ADAPTATION TO THE IMPACTS OF SEA LEVEL RISE IN EGYPT

M. EL-RAEY, KR. DEWIDAR AND M. EL-HATTAB

Institute of Graduate Studies and Research, University of Alexandria, Alexandria, Egypt.

Abstract. Assessment of the vulnerability and expected socioeconomic losses over the Nile delta coast due to the impact of sea level rise is carried out in details. Impacts of sea level rise over the Governorates of Alexandria and Port Said in particular, are evaluated quantitatively. Analysis of the results at Alexandria Governorate indicate that, if no action is taken, an area of about 30% of the city will be lost due to inundation. Almost 2 million people will have to abandon their homeland; 195,000 jobs will be lost and an economic loss of over $3.5 Billion is expected over the next century. At Port Said Governorate results indicate that beach areas are most severely affected (hence tourism), followed by urban areas. The agriculture sector is the least affected sector. It is estimated that the economic loss is over $ 2.0 Billion for 0.50 m SLR and may exceed $ 4.4 Billion for 1.25 m SLR.

Options and costs of adaptation are analyzed and presented. Multi-criteria and decision matrix approaches, based on questionnaire surveys are carried out to identify priorities for the two cases. Analysis of these techniques of two options; the current policy (hard protection measures on some vulnerable areas) and no action (stopping these activities) have the lowest scores. Beach nourishment and integrated coastal zone management (ICZM) have the highest scores, however ICZM has high cost measures. The most cost-effective option is the land-use change, however with relatively very high cost measure. It is recommended that an ICZM approach be adopted since it provides a reasonable trade off between costs and cost effectiveness.

Key words: adaptation, climate change, socioeconomic impacts, Egypt.

1. Introduction

It has been well established that climate change is expected to take place over the next century in spite of the international effort for mitigation of greenhouse gas emissions. It is expected to exacerbate already existing environmental problems in many countries. In particular coastal areas all over the world are expected to suffer from impacts of sea level rise (SLR) as well as other impacts, in addition to already existing problems of coastal erosion, subsidence, pollution, land use pressures and deterioration of ecosystems. In Egypt, the most fertile land of the Nile Delta coast is vulnerable to the impacts of SLR (*e.g.,* Sestini, 1989). A detailed vulnerability assessment of the most important cities along the Mediterranean coast was studied. Cases of the cities Alexandria, Rosetta and

Mitigation and Adaptation Strategies for Global Change **4**: 343–361, 1999.

Port Said have revealed serious potential impacts of SLR on various socio-economic sectors (El-Raey *et al.*, 1995, 1997, and 1998).

If this is the case, then an anticipatory adaptation strategy must be developed in spite of the large uncertainty involved. The foundations, upon which this strategy is built, are the "precautionary principle" and the "no regrets policy". Smith (1994) has illustrated the importance of setting up priorities in spite of uncertainties of climate change. The objective of this paper is to present the results of a study carried out at Alexandria and Port Said Governorates to identify, assess and prioritize options for adaptation to sea level rise, and to carry out an economic evaluation of the required adaptation measures.

2. Adaptation Assessment Methodology

The steps followed for implementation of the adaptation strategy follows the guidelines published by Carter *et al*. (1994). A broad framework for the evaluation of adaptation strategies to cope with climate change can be identified. This comprises the following steps:

- Defining the objectives.
- Specifying the climatic impacts of importance.
- Identifying the adaptation options.
- Examining the constraints.
- Quantifying measures and formulating alternative strategies.
- Weighting objectives and evaluating trade-offs.
- Recommending adaptation measures.

2.1. DEFINING OBJECTS

Some overall goals and evaluation principles must guide any analysis of adaptation. Two examples of general goals commonly propounded are (i) the promotion of sustainable development, and (ii) the reduction of vulnerability. These are open to various interpretations, however, so specific objectives need to be defined that complement the goals. Objectives are usually derived either from public involvement, from stated public preferences, by legislation, through an interpretation of goals such as those stated above, or any combination of these.

2.2. SPECIFYING THE CLIMATIC IMPACTS OF IMPORTANCE

This step involves an assessment, following the methods outlined elsewhere above, of the possible impacts of climate variability or change on the exposure unit. Where climatic events are expected that will cause damage, these need to be specified in detail so that the most appropriate adaptation options can be identified. A complete vulnerability assessment must be carried out so as to identify as accurately as possible the extent of the damage expected.

2.3. IDENTIFYING THE ADAPTATION OPTIONS

The main task of assessment involves the compilation of a detailed list of possible adaptive responses that might be employed to cope with the effects of climate. The list can be compiled by field survey and by interviews with relevant experts, and should consider all practices currently or previously used, as well as possible alternative strategies that have not been used, and newly created or invented strategies. Six types of strategies for adaptation to the effects of climate have been identified:

- ***Prevention of loss***, involving anticipatory actions to reduce the susceptibility of an exposure unit to the impacts of climate.
- ***Tolerating loss***, where adverse impacts are accepted in the short term because they can be absorbed by the exposure unit without long term damage.
- ***Spreading or sharing loss***, where actions distribute the burden of impact over a larger region or population beyond those directly affected by the climatic event.
- ***Changing use or activity***, involving a switch of activity or resource use to adjust to the adverse as well as the positive consequences of climate change.
- ***Changing location***, where preservation of an activity is considered more important than its location, and migration occurs to areas that are more suitable under the changed climate.
- ***Restoration***, which aims to restore a system to its original condition following dam age or modification due to climate.

Numerous options exist for classifying adaptive measures, but generally, regardless of there sources of interest (*e.g.*, forestry, wetlands, agriculture, and water) the prospective list may include among other management measures:

- Legal
- Financial
- Economic
- Technological
- Public education
- Research and training.

2.4. EXAMINING THE CONSTRAINTS

Many of the adaptation options identified in the previous step are likely to be subject to legislation or be influenced by prevailing social norms, which may encourage. restrict or totally prohibit their use. Thus, it is important to examine closely, possibly in a separate study, what these constraints are and how they might affect the range of feasible choices available. Two important criteria should be taken into consideration when considering adaptation strategies: (Smith, 1997)

(1) Flexibility

(2) Benefits must exceed costs

2.5. QUANTIFYING MEASURES AND FORMULATING ALTERNATWE STRATEGIES

The next step is to assess the performance of each adaptation measure with respect to the stated objectives. It may be possible, if appropriate data and analytical tools exist, to use simulation models to test the effectiveness of different measures under different climatic scenarios. Historical and documentary evidence and survey material or expert judgments are alternative sources of this information. Uncertainty analysis and risk assessments are also considered at this stage. This step is a prelude to developing strategies, which maximize the level of achievement of some objectives while maintaining baseline levels of progress towards the remaining objectives.

2.6. WEIGHTING OBJECTIVES AND EVALUATING TRADE-OFFS

This is the key evaluation step, where objectives must be weighted according to assigned preferences and then comparisons made between the effectiveness of different strategies in meeting these objectives. Standard impact accounting systems can be used in the evaluation. For example, a four-category system might consider : *(i)* national economic development; *(ii)* environmental quality; *(iii)* regional economic development; and *(iv)* other social effects. Selection of preferred strategies then requires the determination of trade-offs between the categories.

2.7. RECOMMENDING ADAPTATION MEASURES

The results of the evaluation process should be compiled in a form that provides policy advisers and decision-makers with information on the best available adaptation strategies. This should include some indication of the assumptions and uncertainties involved in the evaluation procedure, and the rationale used (*e.g.,* decision rules, key evaluation principles, national and international support, institutional feasibility, technical feasibility) to narrow the choices.

3. Methodology

The methodology adopted for identifying and assessing adaptation involved two stages:

3.1. IDENTIFY ADAPTATION OPTIONS AND ATTRIBUTES

This is carried out by designing and administering a questionnaire based on a person to person direct contacts with various stakeholders in vulnerable areas. The objective is to collect information on options of adaptation and to upgrade awareness of stakeholders. Scientific, engineering and economic evaluation of obtained adaptation options is carried out, based on pre-specified criteria. The multi-criteria approach of Adaptation Simulation Evaluator (ASE) and Tools for Screening, Evaluation and Selecting Adaptation Measures

(TEAM), are applied. An adaptation decision matrix approach based on cost effectiveness of adaptation measures has also been evaluated.

Identifying evaluation attributes is an important topic to be discussed by the evaluation team. The following attributes were reached at as the most important attributes: expenses, net benefits, environmental impacts, robust and flexibility, chance of success, feasibility and fairness. Each adaptation option will be evaluated based on a score of 10 for each of the above mentioned attributes.

3.2. EVALUATE AND ASSESS EACH OPTION

Data on the costs of various operations have to be collected from previous experience and published and unpublished reports. These must be used together with economic evaluations, and perhaps through contacts with organizations of interest to evaluate and assess each option from various points of view.

4. Case Studies

We shall consider the two cases of Alexandria and Port-Said Governorates. As it is necessary to have in depth understanding of vulnerability of our case studies for decision-making concerning adaptation, we shall consider results of the vulnerability assessment of the two case studies.

4.1. VULNERABILITY ASSESSMENT OF ALEXANDRIA GOVERNORATE

Alexandria (Fig.(1)) is the second largest city in Egypt. It hosts the largest harbor in the country and about 40% of the Egyptian industrial activities. Alexandria waterfront beach is located along the northwestern border of Nile Delta coast. The city is built on a narrow coastal plain extending from Marakia to Abu Quir. The city lies between Lake Mariut to the south and the Mediterranean Sea to the north. Alexandria coastal plain is composed of a series of shore-parallel carbonate ridges (about 35-m elevation), which are separated by depressions of shallow lagoons and sabkhas. Alexandria is the second largest city in Egypt and containing more than one third of the national industries, it is also considered as the principal seaside summer resort on the Mediterranean. The population exceeds 4.0 million. More than one million local summer visitors together with about 4.0 million residents enjoy the summer season at Alexandria every year. Beach erosion. rip currents. sea level rise and pollution are the main problems affecting coastal management at Alexandria (El-Raey, *et al.,* 1995; Frihy, *et al.,* 1996).

A multi-band LANDSAT image (Thematic Mapper, Sept.1995) of the city is classified to identify and map land use classes. A geographic information system was built (El-Raey *et al.,* 1995, El-Raey *et al.,* 1997) in ARC-INFO environment and included layers of:

- City district boundaries

- Topographic maps
- Land use classes
- Population and employment of each district Archaeological sites.

A scenario of 0.25m, 0.50m and 1.0m sea level rise over the next century is assumed, taking land subsidence, (2.5mm/yr), into consideration. Percentage population and land use areas at risk for each scenario are identified and quantified. Table1 shows results of the risk of inundation due to each scenario "if no action is taken". These results are used to assess potential loss of employment for each sector.

Sector/Elevation(m)	0.0	SLR=0.25	SLR=0.5	SLR=1.0
Population	45	60	67	76
Beaches	1.3	11	47.8	64
Residential	26.2	27.5	39.3	52
Industrial.	53.9	56.1	65.9	72.2
Services	45.1	55.2	75.9	82.2
Tourism.	28	31	49	62
Restricted area	20	21	25	27
Urban	38	44	56	67
Vegetation	55	59	63	75
Wetland	47	49	58	98
Bare soil	15	24	29	31

Table 1. Percentage areas, populations, and land use loss for each elevation, contour of the city of Alexandria.

Analyses of the results indicate that, if no action is taken, an area of about 30% of the city will be lost due to inundation. Almost 2 million people will have to abandon their homeland; 195,000 jobs will be lost and an economic loss of over $3.5 Billions, are expected, over the next century. The most severely impacted sectors are agriculture, industry and tourism, respectively. However, employment analysis, shown in Table 2, indicates that the order of severely impacted unemployment sectors will be different. These will be industry, tourism and agriculture, respectively. A detailed assessment of the impact on each district of the city has also been carried out.

Year Sector	2010 SLR=18cm	2025 SLR=30cm	2050 SLR=50cm
Area loss(km^2)	114	190	317
Population displaced x1000	252,000	545,000	1,512,000
Loss of Employment			
a-Agriculture	1,370	3,205	8.812
b-Tourism	5,737	12,323	33.919
c-Industry	24,400	54,936	151.200
Total loss of employment	32,507	70,465	195,443

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

4.2. VULNERABILITY ASSESSMENT OF PORT SAID GOVERNORATE

Port Said Governorate is located on the northeastern part of the Nile Delta between latitudes of 30°50' and 31°00' N; longitudes 32°00' E and 32°30'E. The Governorate has a total area of about 1351 km^2 and is divided into five districts: El Shark, El Monakh, El Arab, El Dawahi and Port Fouad (Table 3). The population of Port Said Governorate is about 0.5 million with average population density of 391 person/km2 and a rate of population growth of 1.45%. The actual cultivated land in Port Said Governorate is about 483 km^2. This represents about 2.38% of Egypt's agricultural activities. The total reclaimed area for agriculture is about 567 km^2. The main income of this Governorate depends on revenue from Suez Canal, tourism, free trade zones and industrial activities. The industrial activities include food canning, cloth making, carpets, and leather industry (IDSC, 1995). The city assumes a strategic importance because of its location on the inlet/outlet of Suez Canal and because of being the largest economic center close to Sinai on the Mediterranean.

Districts	Area (km^2)	Population (person)	Density (person/km^2)	Employment's
El Shark	5.68	52905	9319.8	12700
El Arab	2.52	111621	44276.48	26670
El Monakh	258.97	227011	876.58	54483
El Dawahi	516.66	92877	161.06	22352
Port Fouad	566.52	44350	78.28	10795
Total	1350.35	528764	-	127000

Table 3. Statistics and population census of Port Said districts during 95/96 (IDSC, 1995).

The coastal zone of Port Said area is socio-economically important to most of the population in this area. Tourism is primarily oriented towards swimming and sunbathing. Therefore, the coast, its slope and quality of beach and sea are of prime importance to this industry. Most tourist facilities such as hotels and youth camps are located within 200 to 300m of the coast. There are also important archeological sites along the northern part of Suez Canal. Many environmental problems exist in the coastal zone of Port Said, in general. Of particular importance are problems of beach erosion, pollution, subsidence and sea level rise. These are detailed as follows:

4.2.1. Beach Erosion

The promontories of the Nile delta, Rosetta and Damietta, are presently undergoing extensive change from both natural and anthropogenic pressures. The highest rate of erosion occurs along the outer margins of these promontories. This erosion is a result of the combined effects of cut off of River Nile sediment discharge by the High Dam and prevailing coastal processes (Nafaa and Frihy, 1993).

Erosion along the tip of Damietta promontory has adversely affected homes and condominiums to the east at Ras El Bar, and destroyed the old coastal road from Damietta to Port Said and the lighthouse west of the river (Frihy, *et al.*, 1996). However, a number of

protective structures have been constructed along this promontory to reduce shoal migration in the river entrance. These structures are described in detail by Fanos *et al*., (1995). Sea level rise is expected to enhance rates of erosion.

4.2.2. Pollution Problems

The western and southern sectors of Lake Manzala are supplied by drainage water from seven main sources. Water of these drains enriches the lake with nutrients including phosphate, nitrate and silicate. In addition, some of these drains discharge considerable amounts of sewage and industrial wastes directly into the lake. The Ginka subbasin in the southeast sector of the lake is identified as a "black spot". Sea level rise is expected to enhance dispersion and adverse effects of this pollution.

4.2.3. Subsidence and SLR

The eastern part of Lake Manzala (Port Said and the northern part of Suez Canal) appear to subside faster than any other region along the Nile Delta coast. Sea level rise is expected to cause a land ward shift of the salt wedge and to increase the rate of saline seepage to the topsoil of the delta. This may have a serious impact on agriculture and drainage conditions, and potentially on available groundwater resources in the upper Nile delta. In addition, the salinity in Lake Manzala may increase because of a stronger influence of tidal flows penetrating the lake. Changes in the salinity conditions of Lake Manzala may lead to impacts on Lake Ecology and fisheries. Accelerated sea level rise will enhance increase in salinity. Combined with the notion that it is unlikely that the lake will expand inland (as protection measures will be taken), this leads to the general prediction that shallow wetland areas will decrease and that the reed beds will become less abundant (due to higher salinity).

4.2.4. Socioeconomic Impacts

The most serious impacts of sea level rise on Port Said Governorate would be the threat to recreational beach communities as well as to other activities in the coastal zone. Based on the adopted local sea level rise scenario of 0.50m, 0.75m and 1 .25m, losses of land area, urban areas, industrial areas, vegetation areas, population and employment, are estimated. Estimates of losses were carried out by overlying Brunn's horizontal retreat distances over land use areas obtained from satellite images and ground surveys (El-Raey *et al*, 1998). Tables 4 shows vulnerable areas, population expected to be displaced and possible economic losses for 0.5m SLR scenario. Results indicate, that beach areas are most severely affected (hence tourism), followed by urban areas. The agriculture sector is the least affected sector. Percentages as well as expected economic losses for each sector are tabulated in Table (5). Even though beach areas affected are large, the percentage loss in industrial areas, transportation network and urban areas are the most serious, respectively. It is estimated that the economic loss is over $ 2.0 Billion for 0.50m SLR and may exceed $ 4.4 Billion for 1.25 m SLR.

About 28,000 to 70,000 people are expected to be displaced and a loss of at least 6,700 to 16,700 jobs are expected to be lost for the scenario adopted. The socioeconomic

impacts of excessive beach erosion are dramatic. Industry play a good role for employment income in Port said Governorate, due to the existence of Suez Canal. This sector will be affected by SLR, its loss is about 12.5% in case of half meter SLR (Table 5).

Losses	El Shark	El Arab	El Monakh	El Dawahi	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
Industry area	0.015	0.002	0.018	-	0.016	0.05
Agriculture area	0.000	0.000	0.000	-	0.000	0.00
Aquaculture area	0.000	0.000	0.000	-	0.024	0.024
Municipal services (#)	0.000	0.000	0.000	-	0.000	0.000
Transportation network (km)	10	7	3	-	3	23
Population (persons)	3968	16699	6503	-	1021	28191
Employment's	953	4000	1558	-	248	6759

Table 4. Physical and socioeconomic losses of Port Said Governorate due to SLR 0.50m.

	Losses	Percentage	Value losses (million $)
Beach area	21.26	1.60%	2126
Urban area	0.46	7.80%	92
Industry area	0.05	12.50%	25
Agriculture area	0.00	0.00%	0.00
Aquaculture area	0.024	0.12%	2.40
Municipal services (#)	0.00	0.00%	0.00
Transportation network (km)	23	11.73%	4.6
Population (persons)	28191	5.30%	-
Employment	6759	5.30%	-

Table 5. Summary of Socioeconomic impacts in Port Said Governorate due to SLR 0.50m.

5. Adaptation Studies for Impact of SLR

Evaluating adaptation strategies is an increasingly urgent task for economic sectors of vulnerable regions such as Alexandria and Port Said. A multi-criteria approach may be more effective for anticipatory adaptation evaluation than single-metric approaches such as cost-benefit analysis and multi-attribute utility analysis. This judgment is based on a belief that, social decisions regarding climate change impacts are better considered in the context of a range of attributes that often go beyond those of cost-benefit analysis in its pure form (Smith, 1994). The Environmental Protection Agency supported development of adaptation strategy evaluator as a user friendly software tool that, not only explains the methodology, but also assists in the multi-criteria assessment process with carefully structured analysis steps and presents visual displays.

In this study, we explore the possible solutions to protect Alexandria and Port-Said Governorates against the SLR, using the multi-criteria approach for assessing strategies for anticipatory adaptation to climate change. A questionnaire was administered to the

inhabitants and stakeholders of lowland areas vulnerable to sea level rise. It was designed to assess and upgrade their awareness concerning the problem of sea level rise and to find out acceptable coastal protections and adaptation measures.

To develop an adaptation strategy, the current activities and policy of coastal protection, must be known. A review of coastal protection activities in progress, durability of structures, design and costs of implementation along the Nile delta coast, are presented.

5.1. REVIEW OF COASTAL PROTECTION WORKS

Fanos *et al.,* 1995 presented a review for all the protection works along the Nile delta coast. This, together with a discussion of the lifetime of the structure can be summarized as:

5.1.1. West of Alexandria

The new drain at western Nobariya drain outlet is about 20 km to the west of Alexandria. Two jetties of 65m length were constructed in 1986 to protect the exit from siltation, and they are functioning effectively (Fanos *et al.,* 1995).

5.1.2. Eastern Harbor of Alexandria

A 180m extension of the existing west breakwater would narrow the gap between the west and central breakwaters from its existing 300m width to 100m (Tetratech, 1986). This decrease in gap width would reduce wave heights along the critical area of the Cornish.

5.1.3. Alexandria beaches

Five beaches, El Shatby, Stanley, Sidi Bishr, El Asafra and El Mandra, were nourished by medium to coarse sand transported from the desert near Cairo.

5.1.4. Abu Quir Bay

The Abu Quir Sea wall was built in 1780 and has been maintained by placement of additional large concrete blocks. This wall was modified and reinforced in 1980 by constructing a sloping face (2:1) and placing modified cubes of 0.5 ton each as an armor layer.

5.1.5. West of El Gamil Regulator and Inform of El Fardos village

In 1994, four detached breakwaters began to be constructed in the area to protect it from erosion. Each breakwater is 250m long and is constructed from a barge, mounted plant at a water depth of 4m. The cost of these four breakwaters is 11.7 million pounds (Delft Hydraulics, 1991). These are still under execution.

5.1.6. El-Gamil Outlet

Two jetties of 225 and 200 m on the western and eastern sides of El Gamil outlet, respectively, are constructed to protect this outlet from siltation and migration. The cost of these two jetties was 2.57 million pounds, ((Delft hydraulics, 1991).

5.1.7. Highway near El Gamil Airport

A small bituminous dike of about 4l0m length was constructed to protect the low parts of the coastal road near the airport from flooding. The cost was 3.3 million pounds, (Delft hydraulics, 1991).

5.2. THE LIFE-TIME OF A STRUCTURE

Generally, a structure is designed and built according to the relevant conditions and general design criteria as deemed applicable, including the anticipation of foreseeable changes. The latter may arise from natural trends or human intervention. The structure may be given some extra strength, or measures may be taken to facilitate future adaptation.

In general, shore protection structures in many instances are designed for a life time of 50 to 100 years, depending on their function, type, importance, and on the stability of the coast (Delft hydraulics, 1991). Parts of a structure may have a shorter lifetime; they will have to be replaced or reconditioned at certain intervals within the lifetime of the whole structure.

Reasons for adoption of a structure in the course of the lifetime may be:

- Changes of external physical conditions such as sea level rise, subsidence, erosion and related changes of currents and waves.
- Deterioration of structure.
- Socio-economic developments requiring a higher safety criterion and
- Technological advances.

5.3. LENGTH OF THE STRUCTURE

The length of a sea defense structure is generally determined by the size of the area to be protected and by the expected threat of the sea. Socio-economical and geomorphologic developments may lead to increased length.

5.4. IMPACT OF SEA LEVEL RISE ON THE STRUCTURE

A rise of sea level relative to the crest level of a structure may consist of the following components:

- Compaction of the structure itself and of the local bed
- General subsidence of the subsoil in the area
- Natural sea level rise and
- Extra sea level rise as a consequence of the increased greenhouse effect.

Primary effects of relative sea level rise may be a deepening of the water in front of a structure, greater wave heights inducing more severe wave attack, and more wave run up. A practical point is that design and construction must start well in advance to ensure that an adaptation is completed in time to ensure that safety never falls below the adopted criteria (Delft hydraulics, 1991).

5.5. COSTS OF COASTAL PROTECTION

The actual costs of the basic coastal defense measures against sea level rise along Alexandria coast are given in Table 6 according to the experience of Shore Protection Authority (SPA) and Coastal Research Institute (CRI) (Tetratech, 1986). A 10% increase over the latest published data is expected over the last decade.

BEACH NOURISHMENT PROJECTS	Quantity (m^3)	Cost ($)	Unit price
STANLEY	40,135	340,000	8.47/m^3
EL CHATBY	150,000	1,080,000	7.20/m^3
SIDI BISHIR	33,319	696,000	20.89/m^3
ASAFRA	85,575	620,000	7.25/m^3
MANDARA	104,783	580,000	5.54/m^3
ABU QUIR	34,455	240,000	6.97/m^3
ABU QUIR SEA WALL	4,500m	10,000,000	2,200/m

Table 6. Costs of Recent Coastal Engineering Works (Tetratech, 1986).

6. Adaptation Study Methodology

Two methods are used for evaluating selected measures (Decision Matrix and Adaptation Simulation Evaluator (ASE)). The Decision Matrix analyzes cost-effectiveness of adaptation measures by comparing costs of adaptation measures with benefits measured in a common metric, but not necessarily dollars. Such measurements can be added up across the different policy objectives (weighted based on relative importance) and compared to costs to determine cost-effectiveness (*e.g.*, cost per point on the ordinal scale) and rank measures.

The multi-criteria approach (Adaptation Simulation Evaluator) for assessing strategies for anticipatory adaptation to climate change, developed by U.S. Environmental Protection Agency is adopted. ASE uses a question and answer format to guide users through the process of structuring and performing multi-criteria comparison of strategies. No default assumptions or values are present in the system. Therefore, the comparison is intentionally kept at a simple enough level that specific underlying models are not needed unless the user desires. ASE does include databases of site types, climate change forecasts based on several General Circulation Models (GCMs), potential vulnerabilities, and associated adaptation options. Elements from these databases are provided to users in the form of guidance, and suggestions to consider in the process of structuring an analysis. ASE guides the analyst through five analysis steps:

- Characterize technical and policy objectives and situation and identify critical vulnerabilities to climate change.
- Select or design adaptation strategies.

- Select or design evaluation attributes.
- Score strategies for each attribute (along relative or absolute scales).
- Analyze results using visual displays (changing priorities, sensitivity analysis, *etc*).

Before we carry out evaluation of adaptation measures, we shall consider options in somewhat more details:

6.1. BEACH NOURISHMENT AND GROINS

Beach nourishment includes depositing sand onto the open beach and beach scraping, building artificial dunes as storm buffers and beach sand reservoirs, and laying pipes underneath the beach to suck in the water and trap sand. Groins are accompanied with beach nourishment to trap sand, which fill the beach. These groins are hard structures perpendicular to the coastline. The expense of this strategy is very cheap compared to other strategies. The net benefit (direct and indirect impact) of this strategy is good because it forms new beaches for tourism and creates good chance for employment. The environmental impact of this strategy is fair particularly for the beach. It is good for fishing due to migration of fish to offshore. The flexibility (success of the strategy on the long-term) of this strategy is good against sea level rise. The chance of success is good. This strategy needs periodic nourishment. The public acceptance (feasibility) of this strategy is excellent and the expected environmental impact (fairness) along other coastal areas is excellent, as long as the nourishment is carried out periodically for vulnerable beaches. This strategy has no effect on fishermen, perhaps it increases fishing due to sand material may be contain new source of nutrients for fish. Beach nourishment has no effect on the farmers because it protects their land form flooding and salt water intrusion. Also, this strategy has no effect on the industrial workers because it protects the factories and workers from flooding. The best advantage of this strategy is maintaining the beach for tourism, protecting hotels, and adding jobs for people working in the tourism sector.

6.2. BREAKWATERS

Breakwaters are hard structures used to reduce the wave energy reaching the shoreline. These breakwaters are set up offshore as submerged breakwaters, or build riprap along the shore to absorb wave energy. This strategy is relatively very expensive. The net benefit of this strategy is only along the coastline not on the social community or ecosystem. The environmental impact of this strategy is fair, but it is considered to be the best available tool for protection of lowland areas. The flexibility is good and also the chance of success. The feasibility of implementation of this strategy is good. People staying along the coastal area need to protect themselves from coastal erosion. This strategy affects fishing processes so, the fishermen need new tools and modern motor boats for fishing offshore. Breakwater is a good tool for protecting cultivated land. All infrastructures are located along the coastal areas, so the farmers, industrial workers and employees in tourism sector are not affected by this strategy.

6.3. LEGAL DEVELOPMENT REGULATION

Legal development regulation means taking legal or regulatory actions to restrict development or prohibit redevelopment of a hazard-prone area. For example, adopt erosion based setback regulation, or adopt post storm reconstruction restrictions, or changing tax structure to discourage development. In our case this strategy is poor for expenses, good for net benefits and excellent for environmental impact. But in Egypt it is not effective. Regulations have no active enforcement particularly in prone areas. In any developing country the rules are enforced because public agree to it for public benefit. This strategy is fair for feasibility and fairness. The chance of success of this strategy is bad if socioeconomic considerations are taken into account. This strategy has no effect on the fishermen, farmers and industrial workers, but may affect the businessmen.An institutional capability for monitoring and assessment such as a remote sensing system is necessary for implementation of this option.

6.4. INTEGRATED COASTAL ZONE MANAGEMENT (ICZM)

Coastal areas are experiencing rapid population growth. This growth comes at the expense of natural environments, it increases pollution, and often requires protection against erosion and /or coastal flooding during storm surges. Accelerated sea level rise is another stress on the natural and human ecosystem, which should be taken into account within the planning framework. Redirecting growth away from sensitive lands and toward less vulnerable areas is one option to reduce the risks associated with a sea level rise and also, to reduce vulnerability to other problems of the coastal zone. ICZM implies best possible use of resources under multi-critrial analysis. It requires the availability of a geographic database, monitoring system such as remote sensing and a decision support system, the availability of which requires advanced training and investment.

6.5. LAND USE CHANGE

The option of change of land use in the vulnerable land is still an open one. The objective is to change to a less vulnerability lard use or to another land use which makes better use of the lowland such as aquaculture. A slight or moderate SLR may be quite beneficial for development of aquaculture on the coastal areas (Ibrahim, 1997).

6.6. NO ACTION

This strategy means nothing is done to address the problem and let things continue, as they are. Expenses of this strategy are nothing and net benefit is fair. The environmental impact and feasibility are excellent. This strategy may have future negative effects because it could result in flooding the cultivated land, waterlogging, and damage for hotels, factories and infrastructure facilities. So, the fishermen, farmers, industrial workers and businessmen are affected. This strategy is considered different from the “Business as usual” strategy, as the latter involves continuation of the work in progress.

7. Results of Evaluation

7.A. ALEXANDRIA CASE STUDY

7.A.1. Identification of stakeholders

The vulnerability assessment of sea level rise of Alexandria area has identified stakeholders as:

- Fishermen
- Industry workers
- Businessmen
- Farmers and others

7.A.2. Public perception and awareness, Alexandria

A questionnaire was prepared and administered by direct person to person interviews with a random sample from main stakeholders. The questionnaire is supplemented by Arabic explanation of the problem in order to upgrade awareness of the vulnerable groups. The random sample size represents 100 persons, who cover the main stakeholders of Alexandria Governorate. This sample is not statistically significant, however, it is considered good enough to give qualitative indications of major directions. Table (7) gives a summary of the results of percentage answers of the questionnaire for various stakeholders.

		Fishermen	Farmers	Industrial Labors	Business-men	Tourism
Barriers	• Admin.	3	60	11	29	57
	• Time	15	7	4	5	7
	• Cost	62	13	71	42	29
	• Don't know	20	20	14	24	7
Response	• No Response	9	13	0	8	0
	• Take Action	92	87	100	93	100
Action	• Protect	50	60	50	71	-
	• Immigrate	40	13	21	17	64
	• Change Job	-	-	21	4	7
	• Don't care	10	27	8	8	29

Table 7. Percentage values of opinions on barriers, response and suggested action at Alexandria Governorate.

The most important observations are:

- A strong feeling among almost all stakeholders for the need to protect.
- A strong feeling among all stakeholders that the cost is a main barrier.
- The weak tendency of changing jobs among all stakeholders.
- The wide variation of opinions on barriers, responses and recommended actions among stakeholders. This may reflect their varied interests in coastal problems and their flexibility in responses.
- The weak percentage of stakeholders who do not know barriers and do not care about solutions.

7.A.3. Decision Matrix, Alexandria

The decision matrix for the case of Alexandria is shown in (Table 8). Analysis of the decision matrix indicates that the current policy (hard protection measures on some vulnerable areas) and no action (stopping these activities) options have the lowest scores. Beach nourishment and ICZM have the highest scores, however ICZM has high cost measures. The most cost-effective option is the land-use change, however with relatively very high cost measure. It is recommended that an IZCM approach be adopted since it provides a reasonable trade off between costs and cost effectiveness.

		Weighted objectives					
		Protect Property	Flood Avoid	Coast develop	Wetland preserve		
	Weights	3	3	3	1		
Measures	Scenario					Score	Total score
Current policy	SLR	6	5	4	2	47	95
	No SLR	5	3	7	3	48	
Beach Nourish.	SLR	7	6	8	6	69	150
& Groins	No SLR	9	7	9	6	81	
Breakwaters	SLR	8	8	5	7	70	150
	No SLR	9	8	7	8	80	
Legal Dev.	SLR	2	2	3	4	25	101
Regulation	No SLR	8	8	7	7	76	
ICZM	SLR	8	7	7	7	73	158
	No SLR	9	8	9	7	85	
Land-use Change	SLR	3	2	3	6	30	100
	No SLR	8	7	6	7	70	
No action	SLR	3	2	3	2	26	55
	No SLR	4	2	3	2	29	

Table 8. Coastal Resources Adaptation Decision Matrix (1-10 scale), Alexandria.

7.A.4. Adaptation Strategy Evaluation, Alexandria

Table (9) represents the results obtained from analysis of the adaptation strategy evaluation for Alexandria case study.

	Adaptation strategy options					
Evaluation Attributes	Beach Nourish. & Groins	Break-waters	Legal Develop, Regulat.	ICZM	Land-use change	No action
Expenses	54 Million$	468 Million$	20 Million$	550 Million$	900 Million$	2.5 Billion$
Net benefits	9	5	9	9	4	2
Env.Impact	7	6	8	9	2	3
Robust / Flexibility	9	8	7	8	4	2
Chance of success	9	8	7	8	5	2
Feasibility	9	9	6	8	6	2
Fairness	4	5	4	2	7	8
Total score	47	4	41	36	28	17

Table 9. Adaptation strategy evaluation matrix (scale 1-10) for the case of Alexandria Adaptation strategy options.

Analysis of the results of the ASE again indicates the preference for beach nourishment and groins approach. However, the authors cannot overlook ICZM for its strategic benefits.

7.B. PORT SAID CASE STUDY

7.B.1. Stakeholders in Port Said were identified as:

- Fishermen
- Industry workers
- Businessmen
- Others

7.B.2. Population perception and options, Port Said

A random sample of 100 people was selected for person to person discussions and information exchange. The results of analysis of a questionnaire showed that. about 86% are aware of the problem of SLR, 74% are not welling to move away from the area for any adaptation measures, 32% think that decision makers are not serious in protecting the city against SLR, and 50% think that fish farms are the most proper option for adaptation. Options for adaptation were explained and discussed based on person to person contacts. Results are consistent to a great extent with those of Alexandria case study.

7.B.3. Decision Matrix, Port Said

The decision matrix evaluated based on the questionnaire results and costs from table 6 are presented in table 10.

		Weighted objectives					
		Protect Property	Flood Avoid	Coast develop	Wetland preserve		
	Weights	3	2	3	2		
Measures	Scenario					Score	Total Score
Current policy	SLR	4	2	6	2	38	8
	No SLR	5	3	7	3	48	
Beach nourish.	SLR	7	6	8	6	69	14
& Groins	No SLR	9	7	9	6	81	
Breakwaters	SLR	8	8	5	7	72	15
	No SLR	9	8	7	8	80	
Legal Dev.	SLR	2	2	3	4	27	10
Regulation	No SLR	8	8	7	7	75	
ICZM	SLR	8	7	7	7	78	10
	No SLR	9	8	9	7	84	
Land-use	SLR	3	2	3	5	32	9
Change	No SLR	8	7	6	7	65	
No action	SLR	3	2	3	2	26	5
	No SLR	4	2	3	2	29	

Table 10. Coastal Resources Adaptation Decision Matrix (1-10 scale), Port Said.

Investigation of the results of the decision matrix indicates that, the current policy and no action options are of low and nearly equal scores. However, installation of breakwaters and ICZM are of the highest scores. Even though the cost is very high, the cost effectiveness of land-use change is also high. It is recommended that an ICZM approach be followed since its cost of implementation and cost effectiveness are reasonable.

7.B.4. Adaptation Strategy Evaluation, Port Said

Table (11) presents the adaptation strategy evaluation matrix.

	Adaptation strategy options					
Evaluation Attributes	Beach Nourish, & Groins	Break-waters	Legal Develop Regulat.	ICZM	Land-use change	No action
Expenses	81 Million $	702 Million $	2 Million$	200 Million$	648 Million $	2 Billion$
Net benefits	8	2	9	9	6	2
Env.impact	7	4	8	9	5	4
Robust / Flexibility	8	6	7	8	6	4
Chance of success	9	8	7	9	5	2
Feasibility	9	9	6	8	6	2
Fairness	9	7	4	7	4	2
Total score	50	36	41	50	32	16

Table 11. Adaptation strategy evaluation matrix (scale 1-10) for Port SaidAdaptation strategy options.

Beach nourishment, legal development regulations and ICZM have the highest scores.

8. Summary and conclusion

From the Decision matrix and ASE we get the following results:

- Almost all stakeholders in both vulnerable case studies think that protection is highly needed. Even though costs of some options of protection may be very high, the losses on the long run are even higher. A strategic view must be adopted taken into account considerations such as socioeconomic, awareness and cultural aspects.
- A combination of beach nourishment and hard structures would be best options available for protection of most of the coastal areas on the Nile delta.
- ICZM is the best strategic option in case of availability of financial support. This may involve land use changes to aquaculture in some areas, hard protection in some other areas and legal regulations in the rest of the areas. These options are the most recommended by multidisciplinary study team. However, the implementation of that option may not be easy unless financial support and upgrading of awareness are provided.

References

Carter.T.R.; M.L.Parry; R.Harasawa and S.Nishioka; 1994. *IPCC Technical Guidelines for Assessing Climate Change Impacts and Adaptations;* WGII, l994.

Delft hydraulics. 1991. 'Implications of relative sea level rise on the development of the lower Nile Delta. Egypt.' Pilot study for a quantitative approach. Final Report. April, 1991.

El-Raey, M.. Nasr, S., Frihy, O. Desouki. S. and Dewidar. Kh., 1995. 'Potential impacts of accelerated sea-level rise on Alexandria Governorate. Egypt.' *Journal of Coastal Research,* 14:190-204.

El-Raey, M.. Ahrned, S. and Korany, E., 1998. 'Remote sensing and GIS for vulnerability assessment of the impact of sea level rise over Alexandria city and vicinity, Egypt.' *Int. J. Remote Sensing* (In print).

El-Raey, M., Fouda, Y. and Nasr. 5., 1997. 'GIS Assessment of the vulnerability of the Rosetta area, Egypt to impacts of sea rise'; *Environmental Monitoring and Assessment,* vol 47,1, p59-77.

El-Raey, M., Frihy, O., Nasr, S., and Dewidar, Kh., 1998. 'Vulnerability assessment of sea level rise over Port-Said Governorate, Egypt.'; *J. Environmental Monitoring and Assessment* 00:1-16.

Fanos, A. M., Khafagy, A. A., and Dean, R. G., 1995. Protective Works on the Nile Delta. *Journal of Coastal Research.* 11:516-528.

Frihy, O. E., Dewidar, Kh., and El-Raey, M., 1996. 'Evaluation of coastal problems at Alexandria. Egypt.' *Ocean & Coastal Management,* 30:281-295.

IDSC, 1995. 'Periodic Bulletin produced by the Cabinet Information & Decision Support Center of Port Said Governorate.'

Ibrahim, 1997. *Aquaculture in relation to effect of environmental changes in Egypt*; Unpublished.

Nafaa, M. G., and Frihy, O. E., 1993. 'Beach and nearshore features along the dissipative coastline of the Nile Delta, Egypt.' *Journal of Coastal Research,* 2:423-433.

Sestini, G., 1989. 'The Implications of Climate Changes for the Nile Delta.' Report WG 2/14. Nairobi. Kenya; UNEP/OCA.

Smith, A.E., and H. Q. Chu., 1994. *A multi-criteria approach for assessing strategies for anticipatory adaptation to climate change.* Decision Focus Incorporated (R261 Ia), Washington, D. C. 20036.

Tetratech, 1986. *Shore Protection Master Plan for the Nile Delta.* Report to shore Protection Authority. Ministry of Irrigation. Cairo.