ELSEVIER

Ocean & Coastal Management, Vol. 37, No. 1, pp. 29–40, 1997

Printed in Northern Ireland
PII: S0964-5691(97)00056-2 0964-5691/97 $17.00 + 0.00

Vulnerability assessment of the coastal zone of the Nile delta of Egypt, to the impacts of sea level rise

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ABSTRACT

A survey of the detailed quantitative assessment of the vulnerability of the Nile delta coast of Egypt to the impacts of sea level rise, is presented. GIS and remote-sensing techniques are used together with ground-based surveys to assess vulnerability of the most important economic and historic centers along the coast, the cities of Alexandria, Rosetta and Port-Said.

Results indicate that, in these cities alone, over 2 million people will have to abandon their homes, 214 000 jobs and over $ 35.0 billion in land value, property, and tourism income may also be lost due to a SLR of 50 cm. The loss of the world famous historic, cultural and archeological sites is unaccountable. The vulnerability of other low land in Egypt outside these cities remains to be assessed.

Development of institutional capabilities for ICZM and upgrading awareness are highly recommended for adaptation in the long run. Periodic nourishment of Alexandria and Rosetta beaches, detached break waters for Port-Said, and sand dune fixation are the recommended no regrets management measures.

1. INTRODUCTION

The vulnerability of various resources of Egypt to the impacts of climate change have been recognized since a long time. In particular, qualitative vulnerability assessment of water resources, agricultural resources and coastal zone resources have been investigated thoroughly.[1–4] The coastal zone of Egypt in particular, is most vulnerable to the impacts of climate change, not only because of the impact of sea-level rise, but also because of the impacts on water, agriculture and tourism resources and human settlements. A framework of an action plan has recently been advanced by Egyptian authorities.

The shoreline of Egypt extends for more than 3500 km along the Mediterranean Sea and the Red Sea coasts, (Fig. 1). The Nile delta coast under

General overview and coastal segments

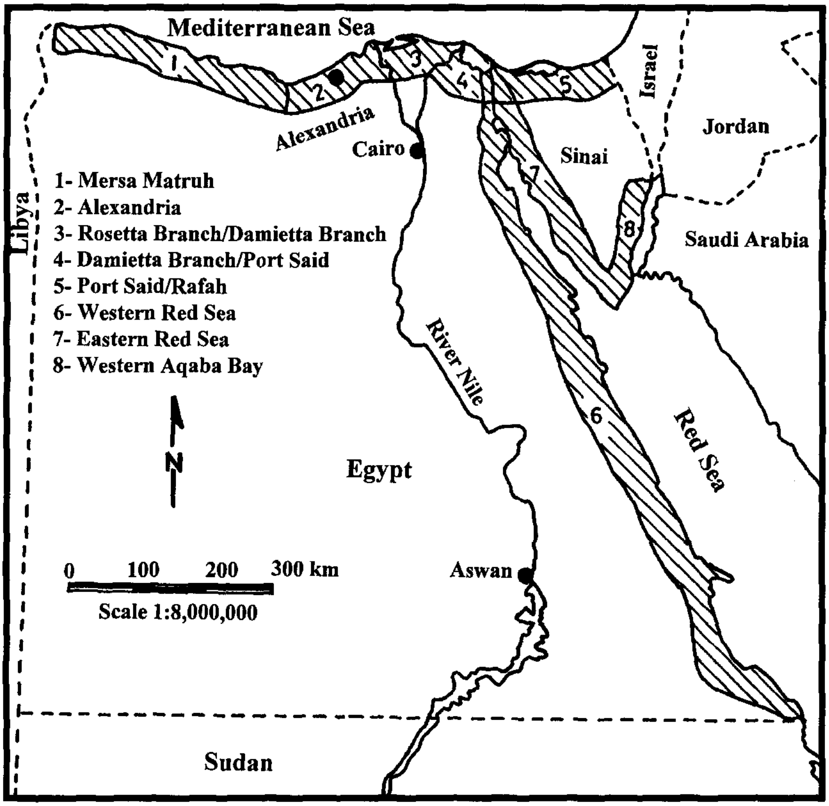


Fig. 1. The coastal zone area of Egypt.

consideration, constitutes only 250 km, and hosts a number of highly populated cities, such as Alexandria, Port-Said, Rosetta, and Damietta. These cities also encompass a large portion of the Egyptian industrial and economic sectors. In addition, the Nile delta coastal zone includes a large portion of the most fertile low land of Egypt. As a result of the large human activities in these cities, it suffers from a number of major problems including population pressure, interference of land use, pollution, water logging, and lack of institutional capabilities for integrated management.

The objective of this work is to survey the results of detailed quantitative assessment of the vulnerability of important cities of Egypt to the Mediterranean Sea; namely Alexandria, Rosetta and Port-Said.

Geographic information systems, remote-sensing and modeling techniques together with ground-based surveys, were used to assess potential impacts on each sector and to evaluate socioeconomic losses. The stepwise vulnerability assessment procedure, suggested by IPCC, has been followed to identify and quantify potential risks of each environmental sector for each district of these cities. A summary of the main results is presented below.

2. ALEXANDRIA CITY

Alexandria city is located to the west of the Rosetta branch of the River Nile and is famous for its beaches, historic and archeological sites. It is the second largest city in Egypt with a population of about 4.0 million. It hosts the largest harbor in the country and about 40% of the Egyptian industrial activities. During summer, the city receives over a million tourists. Extension of the city to the south is delayed by the existence of a large water body, Lake Mariout, south of the city. The level of water in Lake Mariout is kept at 2.8 m below SL by continuous pumping of lake water, into the Mediterranean.

In order to assess impacts of SLR on Alexandria city, a multi-band high-resolution LANDSAT image (TM, September 1995) of the city is classified to identify and map land-use classes. A geographical information system is built and upgraded[5–7] in ARC/INFO environment and included layers of

- City districts boundaries.
- Topographic maps.
- Land cover from satellite image classification.
- Land use classes.
- Population distribution and employment of each district

Figure 2 shows a part of the classified image for Alexandria city.

A scenario of sea-level rise of the city of Alexandria of 0.25, 0.5 and 1.0 m over the next century is assumed, taking land subsidence (2.0 mm yr^{-1}), into consideration. Percentage of population and land-use areas at risk for each scenario level, are identified and quantified by GIS analysis. Table 1 shows results of the risk of inundation due to each scenario, if no action is taken, or 'business as usual'. These results, together with statistical ground-based employment data are extrapolated to assess potential loss of employment for each sector. This is also presented in Table 2.

Analysis of the results indicate that for SLR of 0.5 m, if no action is taken, an area of about 30% of the city will be lost due to inundation. Over 1.5 million people will have to be moved away 195 000 jobs will be lost and an economic loss of land and properties of over $30 billions are expected over the next century. Figure 3 shows estimates of losses for each sector of each district in the city of Alexandria.

Fig. 2. Land use map obtained by satellite image classification.

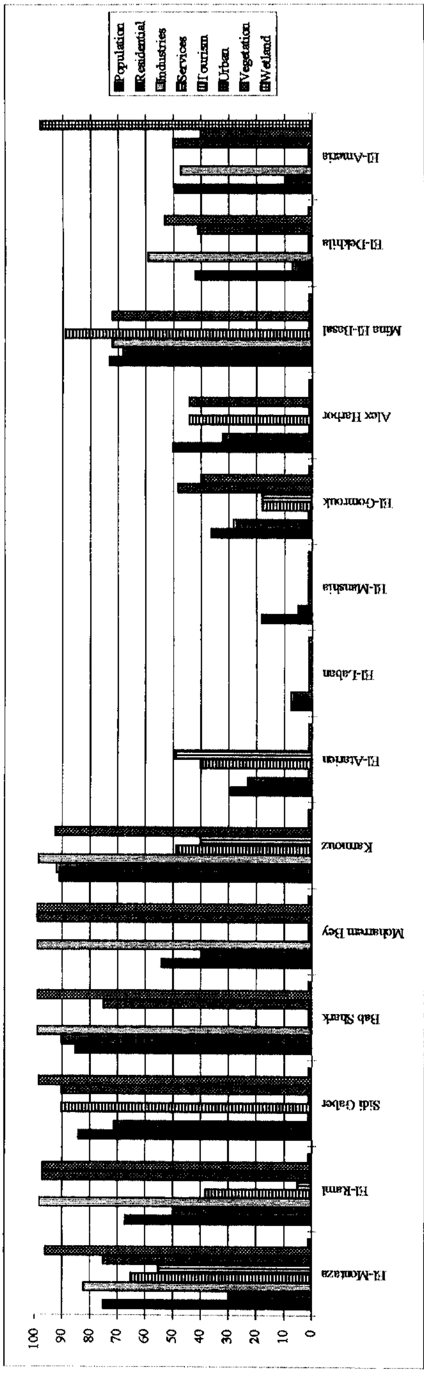
TABLE 1
Percentage areas, populations, and land use above each elevation contour

Sector/elevation (m)	0.0	*SLR* = 0.25	*SLR* = 0.5	*SLR* = 1.0
Population	54.9	40.1	33.1	24.0
Beaches	98.7	89.1	52.2	36.0
Residential	73.8	72.5	60.7	48.0
Industrial	46.1	43.9	34.1	27.8
Services	54.1	44.8	24.1	17.8
Tourism	72.0	69.0	51.0	38.0
Restricted area	80.0	79.0	75.0	73.0
Urban	62.0	56.0	44.0	33.0
Vegetation	45.0	41.0	37.0	25.0
Wetland	53.0	51.0	42.0	2.0
Bare soil	85.0	76.0	71.0	69.0

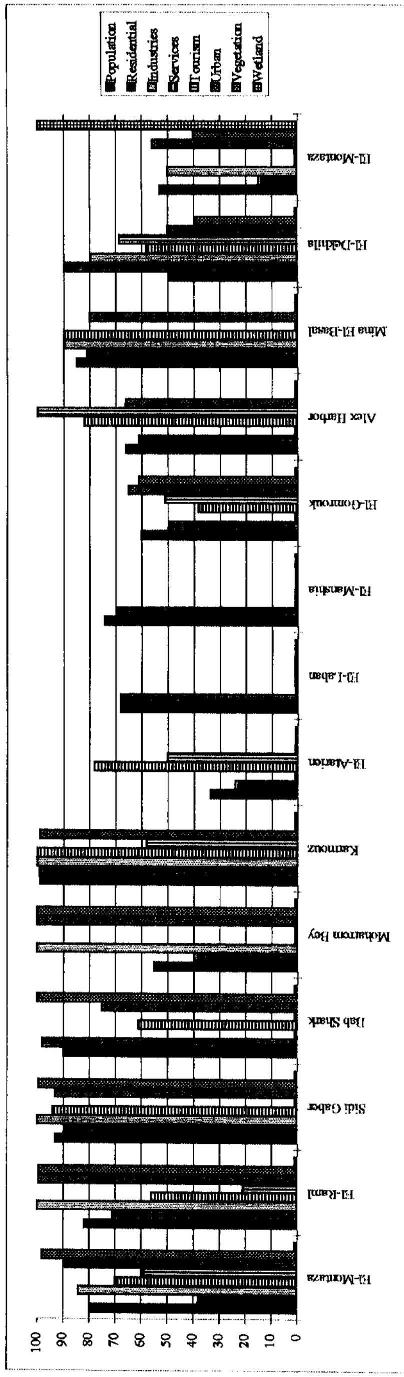
TABLE 2
Population expected to be displaced and loss of employment in each sector due to SLR scenarios in Alexandria Governorate

Year sector	2010, *SLR* = 18 cm	2025, *SLR* = 30 cm	2050, *SLR* = 50 cm
Area loss (km^2)	114	190	317
Population displaced × 1000	252	545	1512
Employment loss			
a–Agriculture	1370	3205	8812
b–Tourism	5737	12 323	33 919
c–Industry	24 400	54 936	151 200
Total loss of employment	32 507	70 465	195 443

In view of the severe losses in Alexandria due to sea-level rise, and the huge development in progress, and in the frame of 'no regrets policy', it is suggested that both a strategic plan and a short-term plan, have to be adopted. An integrated coastal zone management approach, including building provincial institutional capacity, upgrading awareness and expanding GIS and decision making process, must be adopted. On the short-term approach, it is concluded[5] that periodic beach nourishment is the cheapest alternative available, against direct inundation. However, the impact of salt water intrusion impact on water resources, soil salinization and building structures has to be further investigated and mitigated.



Percentage vulnerability to 0.5 m sea level rise of each Alexandria localities



Percentage vulnerability to 1.0 m sea level rise of each Alexandria localities

Fig. 3. Percentage potential loss of each sector and each district of Alexandria city for scenarios of 50 cm and 100 cm sea level rise.

3. ROSETTA REGION

Rosetta city is a well-known Pharaonic and Islamic city located in the Rosetta region near the intersection of Rosetta branch of the River Nile with the Mediterranean, east of Alexandria. Excessive erosional rates have been observed[6] near the Rosetta promontory, due to cessation of sediments after building the High Dam on the River Nile about 1000 km to the south. The region surrounding the city is well known for its water-logging and water-bogging problems.

In order to assess quantitatively possible impacts of sea-level rise, a high-resolution GIS of the city and surrounding area is built. The GIS includes layers of:

(1) Political boundaries
(2) Topographic maps
(3) Land use (urban, vegetation, historic, ...)
(4) Socioeconomic maps.

Detailed ground surveys were carried out to update and verify available maps. Impacts were evaluated based on land cover/land-use losses for every 20 cm of sea-level rise (SLR). Figure 4 shows a series of GIS plots illustrating vulnerable and safe areas for each 20.0 cm of SLR. Results were extended to estimate employment losses and economic losses for 50 cm SLR scenario based on extrapolated scenarios. Estimates[9] showed that about 1/3 of the employment power in the city will be affected and a loss of about $2.9 billion in land and property is expected, over the next century. The loss of historic and archeological sites is again unaccounted for. Table 3 presents results of impacts on each employment sector.

The government has built a massive sea wall near the tip of the promontory, as a protective measure against erosional problems. However, recent observations indicate that this massive hard structure is seriously challenged by coastal erosion. Beach nourishment may be a possible solution. Plans for development of the area should seriously consider ICZM approach in which decision making is based on a detailed GIS suitability analysis.

4. PORT-SAID CITY

Port-Said city is located on the Mediterranean Sea to the east of Damietta branch of the River Nile, at the entrance/exit of Suez Canal. In addition to its strategic position, it is the second largest tourist and trade center of Egypt on the Mediterranean. Lake Manzala, the largest of Nile delta lakes is located just to the west of the city and receives a sizable amount of effluent pollution

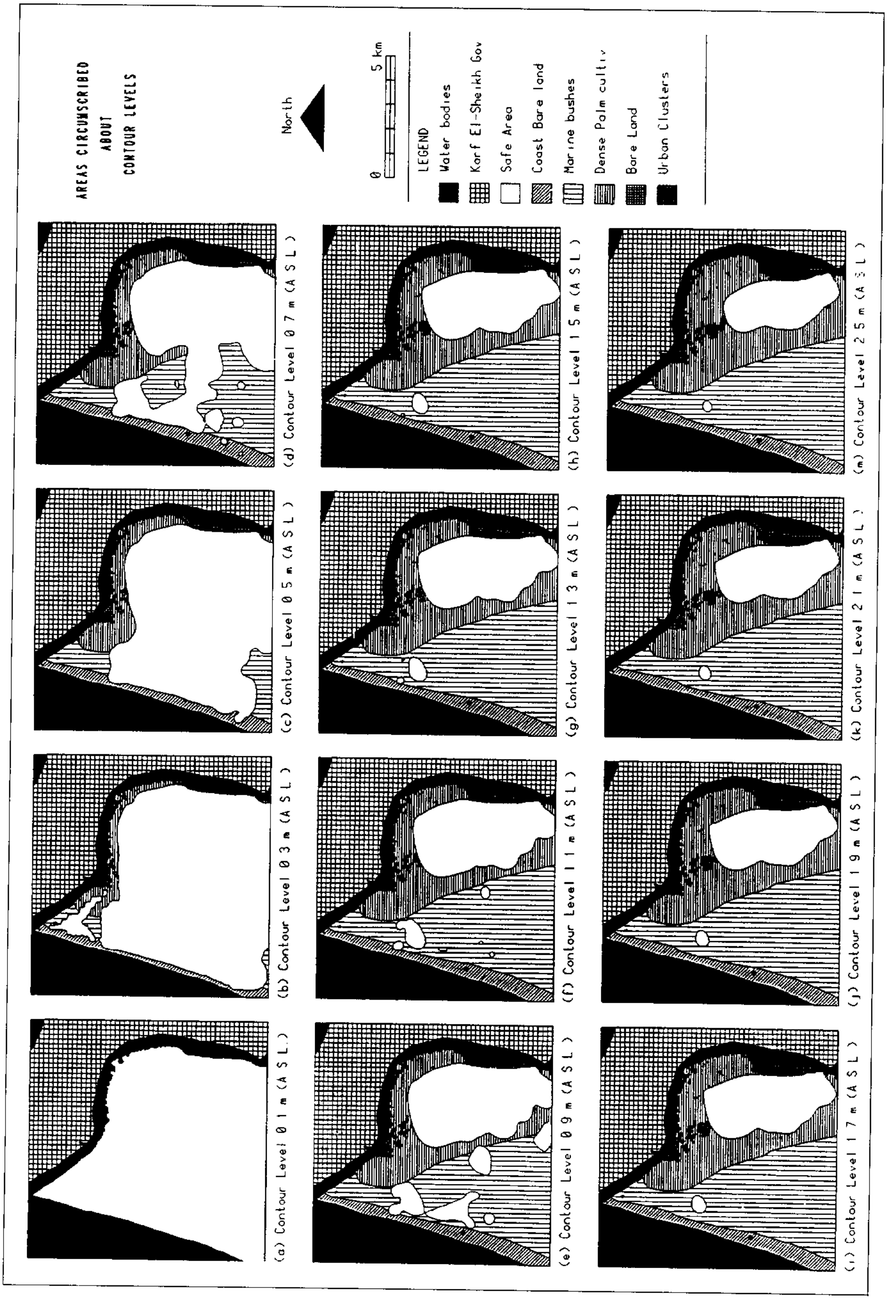


Fig. 4. A sequence of GIS produced maps of Rosetta area under various scenarios of sea-level rise [9].

TABLE 3
Estimation of expected loss in employment sector resulting from a 0.5 m rise in sea level at Rosetta [9]

Sectors of economic activities	*Actual employment* × (10^3)	*Employment expected loss (jobs)*
Agriculture and fishing	18.5	4633
Conversion industries	4.5	502
Municipal utilities	0.139	78
(Electricity, gas and water supplies)		
Construction and buildings	1.355	433
Commercial	2.877	1640
Transportation	2.191	1248
Community services	6.275	3576
Total	35.936	12 110
		(33.7% of all employment)

TABLE 4
Estimation of expected economic loss in land cover of Rosetta — (1995–1996 prices) [9]

Land cover	*Lost area* (m^2)	*Square meter price in US* (\$)	*Total estimated cost in US* (\$) *(Millions)*
Coast bare land	3 581 740	200	716
Marine bushes	4 504 750	150	675
Palm cultivation	5 790 260	200	1158
Bare land	27 508	250	7
Urban clusters	1 251 204	300	375
Total	15 155 462	–	2931

from various sources on the eastern region of the delta. A field survey has concluded that the Mediterranean coast of the city hosts the most important economic and tourist areas of the city, in addition to its relative low elevation. The impact of SLR on this part of the city is carried out in detail.

In order to assess possible impact of SLR, a GIS is built based on land cover land-use classification of a multi-band high-resolution LANDSAT image (TM, 1995) of the city. District boundaries, and socioeconomic data are also included, from ground-based surveys.[7] The city suffers from a relatively high rate of local land subsidence (5 mm yr^{-1}). Added to the (IPCC, 1995) expected rate of sea level rise over the next century (15–95 cm), a scenario of 50 cm, of 75 cm and 1.25 m, is assumed for this area.

Shoreline retreat distance is estimated from Bruun's rule for each scenario, based on survey results of Frihy.[8] Retreat distances are overlaid on various land-use and socioeconomic layers in the GIS. Vulnerable sectors areas are estimated for each district and for each scenario, and are presented in Table 5. The associated socioeconomic impact for each district is also estimated, and are tabulated in Table 6.

The results indicate that the city is highly vulnerable to the impact of SLR. The most severely impacted sectors are expected to be the industrial (12.5%) and transportation (11.7%) sectors. A loss of employment of over 6700 jobs (5.3%) is expected due to a SLR of 50 cm. Again the loss of historic sites is unaccounted for.

TABLE 5

Areas (km^2), population displaced and employment losses due to a SLR of 0.50 m in various districts of Port-Said Governorate [7]

Losses	*El Shark*	*El Arab*	*El Monakh*	*El Dawahy*	*Port Fouad*	*Total*
Beach area	0.426	0.377	7.419	—	13.039	21.26
Urban area	0.034	0.044	0.339	—	0.046	0.46
Industrial area	0.015	0.002	0.018	—	0.016	0.05
Agricultural area	0.000	0.000	0.000	—	0.000	0.00
Aquacultural area	0.000	0.000	0.000	—	0.024	0.024
Municipal service (#)	0.000	0.000	0.000	—	0.000	0.000
Transport network (km)	10.0	7.0	3.0	—	3.0	23.0
Population (persons)	3968	16 699	6503	—	1021	28 191
Employment (jobs)	953	4000	1558	—	248	6759

TABLE 6

Economic evaluation of beach, urban, industry, agriculture, aqua-culture areas (km^2) municipal services (#) and transportation network (km) losses of Port-Said Governorate in case of a SLR of 50 cm

	Losses	*Percentage*	*Value loss (million $)*
Beach area (km^2)	21.26	1.60	2126
Urban area (km^2)	0.46	7.80	48.0
Industry area (km^2)	0.05	12.50	5.0
Agricultural area (km^2)	0.00	0.00	0.00
Aquacultural area (km^2)	0.024	0.12	2.40
Municipal services (#)	0.00	0.00	0.00
Transport network (km)	23	11.73	4.6
Population (persons)	28 191	5.30	—
Employment (jobs)	6759	5.30	—

5. CONCLUSION

Application of the seven-stage vulnerability assessment methodology using GIS, remote-sensing and modeling techniques, have enabled a quantitative assessment of the risks of each sector and each district of three important cities of Egypt on the Mediterranean coast of the Nile delta, due to SLR. The technique has also enabled identification and quantitative assessment of vulnerable sectors and associated employment losses and is readily applicable to other vulnerable areas of the coastal zone of Egypt such as the city of Suez and city of Matruh for future planning.

Results indicate high vulnerability and severe economic losses. The coastal cities of the Nile delta are seriously vulnerable to a SLR of 50 cm, which may result in population displacement of about 2.0 million, loss of jobs of about 215 000 and value losses of over 30 billion, mainly in Alexandria city.

It is concluded that the integrated coastal zone management approach (ICZM) is a necessary tool for long-term sustainable development of the coastal area in Egypt. The severe land-use interference and the large population involved and conflicting requirements for development makes it necessary to use decision-support systems based on GIS for future development and planning of these areas.

Short-term adaptation measures are also necessary in the frame of the no regrets policy. These involve beach nourishment, sand dune fixation, upgrading awareness and building institutional capability in ICZM.

ACKNOWLEDGEMENTS

This work has been supported by US Country Study Program-Phase II, through the Egyptian Environmental Affairs Agency (EEAA) and GAIA multimedia project of EEC.

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