculture processes are going on without any change in the crop types. In such case water table becomes higher approaching the soil surface, which will show a variety of degradation and may be transformed into saline pools. Reduction in the yield is presently observed and desertification is taking place in some lands.

TABLE 9(a). Shore development in km^2, and sand nourishment in 10^3m^3 (with SED).

Assessment / Segment	Coast length	Shore development (km^2) and sand nourishment (10^3m^3)					
		2020		2040		2090	
	Km	Km^2	10^3m^3	Km^2	10^3m^3	Km^2	10^3m^3
Central part of the canal	40.0	–	–	–	–	–	–
Lake Timsah	26.0	0.208	62.4	0.352	176.0	0.703	703.0
G.B. Lake	64.65	0.517	155.1	0.874	437.0	1.748	1748.0
L.B. Lake	50.0	0.400	120.0	0.676	338.0	1.352	1352.0
Southern part of the canal	56.0	–	–	–	–	–	–
Total	236.65	1.125	337.5	1.902	951.0	3.803	380.3

TABLE 9(b). Cost assessment of beach losses and nourishment in MLC (with SED).

Assessment / Segment	Coast length	Capital losses due to beach retreat (MLC)			Full Measures			
					Beach nourishment (MLC)		Coastal wall + nourishment (MLC)	Revetment (MLC)
		2020	2040	2090	2020	2040	2090	2090
Central part of the canal	40.0	–	–	228	–	–	–	104.0
Lake Timsah	26.0	1.248	2.816	430 + 54 = 484	1.87	9.5	260 + 80 = 340	–
G.B. Lake	64.65	3.102	6.992	872 + 1022 = 1894	4.65	23.6	646.5 + 199.3 = 845.8	–
L.B. Lake	50.0	2.400	5.408	57	3.60	18.25	500 + 154 654	–
Southern part of the canal	56.0	–	–	254	–	–	–	142.6
Total	236.65	6.750	15.216	2917	10.12	51.35	1839.8	246.6

Assuming that the present average net financial yield/feddan is 4000 LC/Y and the total affected areas w.r.t. 0. 3 m and 1.0 m ASLR are about 1900 feddan and 4000 feddan respectively, then the decrement in the total yield and financial yield for the vulnerable area are about 13,000 ton and 6.0 MLC/Y (without SED) and 11.0 MLC/Y (with SED) for 2020, while for 2090 the decrement in yields are 63.000 ton and 253.0 MLC/Y (without SED) and 476.0 MLC/Y (with SED) respectively.

If the decrement in the total financial yield is related to GDP of the country, the result is a small fraction, which indicates no problem for the country, but it has a significant socio-economic impact on the local scale.

ii. Changing the Crop Types

The local problem may be solved if the crop types are changed on using new technology. In this domain, land production may be changed from one crop type to another, *e.g.*, field crops may be replaced by vegetables, and fruit trees by field crops. If the intrusion of the saline water into the soil will be much effective, the need for crops with higher salt tolerance would increase.

iii. Changing the Land Use Activity

In case of flooding, the land may be converted to aquaculture or fish farms. The financial yield of fish farms is about 2000 LC/feddan.

iv. Changing the Amount of Irrigation and Drainage Water

As mentioned above, reduction in the yield is presently experienced in some parts along the canal. With accelerated sea level rise, the vulnerable areas will increase. To practice the present crop types more water for irrigation is required, which in turn will produce more drainage water. The amount of drainage water obtained to remove the salt that accumulated in the soil through upward seepage were estimated and given in Table 10.

With ASLR of 0.3 m/30Y and 1.0 m/100Y, the land may suffer from increasing salinity either through sea water inundation or salt water intrusion. In both cases different actions must be correctly sighted and then executed to bring the land to better situation. For example:

a. At present. As already discussed, part of the near coastal land is exposed to salt water intrusion and hence deteriorating the salinity conditions in the root zone, which causes a reduction in the yield. From Table 10, only the fifth sector in the Suez area needs either upraising of the field to about 30 cm, which costs 0.55 million LC, or increasing water irrigation, which will release more drainage water of about 520 m^3/d (43.3 m^3/h). Due to the degradation of the land, few farmers have already started to upraise the land to increase the depth of the water table.

TABLE 10. Upward seepage, irrigation surplus and discharge water in 2020 and 2090.

Scenario & sectors		Area		Seepage		Irrigation surplus		Discharge	
		km^2	Fed.	Rate mm/d	Conc. ppm	Rate mm/d	Conc. ppm	Rate mm/d	Conc. ppm
Present situation	S1	0.228	54.5	0.4	1,200	1.2	0,300	1.6	0,420
	S2	0.218	51.8	0.4	2,000	1.2	0,300	1.6	0,580
	S3	0.762	181.4	0.4	3,200	1.2	0,500	1.6	0,940
	S4	2.357	561.1	0.4	8,000	1.2	0,600	1.6	2,000
	S5	0.368	87.7	0.4	12,400	1.2	0,700	1.6	3,630
Total or average		3.933	936.5	0.4	5,360	1.2	0,480	1.6 weighted av.	1,510 1,780
30 cm SLR (Year 2020)	S1	0.456	109.0	0.6	2,200	1.2	0,300	1.8	0,930
	S2	0.436	103.6	0.6	2,800	1.2	0,300	1.8	1,130
	S3	1.524	362.8	0.6	3,500	1.2	0,500	1.8	1,670
	S4	4.714	1122.2	0.6	17,200	1.2	0,600	1.8	6,130
	S5	0.736	175.4	0.6	21,300	1.2	0,700	1.8	7,570
Total or average		7.866	1873.0	0.6	9,400	1.2	0,480	1.8 weighted av.	3,490 4,820
1.0 m SLR (Year 2090)	S1	1.007	239.8	1.0	3,200	1.2	0,3	2.2	1,620
	S2	0.908	216.1	1.0	4,000	1.2	0,3	2.2	1,980
	S3	4,383	1043.6	1.0	4,600	1.2	0,5	2.2	2,360
	S4	8,564	2039.1	1.0	20,500	1.2	0,6	2.2	9,650
	S5	1.734	412.9	1.0	26,200	1.2	0,7	2.2	12,290
Total or average		16.596	3951.5	1.0	11,700	1.2	0,48	2.2 weighted av.	5,580 7,090

b. For 0.30 m ASLR or at 2020. In this case the 4th and 5th sectors are exposed to sea water intrusion, which they need either:

– To raise-up the land with sand or mud or a mixed stratum to about 60 cm height which costs about 51.0 MLC., or,

– To change the inundated area (2.725 km^2 (into fish farm with a financial yield of 2.6 MLC. Meanwhile, the rest of 2.725 km^2 may be washed from the accumulated salts releasing about 32.360 m^3/d (2700 m^3/h within 12h/d) as drainage water.

c. For 1.0 m ASLR or at 2090. Most sectors need either raising up the land to about 1.3 m height which costs 382.0 MLC, or changing an area of 13.112 km^2 into fish farm with a financial yield of 25.0 MLC, while the rest will need more water for irrigation to help in washing the accumulated salts to give rise drainage water of about 9.4* 10^4 m^3/d or 7800 m^3/h (within 12h/d), *i.e.*, 34.0 million m^3/Y.

From the different aforementioned scenarios, one may expect the followings:

a. Upraising the land seems to be the convenient way to solve the problem and to save the land from inundation or degradation. Although this procedure is regarded as an expensive solution, it has positive socio-economic impacts particularly if nourishment processes start early without any delay. Such treatment may need national or international support.

b. Washing the land from the accumulated salts to practice the present crops means increasing the irrigation supply and drainage water. Such increase in the irrigation water is difficult to attain due to the limiting amount of available water. Meanwhile, the increase of drainage water is also a problem due to the difficulties in drainage system or increasing the pumping capacity. This will cost much money in getting new strong pumps and the other expenses for maintenance and energy, which may cost together 20.0 MLC in 2020, and 40.0 MLC in 2090.

Identification and Specification of Response Strategies and Their Impacts

Identification of Response Strategies

The responses required for protect human life and property fall in three categories, which may be defined as follows:

Retreat

Such process means that no effort is taking place to protect the land and constructions from the sea. In this case, ecosystems will shift landward. Population must migrate and resettle in abandoned area, which needs constructions of new communities with new public facilities and new infrastructure. Accordingly, problems may be initiated due to:

- Interruption in family life,
- Loss of friendships,
- Change of traditions,
- Difficulties in getting new jobs and employments.

Accommodation

This means that life is going on in using land without doing any attempt to save the land from flooding events. In this case, land may be converted into fish-farming or cultivating salt tolerant crops. People may change their activities or may transfer their activities to other safety regions.

In the present case study, no appreciable subsidence observed in this region, and hence is considered statically stable. As a result subsidence is ignored.

Moreover, **the shore area along the lakes is more or less stable as the fetch in the present case study is very small, while the lakes may be considered closed shallow basins.** Generally, the coasts do not threaten by storm surges. Therefore, this response category has no influence on the area and consequently will not appear in the Vulnerability profiles.

Protection

This option requires one of the following solutions:

i. Soft solution using sand nourishment for beaches and lands.

ii. Hard solution by constructing sea walls and dikes.

Presently, the water-table level is high near the soil surface in the coastal plain. Some farms upraised by adding layers of sand translocated from sand dunes surrounding the area. The cost of upraising the threatened land is about 0.55 million LC.

In case of 0.30 m ASLR, both the beaches and low lands will be inundated. In such case soft solution using sand nourishment for beaches and lands will be applied. The process, for beach nourishment, costs 3.0-11.0 MLC (in case without SED) and 10.0-50.0 MLC (in case with SED), while for land nourishment it costs about 50.0 MLC.

In case of 1.0 ASLR, substantial loss will happen. To overcome this problem, hard solution using sea walls construction may be considered as the most preferable process. The costs for such protections may exceed 370.0 MLC (in case without SED) and 1800 MLC (in case with SED).

In addition to the above three categories improving scientific and public understanding of the problem is a critical component of any response strategy.

Specification of Response Strategies

It is proposed by IPCC (1992) to consider in each case study different situations of measures as:

1. A situation without measure, which is considered as a reference situation and will show the maximum impacts of natural and physical changes imposed by ASLR. This situation is specified with DO NOTHING "DONO".
2. The protection measure and in particular the full protection measure, which will reflect the maximum response cost due to minimizing the effects of natural and physical changes. This situation is partially specified into:

i. Local Response "LORE"

This response requires the followings:

a. soft solution using sand nourishment for
*Shore protection.
*Upraising land soil to increase water-table depth, to reduce the influence of flooding, and to practice different crops.

b. accommodation of agriculture processes by looking for crops which are tolerant with salty soil, and increasing irrigation water supply.

c. Improving the drainage system through planning a new system for drainage water particularly in case of 1.0 m ASLR, getting new strong pumps for the expected increase of drainage capacity, and relocation of new ground wells to be ready usable in case of salinization of the old ones.

ii. Full Response "FURE"

This response requires hard solution by constructing sea walls along the shore to protect it and to save the buildings and other facilities imposed to the waterfront.

At present, about 0.55 MLC is needed as assistance to farmers to raise up the field. In 2020 and 2090, assistance will be needed in the order of 50.0 MLC and 130.0 MLC respectively to raise-up the land with sand. More than 1000 MLC will be needed to manage new drainage system, to get new strong water pumps and other expenses for maintenance and energy.

On the other hand, to save the beaches from inundation using soft solution, financial assistance of about 50.0 MLC is needed for the year 2020. When using the hard solution the assistance may reach 1800 MLC.

Impacts of ASLR on Physical, Natural, Socio-Economic and Ecological Systems

Impacts on Physical and Natural System

On using GCM, Wigley (1992) showed that a doubling of CO_2 may increase average temperature in the Nile Delta of 0.5 to 2.5ºC by year 2030 with considerable increase in the rate of evaporation and a greater relative humidity. This warming rate is between two and seven times faster than the warming that has occurred over the past 100 years. Precipitation over Egyptian coastal areas could remain the same or decrease slightly. Accordingly, wind speed and direction will show different variability. Water circulation, wave characteristics and features of storms may also show different patterns. Generally, GCM models are being particularly unable to reproduce present weather condition at a regional scale (Sestini, 1992). The mean salinity is expected to decrease below 42.5 with the ASLR, particularly as the salinity in the Suez Bay showed diminishing values due to the continuous dilution with the domestic and industrial wastes (Soliman, 1996). Lake Timsah will show also drastic changes in salinity whereas water temperature will increase to values between 0.5-2.0ºC.

Such new environmental conditions will allow new marine species to immigrate between the two seas and to settle in the lakes. Hence, the fisheries in the lakes are expected to develop showing high production as well as high yield in the following decades.

On the other hand, the water circulation will show different patterns as a result of variation in sea level between the Red Sea and the Mediterranean, due to variation in the water density as well as to the influence of the dominating wind system. Numerical model has been used by Soliman (1995) to investigate the impact of ASLR on the water level due to semi-diurnal tide along the Canal. The expected water level shows different variability along the Canal, while the current becomes stronger. These changes in water level will be added to the assumed values of sea level rise given by IPCC to give the net change in water level. Moreover, there would be an increase in the water level resulting from storms (Sharaf El-Din *et. al*., 1990). Hence, different levels of impact will be obtained according to the different sea level rise scenarios.

The most threatened ones are those performed by ASLR of 0.5 & 1.0 m. Such levels may damage most of the coastal structures, tourist villages, cultivated lowlands that lying between 0-1 m contour lines as well as the infrastructures existing along the coast.

Impacts on Socio-Economic and Ecological Systems

Actually, there are two types of impacts that related to the physical changes (rise in temperature and increase in relative humidity) and to ASLR. If changes in sea level take place gradually, then the impact may not be quite noticeable within the first two decades.

The effect will seriously appear for more than 0.5 m ASLR, and become distortable when the rise exceeds 1.0 m. At this stage most of the low land areas will be flooded, people must migrate, the shoreline will decade, beaches will disappear, tourist villages may be inundated, and most of the infrastructures and roads would be affected.

Impacts on Lakes and Lagoon Ecosystems

In considering the marine environment it is expected that few species will get benefits due to the increase of temperature such as algae and seagrasses. Marine organisms could migrate landward as sea level rises.

If sand nourishment is applied, no harm will be gained particularly when these organisms accommodate themselves with the new environmental conditions, or when the land is converted to fish farms.

In case of hard structure a certain proportion will be lost. Also, the rise of the water temperature will increase the lakes productivity and helps in improving the environmental conditions for the growth of the different micro-macro- organisms as well as the different fish species and may assist in reappearing of the coral reefs and hence forming their fish communities. Hence, the increase of water temperature and the decrease of its salinity may create a new ecosystem in the lakes.

Therefore, appropriate lake managements are required to be established to develop their production and to encourage the development of the aquaculture projects in the region.

Vulnerability Analyses

It is assumed by IPCC (1992) that two distinct sets of boundary conditions might be used for ASLR to be reached by the year 2090. These two extremities conditions are given by: ASLR1 of 0.3 m and ASLR2 of 1.0 m. Table 11 gives the different cases considered in the present case study as reference and strategy cases.

Evaluation of Vulnerability Profiles

To evaluate the socio-economic impacts due to climatic changes, the vulnerability profiles were assessed for the different response options according to IPCC (1992). The results obtained in the different cases in 2020 and 2090 stage were presented according to three impact groups: "Values at loss", "Values at risk," and "Values at change" and are given in Tables 12 & 13.

TABLE 11. The different cases considered in the present case study.

	ASLR (cm/100 Y)	Time (Years)	Socio-economic development	Strategy
a – Reference cases:				
Case 1	0	0	NO	DONO
Case 2	100	30	NO	DONO
Case 3	100	100	NO	DONO
Case 4	0	30	YES	DONO
Case 5	100	30	YES	DONO
Case 6	100	100	YES	DONO
b – Strategy cases:				
Case 7	100	30	NO	LOCR
Case 8	100	30	YES	LOCR
Case 9	100	30	NO	NATR
Case 10	100	100	YES	LOCR
Case 11	100	100	YES	NATR (FULP)

*DONO : Do nothing, *NATR : National response
*LOCR : Local response, *FULP : Full protection.

TABLE 12. Coastal system vulnerability development scenario I.

Impact category	Present situation Case 1	No measures		Protect	
		No development Case 2	30 yrs development Case 5	No development Case 7	30 yrs development Case 8
Socio-economic value at loss					
1. Capital values (MLC)		153	1897	0	0
2. Subsistence value (per/1000)		28.0	22.0	?	?
Socio-economic values at change					
– Land use damage due to C.C. (MLC)	–	5.0	8.0	–	–
– Land use damage due to S.I. (MLC)	**5.0**	15.0	75.0		
– Other financial damage (MLC)	–	–	–	–	–
Ecological values at loss					
– Ecological area lost (km^2)		6.0	6.0	–	–
– Special area lost (km^2)		1.0	1.0	–	–
Cultural/historical sites at loss					
– Cultural/historical sites (# sites)	–	–	–	–	–
International tourism					
– Capacity (beds)	**9,434**	17,048	17,048	17,048	17,048
– Jobs	**7,076**	12,411	12,411	12,411	
– Income (MLC/y)	**50.0**	95	381	95	381
– Capital investment (MILC/y)	**602.0**	966	1344	966	1344
– Irrigation water (mill. m^3/y)					
– Drainage water (mill. m^3/y)		5.0	5.0	3.0	3.0
Cost of response strategy					
Local (MLC)					
– Lake shore protection	**2.0**	–	–	1.0	2.0
– Agriculture	**1.0**	–	–	2.0	50.0
– Revetment	–	–	–	1.0	1.0
National (MLC)					
– Soft solution	–	–	–	3.0-11.0	10.0-50.0
– Hard solution	–	–	–	113.0	352.0
Total cost (MLC)	–	–	–	124.0	435
– Decrement in agriculture production (Ton)		?	13,493	?	?
– Decrement in agriculture financial yield (MLC)		?	11.3	?	?

Legend:
MLC = Million Local Currency (Million Egyptian Pound) SI = Salinity-Intrusion
p = # people ? = Difficult to be predicted CC = Climate Change

TABLE 13. Coastal system vulnerability development scenario III.

Impact category	Present situation Case 1	No measures		Protect	
		No development Case 3	100 yrs development Case 6	No development Case 9	100 yrs development Case 10,11
Socio-economic value at loss					
1. Capital values (MLC)		800	57,534	–	–
2. Subsistence value (per/1000)		941.0	298.0	–	–
Socio-economic values at change					
– Land use damage due to C.C. (MLC)	–	2120	2900	–	–
– Land use damage due to S.I. (MLC)	5.0	15.0	70.0		
– Other financial damage (MLC)	–	1,500	15,000	–	–
Ecological values at loss					
– Ecological area lost (km^2)		20.0	20.0	–	–
– Special area lost (km^2)		3.0	3.0	–	–
Cultural/historical sites at loss					
– Cultural/historical sites (# sites)	–	2 sites	2 sites	–	–
International tourism					
– Capacity (beds)	9,434	–	–	25,626	34,096
– Jobs	7,076	–	–	18,616	24,822
– Income (MLC/y)	50.0	–	–	238	1,524
– Capital investment (MLC/y)	602.00	–	–	1,300	2,000
– Irrigation water (mill. m^3/y)					
– Drainage water (mill. m^3/y)					13.0
Cost of response strategy					
Local (MLC)					
– Lake shore protection	–	–	–	2.0	5.0
– Agriculture	–	–	–	50.0	130.0
– Revetment	–	–	–	12.0	250.0
– New irrigation system	–	–	–	10.0	1,000.0
National (MLC)					
– Soft solution	–	–	–	100	400
– Hard solution	–	–	–	271	1400
Total cost (MLC)	–	–	–	445.0	3185

Legend:
MLC = Million Local Currency (Million Egyptian Pound) SI = Salinity-Intrusion
p = # people ? = Difficult to be predicted CC = Climate Change

Socio-Economic Values at Loss

These values are based on land area losses and their respective capital or subsistence values.

In case 1, mostly no losses occur since its assess the present situation of the case study area. Small scatter areas seem to be affected by salt water intrusion along the canal which will appear in the case of socio economic values at change. Accordingly, no subsistence values at loss are observed. In case 2 and 5 relatively small areas are affected by shoreline retreat, while fmay cause some damage in the land and hence in the agricultural production.

The losses in capital values in case 5 (1897 MLC) are much greater than that obtained in case 2 due to the socio economic development, while for subsistence value the contrary will take place. In cases 3&6 substantial land areas will be lost. The losses in case 6 is extremely high in compare with case 3, due also to the socio-economic development. In addition, the losses in cases 5&6 are considerably higher than the losses observed in the cases 2&3. On the other hand, the losses of subsistence value are too high with no measure in the cases 3&6, but the losses in case 3 is much pronounced than in case 6. This feature could be easily reached if Table 8 is taken into consideration. It is important to emphasize that the impact due to the explosion of the population will be much worst than any other causes among of them the climatic change. The population in Egypt has the tendency to grow progressively reaching to more than 600 million in 2090, if the growth rate remains constant at 2.5% within the next century, to about 300 million if the growth rate is reduced by 0.01% annually and to about 200 million if reduced annually by 0.02%. Hopefully, much concern would be given to this matter and most likely new articles should be declared in such prospect. With local or national response strategies, no losses would be experienced in the cases 7-11.

Ecological Values at Loss and Change

The shore area is mostly reduced with ASLR, where an area of 60.0 km^2 is expected to be lost in 2020 and about 20.0 km^2 in 2090, which will have a negative impact on tourism activity. Since the case study area mostly extends along the lakes, the losses in lake ecology are difficult to be estimated.

Socio-Economic Values at Risk

These values are involved with people, capital values and subsistence values. Values at risk are expressed as the product of the specific value in a certain risk zone and the probability of a flooding event in the risk zone.

This impact group is actually ignored from the vulnerability profile tables, since the area considered is mainly far from the open sea and extends along the lakes & the proper Suez Canal, which are seemly calm and hence far from any flooding events.

Socio-Economic Values at Change

These values relate to salinity intrusion into the land and the associate water management impacts. Capital values at direct exposure to the sea for without and with socio-economic development are slightly affected with ASLR of 30 cm (cases 2&5). This feature will be completely changed with 1.0 m SLR, since land use damages may reach values of more than 2000 MLC.

As aforementioned, low land areas will suffer from salt-water intrusion, which already existing. It is expected that these areas will increase with ASLR. The farmers try to overcome this problem through upraising soil surface by adding layers of sand translocated from the nearby sandy-dunes. There is up-till now no significant variety of land degradation due to salinity intrusion for the cases 2&3 and the cases 5&6. No financial damage presents in cases 1,2&5, while in cases 3&6 most of the infrastructures will be affected.

Due to the increase of salinity intrusion into the land with ASLR, more water for irrigation is required and accordingly a substantial increase of drainage problems unless a new drainage water is expected, which may create severe drainage problems unless a new drainage system is established and more powerful pumps are added to the present ones located at Fayed and Fanara.

Ecological Values at Loss

These values are expressed in changes of habitat areas. The impact of ASLR and warming on coastal marine habitats as well as on the lake fisheries are difficult to be estimated.

Tourism sector on the other hand, is expected to show continuous development in the next decades. If no measures are considered, both on local and national scales, resort constructions and most of the tourism villages and hotels existing along the lakes may be exposed to a severe damages and the capital investment will be lost.

Cost of Response Strategy

In case of applying protection strategy, the area will be saved from flooding, showing no decrements in agriculture production and financial yield. The shoreline will remain at its present situation, and all structures at direct exposure with the sea will be highly invested.

The total cost for no measure in cases 1,2,3,5 and 6 is zero. Meanwhile, the cost of response strategy for the cases 7&8 in 2020 is 124.0 and 345.0 MLC respectively, and that for the cases 9&10 in 2090 is 445.0 and 3185.0 MLC respectively. It is clear that the protection cost, when applying either the soft or hard solution or both, will increase sharply from year to year and from decade to another.

Types of Assistance

In case of applying soft solution processes (sand nourishment), there is no difficulty in managing the work. Meanwhile, in case of ASLR of 1.0 m and applying hard solution processes (concrete wall), national and international Institutions in co-operation with the existing local ones are capable to implement and manage such work. In addition, there is a great need of financial support.

Conclusions

Due to Global warming and accelerated sea level rise, the environmental conditions of the coastal zone along the Suez Canal and its associated lakes will show in the next few decades rapid changes particularly in the soil nature. This is due to increase of evaporation, change in wind forces, more decrease in fresh-water supply particularly after the future expansion of land reclamation on both sides of the Canal, and to intrusion of salinity water.

1 – The impact of CO_2 and temperature increase will be of great concern particularly when it is combined with the population. The population in this area is expected to increase from about 700,000 in 1996 to 1.17 million in 2020 and 3.8 million in 2090 in Ismailia Governorate and from about 0.4 million in 1996 to 0.77 million in 2020 and 3.0 million in 2090 in Suez Governorate. In Egypt, the population tends to increase from about 61.0 million in 1996 to 100 million in 2020 and 308.6 million in 2090.

2 – The growth of population in the case study area will increase the encroachment of urban areas on agricultural lands and hence the crops production will be reduced, which is considered as one of the main components of the national income.

3 – Erosion and sedimentation may not have significant influence on the area, but inundation with 1.0 m ASLR may be one of the major events that deteriorate the environment.

4 – Accelerated sea level rise will threaten also the shoreline, the coastal communities, the infrastructures (as roads, fresh water supply includes drinking water, energy and sewage installations) and finally tourism activities.

5 – The impact on beach resorts without protection is expected to be negative. But adaptation to environmental hazards will manifest as a use of swimming pools, as experienced in the Red Sea and Mediterranean Sea tourist projects, as a result of marine pollution.

6 – Also, with the increase of temperature, few species may get benefits as algae and sea grasses, the production will increase, which may assist in reappearing of the coral reefs and hence forming their fish communities. Meanwhile, with ASLR marine organisms could migrate land wards. In case when sand nourishment will be applied, no harm will be gained particularly when these organisms accommodate themselves with new environmental conditions, or when the land is converted to fish farms.

Recommendations

1) The impact assessments of ASLR on natural, socio-economic and ecological systems after 30 or 100 years are actually difficult to be precisely evaluated. Shorter periods are more convenient in the assessment.

2) Most of the developing countries have no capability and expertise to organize the required pro-

cesses as well as possibility to manage and support projects on the impact assessments of ASLR.

3) ASLR, more or less, up till now is a phenomenon, which is not conveniently accepted either by the government or by the public. Therefore, information should be disseminated to the public (through newspapers, TV. and Radio)as well as to the decision-makers about the possible consequences of gradual changes in climatic conditions.

4) Due to the lack in data, it is recommended on regional or local scale to make plans to start a program for collecting data as a base line in different aspects to help in identifying the problems such as:

i. Monitoring of sea level rise, climatic conditions, water resources and salinity changes.

ii. Continuous estimation of the population intensity and growth rate.

iii. Surveying the distribution of the existing dunes.

iv. Getting satellite images of the region to follow up any changes, which are taking place with time.

5) Much concern must be given to all studies of the physical conditions and the application of the most appropriate technology for the alleviation of the impacts.

6) It is important to promote research works on the impact of warming on the behavior of marine organisms.

7) Concerns must be directed towards the studies on coastal-management and shore protection processes. In addition, no allowance might be given for new constructions along the coast without making sure that these areas are threatened one.

8) Real attempts must be strongly acted to demographic growth within the next decades to reduce as much as possible the population number.

9) Technical and financial assistance on the national level are needed to develop and implement strategies.

10) Any delay in conducting the protection strategies will increase the size of the problem and the costs of the protection processes.

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تقييم الخسائر الناجمة عن الانحباس الحرارى والارتفاع السريع لمنسوب سطح البحر وأثره على المناطق الساحلية الجنوبية لقناة السويس

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المستخلص. إن الزيادة في غاز ثاني أكسيد الكربون ودرجة حرارة الغلاف الجوى سوف يكون له أعظم الأثر ، خاصة عندما يؤخذ في الحسبان الزيادة المضطردة في عدد السكان في منطقة قناة السويس . ومن المتوقع أن يزيد عدد السكان في محافظة الإسماعيلية من ٧٠٠ آلف نسمة عام ١٩٩٦ إلي ١,١٧ مليون نسمة في عام ٢٠٢٠ وإلى ٣,٨ مليون نسمة في عام ٢٠٩٠ . وعلى هذا فإن الزيادة في عدد السكان في منطقة الدراسة سوف تؤدى إلى إغارة المناطق الحضارية على المناطق الزراعية ، وبالتالي إلى انخفاض الإنتاج الزراعي . وعمليات التآكل والترسيب ربما لا يبدو لها تأثير جوهري في منطقة الدراسة ، ولكن غمر الأراضي نتيجة للارتفاع السريع في منسوب سطح البحر ربما يعتبر أحد العناصر الغالبة التي تضر بالبيئة . بالإضافة إلى ذلك فإن التغير المتوقع في خواص المياه الجوفية في الأراضي المنخفضة قد يؤثر أيضا على إنتاجية المحاصيل . كما أن الارتفاع السريع لمستوى سطح البحر سوف يهدد أيضًا الشواطئ - المجتمعات الساحلية - البنية التحتية والأنشطة السياحية . ومن جهة أخرى ، فبعض الكائنات البحرية قد يجنى بعض الفوائد من زيادة درجة حرارة الغلاف الجوى مثل الطحالب والحشائش البحرية ، كما أن الإنتاجية الأولية قد تزداد ، والتي قد تساعد في إعادة ظهور الشعاب المرجانية في المنطقة ، وبالتالي إلى تكوين التجمعات السمكية الخاصة بها ، وقد تلجأ بعض الكائنات البحرية إلى الهجرة في اتجاه اليابسة لتتواءم مع المنسوب الجديد .

وبتقسيم منطقة الدراسة إلى قطاعات أمكن تقييم حجم الخسائر التى يمكن أن تنجم في المناطق المنخفضة على امتداد الساحل بالنسبة للسيناريوهات المختلفة (بعد: ٣٠ ؛ ٥٠ ؛ ١٠٠ سنة) على امتداد الساحل سواء في انحسار الشاطئ ذاته أو في المنشأت السكنية والسياحية إلى جانب الخدمات والبنية التحتية .

كما تم تقدير قيمة هذه الخسائر لكل سيناريو تبعا لنوعية الحلول المستخدمة إن كانت بسيطة عن طريق رفع مستوى المناطق المعرضة للغمر بالرمال خلال العقود الأولى ، والتي

يمكن معالجتها محليا ، أو حلول مركبة باستخدام الكتل الأسمنتية أو إقامة حواجز خرسانية على امتداد الشاطئ ، وقد تحتاج لمساعدات إقليمية ودولية . وفى حالة تطبيق الحلول البسيطة عن طريق ردم هذه المناطق بالرمال – لعلاج المشاكل التي قد تنجم عن غمر الشواطئ بمياه البحر – فإنه لن تظهر أية أضرار تذكر على الكائنات البحرية ، وخاصة عندما تتأقلم على الظروف الجديدة ، كما أنه يمكن تحويل هذه الأراضي المغمورة إلى مزارع سمكية .