Impact of Sea Level Rise on the Arab Region

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Glossary

AFED	Arab Forum for Environment and Development
CCI	Climate Change Index
COP	Conference of Party
DEM	Digital Elevation Model
HDI	Human Development Index
HFA	Hyogo framework of Action
ICZM	Integrated Coastal Zone Management
IPCC	Intergovernmental Panel on climate Change
LAS	League of Arab States
PPP	Public – Private Partnership
RCDRR	Regional Center for Disaster Risk Reduction
RCM	Regional Circulation Model
SLR	Sea level rise
UNFCCC	United Nations frame work convention on climate Change
UNISDR	United Nations International Strategy for Risk Reduction
WRI	World Resources Institute

Contents

1 Executive Summary

A survey has been carried out basic findings of global warming and its implications to the coastal zone with particular emphasis on sea level rise. The vulnerability of the Arab countries to potential impacts of sea level rise and frequency of extreme events has been considered. It was well recognized that many locations in the Arab region are highly vulnerable to the potential impacts of sea level rise, salt water intrusion and increase of frequency and severity of storm surges. In addition it was also well recognized that the population at large and stakeholders and decision makers in particular are unaware of the kind of risk they will be exposed to in the future.

The Nile delta region in Egypt as well as the northern part of Mauritania and many coastal sites in the Gulf countries and North Africa are found to be highly vulnerable. The vulnerability is not only due to direct inundation of large areas but also due to salt water intrusion and its potential impact on groundwater resources and soil salinization. The impacts are reflected on land productivity, income and health conditions of the population. Implications of increasing severity and frequency of extreme events will also be reflected in higher risk of droughts, water scarcity, flash floods, increasing mortality and economic losses.

The objective of this report is to identify and assess some of the main vulnerable areas to sea level rise in the Arab world. A survey of a country by country case studies, based on initial national communications and second national communication as well as recent published literature is also presented. The main objective is to identify vulnerabilities to sea level rise and to assess adaptation measures and point out the urgent need to build up institutional and human capacities to approach the problem and to identify gaps, points of strength and points of weakness, options of adaptation and needs for sustainable development.

A SWOT analysis identifying points of weakness and points of strength of various aspects of climate adaptation in the Arab countries has also been worked out. A critical analysis of threats and opportunities for action in the Arab world has also been presented. It was concluded that:

1. *Most of the Arab countries, if not all, are extremely vulnerable to the impacts of sea level rise not only through direct inundation but also due to salt water intrusion*

2. *Shortage of institutional systems for climate change in general and sea level rise in particular has severely limited proactive planning and development of policy and measures to adapt to potential impacts which cover all sectors of development*
3. *Shortage systematic observation of coastal systems and changes, lack of integrated geographic data basis of indicators(e.g. land subsidence in particular), regional models and awareness represent serious gaps in the process of decision support*
4. *Vulnerability to sea level rise and its implications on water resources, food security, tourism and public health for all Arab countries cannot be overlooked*
5. *With the expected increase of frequencies and severities of extreme events, the shortage of institutional systems for preparedness and risk reduction mechanisms could be detrimental.*

The pressing need for integrated adaptation infrastructure and institutional capability for monitoring, building data basis and periodic assessment and risk reduction in all Arab countries is an important prerequisite for proactive planning, follow up and sustainable development. Options for adaptation and criteria for selection are based on established criteria and priority issues of each country taking into account activation of the precautionary principle. These mainly include;

1. *Building infrastructure and institutional capabilities for monitoring, modelling, vulnerability assessment and development of policies, measures and enforcement of regulations*
2. *Carrying out research on water availability and management, food security and salt tolerant plants, coastal extreme events and water conservation programs*
3. *Creating job opportunities and development plans in safe areas and enforcement of Strategic Environmental Assessment (SEA) and Environmental Impact assessments (EIA) taking into account climate changes and sea level rise implications*

The report ends with a set of analytical conclusions and adaptation recommendations which include:

4. *All Arab countries are particularly vulnerable to potential impacts of sea level rise. Almost none has established a strong institutional capability for adaptation with particular emphasis on monitoring capabilities*
5. *All Arab countries should carry out massive programs for detailed vulnerability assessment, investigate open options for adaptation and develop strategies, policies and measures in all sectors of development*
6. *Almost all Arab countries need to build up resilience for vulnerable communities and carry out proactive planning for integrated coastal zone management and job creation and development in non-vulnerable coastal areas*
7. *Regardless of the expected magnitude of the sea level rise, taking action for adaptation is necessary whether we have sea level rise or not*

2 Introduction to Global SLR as a Phenomenon

Global warming and climatic change processes are now unequivocal. The global warming due to increasing concentrations of greenhouse gases in the atmosphere is estimated at 0.13 degree per decade (IPCC, 2007) and is expected to have a full range of temperature projection of 1.1 degree to 6.4 degree by the end of this century. This range of temperature rise is expected to lead to melting of polar caps and expansion of water in deep oceans with a corresponding increase of sea level. It was estimated (IPCC, 2007) that a sea level rise between 18 and 58cm is expected by the end of the century. However, recent published estimates have greatly expanded these values to reach more than 180cm as shown in Fig (2.1).

In addition to expected sea level rise, global warming is also expected to be associated with an increase of the severity and frequency of extreme events. These changes are expected to seriously impact water resources, food security, tourism, natural resources and socioeconomic conditions which would have important implications on the sustainable development in the region.

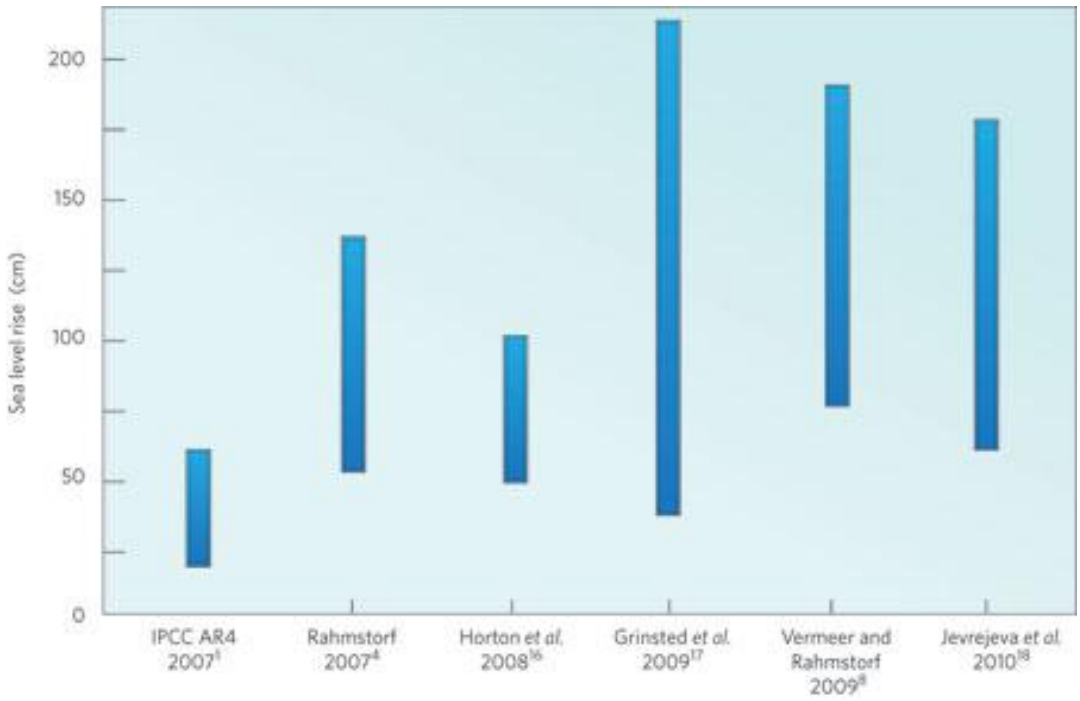


FIGURE 2.1 RECENTLY PUBLISHED ESTIMATES OF SEA LEVEL RISE DUE TO GLOBAL WARMING

Recent measurements by ground based observations as well as satellite observations have indicated an acceleration of the rates of sea level rise (Figure 2.2.). However, a number of researchers are still discussing the accuracy of the magnitudes of sea level rise

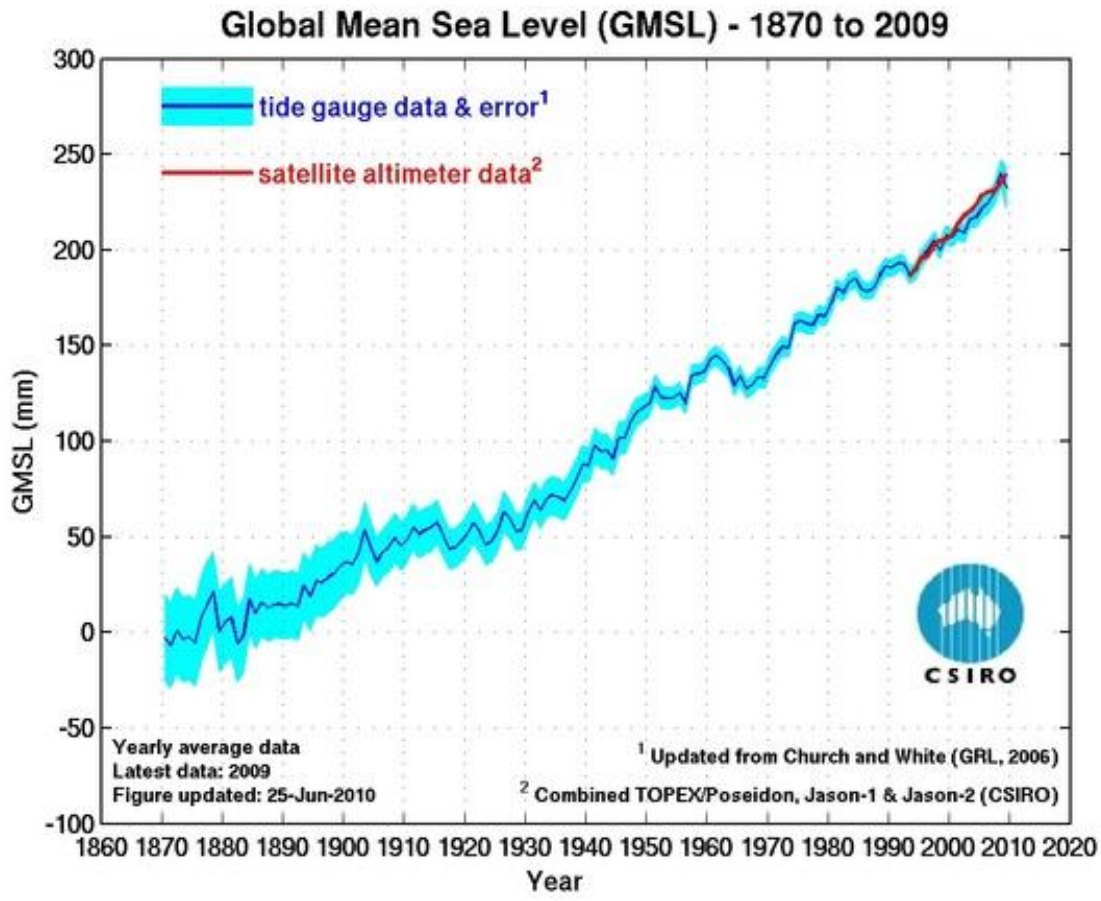


FIGURE 2.2 MEASURED GLOBAL MEAN SEA LEVEL (GMSL) OVER THE PERIOD (1860-2010) AS OBSERVED BY GROUND BASED AND SATELLITE OBSERVATIONS ILLUSTRATING CHANGING RATES OF SEA LEVEL RISE

Realizing the seriousness of problems of climate change and sea level rise in Rio World Conference 1992, member countries of the UN signed the United Nations Framework Convention on Climate Change (UNFCCC) and afterwards Kyoto Protocol for controlling greenhouse gas emissions. They have also attended a number of conferences with the

intention of reaching agreement between developed and developing countries concerning control of greenhouse gas emissions. The Intergovernmental Panel on Climate Change (IPCC) through its intensive programs has identified and assessed problems on the global scale and has recommended immediate mitigation and adaptation measures for developed and developing countries. So far, no final satisfactory agreement has been reached and many developing countries are still looking forward for the next Climate Change Conference of Parties (COP 16) in Cancun, Mexico during Dec, 2010 for a new start.

Also, the United Nations International Strategy for Risk Reduction (UNISDR) has realized the growing global understanding of threats associated with increasing frequency and severity of extreme events and weather disasters and adopted the Hyogo framework for action 2005-2015 on "Building the Resilience of Nations and Communities (HFA)". One hundred and sixty eight nations committed themselves to substantially reduce the loss of life and livelihood from disasters by implementing HFA.

3 Climate Change and Sea Level Rise in the Arab Region

The Arab region, which mainly covers North Africa and the Middle East, is located in area of hyper Arid to semi-arid environment with excess of energy resources (solar and petroleum) but with very limited water resources, relatively low food production efficiency and severe shortage of technical and human capacity. The region already suffers from extreme climatic phenomena such as excessive rates of desertification, droughts, sand and dust storms, heat waves and flash floods.

The Arab region consists of 22 countries who are all members of the League of Arab States (LAS), 10 in Africa and 12 in West Asia. It enjoys extended coastal zones on the Mediterranean Sea, the Red Sea, the Arabian Gulf and the Atlantic Ocean where large percentages of population live in a number of highly populated cities along the coast. In addition, a trend of growth of population and tourism in the coastal area has been well observed (Massoud et al, 2003).

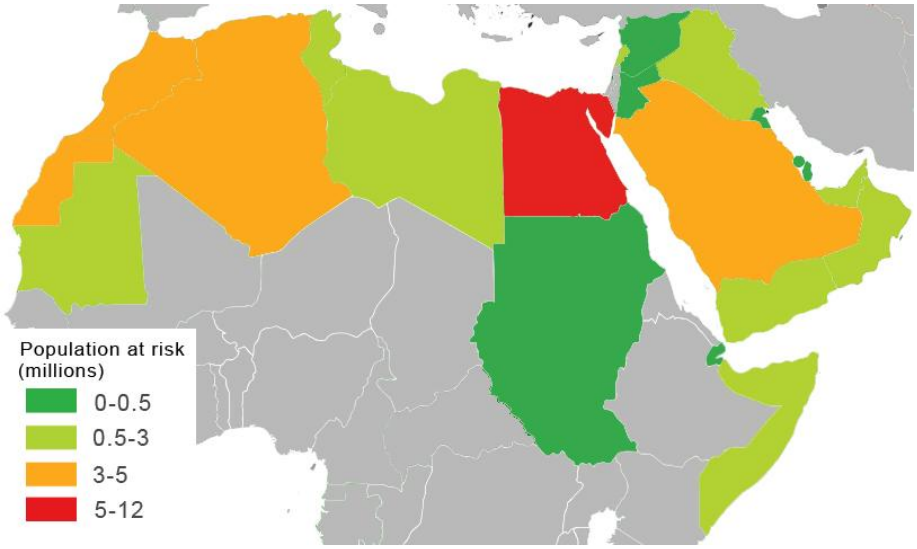


FIGURE 3.1 ARAB WORLD INDICATING POPULATION AT RISK OF IMPACTS OF CLIMATE CHANGE IN COLORS (AFED,2009)

In 2003 the total population of the Arab region reached 305 million (4.7 percent of the world's population). Over the last two decades, the population grew at an average rate of 2.6% per annum, with an increase in the total urban population from 44% to almost 54%. Meanwhile, the development and poverty situations in the region are highly uneven and poverty is a serious problem in many Arab countries. Almost 85 million people are below the poverty line of $2/day, accounting for almost 30% of the region's total population in 2000 (LAS, 2006). Figure (3.1) gives an overall view on the amounts of population at risk of impacts of climate change in general in the area.

The Arab region's coastal zones are of immense importance. The total length of the coastal zone in the Arab region is 34,000 km, of which 18,000km is inhabited. Most of the region's major cities and economic activity is in the coastal zones. The amount of population within 100km of coast is portrayed in Table (3.1). Vastly fertile agricultural lands are located in low-lying, coastal areas such as the Nile Delta, and popular tourist activities depend on marine and coastal assets, like coral reefs and associated fauna (AFED, 2009).

TABLE 3.1 THE ESTIMATED AREA, COASTLINE AND THE POPULATION WITHIN 100KM OF THE COAST IN THE ARAB COUNTRIES

Country	Area (Km^2)*	Coastline (Km)**	Population /1000***	Population Growth (%)***	Population within 100 km of coast (%) in 2000****
1. Bahrain	740	590	753	1.8	100
2. Iraq	435,052	58	28993	----	5.7
3. Kuwait	17,818	499	2851	2.5	100
4. Oman	309,500	2092	4017	2.2	---
5. Qatar	11,427	563	2595	1.8	88.5
6. United Arab Emirates	83,600	1318	4380	2.3	84.9
7. Saudi Arabia	2,250,000	2640	24735	2.4	30.3
8. Djibouti[1]	23,200	370	833	1.6	100
9. Jordan	92,300	26	5924	3.2	29
10.Somalia	637,657	3025	8699	3.1	54.8
11.Sudan	2,505,000	853	38560	2.1	2.8
12.Comoro	2,236	340	839	2.2	100
13.Yemen	555,000	1906	22389	3.1	63.5
14.Egypt	1,002,000	2450	75498	1.8	53.1
15.Palestine (Gaza Strip)	27,000	40	841	---	100
16.Lebanon	10,452	225	4099	1.1	100
17.Syria	185,180	193	19929	2.4	34.5
18.Algeria	2,381,741	998	33858	1.5	68.8
19.Libya	1,775,000	1770	6160	1.9	78.7
20.Mauritania	1,030,700	754	3124	2.7	39.6
21.Morocco	710,850	1835	31224	1.2	65.1
22.Tunisia	165,150	1148	10327	1.0	84
TOTAL	14,211,603	22,105	262628000		

(Sources: Modified after: (WRI/EarthTrend, 2000); The World Fact Book**, 2006; Encyclopedia Britannica[1]; POPIN***, 2006, (WRI/EarthTrend, ****, 2000)*

Even though most reserves of petroleum are located in or near the Arab world, the Arab region does not contribute significantly to world emissions of greenhouse gases. In fact, it was estimated that the Arab region contributes less than 5% of world emissions of greenhouse gases (IPCC, 2007). In spite of the relatively very low emission rate, the Arab region is considered one of the most vulnerable regions to the adverse impacts of climate change. It will be especially exposed to diminished water resources, loss of agricultural productivity, higher likelihood of drought and heat waves, inundation and salt water intrusion in coastal low-lying areas with considerable implications on human settlements and socioeconomic systems (IPCC, 2007). Specifically, the impact of sea level rise, salt water intrusion in the very limited water aquifers and coastal soil salinization are considered serious for many of the Arab countries (e.g. Agrawala et al, 2004; Dasgupta et al, 2007). According to the Climate Change Index (CCI) developed by Maplecroft, a British risk analysis consultancy, the region is home to 5 of the top 10

countries most exposed to the impacts of climate change: Djibouti, Egypt, Iraq, Morocco, and Somalia. (Troubled water)

Given the very high vulnerability of Arab countries to the projected impacts of climate change, it cannot afford inaction on either the global, regional, or national scales. Based on the findings of the Intergovernmental Panel on Climate Change (IPCC) and the Arab Forum for Environment and Development (AFED), we can categorically state that the Arab countries are in many ways among the most vulnerable in the world to the potential impacts of climate change, the most significant of which are increased average temperatures, less and more erratic precipitation, and sea level rise (SLR), in a region which already suffers from aridity, recurrent drought and water scarcity. Fig (3.2) illustrates the most vulnerable areas of North Africa and the Middle East to the impacts of sea level rise. It indicates that Mauritania, Tunisia, Libya, the Nile delta, the Gulf States including Qatar, Bahrain, Kuwait and Iraq are most vulnerable areas

According to recent results of World Bank studies, (Das Gupta et al, 2007), individual Arab countries will be affected differently under various sea level rise scenarios. Qatar, the UAE, Kuwait, and Tunisia are most vulnerable in terms of their land mass: 1 to 3 % of land in these countries will be affected by a 1 m SLR. Of these, Qatar is by far the most exposed: under various SLR projections where figure rises from approximately 3% of land (1m) to 8% (3m), and even up to more than 13% (5m). As for SLR's effect on GDP, Egypt's economy is by far the most vulnerable: for SLR of 1 m, more than 6% of its GDP is at risk, which rises to more than 12% for an SLR of 3 m. Fig (3.3) and Fig (3.4) represent the results of the World Bank assessment (Das Gupta et al, 2007) portraying respectively the area and GDP impacted by various scenarios of sea level rise.

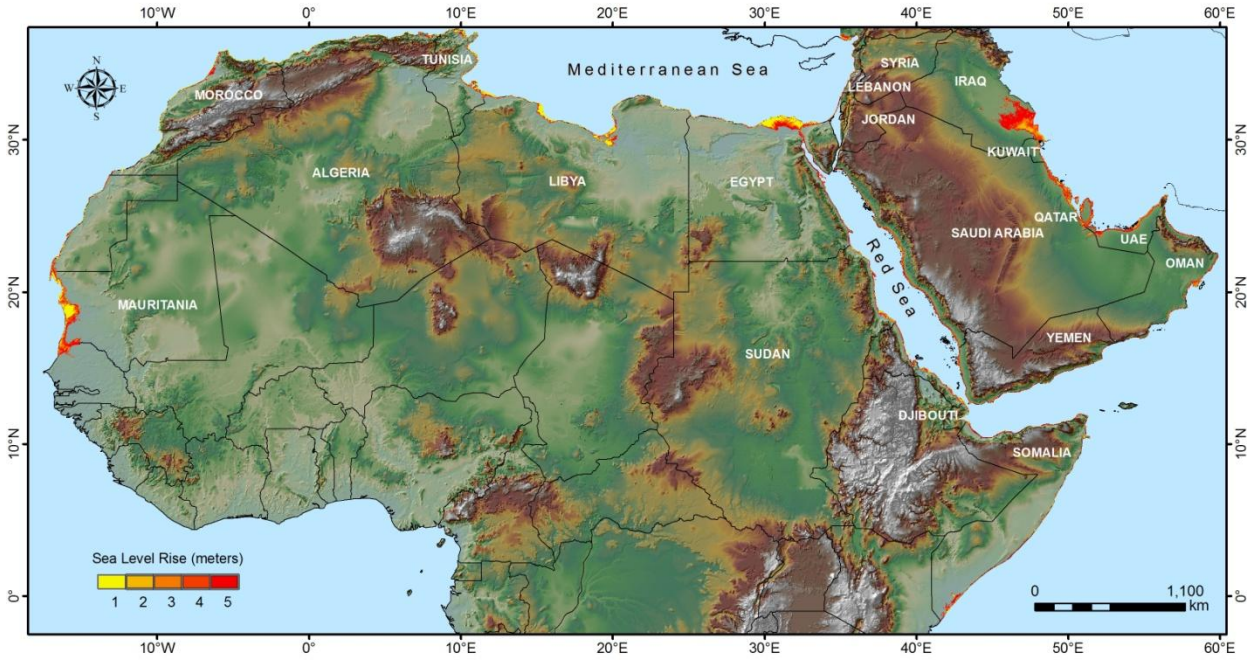


FIGURE 3.2 AN OVERVIEW OF MOST VULNERABLE COASTAL AREAS OF THE ARAB REGION DUE TO SEA LEVEL RISE (TOLBA AND SAAB, 2009)

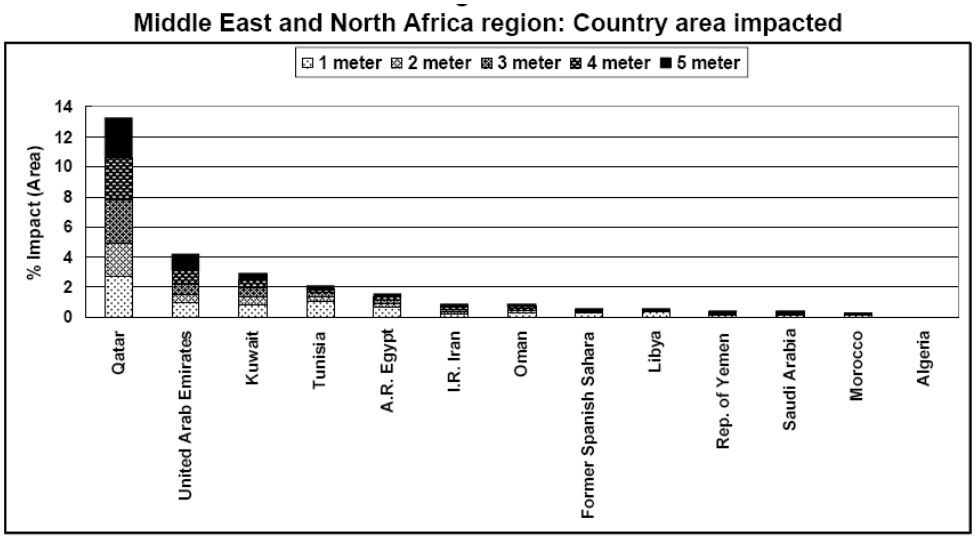


FIGURE 3.3 A COMPARISON BETWEEN THE ARAB COUNTRIES OF AREA IMPACTED BY VARIOUS SCENARIOS OF SLR (DAS GUPTA ET AL, 2007)

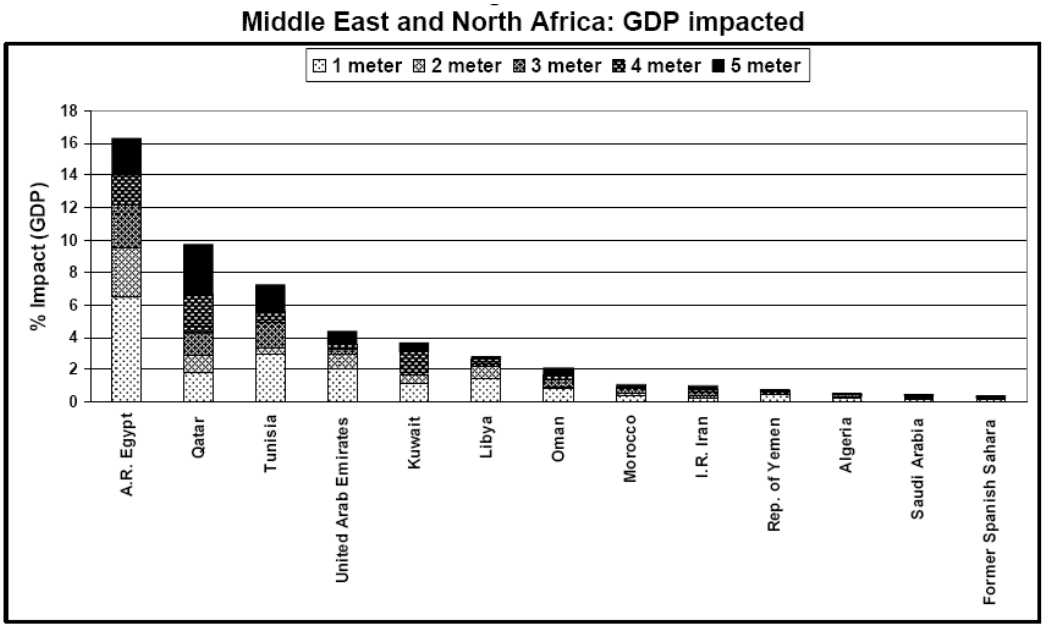


FIGURE 3.4 A COMPARISON AMONG ARAB COUNTRIES OF THE GDP IMPACTED BY VARIOUS SCENARIOS OF SLR (DAS GUPTA ET AL, 2007)

Many of the coastal lines of the Arab countries have low lying areas. These areas are being backfilled or elevated for development projects. The backfills became prime land with major commercial development which could be vulnerable to sea level rise. Many

of these first order impacts are linked and will be influenced by feedback from changes to other environmental parameters such as increased temperature, humidity and changed rainfall and/or wind patterns. As consequences of first order impacts in coastal zones, a variety of second order impacts can be identified which include the following:

- Changes in offshore bottom profile
- Changes in sediments and nutrient flux rates
- Changes in marine primary and terrestrial production

Extreme events are also expected to be elevated by climate changes in both severity and frequency. The potential impacts of extreme events such as storm surges on the coastal zone of the Arab region have also been investigated by the World Bank (Das Gupta, 2009). It has also been realized that these add to the vulnerability of the coastal zone. Fig (3.5) indicates estimated percentage increase of storm surges due to climate changes over the coastal areas of various Arab countries. It indicates that increasing surges will negatively impact Egypt, Algeria and Libya the most.

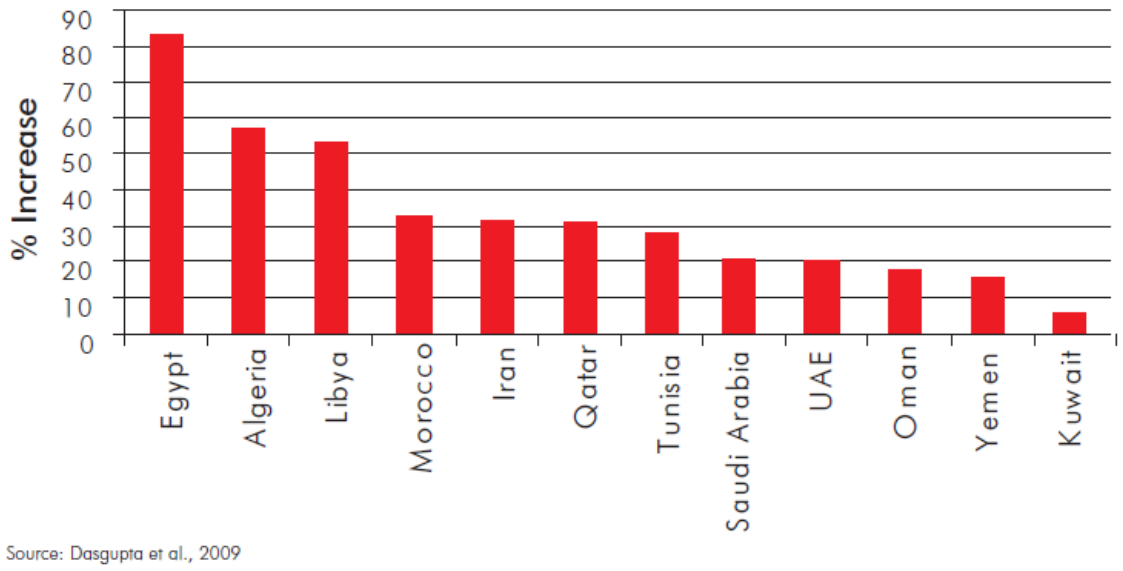


FIGURE 3.5 PERCENTAGE INCREASE OF IMPACT OF STORM SURGES ON THE COASTAL ZONE OF THE ARAB COUNTRIES AFTER (DAS GUPTA ET AL, 2009)

It is well realized that, the high rates of growth of urbanization in the coastal zone of the Arab world without due consideration to the capacity and potential impacts of urbanization as well as the unknown land subsidence rates and mismanagement of resources already place severe pressures in the coastal zone. In addition, the strong economic driving forces, shortage of awareness and weak enforcement of regulations have also added to these pressures

However, it is well known that the Arab region already suffers from severe shortage of water resources, food insufficiency, impacts of sea level rise and salt water intrusion, increasing severity and frequency of extreme events such as droughts, flash floods, dust and sand storms and heat waves. The socioeconomic implications of these impacts constitute important pressures on health and socioeconomic systems in the region. The shortage of access to technology and weak enforcement of regulations exacerbate vulnerability of many systems

Recent observations of present day sea level rise rates at 3.2mm/yr as well as estimates of sea level rise have prompted all countries to reconsider its coastal policies.

4 Impacts of Sea Level Rise

The impacts of sea level rise on coastal areas may cover many aspects including impacts on water resources, agricultural and health resources in the coastal areas. Usually impacts are exacerbated by other phenomena such as subsidence, presence of ground water aquifers and coastal agriculture. We shall consider the following impacts in some details.

4.1 Direct Inundation

Direct inundation may occur on low land areas such as the Nile delta of Egypt and Delta of Mauritania. Beaches on the Mediterranean coast in Tunisia, Western Libya, Alexandria, Gamasa and Port Said may also suffer direct inundation due to sea level rise. Direct inundation will have serious implications on the coastal shape, resources and tourism

4.2 Salt water intrusion

Salt water intrusion is again a direct impact on groundwater resources, soil salinity, agricultural productivity and quality in the coastal zone. The Nile delta and its deterioration due to salt water intrusion is an example. Impacts of salt water intrusion include increase of soil salinity, deterioration of land productivity and socioeconomic and health implications. It may lead to group migration of farmers looking for jobs somewhere else

4.3 Extreme events

The Arab region is well known to suffer from impacts of extreme events such as droughts, storm surges heat waves, dust storms and flash floods. The severity and frequency of these extreme events are expected to be exacerbated by climate changes. This phenomenon is not limited to coastal zones; however, due to the high sensitivity of the coastal zone, these changes are expected to hit the coastal zone the most. The Saharan dust flows yearly from North Africa across the Mediterranean Sea to Europe and cause severe damage in Europe on crop acreage and health. These extreme events in many cases lead to disastrous situations and require risk reduction on a large scale

4.4 Loss of Biodiversity

Coral reefs of the Red Sea are among the most spectacular in the world. It is the main attraction of tourism all over the region. The rise of sea level will limit the light that reaches deep lying coral reefs which will no longer be capable of sustaining growth. Again the direct interrelationship of global warming, increase of ocean salinity and biodiversity of coral reef and marine life are well recognized in the coastal zone. Its implication on tourism and national income may be severe. The loss of biodiversity of medicinal plants, marine life and on land fauna and flora in coastal zone is also an important factor

4.5 Socioeconomic and health implications

Direct and indirect implications on the socioeconomic systems are important factors that have to be taken into consideration. The loss of land productivity will force a large number of farmers and/ or fishermen to move away from the non-fertile land or fishing grounds and go searching for jobs somewhere else. Again the Nile delta region, where several million people are expected to leave the infertile land, is an important example.

Other examples include drought areas such as Darfur where changes of the precipitation and grazing grounds forced movement of population from one place to another where conflicts occur.

Numerous health impacts are expected due to sea level rise and salt water intrusion in ground water aquifers. Water-borne diseases are expected to be enhanced

5 Country Examples of Impacts of Sea Level Rise

We shall consider vulnerabilities of various Arab countries to potential impacts of climate change with particular reference to sea level rise.

5.1 Egypt

5.1.1 Background

Egyptian coasts extend for about 3,500 km along the Mediterranean and the Red Sea. In addition, Egypt hosts a large number of inland lakes, the largest being the fresh water Lake Nasser and the saline Lake Qarun in Fayoum. The coastal zones of Egypt host a major part of the industrial activities including petroleum, chemicals and tourism distributed among a large number of highly populated economic centers such as the cities of Alexandria, Rosetta, Damietta, Port Said, Suez and Hurghada. Trading and transportation centers are also distributed among a large number of harbors which are considered highly attractive to employment from all over the country. The coastal zones are also considered an important source for fisheries and income generation. Egypt's overall production of fish, according to the 2004 statistics (FAO, 2004), is about 876000 tons, of which 116,600 tons (13.3% of the overall production) are from coasts.

5.1.2 Vulnerability to Sea Level Rise

The coastal zones of Egypt are perceived as vulnerable to the impacts of climate change, not only because of the direct impact of sea level rise, but also because of the potential impacts of climate changes on their water resources, agricultural resources, tourism and human settlements. In particular, the low lying Nile Delta region, which constitutes the main agricultural land of Egypt and hosts over one-third of the population and

nearly half of all crops (World Resources Institute, 2007), industrial activities and commercial centers, is highly vulnerable to various impacts of climate change.

Mediterranean Sea Coastal Zone:

The Mediterranean coastal shoreline includes five large lakes which constitute about 25% of the total area of wetlands in the Mediterranean region. The Mediterranean coastal zone hosts a large number of economic and industrial centers as well as important beaches and tourist resorts. The precipitation along the coastal zone in winter varies between 130 and 170 mm/year and decreases gradually to the south. The tidal range is about 30-40 cm.

The Mediterranean coastal zone of Egypt suffers from a number of problems, including a high rate of population growth, unplanned urbanization, land subsidence, excessive erosion rates, salt water intrusion, soil salinization, land use interference, ecosystem pollution and degradation and lack of appropriate institutional management systems. This zone hosts Alexandria city, which is the main harbor on the western side of the Delta located at a partly low elevation land. The city hosts about 40% of the country's industrial capacity, in addition to being an important summer resort. Other vulnerable large cities include the cities of Rosetta, Damietta, and Port Said.

Red Sea Coastal Zone:

The coastal zone of the Red Sea of Egypt is generally narrow because of the relatively close mountains parallel to the shoreline. The coastline is composed of a large number of embayments, small gulfs and small pocket beaches. Fragmented and extended coral reef communities with associated rich marine life extend over large areas of the coast. The tidal range varies between 110 and 130cm.

The Egyptian Red Sea coast in general has very limited freshwater resources due to its geographical location in the arid sub-tropical region. Human populations are concentrated in a number of cities along the coastline and in few scattered villages in between. It hosts a large number of well-known diving sites based on world famous rich and highly diversified coral and mangrove communities. Tourism along the coastal zone of Sinai and eastern Egypt on the Red Sea now contributes a significant portion of the GNP. Fishing and diving activities have supported a growing human population.

This coastal zone suffers from increasing losses of habitats due to growing unplanned urbanization, pollution, coastal land filling, flash flooding and increasing negative impacts of tourism. In addition, low precipitation has recently been well observed over a large part of the coastal zone, which has already been reflected over the quality of life in the region.

The impact of climate change on world famous coral communities in the Red Sea will include coral bleaching due to increasing temperatures, loss of habitats and loss of biodiversity hence deterioration of tourism. The shortage of institutional capabilities of monitoring and control will further exacerbate these impacts

Coastal Zone of the Nile Delta Region:

The Nile Delta region (Figure 5.1) is the most fertile land of the country and hosts most of the agricultural productivity and the largest part of the population of the country. Its shoreline has relatively low elevation areas. In addition the Delta suffers from land subsidence that increases from west to east. Hence it is highly vulnerable to potential impacts of climate change.

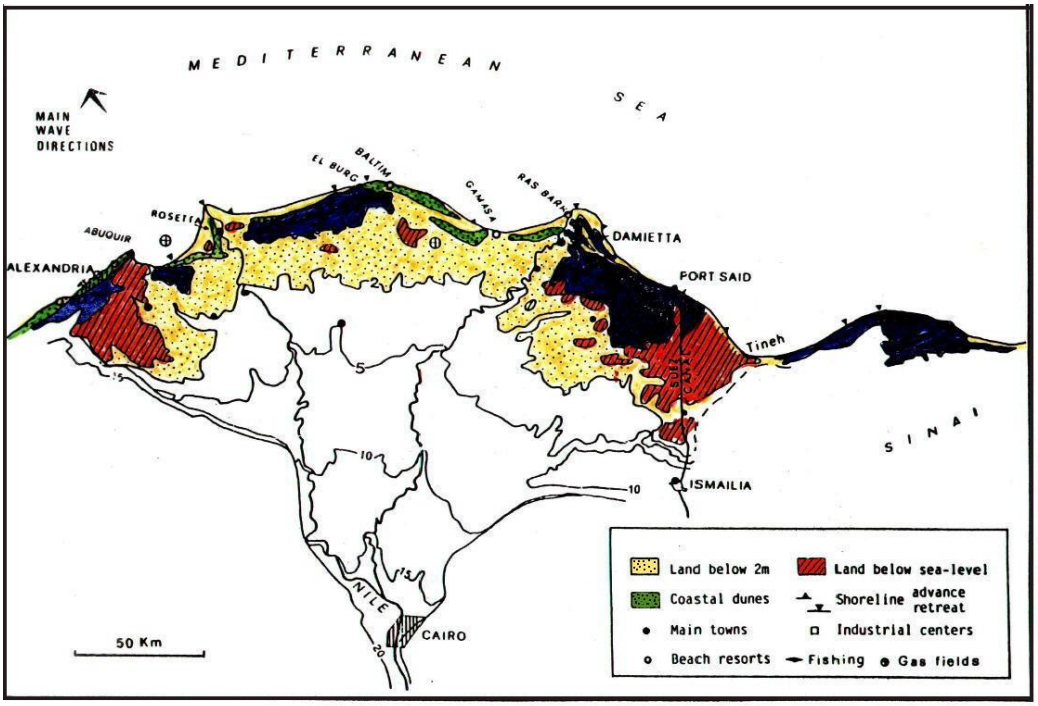


Figure 5.1 General Topography Of The Nile Delta Indicating Areas Below Mean Sea Level In Red And Areas Below 2m Contour Level In Yellow (El Raey, 2009).

The Nile Delta shoreline extends from Alexandria to the west to Port-Said to the east with total length of about 240 km and is typically a smooth wide coast. This zone consists of sandy and silty coasts of greatly varying lateral configurations, depending on where the various old branches of the Nile have had their outlets. The coastline has two promontories, Rosetta and Damietta. There are three brackish lakes connected to the sea: Idku, Burullus, and Manzala. In addition, there are several harbors located on the coast including: Alexandria, Edku fishing harbor, Burullus fishing harbor, Damietta commercial harbor, El Gamil fishing harbor and Port Said commercial harbor. Two main drainage canals, Kitchener and Gamasa, discharge their water directly to the sea within this zone.

The Nile Delta region is presently subject to changes, including shoreline changes, due to erosion and accretion, subsidence and sea level rise due to climate changes. Agrawalia et al., 2004 surveyed specific large economic centers of Alexandria, Rosetta and Port Said and obtained quantitative estimates of vulnerable areas and expected loss of employment in case of no action. They concluded that the Nile Delta coastal zone is highly vulnerable to the impacts of sea level rise through direct inundation and salt water intrusion. Low elevation coastal zones constitute high risk areas due to potential damage of sea protection from earthquakes or human activities.

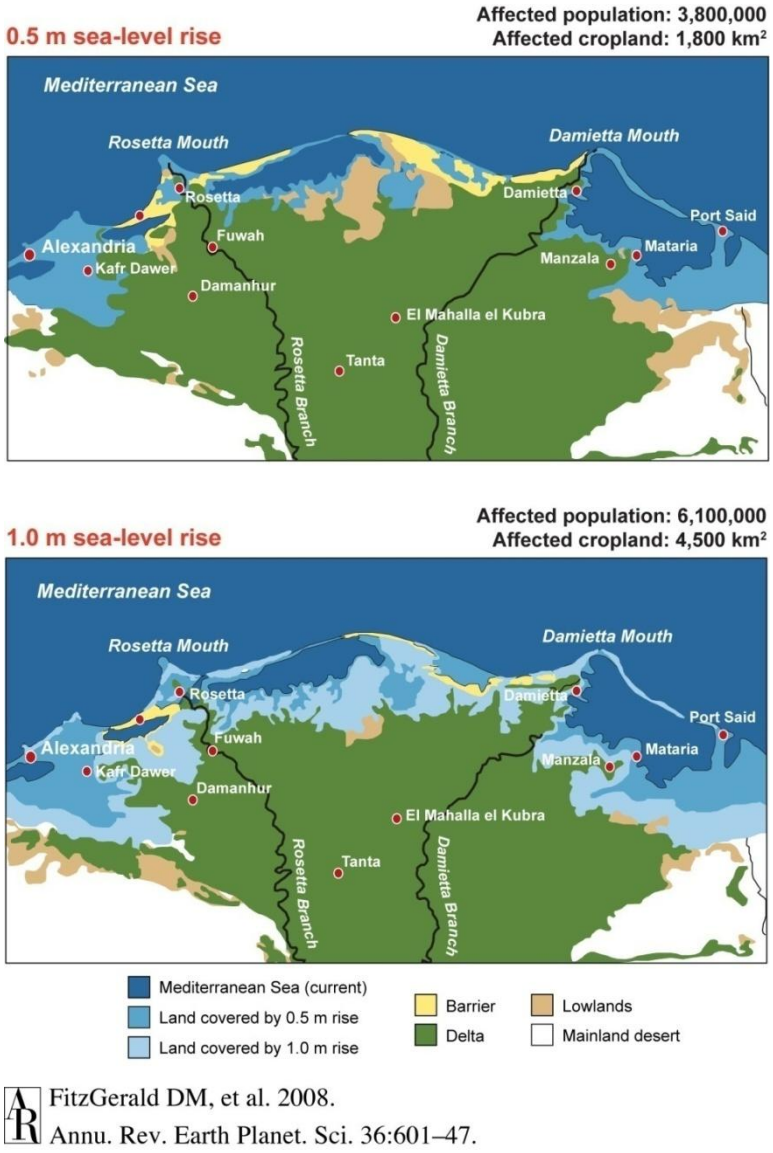


FIGURE 5.2 POTENTIAL DIRECT INUNDATION OF THE NILE DELTA REGION WITH TWO SCENARIOS OF SEA LEVEL RISE INDICATING VULNERABLE CITIES OF THE DELTA (FITZGERALD ET AL, 2008)

Egyptian delta coasts are also vulnerable to subsidence. Tide gauges data from the Coastal Research Institute of Alexandria revealed a land subsidence of about 1.6 mm/year at Alexandria (Figure 5.3), 1.0 mm/year at Al-Burullus, and 2.3 mm/year at Port Said (Stanley and Warne,1993). However, survey measurements carried out by Stanley and Warne (1993) has revealed rates greater than 4mm/year at Port Said and about 2mm/year at Alexandria for the Holocene period.

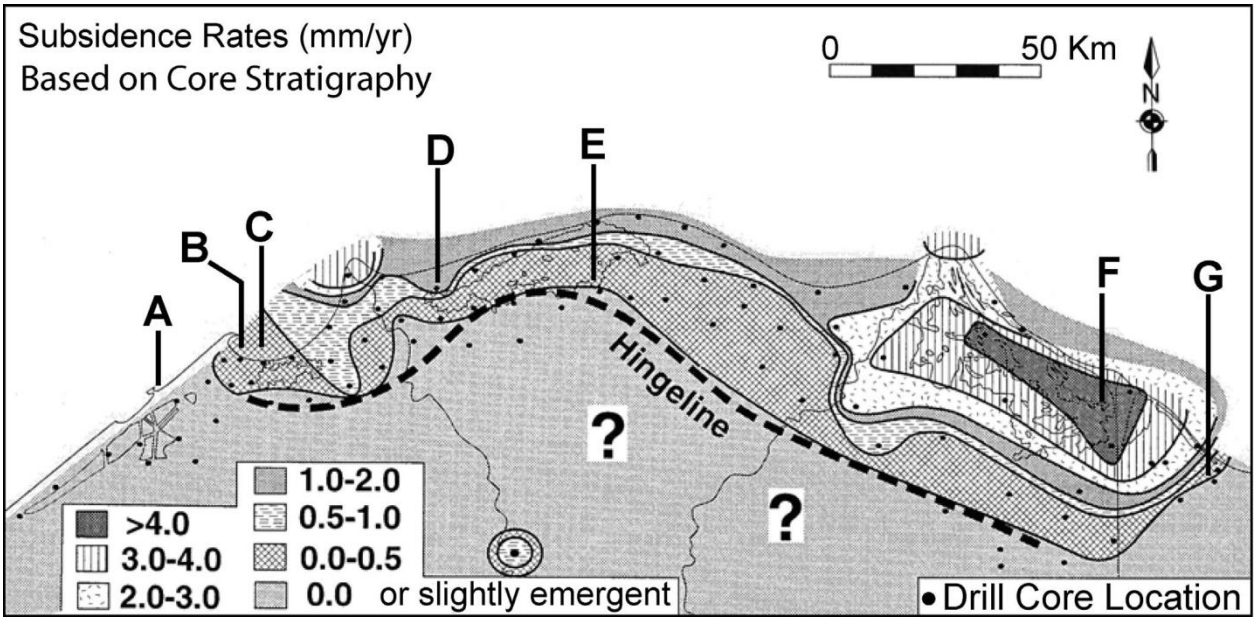


FIGURE 5.3 LAND SUBSIDENCE RATES MAP IN THE HOLOCENE PERIOD AS MEASURED AT ALEXANDRIA, BURULLUS AND PORT SAID (STANLEY AND WARNE, 1993).

Recently, work carried out by Becker and Sultan, 2009 on Damietta region using Radar satellite interferometry has revealed rates of subsidence that may reach up to 8mm/year. This prompted carrying out radar image interferometry for Alexandria (ESA, Altamira, 2010), which has revealed rates that varies between 5mm/year and 9mm/year at some specific areas of the city. Fig (5.4) illustrates the results obtained for one of the radar satellites output (ESA, Altamira, 2010).

From analysis of the three satellites data, it is found that about 6.5 to 6.9% of the city are subsiding at rates that vary between 5-9mm/year. These areas are associated with already low land urban centers. Very limited small areas encounter emergence. A detailed investigation based on most accurate ground based measurements is warranted.

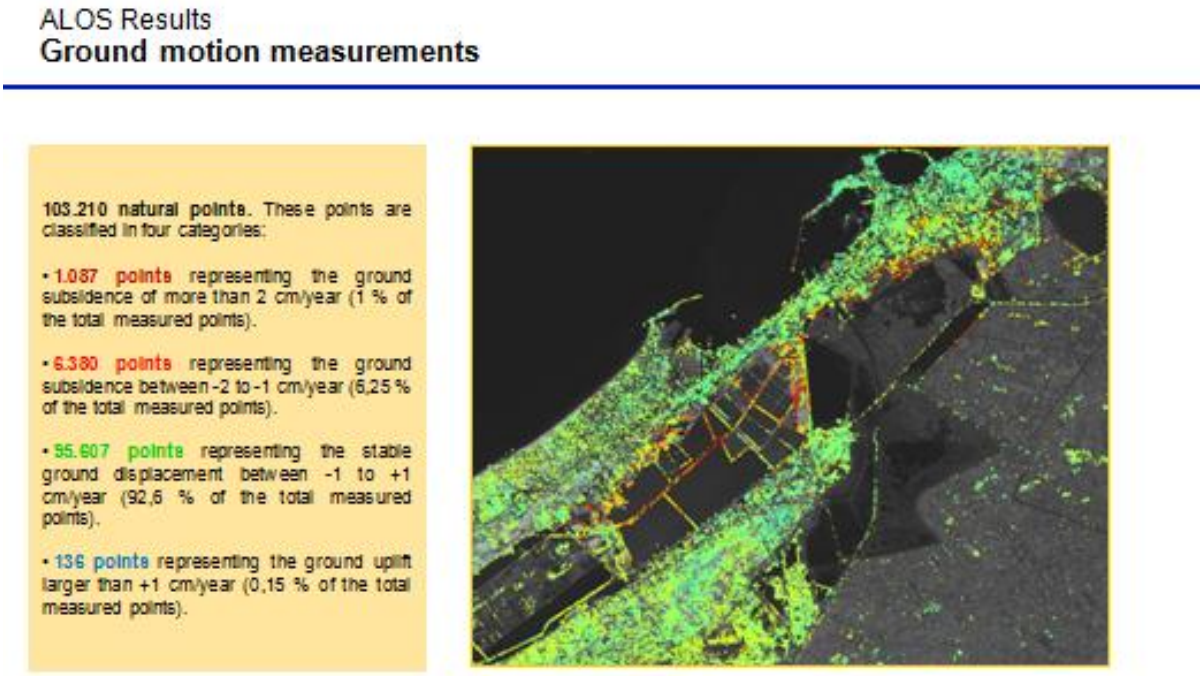


FIGURE 5.4: LAND SUBSIDENCE AND EMERGENCE AT ALEXANDRIA AS MEASURED BY ALOS RADAR SATELLITE 'INTERFEROMETRY (ESA, 2010)

Salt water intrusion and its potential impacts on ground water quality in the coastal zone cannot be overlooked especially in low land areas along the Mediterranean coast of Egypt. In addition, water logging and water bogging problems are expected to exacerbate soil salinization which will lead to deterioration of crop quality and productivity. This will in turn lead to increasing health problems and loss of tourism. This phenomenon is considered of utmost importance and warrant full investigation as it may lead to group immigration for other safe areas.

Extreme Events of Heat Waves, Marine surges and Dust storms

The increase of intensity and frequency of extreme events is also expected to affect the coastal zones of Egypt and extend over the whole country as well as across the Mediterranean. Saharan dust, marine surges and heat waves are well known to seriously affect land agricultural productivity, materials lifetime and public health. Increased intensity and frequency of marine storms will also necessarily increase risks of accidents in maritime transport systems.

5.1.3 Institutional adaptation

A national committee of the highest sectoral authorities as well as national experts has been formulated by a pri-ministerial decree. The committee has explored options of adaptation and has recommended policies for different vulnerable sectors. A pri-ministerial decree has been issued 2009 to establish a national Center for Climate Change. This center could be an important step towards establishing an institutional integrated system for coordination among various adaptation measures of various sectors.

The Egyptian National Assembly has recently approved new regulations to include Integrated Coastal Zone Management (ICZM) into developmental plans needed for better management of coastal resources and protection against impacts of climate change. This makes it necessary to have a strong institutional monitoring capability in addition to a decision support capability for adoption of options for adaptation. Options of adaptations are generally site-dependent and necessarily involve multi-criteria analysis to assess levels of technology, maintenance, impact assessment and cost (El Raey et al., 2000). A national adaptation strategy is already in progress with the following main aspects:

1. Upgrading adaptive capacity through establishment of institutional systems for monitoring, building data basis , modeling and upgrading awareness
2. Adopting a proactive no regrets policy in planning and enforcing regulations for follow up
3. Carrying out research on renewable energy, salt tolerant plants, desalination,
4. Considering geo-engineering activities for protection against sea level rise

5.2 Saudi Arabia

5.2.1 Background

The Kingdom of Saudi Arabia comprises about four-fifths (80%) of the Arabian Peninsula, occupies approximately 2,250,000 km^2 area and bordered on the west by the Red Sea; on the east by the Arabian Gulf, Bahrain, Qatar and the United Arab

Emirates; on the north by Jordan, Iraq and Kuwait; and on the south by the Sultanate of Oman and Yemen.

Saudi Arabia's Red Sea coast on the west stretches to approximately 1760 kilometers, while its eastern coast on the Gulf covers 650 kilometers, including 35 sq. km of mangroves and 1480 sq. km of coral reefs. The country has an arid climate with an average annual rainfall of 70.5 mm. Almost two thirds of the country is arid steppe and mountains with peaks as high as 3,000 meters, and most of the remainder is sand desert.

Saudi Arabia consists of a variety of habitats such as sandy and rocky deserts, mountains, valleys, meadows, salt-pans ('sabkhas'), lava-areas, etc. It includes most types of terrain which can be generally divided into two distinct groups of rocks; the Arabian shield and the Arabian Platform.

The population of the Kingdom in 1992 was estimated at 16.9 million with a population density of 7 per square kilometer. Life expectancy at birth in 1991 was 69 for both men and women. Births that year were 37 per 1000 people, and deaths 5 per 1000, with an average annual population growth for 1991-2000 of 3.5%. Seventy eight percent of the population is concentrated in the urban areas (Saudi, 2005).

Coral Reefs represent the most significant habitat found along the Saudi shores (both Red Sea and Arabian Gulf). Coral reefs play an important role in the coastal ecosystem. These reefs as well as the Mangrove forests form the basic framework of tropical habitats and provide shelter and food for wide array of marine life. The highest coral diversity occurs in the central Saudi Arabian Red Sea area. Coral reef harbors a longstanding and important artisan fishery.

5.2.2 Vulnerability to Sea Level Rise

While mangroves are found scattered along much of the Red Sea coast, the major concentration is in the southern red sea where factors such as increased sediments create an environment more conducive to their development. Agricultural development, properly planned and managed, could be beneficial to certain coastal habitats such as mangroves. Mangroves have a variety of values: they provide food in the form of detritus, shelter for numerous organisms (such as mollusks, crabs, shrimps, and fish),

fodder for camels and goats, and fuel for human use. Mangroves are also important nesting sites for several species of birds. The development of coastal recreational facilities and coastal villages in Ras Hatiba area north of Jeddah and shrimps aquaculture along the southern Red Sea coast have contributed to the decline of Saudi Arabia's coastal mangroves.

Coastal cities of Saudi Arabia extend along the Red Sea coast as well as the Arabian Gulf coast. Four coastal cities have been selected as the most vulnerable cities to Accelerated Sea level Rise (ASLR) along the Red Sea namely Jeddah, Rabigh, Yanbu and Gizan (Figure 5.6). The selection of these cities was based on the population growth, socio-economic activities and historical and cultural importance to the Kingdom. Again, on the Arabian Gulf cities such as El Khafji, Al Jobail, Al Dhahran and El Khobar (Figure 5.5) could be considered vulnerable.

FIGURE 5.5 THE ARABIAN GULF COAST AND VULNERABLE CITIES ALONG THE COAST OF SAUDI ARABIA

FIGURE 5.6 COASTAL CITIES OF SAUDI ARABIA ON THE RED SEA

The following potential impacts were identified in a study on Saudi SLR impacts (Saudi, 2005).

An increase in sea level rise will increase intrusion of saline water from both the Arabian Gulf and the Red Sea into coastal aquifers, which will potentially affect the freshwater supply in coastal zones. In cases of flooding in coastal areas, salt water will further intrude into aquifers. This intrusion will increase the demand for freshwater from other sources, mainly Desalination Plants. At the same time, sea level rise will increase saltwater intrusion of estuaries, potentially benefiting marine fish at the expense of freshwater ecosystems.

Groundwater levels in these areas might also be affected by the intrusion of saline water. The groundwater level itself and the soil structure determine the potential for intrusion of saline waters. Managed areas with a reduction in groundwater level because of drainage are more vulnerable for intrusion.

Sehat and Qateef are the main agricultural cities along the Arabia Gulf and Gizan along the Red Sea. These cities could be impacted by Accelerated Sea Level Rise. Recently increase of soil salinity has been observed in some of these coastal cities. This increment has impacted the production of cultivated products. It is suspected that salt water intrusion may be one of the factors impacting the agricultural activities.

One of the most significant impacts of sea-level rise is acceleration of coastal erosion as well as inundation of mangroves, wetlands, and coral reefs. The rich biodiversity of the wetlands in Saudi Arabia is seriously threatened by loss of wetlands due to sea level rise. The effect of sea level rise will depend on the type of mangrove forest. These mangrove forests may either keep pace with the rising sea level rise or may be submerged. Large scale changes in species composition and zoning in mangrove forests are also expected due to changes in sedimentation and organic accumulation, nature of coastal profile and species interaction.

An additional threat of Accelerated Sea Level Rise affecting the Saudi Arabian coasts will come from an exacerbation of sandy beach erosion. As the beach is lost, fixed structures nearby are increasingly exposed to the direct impact of storm waves, and will ultimately be damaged or destroyed unless expensive protective measures are taken (Figure 3.4.8). It has long been speculated that the underlying rate of long term sandy beach erosion is two orders of magnitude greater than the rate of rise of sea level. Therefore, any significant increase of sea level has direct consequences for coastal inhabitants.

Results from studies on various aspects of the impacts and possible responses to sea level rise on the Saudi Arabian coasts indicate that a sizable proportion of the Arabian Gulf and Red Sea will be affected to a combination of inundation and erosion, with consequent loss of developed properties including industrial, recreational and Residential areas.

No detailed socioeconomic study of accelerated sea level rise has been carried out yet in Saudi Arabia. However it has been estimated that 20% of Saudi Arabian coastal areas have been subject to development, 130 km along the Arabian Gulf coasts and 352 km along the Red Sea coasts. A conservative scenario of 1% annual coastal development was applied on the Arabian Gulf and Red Sea coasts. This scenario was applied on the coastal erosion model to estimate the area of sandy beaches that may demolish as a result of sea level rise

Considering the annual coastal development in the Kingdom is 1% and the IPCC Sea Level Rise projection Scenarios towards year 2100 and by applying Bruun model to estimate the high risk areas subjected to coastal erosion along the Arabian Gulf, it was found that:

- For the Low Sea Level Rise Scenario (LSLRS) of 0.2m rise, 401 hectares of sandy beaches are estimated to be lost by the year 2100.
- For the Medium Sea Level Rise Scenario (MSLRS) of 0.49m rise, 984 hectares of sandy beaches are estimated to be lost by the year 2100, and
- For the High Sea Level Rise Scenario (HSLRS) of 0.86m rise1, 726 hectares of sandy beaches are estimated to be lost by the year 2100.

5.2.3 Institutional and Practical Adaptation Measures

It is well recognized that the following adaptation measures are needed:

1. An integrated institutional structure must be developed. A Regional Circulation Model (RCM) has to be developed and a strong institutional monitoring system has to be established.
2. A monitoring system of tide gauges and systematic observations of the coastal zone with provisions for land subsidence must be established

3. Early warning systems of extreme events such as heat waves, flash floods and dust storms must be established
4. Policies and measures should be developed based on model studies and participation of stakeholders
5. Awareness programs of stakeholders should also be carried out

5.3 Republic of Yemen

5.3.1 Background

Yemen is well known arid country, occupying an area about of 530,000 square kilometers at the southern end of the Arabian Peninsula. It is bordered to the north by Saudi Arabia, to the East by Oman, and to the South and West by a 2,200 km coastline along the Gulf of Aden, Arabian Sea and the Red Sea excluding the islands. According to the 2004 census, the total population of Yemen is around 20 million, with annual growth rate 3 percent. About 1,080,000 people live in major coastal settlements. Along the coastline of Yemen, many people depend and engaged in fishery sector. Fish wealth is considered as the second sector in the national economy after oil. The food security in Yemen depends highly on marine products. The climate of Yemen is hot and humid on the coastal strip, moderate on the mountains, and desert climate in desert areas.

5.3.2 Vulnerability to Seal Level Rise

Yemen is highly vulnerable to climate change-related impacts such as drought, extreme flooding and changes of rainfall patterns, increased storm frequency/severity and sea level rise. These are serious concerns as Yemen's economy largely depends on its natural resources. According to the Intergovernmental Panel on Climate Change (IPCC), coastal cities such as Aden and Hodiedah are particularly vulnerable to sea level rise. The IPCC ranked Aden 6th among twenty five cities vulnerable to danger due to rising sea levels.

The First National Report states that the climate of Yemen is expected to change significantly over the next fifty years. It is expected that the temperature will increase between 1.4°C and 2.8°C by the year 2050. Due to high uncertainties of predictions,

rainfall estimates are expected to vary between a decrease by 24% and an increase by about 50% over the same period.

Between October 23-25, 2008, Yemen was faced with heavy sustained rains as a result of a level-three tropical storm that hit the country. The storm caused widespread flooding in several locations in the two eastern Governorates of Hadramout and Al-Mahra. Yemeni low lying islands and coastal areas could be submerged if climate changes cause a rise in sea level.

Some of Yemen's ecological zones are confined to small areas (e.g., islands), with human communities, flora and fauna highly adapted to subsist within them. Other zones are much larger (e.g., Temperate Highlands) and support the majority of the country's agricultural production. In both cases, climate change poses a major threat.

FIGURE 5.7 A MAP OF YEMEN INDICATING COASTAL CITIES

Sustainable use of the marine and coastal environment is a potentially important driver of development. Coral reefs, sea-grass and mangroves provide coastal zones with important biodiversity and fishery potential. Yet, Yemen's coastal ecosystems are already experiencing degradation from manmade as well as climatic causes.

Yemen has identified three main sectors that are vulnerable to climate change: water resources, coastal zones and agriculture. Yemen is promoting sustainable use through optimal allocation of water resources. Sustainable use of marine and fishery resources is developed through a strict implementation policy of legislative management and maintaining agricultural resources and developing sustainable agricultural programs. The coastal areas of Yemen generally not densely populated with exception of a few cities such as Aden, Al-Hodiedah and Al- Mukalla (Figure 5.7). Yet the most important

factor is that many activities centers are concentrated at the coastal front, directly on beaches, particularly in Aden. Aden; Hodeida and Hadramout Governorates are classified among areas at risk from the impact of sea level rise and coastal flooding. Extended wetlands along this area are liable to become submerged. Some of these have already experienced coastal flooding and with storm surges.

5.3.3 Practical and Institutional Adaptation Measures

Based on the above conditions it is therefore recommended to carry out the following:

1. Establishing institutional capacity for climate change in general and sea level rise impacts in particular. The capacity includes monitoring systems and human capabilities. Establishing monitoring systems for coastal subsidence is an important aspect
2. Enhancing adaptive capacity through encouraging establishment of rainwater storage systems, upgrading water management and development of integrated coastal zone planning
3. Encouraging and support of research in drought tolerant crops, salt tolerant plants and upgrading of awareness
4. An early warning system for flash flood and/or Tsunami may be of great benefit
5. Encouraging geo-engineering activities for protection measures against impacts of sea level rise

5.4 United Arab Emirates

5.4.1 Background

Population in UAE has grown rapidly nearly ten-fold since 1975, qualifying the UAE as having one of the highest population growth rates in the world over the period 1975-2005. However, much of this population increase is associated with non-nationals coming to the country on temporary work assignments. With a low ratio of nationals to non-nationals remains low, the national population is increasing at an average annual rate of 2.9%, while the corresponding figure for expatriates is about 6.9%. The UAE's government is a constitutionally-based federal system.

The UAE's economy is well diversified and has experienced robust growth in recent years. Despite being a major oil-exporter possessing the sixth largest proven oil reserves and the fifth largest proven natural gas reserves in the world, oil and gas activities accounted for only about 38% of national GDP in 2007. Overall GDP has been growing at an average real annual rate of 11.2% for the past dozen years. The UAE is also a large international trading partner with trade in 2007 totaling nearly US$0.3 trillion, accounting for approximately 22% of the total Arab commercial exchange despite the fact that the population of the UAE is under 2% of the population in the Arab bloc. Wealth from natural resources has lead to ambitious coastal development projects aimed at recreation, tourism and estate industries (Figures (5.8) and (5.9)).

FIGURE 5.8 UAE DEVELOPMENTS IN THE COASTAL ZONE (AL JENEID, 2010) INDICATING HUGE COASTAL INVESTMENT AND LOAD

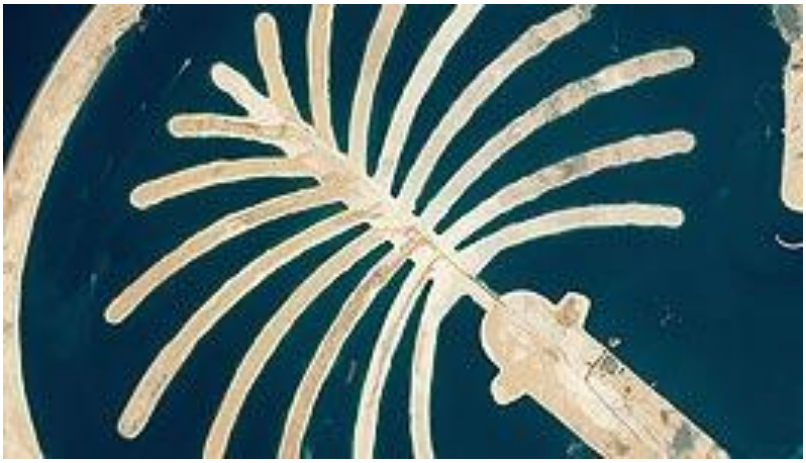


FIGURE 5.9 A CLOSE UP OF SATELLITE IMAGE OF ONE OF THE PALM TREES URBAN DEVELOPMENTS ON THE COASTAL ZONE OF UAE

Natural resources have always been recognized in the UAE as precious and fragile assets to be preserved. Several long-term environmental sustainability strategies have been launched to protect urban air quality, impose tighter regulatory regimes on industrial and other development activities, establish conservation areas for biodiversity and endangered wildlife habitats, and sustainably manage scarce water resources. The climate is hot and arid and is subject to ocean effects due to its proximity to the Arabian Gulf and the Gulf of Oman.

5.4.2 Vulnerability to Sea Level Rise

Climate change will lead to higher sea levels, increased sea surface temperatures, and changes in wave dynamics. For coastal zones in the UAE, home to approximately 85% of the population, over 90% of the infrastructure, many sensitive ecological subsystems, and important cultural heritage sites, vulnerability to climate change is very high. Moreover, the coasts of the UAE are home to multiple ecological subsystems (Alsharhan and El Sammak, 2004) and important cultural heritage sites and artifacts. Climate change-induced sea level rise will adversely affect existing and new infrastructure, valuable coastal ecosystems, and planned development.

The most recent findings of the Intergovernmental Panel on Climate Change suggest that the expected range of sea level rise, not considering glacier melting, is between 0.37 and 0.59 meters by 2100. If glacier melting is included, the IPCC notes that 10 meters or more in climate change-induced sea level rise is possible beyond 2100 (IPCC, 2007).

Unless accounted for in future adaptation planning and strategies, the economic damages for the UAE's coastal zones will be unacceptably high.

To account for uncertainty in potential levels of sea level rise, a study was undertaken that applied a scenario approach to analyze the vulnerability of the UAE to sea level rise (Environmental Agency of Abu Dhabi, 2009a). Two plausible sea level rise scenarios for the years 2050 and 2100 were considered.

A key finding is that coastal areas are projected to be extensively inundated due to sea level rise as current shorelines migrate inland substantially. Indeed, all coastal cities in the UAE will experience progressively increasing inundation, depending on the scenario analyzed. Taking Abu Dhabi as an example, even the smallest sea level rise scenario shows that significant areas of the built environmental in coastal regions will be inundated. With the highest sea level rise scenario, the inundated area is quite extensive in comparison and leads to the shoreline migrating southward by about between 25 and 30 km.

Other Emirates in the UAE show similar inundation impacts. Depending on the particular sea level rise scenario, total land area inundated in the UAE ranges from 1,155 km^2 to almost 5,000 km^2, or roughly between 1% and 6% of the country's total land area. These inundation levels will lead to a number of adverse impacts on sensitive ecosystems and natural areas along the UAE shoreline. In addition, excessive coastal activities of oil extraction and urbanization are expected to cause some kind of subsidence. The subsidence rates have never been measured to the author's knowledge. The impact of ASLR on the coastal areas could be summarized as briefly outlined below:

- *Sabkhat areas* are found only a few meters above sea level, and thus, highly susceptible to sea water intrusion and changed salinity. In the future, Sabkhat areas will likely experience migration;
- *Mangrove forests* are sensitive to sea temperature, water depth, and salinity. Roots need to be totally exposed for certain periods of the day, which future sea level rise will make impossible unless mangroves are able to migrate upslope. If not, the UAE's mangrove forests will be destroyed due to submergence;

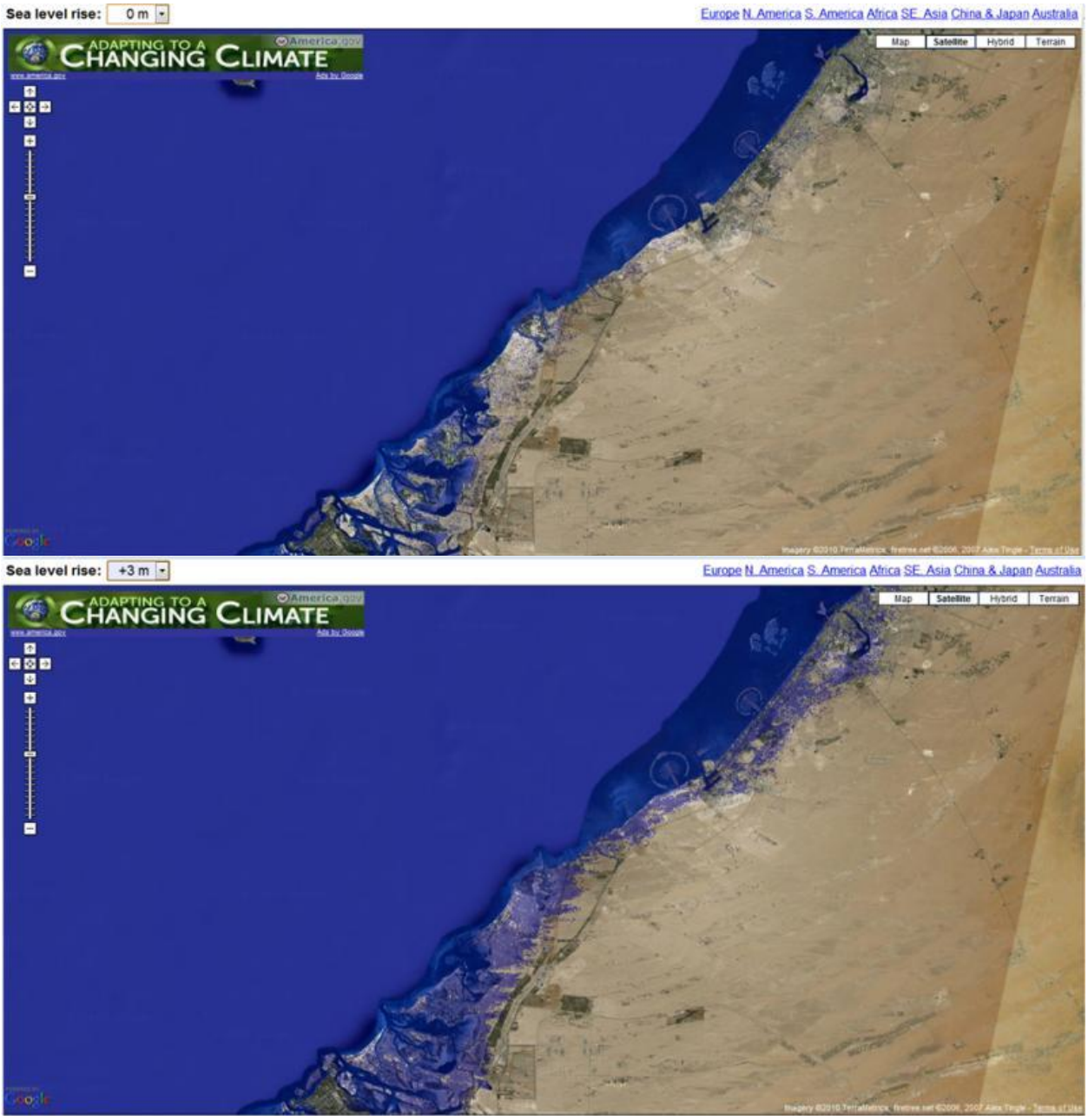


FIGURE 5.10 IMPACT OF PROJECTED SEA LEVEL RISE ON EMIRATES: TODAY'S LEVELS, AND 3.0 M SEA LEVEL RISE. NOTICE THE EXCESSIVE COASTAL URBANIZATION.

(RIVER SURVEYOR: HTTP://FLOOD.FIRETREE.NET)

 Sea grass habitats are important for their role in maintaining local biological diversity, a critical part of dugong and hawksbill turtles and other species' food chains. Climate change induced sea level rise undermine this habitats by

increased sea surface temperature, tidal variations, salinity content, changing water depths, as well as by ocean carbon dioxide content;

 Coral reefs are vulnerable to thermal stress and recent increases in seawater temperature. The expected increases of 1.5 to 2.6°C will exceed coral's physiological limits and result in more frequent coral bleaching events, on par with extreme bleaching most recently witnessed in 1998; and

 Fisheries: Depending on how ambient and sea surface seasonal temperatures change over time, the abundance of some of the Emirate's most important fisheries like kingfish will be adversely affected, as will hawksbill turtles and Dugongs which depend on the viability of sea grass habitats.

The area expected to be inundated for each emirate under 4 scenarios have been worked out and presented in Table (5.1) (Emirates second National Communication 2010), where it is clear that Abu Dhabi emirate is the most vulnerable emirate followed by Dubai

TABLE 5.1 ESTIMATED IMPACT OF SEA LEVEL RISE ON AREAS TO BE INUNDATED IN EACH EMIRATE AREA FOR FOUR SCENARIOS OF SEA LEVEL RISE (EMIRATES SECOND NATIONAL COMMUNICATIONS, 2010)

	Inundation in km2 for sea level rise of:			
Emirate	**1 m**	**2 m**	**3 m**	**9 m**
Abu Dhabi	722	983	1,405	3,904
Ajman	18	270	326	526
Dubai	217	74	87	158
Fujairah	6	24	32	59
Ras al-khaimah	82	93	106	158
Sharjah	60	66	78	143
Umm al-Qaiwain	50	9	11	36
UAE	**1,155**	**1,519**	**2,045**	**4,984**

In addition, groundwater in the Emirate will be definitely affected by salt water intrusion in the coastal areas. Fig(5.11) represents to what extent would salt water intrusion affect the groundwater resources in Emirates (GTZ, 2005)

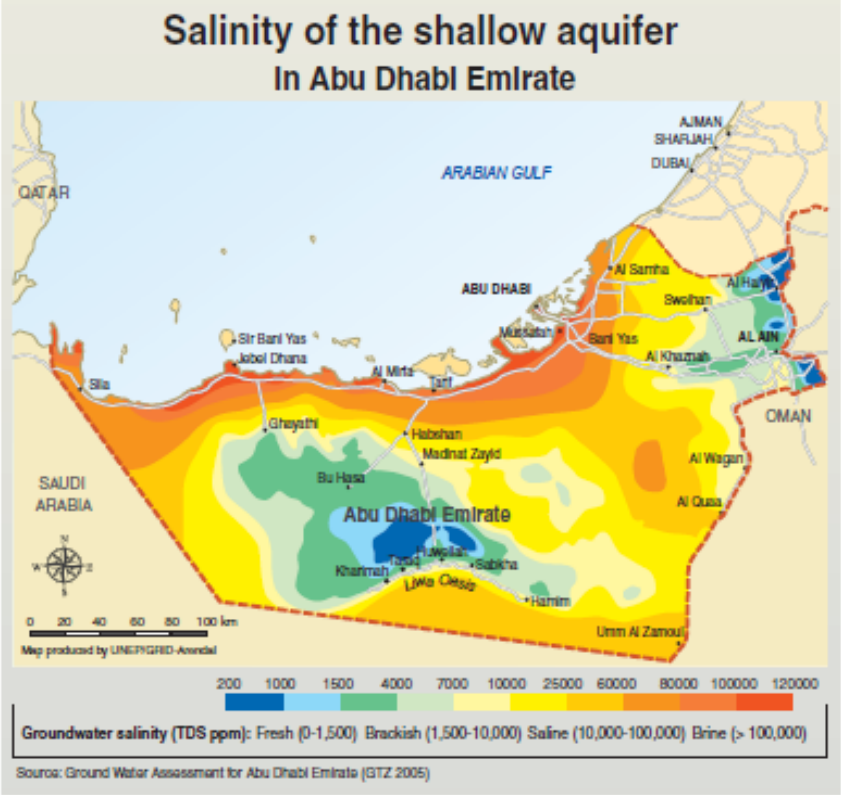


FIGURE 5.11 POTENTIAL IMPACT OF SALT WATER INTRUSION ON THE COASTAL AQUIFER IN ABU DHABI, UNITED EMIRATES (STATE OF ENVIRONMENT REPORT, ABU DHABI,2007)

5.4.3 Practical and Institutional Adaptation Measures

To address the major findings above, it is important to the UAE to understand its adaptation options in the near, mid and long-term. Two near-term strategies are under consideration. The first strategy is to develop strategic information systems for coastal zones. Data collection and information development are prerequisites for coastal adaptation as technologies and measures to protect coastal areas, retreat inland, or accommodate sea level rise requires a considerable amount of data on a range of coastal parameters and dynamics.

In particular:

1. Establishing an institutional capacity for climate risk reduction, capacity building and upgrading awareness

2. Establishing a network of coastal monitoring systems with special reference to tide gauges to assess rates of subsidence and potential cavities in coastal areas in view of extensive urbanization in progress
3. Increasing the understanding of coastal systems through development of databases on coastal adaptation technologies and measures, preparation of planning studies, undertaking further sea level rise impact assessments, and raising awareness.
4. Undertaking an assessment of zoning, building codes, and other regulations to identify future planning options and approaches within an integrated coastal zone management framework.
5. Carrying out research on salt tolerant plants and drought

5.5 Kingdom of Bahrain

5.5.1 Background

The kingdom of Bahrain is a low-lying archipelago of 36 islands and shoals, is a nation of dynamic social and ecological systems as well as a plethora of accompanying climate related challenges (initial National communication,). The total land area of the Kingdom is 706.0 km^2. There is approximately 400km of coast line. The capital city, Manama, is located on the largest island, Bahrain, which accounts for 84% of the total area of the country. Land and freshwater resources in Bahrain, like many small islands, are subject to competing demands for urban development, agriculture, industry, and other uses. These two resources are vital for meeting basic human needs, economic growth and improved access to goods and services.

The total land area of Bahrain has been steadily increasing through land reclamation and dredging activities. Many sites along the northern and northeastern coastal areas were dredged and reclaimed for industrial, recreational and residential purposes. As a result, the country's total land area has increased from 662 km sq in 1975 to 710km sq in 2000. Although reclamation activities have significantly increased prime and suitable land for various development projects, they included a host of adverse social, economic and environmental impacts. In an effort to lessen the adverse impacts associated with

future reclamation efforts, discussions are underway for Bahrain to adopt an integrated coastal area management approach for strategic planning.

Due to rapid urban and industrial development, valuable agricultural land in Bahrain has been increasingly lost. Arable lands have been converted to residential areas as demand has continued to increase for housing and recreational facilities. Moreover, high soil salinity resulting from the use of groundwater for irrigation has been gradually increasing

Bahrain has no natural fresh, surface water resources. Hence, groundwater and desalinated seawater are the only sources to meet water needs for households, industry and agriculture. Annual water consumption is about 320million m^3, 60% of which is consumed in agriculture sector, which relies heavily on irrigation.

5.5.2 Vulnerability to Sea Level Rise

Bahrain's total population is just over 600,000. The country has experienced large population growth over the years, with an annual national population growth of 3.6% making it one of the largest in the world. Most of the population of Bahrain is concentrated along coastal zones particularly in the north and northeastern parts of the main island Bahrain. High population densities 700-900 persons/km2 characterizes these areas. This makes seal level rise a very significant issue when considering climate change adaptation in Bahrain.

In order to assess the potential impact of sea level rise on the kingdom of Bahrain, a satellite imagery analysis for identification of land use and GIS estimation has been carried out (Al Jeneid et al, 2007). Analysis of overlays has also indicated high vulnerability of the coastal zone to potential impacts of sea level rise. This is shown in Fig (5.12). Results indicated that if the sea level rises by only 50cm, about 11% of the area of the Kingdom of Bahrain will be directly inundated. No consideration of salt water intrusion and/or land subsidence has been estimated

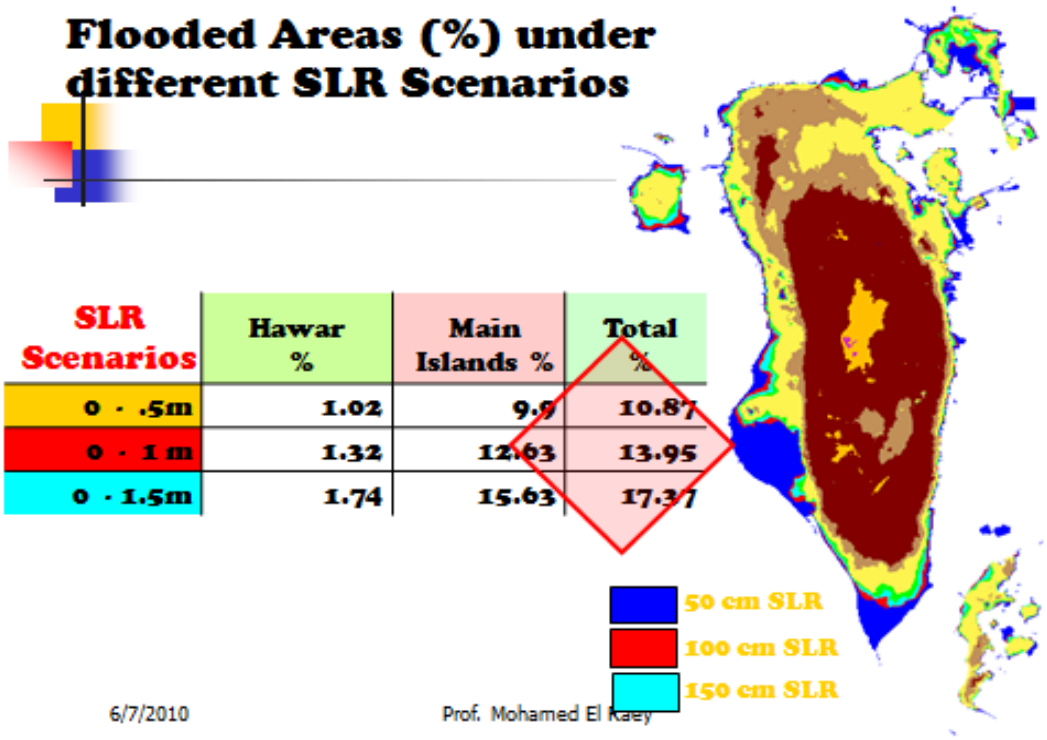


FIGURE 5.12 TOTAL PERCENTAGE OF INUNDATED LAND FOR THE KINGDOM OF BAHRAIN UNDER THREE SCENARIOS OF SLR (AL JENEID ET AL, 2007)

5.5.3 Practical and Institutional Adaptation Measures

In view of the high vulnerability of the kingdom it is necessary that a strong adaptation capability be established. In particular

1. Developing the institutional capability with special reference to a strong monitoring system, Building up national capacities for monitoring, assessment and risk reduction Particular emphasis on land subsidence monitoring and assessment systems
2. Building up capacities for proactive planning and ICZM and upgrading follow up
3. Upgrading awareness of policy makers and stakeholders

5.6 Kuwait

5.6.1 Background

The State of Kuwait is situated in the northeast of the Arabian Peninsula in Western Asia. It is bordered by Saudi Arabia to the south and Iraq to the north and lies on the northwestern shore of the Persian Gulf (Figure 5.13). Kuwait covers an area of 17,820 km^2 and has a population of about 2.7 million. Kuwait has nine islands, all of which with the exception of Failaka Island are uninhabited. With an area of 860 km^2, the Bubiyan is the largest island in Kuwait and is connected to the rest of the country by a 2,380 m long bridge. The land area is considered arable and sparse vegetation is found along its 499 km long coastline. Kuwait City is located on Kuwait Bay, a natural deep-water harbor. The state has some of the world's richest oil fields with the Burgan field having a total capacity of approximately 70 billion barrels (1.1×10^{10} m^3) of proven oil reserves. The oil spills during the Persian Gulf War also drastically affected Kuwait's marine resources.

Kuwait's coastal area is considered to have special importance because most urban, industrial, commercial and recreational activities are concentrated in this zone. It also represents the main source of fresh water and electricity in the country. Besides, the coastal zone has a unique ecosystem and is a significant nursing ground for fish and shrimp.

FIGURE 5.13: A MAP OF KUWAIT INDICATING COASTAL AND VULNERABLE SITES

Kuwait, being a maritime and mercantile country with more than 500 km of shoreline, depends to a great extent on its marine environment for its drinking water supplies, fishery resources, through desalination cooling water for power plants, oil transporting through oil-loading terminals and recreation. The harbors of the country are used for transportation of commercial goods to and from Kuwait. Hence, Kuwait's territorial waters are Kuwait's life line. Therefore, the protection of its coastal zone, as well as the marine environment, is of utmost importance to Kuwait.

5.6.2 Vulnerability to Sea Level Rise

There are many areas that are very sensitive and vulnerable to the potential sea level rise along the coastal zone of Kuwait. Figure (5.14) illustrates the digital elevation model extracted from topographic map of scale 1:50000. In general, the lowlands are concentrated on the eastern part of Kuwait. Figure (5.16) illustrates three main sites

that may be at risk from any potential sea level rise. Bubyan Island that is located in the northeastern part of Kuwait is one of the most vulnerable sites in Kuwait. The elevation at some points is below the sea level and the elevation on the northern part of the island ranges from few centimeters up to 2 meters. The second vulnerable site is Qaruh Island. This island is totally highly vulnerable regarding any potential sea level rise. The disappearance of such island due to any rise to the sea level is one of the expected scenarios. The third vulnerable site in figure (5.16) is Al-Khiran region, at the southeastern part of the coastal zone.

Figure (5.15) shows the vulnerable sites along the coastal zone of Kuwait Bay. The main and large vulnerable site is located to the north of Kuwait bay (Fig. 5.14). There are many other vulnerable sites along the bay but are of smaller areas (see also Fig. 5.17).

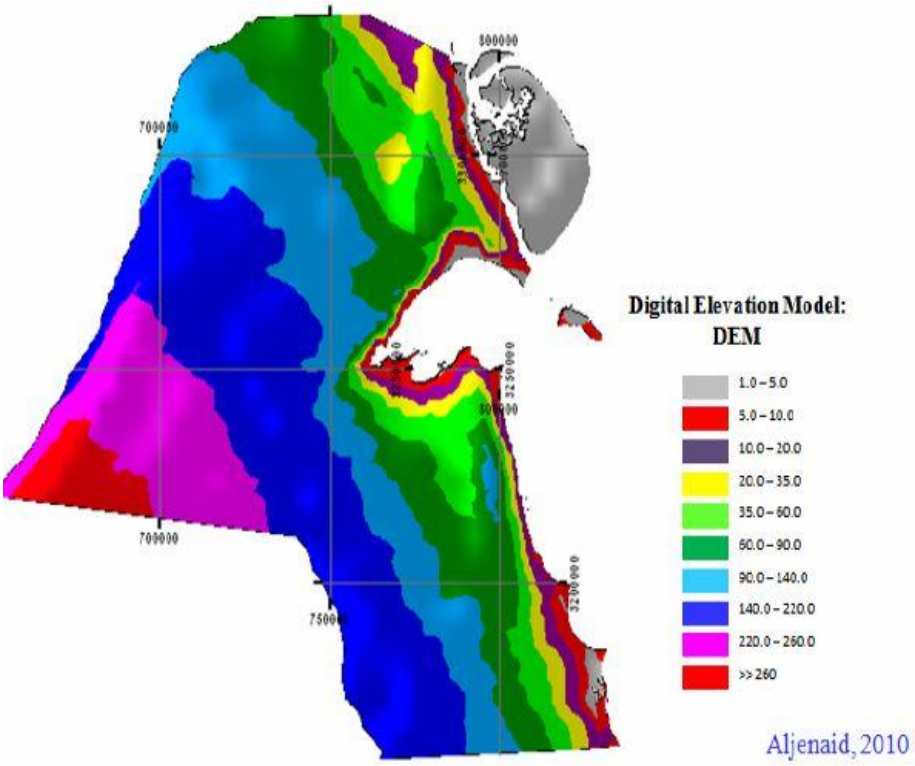


FIGURE 5.14 TOPOGRAPHY OF KUWAIT (ALJENEID, 2010)

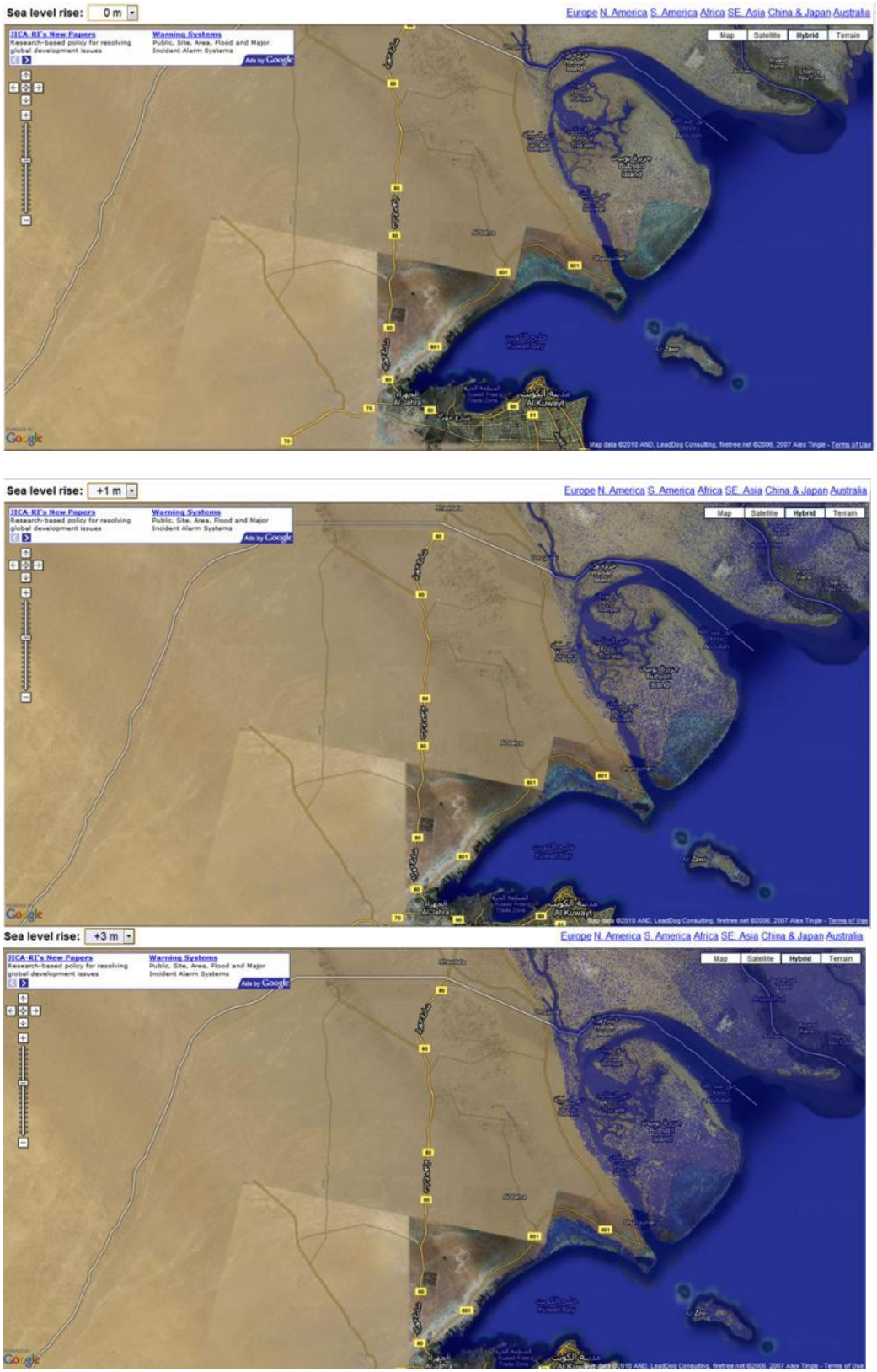


Figure 5.15: Impact of sea level rise on the North East of Kuwait and Bubyan Island for three possible scenarios of sea level rise (0, 1m and 3m, respectively)- (Source: River Surveyor: http://flood.firetree.net)

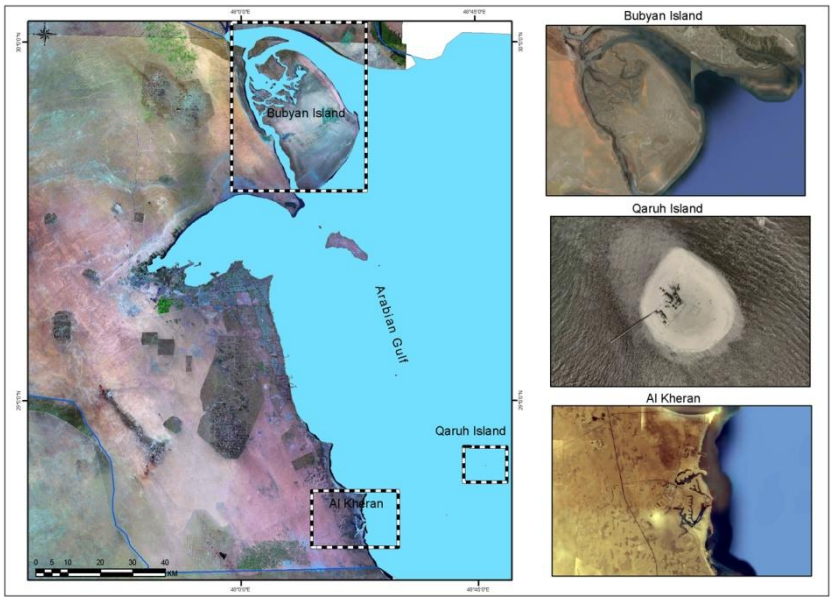


FIGURE 5.16 THREE SELECTED VULNERABLE AREAS (BUBYAN ISLAND, QARUH ISLAND, AND AL-KHIRAN COASTAL REGION) TO THE POTENTIAL SEA LEVEL RISE IN KUWAIT.

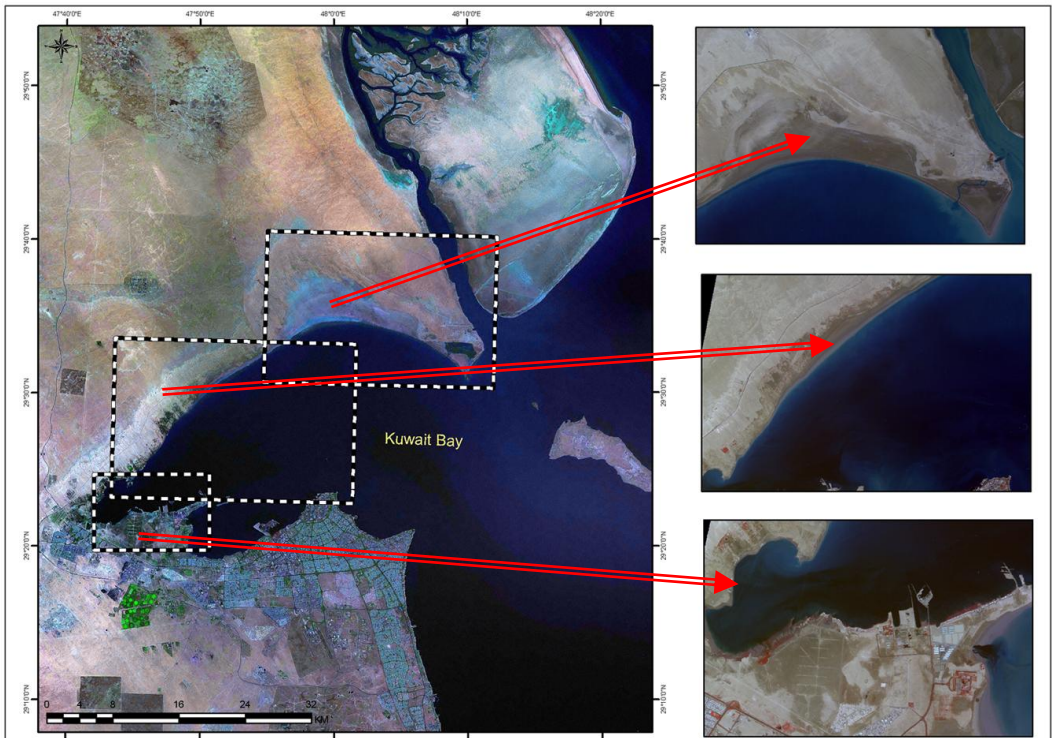


FIGURE 5.17: A SATELLITE IMAGE AND MAGNIFICATIONS INDICATING SOME OF THE VULNERABLE AREAS IN KUWAIT

5.6.3 Practical and Institutional Adaptation Measures

Due to the importance of the coastal zone of Kuwait to the wellbeing of population, it is well realized that adaptation measures should include:

1. Creating a strong Institutional capacity that includes capacity to monitor the coastal areas and related indicators
2. Establishing and enforcing Proactive planning and ICZM with a follow up
3. Upgrading awareness of decision makers and stakeholders concerning sea level rise and its potential implications

5.7 Republic of Djibouti

5.7.1 Background

The Republic of Djibouti is situated in the Horn of Africa, between the tropic of Cancer and the equator, at the junction of the Gulf of Aden and the Red Sea. The country has an area of 23,200 km^2 and a coastline 370 km long. As it is located in an area of tectonic plate separation, the landscape is largely made up of volcanic formations. It has a dry climate with a mean annual rainfall of about 150mm average daytime temperatures vary between 17°C and 42° C and relative humidity is fairly high, between 40 per cent and 90 per cent. There are occasional catastrophic floods resulting in massive damage to people and property. The drought of 1986-1988 was followed in 1989 by a record rainfall of 692.9 mm, of which 543.6 mm fell in the month of April alone. Almost 82 per cent of the population lives in urban areas and 65.5 per cent of those live in the city of Djibouti. The population growth rate is 3 per cent and the population is a young one, with 54 per cent under 20 years old and slightly more females than males.

5.7.2 Vulnerability to Sea Level Rise

Djibouti is ranked globally as the most exposed to the impacts of climate change, scoring 0.00 overall (CCI values closer to zero represent higher levels of exposure to the consequences of climate change). Djibouti's is already regularly buffeted by tropical

storms from the Indian Ocean (Hamid, 2009). With 7.1 percent of the population living less than 5 meters above sea level, Djibouti will be increasingly vulnerable to inland flooding as sea levels rise. Djibouti, like other countries is rated “extremely” affected by climate change, will also suffer public health impacts, including more severe heat waves. In many places around the world, these dangers have already begun to take a significant toll.

Added to all this, the cities face other problems related to urban infrastructure, such as sanitation and the draining of rain water. The high level of unemployment is linked to the economy’s failure to create new jobs. Women, who form the majority of the employable population, are under-employed at a rate of 34 per cent. Furthermore, the formal sector is the largest supplier of employment, accounting for almost half of all registered jobs (44 per cent). In the area of health, national policy is mainly directed towards primary health care, although the infrastructures are still inadequate and there is a shortage of medical staff. Life expectancy is only 50 years and the rates of child and maternal mortality remain high.

Sea level rise represents the greatest threat to Djibouti town where about 70% of the population is concentrated. The information gathered from satellite imageries (Fig 5-18) and in the field on vulnerability can be summarized as follows:

- Direct flooding of many parts of Djibouti City and salt water intrusion in coastal areas including inland Lake Asal
- Water supplies will record a deficit at least equal to the decline in rainfall, causing a reduction in the quantity of water soaking into the water table and the lowering of piezometric levels;
- Given the country’s specific hydrogeological conditions, with a relatively high level of mineralization of its water, we may expect a rise in the salinity of the ground water; Sea-level rise, linked to the decline in rainfall, will mean a gradual increase in the influx of sea water into coastal regions;
- Ultimately, in both urban and rural areas, the problems entailed in providing water for human consumption, agriculture, stock-raising and industry will become increasingly serious.

- The study of the vulnerability and adaptation of the coastal region focuses primarily on the city of Djibouti, an extensive urban sprawl and hive of economic and social activity, which is in the throes of rapid urban development and a marked population growth

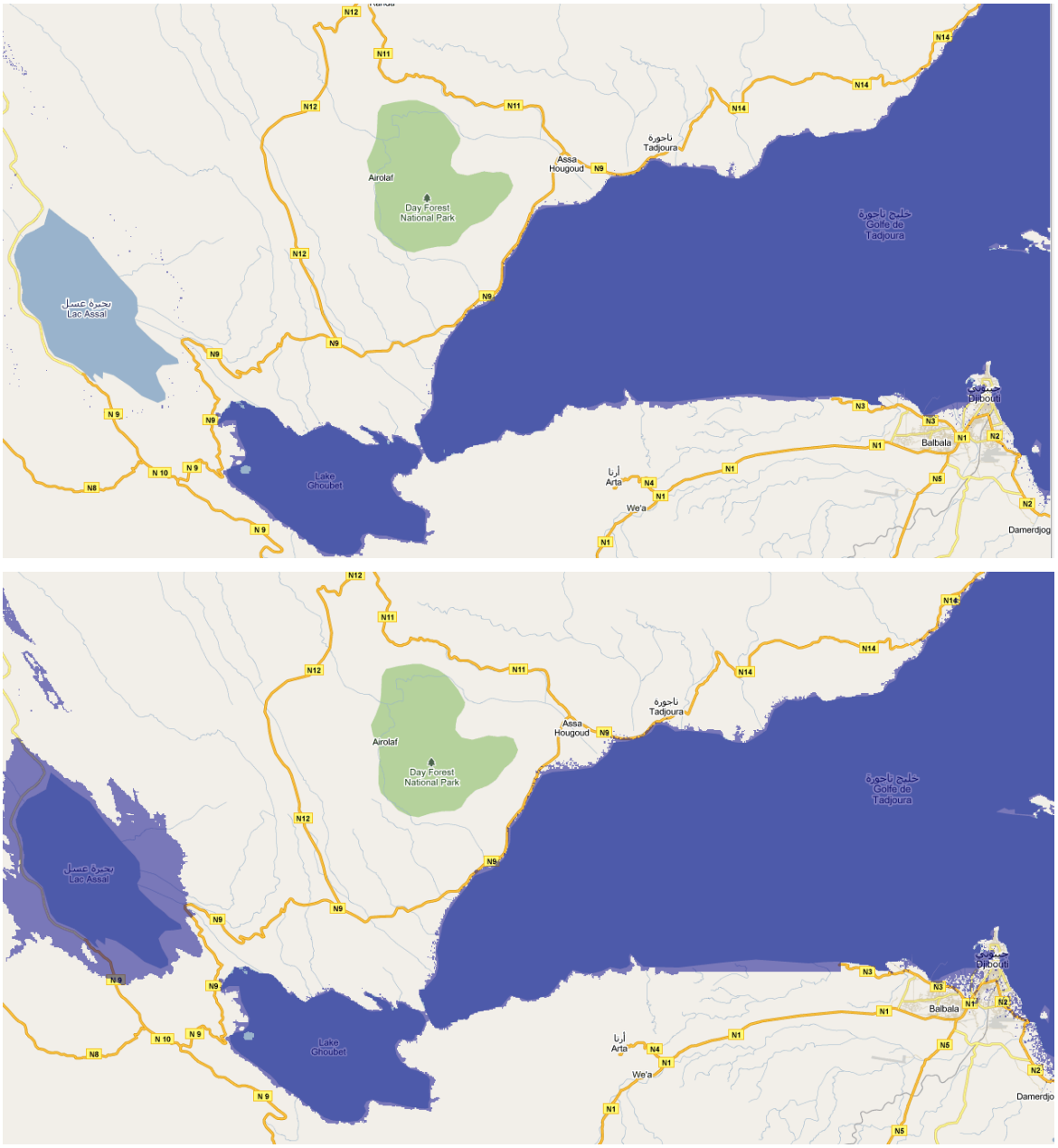


FIGURE 5.18 IMPACT OF SEA LEVEL RISE ON THE COASTAL AREA OF DJIBOUTI (UPPER 0LEVEL)-(LOWER 3M SLR). NOTICE EXCESSIVE EXPANSION OF LAKE ASAL BY SALT WATER INTRUSION AND FLOODING IN DJIBOUTI CITY AND VICINITY (RIVER SURVEYOR: HTTP://FLOOD.FIRETREE.NET)

- For estimated flood levels which lie between 1.88 m and 2.78m, the rising water levels would have a significant impact throughout the city of Djibouti, affecting between 26per cent and 45.5 per cent of the population. Between 18 per cent

and 30.8 per cent of homes would be affected, between 47.1 per cent and 52 per cent of economic activity, between 25.4 per cent and 30 per cent of public utilities and between 61 per cent and 76 per cent of its nature areas. These figures are indicative of the serious problems faced in any future urban planning and development in the city of Djibouti.(Initial Nat. Comm2001) (River Surveyor: Http:// Flood.Firetree.Net).

Preliminary investigations indicate that the most vulnerable area is the city of Djibouti itself. Direct inundation of large areas and salt water intrusion may be the most obvious modes of impacts (Figure 5.19). Table (5.2) presents an estimate of approximate losses due to 2m and 3m SLR scenarios (Djibouti,2001) indicating the seriousness of the impacts

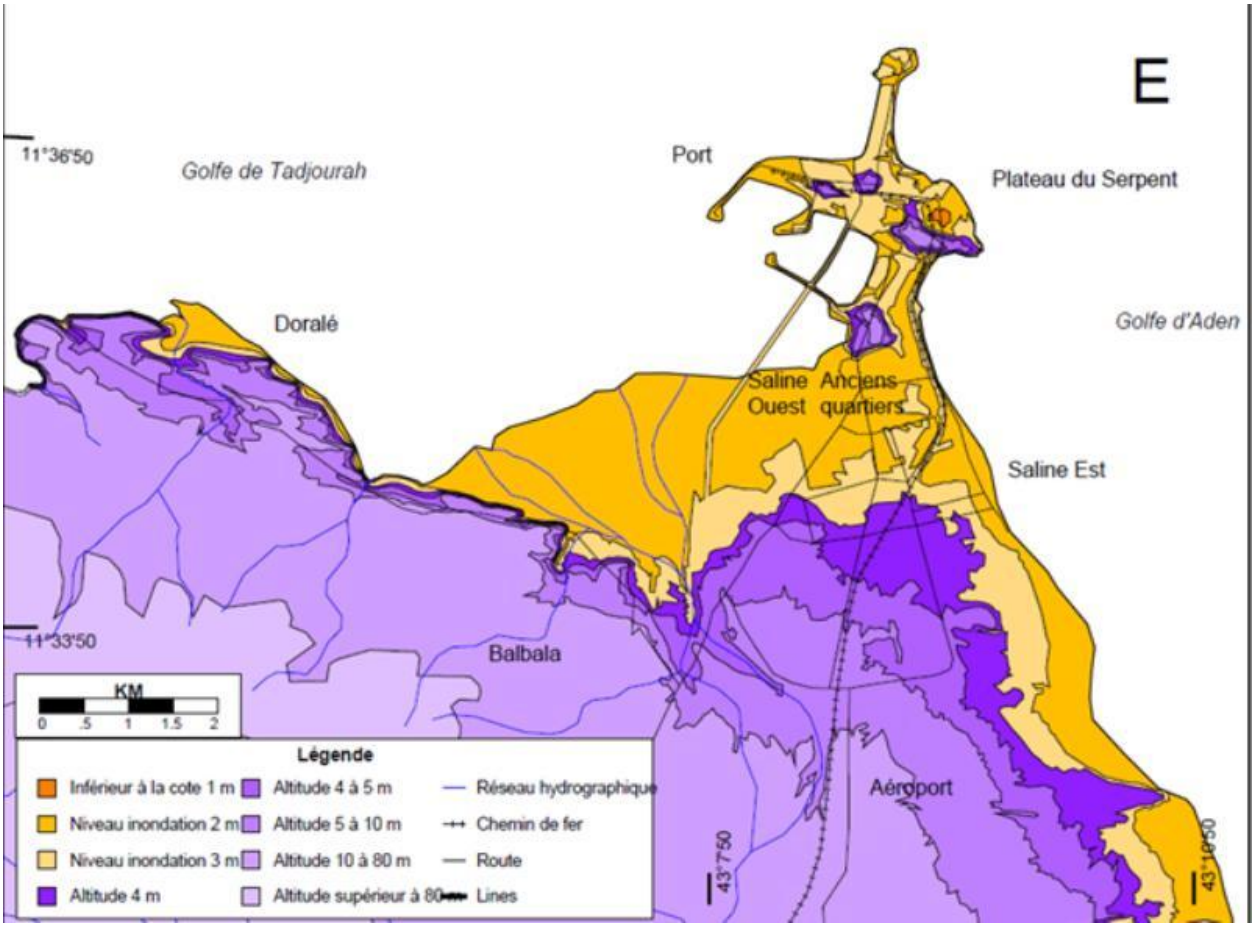


FIGURE 5.19 DETAILED ELEVATION OF THE CAPITAL DJIBOUTI INDICATING LOW AND HIGH ELEVATION AREAS AND VULNERABILITY TO SLR (INITIAL NATIONAL COMM, 2001)

TABLE 5.2 A TABLE INDICATING AREAS THAT ARE SUBJECT TO INUNDATION IN CASE OF SEA LEVEL RISE FOR TWO SCENARIOS OF 2M AND 3M (INITIAL NATIONAL COMM, 2001)

Fonctions	Inondation minimum (2 m)		Inondation maximum (3 m)	
	ha	%	ha	%
Habitat	208	18	358.1	30.8
Activités économiques	150.8	47.1	262	52
Equipements Publics	37	30	75.5	25.4
Zone militaire	65	13.3	69.4	14.25
Zone d'extension	70	3.3	122.6	6
Zone naturelle	802.9	61	983	76
Total	1 333.7	22.7	1 870.6	31.9

5.7.3 Practical and Institutional Adaptation Measures

It is clear that the capital city Djibouti is highly vulnerable to impacts of sea level rise and adaptation measures have to be addressed immediately. The following is a

summary of the proposed adaptation measures, which must form part of a comprehensive social and economic approach (First National Communication, 2001):

- Coastal protection especially close to highly populated areas;
- Strengthening of rock rubble breakwaters on the marine coastline;
- Reforestation of dunes;
- Banking up the walls of landfills;
- Installing a drainage system for rainwater ;
- Implementing regulatory and institutional measures.

The consideration of coastal, marine and land ecosystems, which looks in particular at mangroves, coral, fauna and forest areas, assesses their current state as fragile and vulnerable. Given the gravity of the situation, the following measures are proposed:

- Creation of a national network of protected areas;
- Putting in place a follow-up program for ecosystems;
- Examination of the vulnerability of ecosystems;
- Establishment of an integrated development program for the Day forest;
- Conduct of institutional measures.

5.8 Morocco

5.8.1 Background

The Moroccan Atlantic coast is the most important area for the national economy, taking into account its demographic and economic weight. The Atlantic coast of Morocco is divided into:

- 61% of the urban population of the large cities
- 80% of permanent manpower of industries
- 53% of the tourist capacity
- 92% of the foreign trade.

However this situation is changing with the realization of the new port Tangier Med and the economic development it brings to the Mediterranean coast of Morocco (Etude V&A; 2006).

The total coastal population represented more than 50% of the population of Morocco, increasing on average by 2.77% per annum, whereas the total population of Morocco increased only by 2.5% per annum on average for the same period. The densely populated coast is subject to major pressures from human development and this is only projected to increase in the future. The urban population of the coastal areas did not cease growing since the beginning of the century. The density of the population reaches 162 habitants/km ^{2} between Kenitra and Casablanca, compared to the 93 inhabitants/km ^{2} in the Mediterranean coast (Etude V&A; 2006).

77% of Morocco's industrial activities are located at the coastal areas and 98% of Moroccan foreign trade relies on shipping as transportation method. Therefore the economic importance of coastal areas is imperative. Also increasing popularity of beach tourism highlights the importance of coastal areas to Morocco's economy. Beach holiday was the primary motivator for both international and national tourism in Morocco, and the coastal areas boast more than 50% of accommodation capacity, the most dynamic centers being Agadir and Casablanca (Etude V&A; 2006).

5.8.2 Vulnerability to Sea Level Rise

The coasts of Morocco already strongly weakened by human activities would be confronted with major socio-economic and environmental difficulties if no adaptation measures or vulnerability studies are undertaken. A 2002 study by the Ministry of Environment identified two coastal zones as being most vulnerable: The coast of Saïdia and the coast of bay of Tangier (Etude V&A; 2006).

Fig 5.20 through Fig 5.21 shows the variation of land use and elevation along the coastal strip of the Mediterranean coast of Morocco. The figures demonstrate the vulnerability of the dense urban areas and tourist units to potential impacts of sea level rise and salt water intrusion. Fig 5.22 presents a simulation of the land to be flooded in case of SLR of 2m

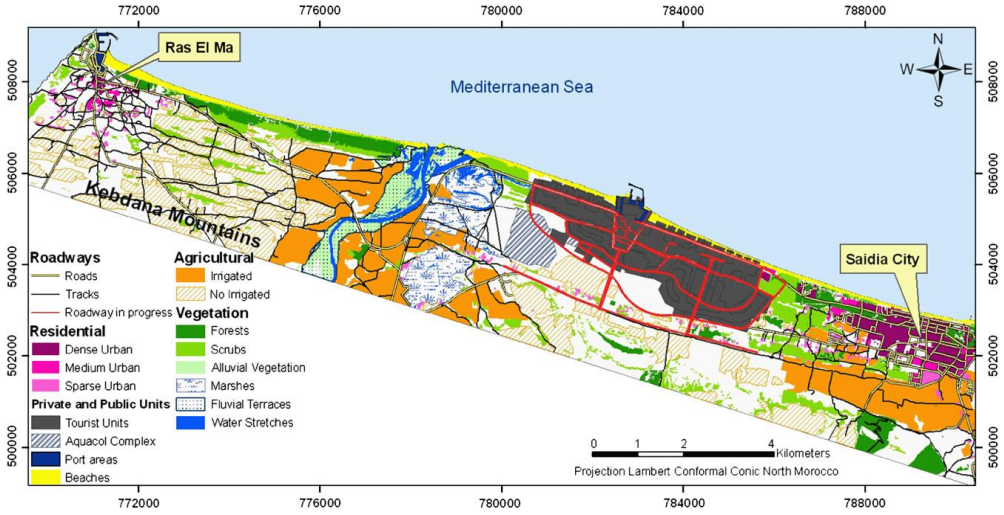
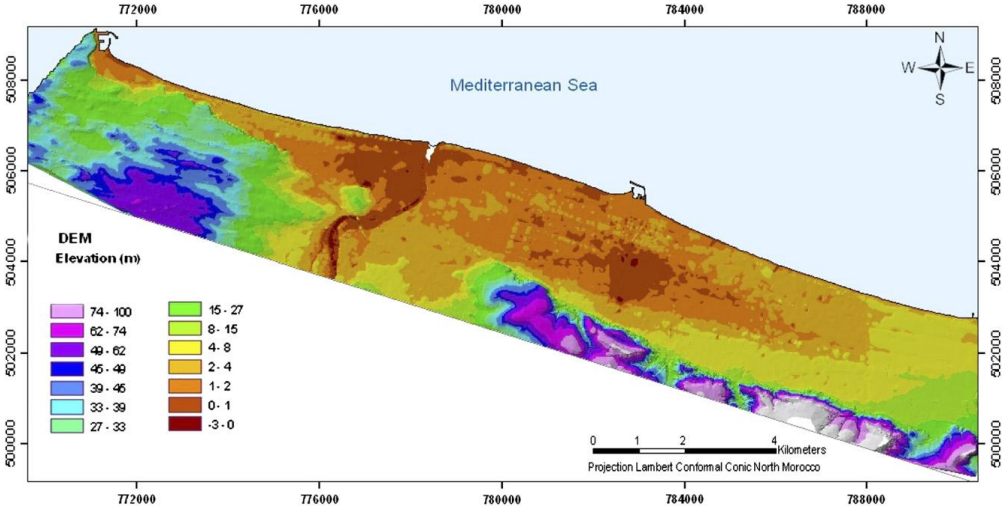


FIGURE 5.20 LAND USE IN ONE OF THE VULNERABLE AREAS OF MOROCCO (SNOUSSI ET AL, 2008)



5.21 DIGITAL ELEVATION MODEL (DEM) OF THE EASTERN MEDITERRANEAN COAST OF MOROCCO INDICATING VULNERABLE COASTAL AREAS (SNOUSSI ET AL, 2008)

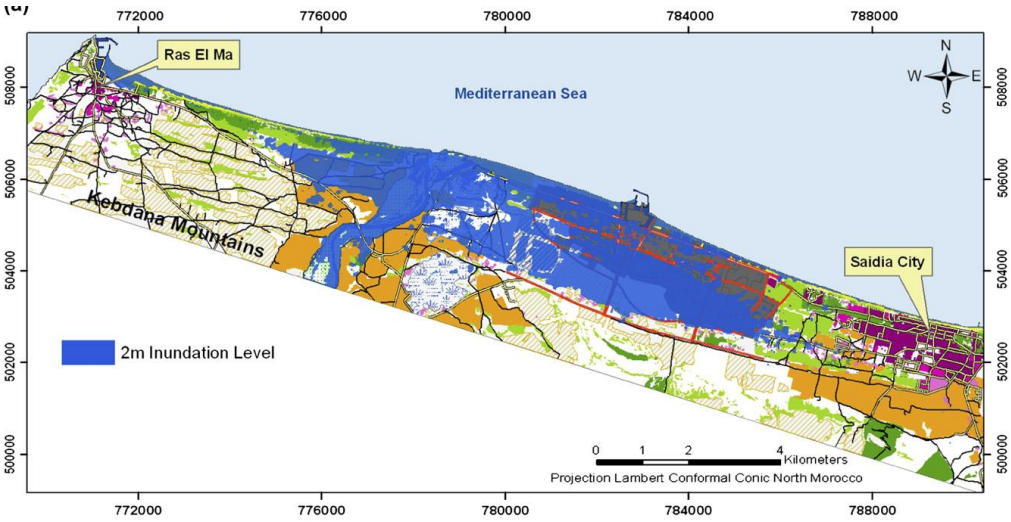


FIG 5.22 AREAS TO BE FLOODED DUE TO A SLR OF 2M OF THE EASTERN MEDITERRANEAN COAST OF MOROCCO (SNOUSSI ET AL, 2008)

Biogeophysical Impacts of SLR

Impacts of sea level rise on coastal areas are numerous and varied but the most significant are generally and in the case of Morocco: the low-lying coastal flooding, coastal erosion and salinization of estuaries and coastal aquifers (Etude V&A; 2006).

• **Phenomenon of flooding**: The first threat is that of flooding of evergreen coastal marine waters which are currently poorly or partially emerged, as the shores of deltaic plains, salt marshes, mangroves, coral reefs, etc. There seem has increased the intensity and wave heights over the past three decades, and that the waves of storms were more frequent with the expected climate CC.

In Morocco, the importance of the coastline (3500 km), is marked by a large number of environments margino-coastal and coastal wetlands such as lagoons, estuaries, berries or more less closed beaches, coastal islets and predisposes. These areas generally have a low topography and high vulnerability to flooding by sea water.

Coastal wetlands of Morocco are renowned for their ecological values, as well as goods and services they provide to local populations, who long have developed know-how traditional use of natural resources. The flooding of these wetlands could ultimately damage their ecological, social and economic conditions and force people who depend on their activities (including agriculture and livestock) to new conditions by their conversion to fishermen, aquaculturists and others. The barrier beaches could also be readily admits a cross-cut larger volume of seawater, which could be detrimental to the vegetation of halophilic salt marshes, which will be subject to a longer duration of submergence and higher salinity, for all species sensitive to salinity and water column, for salt marshes which could be used for grazing, and for the protection works (breakwaters, jetties, groins, etc..)

• **Coastal Erosion**: In Morocco, two thirds of the beaches are eroding, particularly among the cliffs Jorf Lasfar and Oualidia recede seven major coastal environments of the Atlantic are total or partial closure and port facilities have increased volumes dredging of 15% during the last 5 years. It is often difficult to attribute these changes to a single cause. While the share of anthropogenic activities is undeniable, these findings could provide tangible evidence of a rise in sea level combined with strong swells storms becoming more frequent.

• **Phenomenon of salinization**: The phenomenon of salinization (Increasing the salt content of freshwater by seawater intrusion) is likely to affect estuaries and coastal aquifers. Indeed, the SLR may lead to an increase in the depth of estuaries but especially a greater penetration upstream intrusion of salt water. Increased salinity of surface water will no doubt have an impact on the fauna and flora. It seems that disturbances of this kind should be more sensitive in areas with low tidal range.

With regard to fresh groundwater, if the sea level increases, the separation between the continental freshwater and saltwater marine will move sideways to the ground and level piezometric groundwater will be enhanced. Thus this will result in a reduction in the volume of fresh groundwater through salt wedge intrusion. The hydrogeology of low areas, often composed of alluvial sedimentary permeable soil can be changed. The aquifers at risk of a rise of the same order as that of sea level would have considerable impact on vegetation, and even at ultra-high elevations.

Many studies have shown salinity more or less advanced into coastal aquifers. This has been attributed to several anthropogenic factors (including over-pumping, return of irrigation water, etc.) which are the main cause of the decrease levels of fresh water as a result of the invasion of salt wedge. However, no study has explicitly linked salinity to sea level rise due to CC. The penetration of the salt tide further upstream is felt in several estuaries, without series temporal data can confirm. Many living species may disappear because they cannot adapt to changes in salinity.

Socio-economic impacts of SLR

• **Agriculture:** The intrusion of saltwater into groundwater can affect the quality of products and yields significantly.

• Water resources: As the sea rises, the fresh groundwater and surface water can be displaced by salt water, which can have significant adverse impacts on drinking water supply. Following CC, prospective studies have shown that in 2020 the water cut by 10-15%. The SLR would therefore exacerbate the reduction in coastal areas.

• **Fisheries and Aquaculture**: SLR could affect coastal activities such as (fishing, coastal lagoon, the harvest of shellfish and seaweed, etc.). In addition, aquaculture activities that are related to physical and chemical conditions (salinity, chemistry, temperature,

oxygenation, etc.) specific husbandry should adapt to changes associated with SLR, the increase temperature and salinity.

• Tourism: Impacts of CC and the SLR on tourism will affect quality and availability of water resources, erosion of beaches and loss /degradation coastal infrastructure.

A very powerful example is that of the Bay of Tangier, which represented the first station
national tourism in the years 1970-1980. It has fallen sharply in the years 1990, mainly because of the chronic degradation of its coastline. Thus, Tangier has lost 53% of its international nights, resulting in a decrease in tourism revenues ($ 20M / year), income crafts (25%) and tourist transportation (40%) (Snoussi and Long, 2002). SLR would have catastrophic effects if nothing is done to rehabilitate and protect the bay.

• **Industry:** The Moroccan coastline is the area where the main focus of activities industry. Thermal power plants installed on the coast, refining plants and deposits industrial centers and roads along the coast, are particularly vulnerable to SLR plus swells from storms or surges.

• **The sanitation sector**: In the big coastal cities, were particularly systems of sewage and storm water that would be threatened by SLR? Coastal stations of water treatment may be damaged and no longer fulfill their function, which will be detrimental to water quality, and consequently to health of populations.

• **Forests**: Forests on the coast would be affected by the marine invasion and salinization waters of the aquifer.

As a conclusion:

- A change in sea level, even a few inches may, in different segments of coastline, cause a significant withdrawal of the shore either by erosion or flooding;
- The intrusion of sea water can lead to forms of degradation by salinization in extensive grounds operated by coastal agriculture;
- The main coastal port structures, harbor pools and sanitation are also vulnerable to rising sea level

Rising sea levels will not only impact the environment but also different sectors of the economy including in particular tourism, and will require interventions (protection, rehabilitation) which are not always easy or even possible sometimes. Hence the interest is to give priority to the issue of rising sea levels in future decisions for management of coastal environments. The studies and research to identify vulnerabilities to rising sea level across Morocco have remained very limited and data that may help in realizing such studies are unavailable. Also, it is urgent to establish a research program integrated with sampling measurements and modeling of the tidal effect of the elevation sea level on coasts and in the image of what has been done in neighboring countries

5.8.3 Practical and Institutional Adaptation Measures

Based on previous considerations, it is suggested that the following adaptation measures are necessary:

1. Projects for vulnerable sectors (such as the coastline, forest or precarious human establishments) have to be identified and protection measures worked out.
2. Establishing a strong institutional capacity for monitoring, building geographic data base, modeling and assessment
3. Adopting proactive planning and integrated coastal zone management approaches for development along the coast
4. Upgrading awareness of decision makers and stakeholders of the potential impacts of sea level rise on various aspects of development

But, it is clear that the Moroccan economy, which is still caught up in the problems of development and struggles against poverty, cannot withstand the costs of such projects without sacrificing the major components of its social and economic development programs (education, health, basic infrastructures, rural development, etc.).

5.9 Sudan

5.9.1 Background

Sudan encompasses an area of about 250.6 million hectares, bounded on the east by the Red Sea and on the other sides by nine African nations. The country is divided administratively into 26 States. It is composed of vast plains interrupted by a few widely separated ranges of hills and mountains. It lies within the tropical zone between latitudes 3º and 22º north and longitudes 22º to 38º east.

Arable land of Sudan constitutes about one third of the total area of the country, however only 21% of this arable land is actually cultivated. Over 40% of the total area of Sudan consists of pasture and forests. Natural pasture provides grazing land for nearly all livestock. Sudan is characterized by a wide range of climate variations which vary from desert in the northern part of Sudan, where it seldom rains, through a southward belt of varying summer rainfall, to an almost equatorial type of rain in the extreme southwest, where the dry season is very short. Rainfall, which provides much of the available surface water and supports most of the country's agricultural activity, varies significantly from the northern to southern ranges of the country. Annual rainfall in the northern half of Sudan varies from close to zero near the border with Egypt, to about 200 millimeters around the capital Khartoum. Where it rains, the rainy season is limited to two or three months with the rest of the year remaining virtually dry. Moreover, the rain usually comes in isolated showers, which are highly variable in time and location, with a coefficient of variation ranging between 40% and 60%. In the quarter south of the country's center, the annual rainfall rarely exceeds 700 mm. Rains in that quarter are concentrated in less than four months of the year with a coefficient of variation between 20% and 40%. In the southernmost quarter, where the annual rainfall exceeds 700 mm, the area is dominated by swamps and inhabited by the tsetse fly, which is hazardous to human and animal life. The erratic nature of rain, and its concentration in such a short season, creates a vulnerable situation, especially for rain-fed agricultural areas.

5.9.2 Vulnerability to Sea Level Rise

The coastal zone of Sudan on the Red Sea is one of the Rich coasts with coral reef, mangrove and Marine life. It has many promising sites for petroleum extraction and tourism. Unfortunately, it is exposed to the same problems of impacts of sea level rise on corals, mangrove and marine life.

The Red Sea governorate is the only governorate that lies on the Red Sea. The City of Port Sudan is the main coastal city of large population, which may be considered vulnerable to potential impacts of sea level rise and impacts of extreme events on coastal structures. However, other towns such as Swaken may be equally vulnerable. A large area to the north east, east and south east of Tokar is noticed to be vulnerable to even a 1m sea level rise as observed by Sea level explorer (Figure 5.23). The impact of sea level rise in this area on the coral reef and mangrove may be devastating

FIGURE 5.23 THE COASTAL ZONE OF SUDAN ON THE RED SEA INDICATING VULNERABILITY OF THE CITIES OF PORT SUDAN, SWAKEN AND THE AREA TO THE NORTH AND SOUTH OF TOKAR BY DIRECT INUNDATION AND/OR SALT WATER INTRUSION. (LEFT TODAY, RIGHT 1M SEA LEVEL RISE)- (BASED ON ANALYSIS BY RIVER SURVEYOR: HTTP://FLOOD.FIRETREE.NET)

5.9.3 Practical and Institutional Adaptation Measures

1. It is most essential that an institutional system for climate change and sea level rise including monitoring capabilities, be established
2. Geo-Engineering protection measures of flooding on the Red Sea such as required walls and/or nourishment and protection of coral reef and mangrove must be established
3. A detailed vulnerability assessment of potential impact of Sea level rise on the Red Sea coastal area has to be taken to identify and assess options for adaptation
4. A program for upgrading awareness of decision makers, civil society and stakeholders, must be undertaken

5.10 Qatar

5.10.1 Background

The State of Qatar is situated halfway along the West coast of the Arabian Gulf covering an area of 11,437 km2 and protruding about 160 km along its north-south axis into the central zone of the Gulf. It includes, in addition to the mainland, several islands in the coastal waters of the peninsula, the most notable of which are Halul (the main oil storage and exporting centre), Sharauah, Al-Bashiriya, Al-Asahat, Al-Safiliya and Al-Aliya islands.

Qatar measures about 80km at its widest point from coast to coast. It is surrounded by the Arabian Gulf from the north and east and by the Gulf of Bahrain from the west. Major towns are located on the eastern sea coast, such as the capital Doha, and the major cities of Al Wakra, Al Khor, Al Thakhira and Al Shamal, in addition to the industrial cities of Mesaieed, Ras Laffan and Dukhan. 83 per cent of inhabitants reside in Doha and its main suburb Al-Rayyan.

Qatar's population grew from about 422,000 in 1990, to about 617,000 in 2000, and then reached 1.4 million in mid-2008 – more than tripling population size in just 18 years. Qatar's exceptionally rapid population growth, averaging 16 per cent per year between 2005 and 2008, is virtually unprecedented historically and globally.

Qatar's terrain is flat and rocky with some low-rising limestone outcrops in the Dukhan area in the west and Jabal Fiwairit in the north. It is characterized by a variety of geographical phenomena including many coves, inlets, depressions and surface rainwater-draining basins known as *Riyadh* (gardens), which are found mainly in the north and central part of the peninsula. These areas have the most fertile soil and are rich in vegetation.

Extensive dredging and land reclamation, especially in Doha, has radically modified that section of the coastline. Intensive building activity is creating a new central business district in which more buildings are currently under construction than are operational, and unprecedented demand has already resulted in non-conventional water supplies (desalinated and treated wastewater) almost totally replacing conventional water

supplies (from rainfall and groundwater) except for agriculture, which is rapidly depleting the remaining fossil water drawn from natural aquifers.

5.10.2 Vulnerability to Sea Level Rise

FIGURE 5.24 IMPACT OF SEA LEVEL RISE ON QATAR AS IDENTIFIED BY COMPARISON BETWEEN PRESENT DAY MAPS (LEFT) AND SIMULATION OF 1M SEA LEVEL RISE (RIGHT). NOTICE DIRECT IMPACTS OF SEA LEVEL RISE AND/OR SALT WATER INTRUSION ON NORTH WEST REGION AS WELL AS THE SOUTH EASTERN REGIONS. (BASED ON ANALYSIS BY RIVER SURVEYOR: HTTP://FLOOD.FIRETREE.NET)

According to AFED (2009), Qatar is by far the most exposed: under various different SLR projections the figure rises from approximately 3% of land (1m) to 8% (3m), and even up to more than 13% (5m). Das Gupta et al, 2007 predicted that Qatar is the most exposed country of the Arab region in terms of its percentage land area affected by sea level rise (see Fig 3.3).

Figure 5.24 represent a preliminary comparison analysis of potential impact of sea level rise on Qatar. It shows a comparison between the two situations of present day and in case of 1m sea level rise. It indicates that a 1m sea level rise will have serious direct and indirect impacts on the coastal area of Qatar, especially that most of the major cities are located on the coast.

5.10.3 Practical and Institutional Adaptation Measures

1. Establishment of a strong institutional system for monitoring of coastal indicators, identifying and assessing in particular, the land subsidence in the coastal area.
2. Carrying out proactive planning and Strategic Environmental Assessment (SEA) for future developmental plans with strong follow up taking SLR into consideration
3. Building up a strong early warning system and contingency plans against extreme storm surges
4. Upgrading awareness concerning impact of climate change in general and SLR in particular

5.11 Iraq

5.11.1 Background

Iraq's only outlet to the sea is a short stretch of the coast on the northwestern end of the Arabian Gulf, including the Shatt al Arab waterway. Basra and Umm Qasr are the main ports. Iraq is approximately coextensive with ancient Mesopotamia. The southwest, part of the Syrian Desert, supports a small population of nomadic shepherds. In the rest of the country, life centers on the great southeast-flowing rivers, the Tigris and the Euphrates, come together in the Shatt al Arab at the head of the Arabian Gulf (Fig 5.25). The marshy delta was largely drained in the early 1990s as part of a government program to control terrorism; by 2006 roughly half the area had been restored. Between the two rivers are numerous wadis and water basins.

Very little rainfall occurs in Iraq except in the northeast, and agriculture mainly depends upon river water. The sandy soil and steady heat of the southeast enable a large date crop and much cotton to be produced. The rivers cause destructive floods, though they occur less often as a result of flood-control projects undertaken since the 1950s. Farther upstream, as the elevation increases, rainfall becomes sufficient to grow diversified crops, including grains and vegetables.

Iraq is on the front line of climate change. It lies in a water-stressed region with scarce water resources of its own. Iraq is mostly a desert, with most areas receiving less than 150 mm of rain per year; only about 13% of the land area is arable. Iraq is therefore extremely dependent on neighboring countries for most of its surface water. The situation is very alarming. A projection of rainfall and stream flow in the Fertile Crescent (Figure 2.25), using a high resolution global climate model (20 km resolution), indicates that the Fertile Crescent will lose its current shape and might simply disappear altogether by 2100, with the discharge of the Euphrates River possibly decreasing by 29-73% (Kitoh et al, 2008).

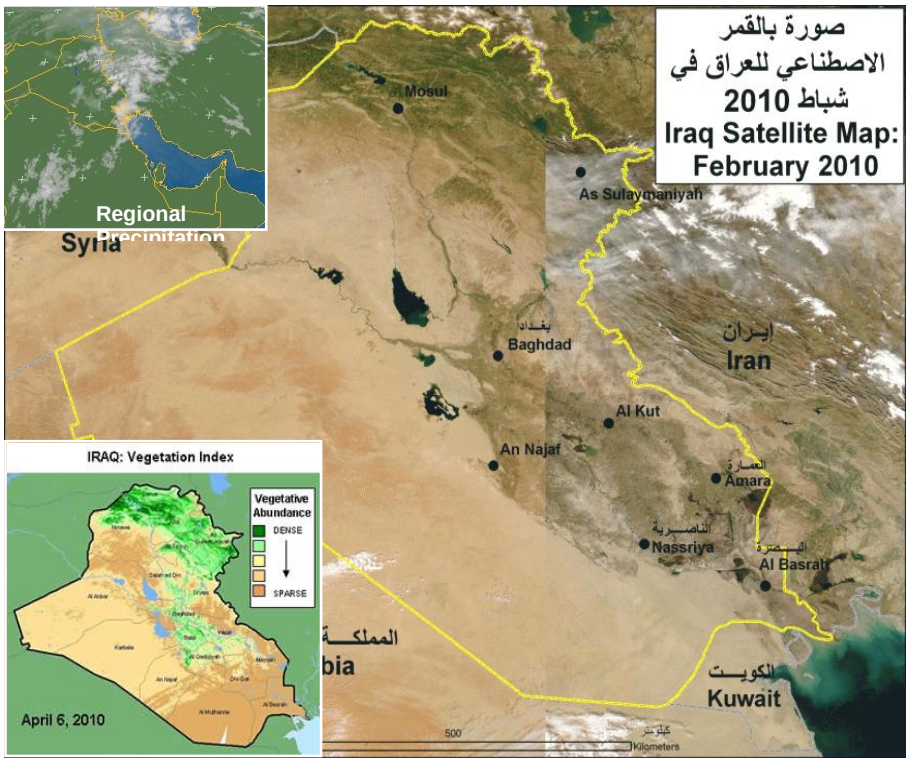


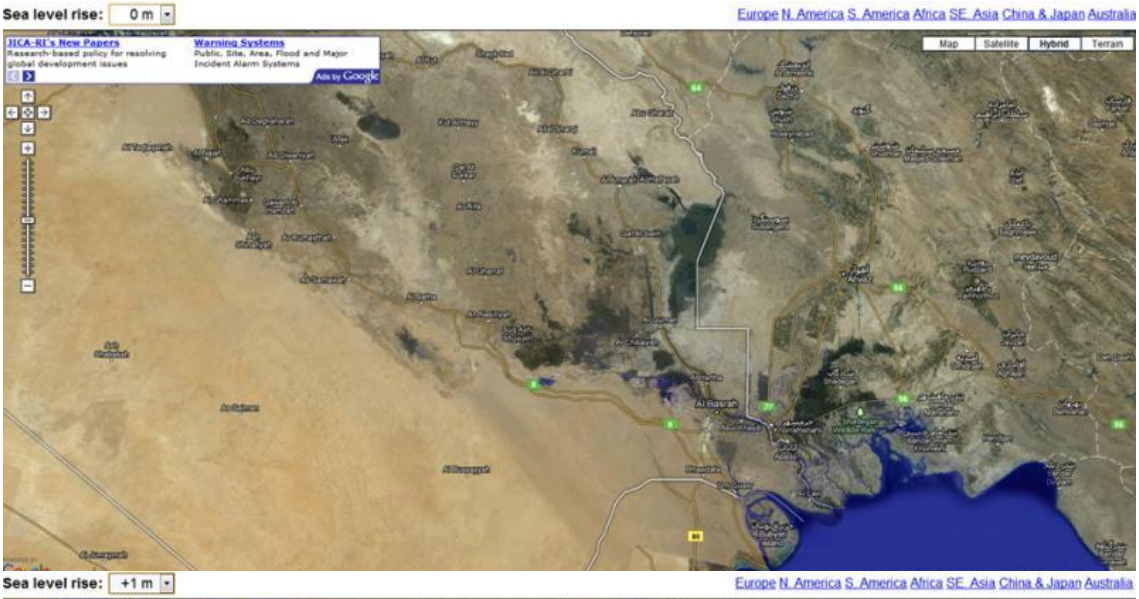
FIGURE 5.25: A MAP OF IRAQ ILLUSTRATING LOCATION OF VEGETATED AREAS

5.11.2 Vulnerability to Sea Level Rise

The shoreline of Iraq on the Arabian Gulf is very limited; however, it is considered one of the most vulnerable areas in the region because of its low elevation with respect to sea level. The low elevation areas appear to extend through Basra City even for 1m sea level rise. The potential impact may affect soil salinity by salt water intrusion and may cause serious inundation of many parts of the region (Fig 5.26).

Sea level rise: 0 m

Europe N. America S. America Africa SE. Asia China & Japan Australia



Sea level rise: +1 m

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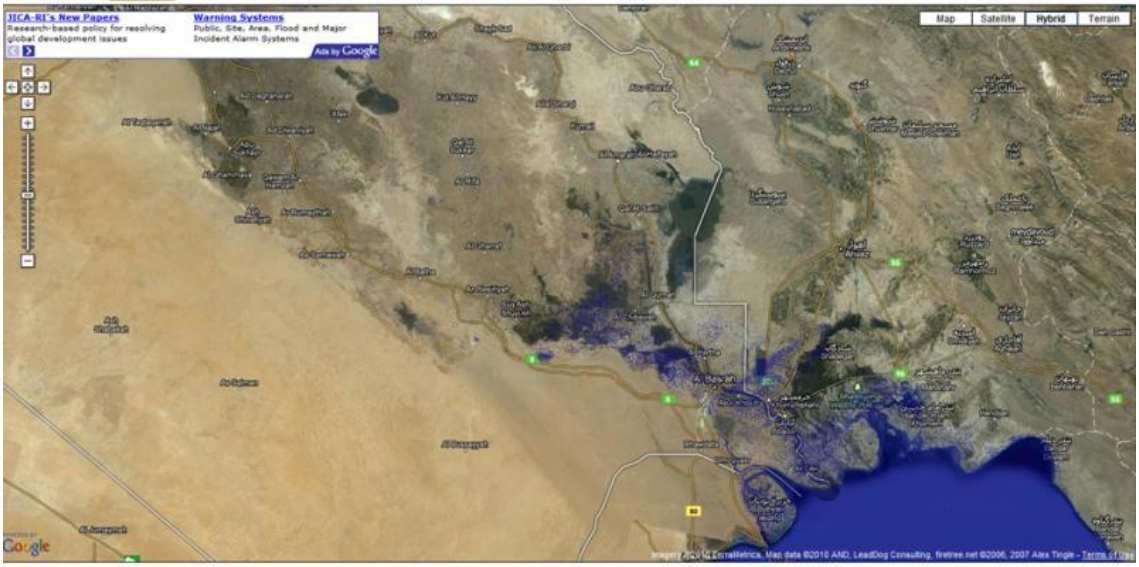

Sea level rise: +3 m

Europe N. America S. America Africa SE. Asia China & Japan Australia

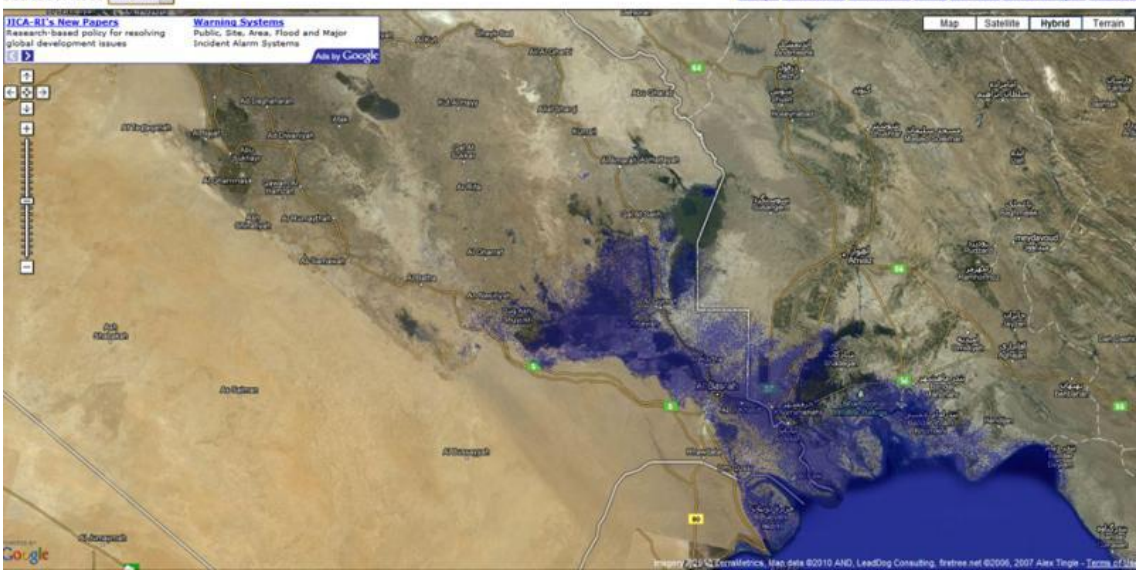

FIGURE 5.236: EXTENSION OF SEA LEVEL RISE IN IRAQ AS REPRESENTED BY THREE SCENARIOS OF SEA LEVEL RISE(0M, 1M AND 3M) INDICATING THE SERIOUSNESS OF IMPACT AT LEAST THE CITY OF BASRAH

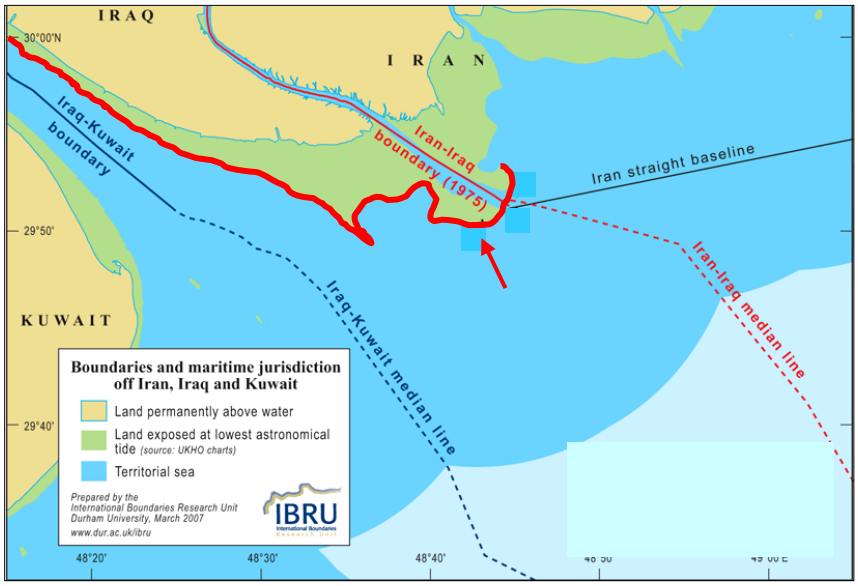

FIGURE 5.24 DEPENDENCE OF THE IRAQ MARITIME BORDER ON THE LINE OF LOWEST LOW-WATER (LLWM), WHICH WILL CERTAINLY CHANGE WITH SEA LEVEL RISE AND LACK OF SEDIMENTATION FROM THE SHATT AL-ARAB (LLWM RECEDING TOWARDS THE COAST)(SOURCE, IRAQ WATER PROBLEM.

On the coast, Umm Qasr and Al Faw, which support trade, shipments, and various businesses and industries (including oil production and storage), may be vulnerable to sea level rise and changing weather patterns that may increase erosive action on the natural features of the coast, as well as infrastructure. This area is very low-lying (see Figure 5.27) and susceptible to any amount of sea level rise, as well as being subjected to redistribution of coastal and marine sediments during extreme storm events, which clogs shipping channels and forces frequent dredging. Sea level rise, and constant movement of the lowest low-water mark which defines the maritime borders with Kuwait and Iran, has the potential to create international conflict with regard to the location of shipping (there have already been several incidents related to this in recent years – between Iran and Iraq. As noted previously, Shatt al-Arab is already suffering from salinity intrusion mostly related to lack of freshwater discharge; sea level rise will exacerbate this problem (Problem Statement, Iraq 2010).

Almost all the possible impacts of climate variability in Iraq are currently being felt in the Marshlands and adjacent areas in the south, due to the fact that this area is a receptacle for all river discharge and irrigation drainage in Iraq (upon which they depend, actually) and is also exposed to the influences of sea level rise (increasing salinity in the southern fringes, through the Shatt al-Arab and into portions of the Hammar Marsh). Thus, it is a globally significant area (wetlands with high biodiversity and traditional cultures) that is being assaulted on two fronts (from the north and from the south). Furthermore, the Marshlands are being compromised by planned expansion of oil and gas activities, which permeate many areas in and around the Marshlands, an additional burden on an already sensitive habitat (Problem Statement, Iraq 2010)

5.11.3 Practical and Institutional Adaptation Measures

1. A detailed assessment of the vulnerability of southern area of Iraq to potential impacts of sea level rise has to be carried out
2. An institutional system for monitoring and assessment of coastal changes has to be established south of Iraq
3. A program for protection of vulnerable areas and upgrading awareness of decision makers, stakeholders and civil society must be initiated

5.12 Mauritania

5.12.1 Background

Three-quarters of the Mauritanian territory is covered by Saharan desert, and the remaining one quarter is a Sahelian zone. Each of the zones has a coastal element and a mainland element. The district of Nouakchott alone, on the Atlantic coastline, accounts for about a quarter of the country's entire population living in less than 1% of the country's surface area. The economic potential of Mauritania relies mainly on the mining sector, fishing, raising of livestock, and to a lesser degree, agriculture. Fisheries and marine resources account for more than 12.5% of Mauritania's GDP: 46% of its population lives on less than a dollar a day, so it ranks among the least developed countries in the world. The coastal town of Nouakchott holds over 25% of the country's population, a great part of industry (fish processing, tourism and construction), and commerce and of other socio-economic infrastructures. Most of the town's suburbs,

industries and infrastructure, some of which are vital to the development of the country, are in the low-lying areas susceptible to Flooding (Sebkha and Aftouts) (Mauritania NAPA, 2004).

5.12.2 Vulnerability to Sea Level Rise

The rise in sea level brings with it increased flooding in the rainy season, coastal erosion, the infiltration of sea water in the water-tables, the disappearance of low-lying wet lands and related biodiversity changes place major impacts on the human habitat and on all the coastal socio-economic infrastructures.

Topographical maps of the different parts of the coastline reveal the existence of a number of low areas or areas made vulnerable by human activities, which are threatened by the rise of sea level. Simulations carried out by experts during the Initial National Communication on Climate Change in 2001 estimated that the potential damage of marine transgression or flooding, as a result of climate change, could generate losses amounting to US$ 3,956 million by 2020 and US$ 6,330 million by 2050. For instance, the NPBA ecosystem, noted for its high biological productivity, would be among the first to be affected by a rise in sea level. The rise in the level could mean that these marshes would be submerged, or that they would have to be maintained after being moved inland, or that they might even be extended if they experience a high level of vertical and lateral sedimentation." (Mauritania NAPA, 2004)

Rural migration to Mauritania's coastal cities of Nouakchott or Nouadhibou offers no certain refuge from the perils of climate change. Originally planned as a modest administrative centre, Nouakchott has mushroomed into a capital of uncertain population. In the absence of urban regulations, up to one million people may have settled on the flood plains.

As the sea level rises and natural sand dune defenses crumble or retreat, most of the Nouakchott region has been assessed to be at serious risk of permanent inundation within a generation (Figure 5.28). Beyond the city, the coastline is threatened with flooding, salt water intrusion and loss of wetland biodiversity.

Whilst fishing and marine livelihoods have in the past contributed over 12% of Mauritania's GDP, this sector has diminished in value in recent years. The presence of high technology European trawlers is a principal cause but rising sea temperature is known to affect breeding and habitat of local fish stocks.

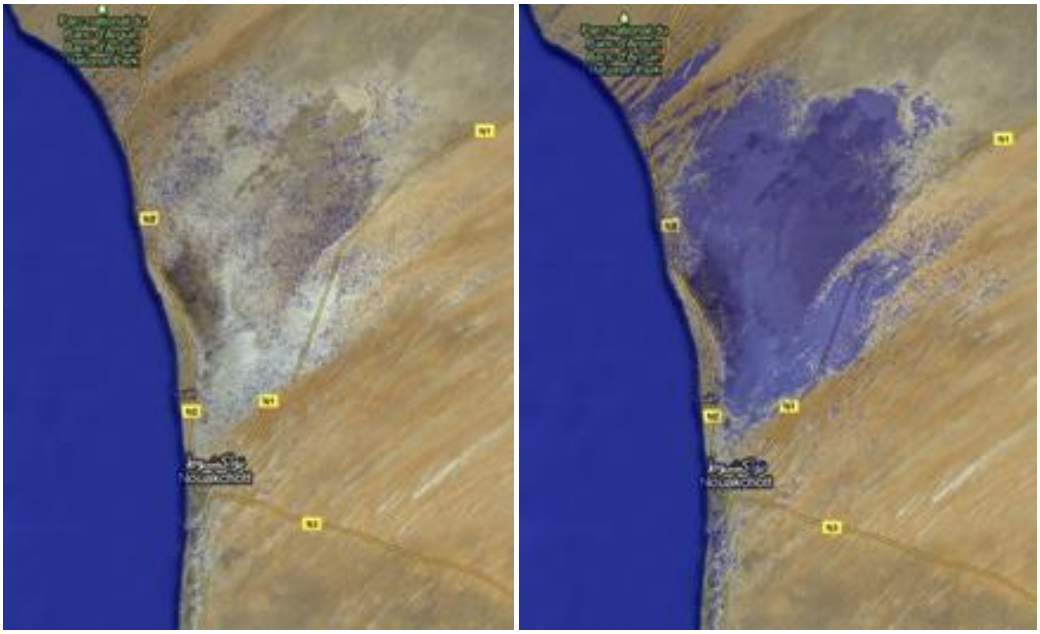

FIGURE 5.25 A SATELLITE IMAGE OF NOWAKCHOT TODAY (LEFT) WITH CORRESPONDING SIMULATION FOR A SEA LEVEL RISE OF 1M (RIGHT) INDICATING POTENTIAL IMPACTS OF INNUNDATION AND/OR SALT WATER INTRUSION ((BASED ON ANALYSIS BY RIVER SURVEYOR: HTTP://FLOOD.FIRETREE.NET)

5.12.3 Practical and Institutional Adaptation Measures

1. An institutional capability for integrated coastal zone management must be established
2. An institutional capability for monitoring of various indicators including provisions for monitoring land subsidence must be established
3. Proactive planning and ICZM concepts should be introduced as well as capacity building in these directions with follow up procedures
4. Upgrading awareness of decision makers and stakeholders is a necessary prerequisite for sustainable development

5.13 Libya

5.13.1 Background

Officially the Great Socialist People's Libyan Arab Jamahiriya is located in North Africa. Bordering the Mediterranean Sea to the north, Libya lies between Egypt to the east, Sudan to the southeast, Chad and Niger to the south, and Algeria and Tunisia to the west. With an area of almost 1,800,000 km^2 Libya is the fourth largest country in Africa by area. The capital, Tripoli, is home to 1.7 million of Libya's 5.7 million people. The three traditional parts of the country are Tripolitania, Fezzan, and Cyrenaica. Libya has the highest HDI in Africa and the fourth highest GDP (PPP) per capita in Africa as of 2009, behind Seychelles, Equatorial Guinea and Gabon. These are largely due to its large petroleum reserves and low population.

Libya has a small population residing in a large land area. Population density is about 50 persons per km^2 in the two northern regions of Tripolitania and Cyrenaica, but falls to less than one person per km^2 elsewhere. Ninety percent of the people live in less than 10% of the area, primarily along the coast. About 88% of the population is urban, mostly concentrated in the two largest cities, Tripoli and Benghazi. With the longest Mediterranean coastline among African nations, Libya's mostly virgin beaches are important social gathering place.

5.13.2 Vulnerability to Sea level rise

Regardless of the inland areas that lie below the sea level, most of the coastal area at the southern part of Sert Bay is vulnerable to direct inundation and/or salt water intrusion as seen by comparison to the simulation of sea level rise of 1m (Figure 5.29). In addition, many of the coastal cities such as Benghazi, Libya's second largest city are considered vulnerable to sea level rise and to potential impacts of extreme storm events. Salt water intrusion on already scarce groundwater resources may also be damaging to important water resources.

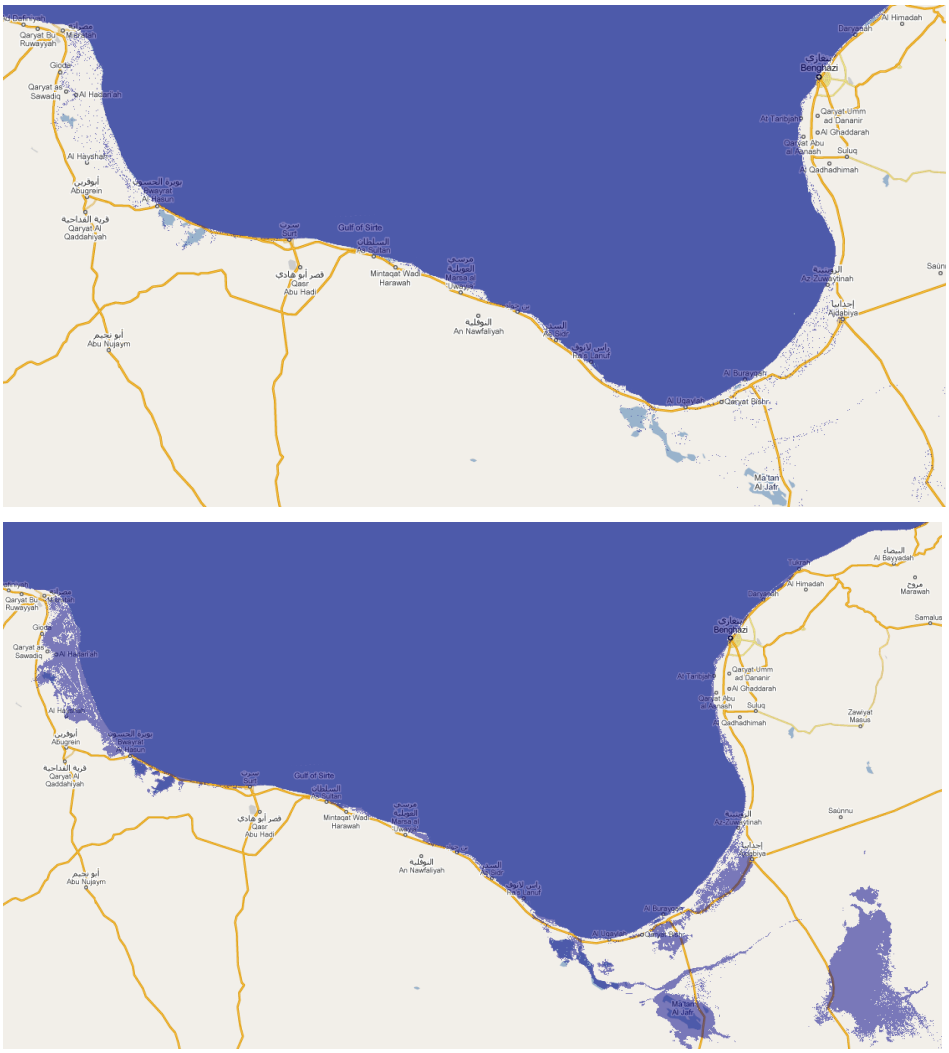

FIGURE 5.26 THE MEDITERRANEAN COAST OF LIBYA INDICATING VULNERABLE AREAS OF SEA LEVEL RISE (UPPER - TODAY) AND LOWER (SIMULATING I.0M SLR). (BASED ON ANALYSIS BY RIVER SURVEYOR: HTTP://FLOOD.FIRETREE.NET)

5.13.3 Practical and Institutional Adaptation Measures

1. Building up institutional and human capacity for monitoring coastal parameters including land subsidence, developing databases and modelling are necessary prerequisites for adaptation
2. Development of proactive planning and integrated coastal zone management are also necessary
3. Carrying out a complete vulnerability survey of the coastal zone and associated protection measures are necessary

4. Upgrading awareness of decision makers and vulnerable communities

6 SWOT Analysis of Policies, Measures and Programs

6.1 Gaps of Knowledge

Identifying and assessing general aspects of gaps of infrastructure, knowledge necessary to identify and assess present day conditions

The shortage of long term data and information on various aspects of climatic variations and its impacts makes it very difficult to make decisions at early times. Missing data over many of the Arab countries include:

a. Time series data concerning climatic parameters
b. Data on tide gauges at a number of strategic positions indicating land subsidence or emergence
c. Socioeconomic and health data in highly vulnerable areas
d. Accurate topographic data on many of the vulnerable low land areas
e. Very limited information is available on potential impacts on coral reefs, cultural heritage and fish catch
f. Development of RCM for temperature, precipitation and wind speed and direction
g. Socioeconomic adoption of adaptation policies, measures and programs
h. The role of mass communication in motivating decision makers to put strategic policies of proactive planning in their consideration

6.2 SWOT Analysis

A critical SWOT analysis of policies, measures and programs carried out by individual countries of the Arab region based on preliminary communications and survey of published and unpublished literature (e.g. Agoumi, 2003, Tolba and Saab, 2009, El Raey, 2010,)

Item	Points of strength	Points of weakness

1. Institutional structure	• At least Egypt, Morocco and Tunisia have developed institutional structures for adaptation including integration among vulnerable sectors • Implementation of some regulations have proved to be efficient such as EIA, ICZM • A national committee for climate change has been formulated by many countries	• Few countries are still in the process of developing institutional structures and • Many countries have not considered that because of national priorities • Many institutional systems are still too weak to enforce regulations
2. Awareness of Decision makers	• Most of decision makers in most Arab countries are well aware of the problem	• Awareness does not mean action of any kind and priorities of immediate needs are preferred
3. Awareness of the community	• Vulnerable communities and stakeholders are aware of the problems in Egypt, Tunisia, Emirates, Morocco and Saudi Arabia	• There are still many mal practices in the community • Economic driving force is very strong in poor communities • Weak enforcement of regulations
4. Vulnerability assessment and seriousness of impacts	• Most of the countries have carried out vulnerability assessments reported through UNFCCC initial national communications. Countries such as Somalia, Iraq, Palestine however vulnerability assessments may not be complete. Who has?	• Initial national communications do not reflect actual vulnerability due to the lack of monitoring capacities and systems, data, and capacity • No information is available on land subsidence in many coastal countries in spite of massive programs of oil, gas and groundwater extraction
5. Availability of Monitoring systems and indicators	• Human capacities for monitoring systems may be available subject to training • Some countries have participated in EWS?	• Systems and systematic observations are very limited • Very limited plans for development of such systems except in Gulf countries
6. Adaptation Strategy, planning ,Policy and measures	• Adaptation strategies are under consideration in some of the Arab countries such as Egypt, Tunisia, Morocco and Saudi Arabia	• Many countries have not taken initiatives for strategies yet (opportunity: could use regional support?)
7. Adaptation action Plan	• Some such as Egypt,	• No strategies have been

	Morocco, Tunisia and Sudan have carried out Action Plans. Others such as Mauritania, Yemen, Iraq and Libya have not. Very limited implementation of action plans have been realized	developed by the majority of Arab States • No implementation on the individual or regional scales and no monitoring systems for enforcement
8. Extreme Events	• Many countries have realized the importance of extreme events and needs for preparedness (e.g. Egypt, Tunisia, Morocco, Saudi Arabia and Oman) Some have realized probabilities of internal conflicts and issued regulations (e.g. Egypt and Tunisia)	• Shortage of transparent data • Very limited enforcement is available • Many mal practices with strong economic driving forces • Shortage of monitoring systems, early warning systems and follow up
9. Risk reduction and preparedness	• Many countries have adopted Hyogo Protocol and started to put preparedness policies into practice • A regional center for Disaster Risk Reduction has been developed by the Arab League	• Many vulnerable countries have not adopted Hyogo framework of action or other risk measures(e.g. Iraq, Djibouti, Sudan, and Yemen) • No emergency responses have been developed • Very limited institutional and human capacity
10. Law enforcement	• Regulations are available	• Very weak enforcement of environmental regulations due to shortage of monitoring systems and awareness
11. Group Migration	• Problems of migration have been well realized in Egypt, Sudan(e.g. Darfur), and Djibouti	• No serious plans have been developed • No firm policies have been implemented
12. Adaptation Implementation	• Adaptation Strategies are in development (e.g. Egypt, Tunisia, Morocco and Gulf States)	• Strong gaps of accurate vulnerability assessments • No adaptation strategies or policies have been documented • No co-operation?
13. Socioeconomic Implications	• An early warning of the potential implication so there is time for proper proactive planning	• Excluding Gulf countries, severe pressures are exerted on economies of most Arab countries

Threats and opportunities are also considered at the present situation

Item	Threats	Opportunities
1. Institutional structure	• Time delays means loss of opportunities for adaptation and economic loss	• Integrating efforts, capacities and coordinating activities easier now since all sectors are encountering problems of climate changes
2. Awareness of decision makers	• More programs will be implemented with no consideration to climate change. • More damages and losses over all sectors on the regional scale	• The early we start the more we save
3. Establishment of regional monitoring systems	• Many impacts will go unaccounted for with Economic and health losses	• Success of preliminary and integrated early warning systems for flash flood and heat waves on the regional scale will save lives and resources
4. Awareness of stakeholders	• Continuation of over consumption, unplanned urban development and interference of land use	• Now increasing with stakeholders feeling heat waves and flash floods
5. Vulnerability assessment and preparedness	• Necessary for proper identification of proactive planning. Loss of time	• Prerequisite for proper proactive planning with risk reduction
6. Extreme events	• More lives and economic damages may occur	• Continuing development on stable foundations
7. Socioeconomic implications	• Severe pressures will be exerted when time for hard decisions comes	• The earlier we plan for safe development the better

7 Suggested Strategy for Adaptation and Action Plan

A general strategy for adaptation will be outlined taking into account various activities of the League of Arab states in the frame of disaster risk reduction taking into consideration recent experience of preparedness for flash flood. The strategy should include:

a. Institutional setup

b. Proactive Planning

c. Monitoring system and Research capabilities

d. Identification and assessment of options for adaptation

e. Upgrading resilience and awareness

f. Regional follow up of implementation

g. Adoption in the educational system

8 Summary of Action Plan

Institutional capacity

1. Arab countries must develop a regional center or organization for climate change. The center should collect and analyse data, build geographic data base and establish monitoring systems for indicators of concern to all Arab countries. It should be responsible for carrying out and enforcing strategies, plans, policies and measures for proper adaptation
2. Arab countries must introduce concepts of ICZM and disaster reduction in the educational system and must develop institutional capability for integrated coastal zone management and build up capacity and follow up in these direction
3. Arab countries must develop institutional capability for risk reduction by adopting Early Warning Systems of flash flood, storm surges and heat waves.
4. Arab countries must develop transparent data and information systems so as to allow early warning of problems

Awareness

1. All Arab countries must develop awareness programs for upgrading resilience of vulnerable communities, population, stakeholders and investors
2. Work to create new job opportunities in safe areas and exercise environmental law enforcement of regulations such as SEA, EIA

Monitoring

1. It is necessary to monitor and assess land subsidence especially in coastal areas of excessive urban loads and excessive rates of oil and/or water extraction

2. It is necessary to monitor and assess coastal vulnerabilities and rates of land subsidence, especially that extraction of oil from coastal regions are progressing at high rates
3. It is necessary to build geographic data basis for each of the Arab countries making sure that data are available for decision makers and researchers

Management

1. Build capacities for protection of coral reef, marine reserves and proactive planning
2. Proper management and protection of coral reef in coastal areas against mal practices of tourism, is necessary

Research

1. Arab countries must adopt scientific research as the main defence against natural and manmade risks, and introduce pupils to environmental protection from the early education steps
2. Research has to be carried out on salt tolerant plants, suitable crop cultivation in the coastal zone, monitoring systems, analysis of extreme events and early warning systems
3. Research on extreme events on coastal areas and implementation and training on early warning systems has to be investigated on a regional scale

9 Conclusions:

1. All Arab countries are highly vulnerable to potential impacts of sea level rise with varying magnitudes. Many such as Egypt, Saudi Arabia, Emirates, Tunisia and Morocco have realized the seriousness of these impacts to their economy and have started steps towards adaptation and risk reduction and many have not yet realized the potential impacts on their economy and socioeconomic conditions.
2. Excessive coastal urbanization, oil and groundwater extraction especially in high population densities areas and gulf countries, constitutes serious risk to coasts and coastal properties, especially in the absence of accurate data and information on coastal land subsidence
3. No systematic observations on coastal land subsidence and changes especially of areas subject to excessive petroleum and gas extraction. There is a high shortage of human capacity in most countries

4. Increasing severity and frequency of extreme events constitute a serious threat to the coastal and non-coastal communities due to increasing rates of droughts, flash floods and heat waves. Very limited institutional capacities for risk reduction already exist.
5. The shortage of systematic observation systems, lack of awareness and weak enforcement of environmental regulations constitute basic obstacles for proper implementation of proactive planning for sustainable development
6. Many decision makers take advantage of uncertainties of sea level rise not to take strategic decisions. However, it should be noted that all required decisions are needed whether we have a sea level rise or not. All countries should take action for adaptation the sooner the better.

10 Recommendations

1. A Regional integrated center for climate change and risk assessment has been established (RCDRR) and needs to be supported for development of data base and systematic observations of the region. The center should be capable to provide data and information to researchers
2. A data base of systematic observation of sea level parameters such as sea level, storm surges, water and soil salinity, coastal temperatures and phytoplankton, erosional pattern and coastal socioeconomic parameters, must be established
3. Systematic observations of land subsidence has to be carried out by radar imagery interferometry in coastal areas of oil extraction to identify and assess rates of land subsidence and vulnerability to sea level rise
4. Encouraging and supporting research and building capacities in the lines of systematic observations, time series analysis, modelling, water desalination and wastewater treatment , salt tolerant plants, extreme events and awareness programs for vulnerable communities
5. Upgrading awareness and building national capacities

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