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TOWARDS A CLIMATE CHANGE ADAPTATION STRATEGY FOR THE WATER SECTOR IN EGYPT

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Climate Change Risk Management in Egypt
Integrated Water Resources Management and Forecasting Component

TOWARDS A CLIMATE CHANGE ADAPTATION STRATEGY FOR THE WATER SECTOR IN EGYPT

By
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October, 2012

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FOREWORD

This book is an output of the Forecasting and Integrated Water Resources Management (F & IWRM) component of the MDG-F Joint "Climate Change Risk Management Programme in Egypt" CCRMP. This program aims at achieving the Millennium Development Goals, eliminate poverty and support environmental sustainability in Egypt. This particular activity was supported by the UNESCO Cairo Office.

This book covers the involvement and technical activities of the Forecasting and Integrated Water Resources Management (F & IRWM) component in the Climate Change Risk Management program CCRMP. It also contains the impacts of climate change on the Nile Basin in terms of rainfall, temperature, evapotranspiration, and discharges and the estimation of the flooded areas due to the anticipated sea level rise using GIS and flow modeling techniques. The book elaborates the supporting adaptation efforts and plans and provides policy recommendations for adaptation.

This book has been edited by Dr. Akram ElGanzori, drawing upon two primary consultant inputs: "Impacts of climate change on the Nile Basin" by Dr. Mohamed Elshamy (Ministry of Water Resources and Irrigation, Egypt) in close collaboration with Nile Forecast Center staff (Eng. Doaa Amin, Mr. Taha Kassem, Mr. Sherif Foda, and Mr. Alaa Mabrouk); and "Improving the Estimation of Sea Level Rise Flooding Impacts on the Nile Delta Using a Flow Routing Model" by Dr. Mohamed Ahmed (Ministry of Water Resources and Irrigation, Egypt) in addition to contributions by the editor himself. A collaborative effort between the author and Prof. Mahmoud H. M. Ahmed (NARSS) and Prof. Mohamed Abd-Rabo (Alexandria University) has added a significant value to the book contents. The author is also grateful to HR Wallingford Ltd (UK) for providing necessary support in particular for Chapter 4.

The author would like to express his thanks to UNESCO-Cairo Office for support, review & revising the book.

EXECUTIVE SUMMARY

Egypt faces several serious risks from climate change. Perhaps of greatest concern is the potential for a significant reduction in flow of the Nile River. Also of major concern is the sea level rise and higher temperatures. Reduced water supplies, loss of land, and higher temperatures could adversely impact economy, human health, and ecosystems in Egypt. Therefore, adaptation to climate change impacts in water resources sector in Egypt is closely linked with development choices and pathways for the country and the region. The uncertain changes in supply due to climate change will occur alongside the more certain demographic trends and potential abstractions by upstream riparian countries which mean that Egypt already faces major water management challenges. It is obvious that reduction in Nile supply due to climate change may exacerbate the problem. Thus, it is crucial for Egypt to increase its understanding of the potential risks from climate change and to reduce its vulnerability to these effects.

Egypt was among the first Arab states to participate in the international initiatives on climate change, and has ratified both the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol. Egypt has several domestic initiatives to address climate change, including an inter-ministerial National Committee on Climate Change established in 1997, an ongoing GEF Climate Change Capacity Building program, the Energy Efficiency Council which is a consortium of public and private agencies, and the Integrated Coastal Zones Management Committee. The First and Second National Communications of Egypt were submitted in 1999, 2010 and included assessments of climate change impacts on several key sectors. With several other pressing concerns, including the increase of costs of living and food, and the reduction of land productivity in coastal areas, climate change is still low in the priority list of national decision-makers.

The analysis in this book has focused on Egypt's Nile water resources and coastal zones, which were identified as two of the most vulnerable sectors to climate change. The most significant finding was that most of climate models project decreased flows in the Nile Basin. However, the projected changes in rainfall in the different source regions of the Nile as well as their impact on the river flow into Egypt remain considerably uncertain. Conversely, the increase in temperature over the Nile Basin as a result of climate change is more certain. Egypt's water resources are already very limited, and the population growth will merely make them even more limited. A reduction in flow of the Nile River would put additional stress on water resources throughout Egypt. Such a reduction would have the most serious consequences for agriculture, which is currently responsible for the consumption of 85% of all water consumed. Thus, any reduction in water supplies will limit irrigation water.

Projected change in flow of the Nile by 2030 ranges from an increase of more than 10% to a decrease of almost 20%. A middle projection is for a reduction in flow of about 5%. Agriculture is also projected to be negatively affected by higher temperatures resulting in lower crop yields and loss of some agricultural lands in the Nile Delta. Yields of major crops are estimated to decrease by 1 to 17%. In addition, a small percentage of agricultural land in the Nile Delta is at risk of inundation.

The above factors combined with the population increase would result in a projected 12% reduction in agricultural production by 2030, and a 16% increase in prices, but only a 2% decrease in employment. Should the Nile River flow is reduced according to the most pessimistic climate model, then by 2030, agricultural production would fall by 23% with a commensurate reduction in employment and increase in prices. Even an increase in Nile flow of almost 10 % would still result in a small reduction in agricultural production. This is likely to result mainly from the projected decreases in crop yields. While those farmers will be able to grow crops would benefit by higher prices, their gains would be outweighed by the losses to consumers from those higher prices. Indeed, higher prices and increased unemployment would likely result in more poverty and malnutrition that would happen even if the climate does not change.

By 2060, the effects of climate change are projected to be more negative, especially with additional population increases. The estimated reduction in flow of the Nile in the middle model is over 10%. The wettest climate model results in an increase of almost 30%, but the driest model results in a reduction in flow of 37%. Crop yields are projected to decrease by 2 to almost 30% as a result of higher temperatures.

These effects combined with further decrease in agricultural production and higher prices would results in drops of production by 27% and employment by 18%. Meanwhile prices would rise by 40% under the middle model. The driest scenario would be even worse. Agricultural output would decline by 43%, with a decrease in agricultural employment by 37% and rise in prices by 65%. Some of the shortfall could be alleviated through allowing more imports, which would reduce the price rise. But, this would further reduce agricultural production and employment. Even under the wettest climate model, agricultural production drops by 9% and employment is off 5%, while prices rise by 12%.

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ASME	Agriculture Sector Model of Egypt
BCM	Billion cubic meters
CAPMAS	Central Agency for Public Mobilisation and Statistics
CO_2	Carbon dioxide
CoRI	Coastal Research Institute (part of Ministry of Water Resources and Industry)
DALY	Disability adjusted life year
EASM	Egypt Agriculture Sector Model
EGP	Egyptian pounds (currency; we assume that 1 USD = 5.5 EGP)
GCM	General circulation model
GDP	Gross domestic product
GIS	Geographic information systems
HAD	High Aswan Dam
ICZM	Integrated Coastal Zone Management
IPCC	Intergovernmental Panel on Climate Change
M&I	Municipal and industrial
MWRI	Ministry of Water Resources and Industry
NARSS	National Authority for Remote Sensing Sciences
PET	Potential evapotranspiration
PM	Particulate matter
SNC	Second National Communication (Egypt)
SRES	Special Report on Emissions Scenarios
UNFCCC	United Nations Framework Convention on Climate Change
USD	U.S. dollar

CHAPTER 1

INTRODUCTION

1. INTRODUCTION

Most scientists around the world now agree that the climatic changes occurring internationally are the result of human activity. Although responsibility for the causes of climate change rests primarily with the developed and industrialized nations, the costs of climate change will be borne most directly by the poor.

Climate change is having, and will continue to have, the greatest impact upon the lives of the developing countries. Most developing countries are in tropical or arid regions, which will experience climate change sooner and with a greater magnitude than temperate regions.

The United Nations Framework Convention on Climate Change (UNFCCC) defines climate change as, "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods". The future effects of climate change on water resources in Egypt will depend on trends in both climatic and non-climatic factors. Evaluating these impacts is challenging because water availability, quality and stream flow are sensitive to changes in temperature and precipitation. Other important factors include increased demand for water caused by population growth, changes in the economy, changes in crop water requirements associated with temperature rise, development of new technologies, and changes in water management practices. In addition to the typical impacts on water management, climate change introduces an additional element of uncertainty about future water resource management.

The Climate Change Risk Management Programme (CCRMP) is a national cross-cutting programme implemented across multiple ministries and sectors, targeting both adaptation and mitigation. It was initiated in October 2008 with the involvement of 6 UN agencies (UNDP, UNESCO, UNIDO, UNEP, FAO, and IFAD) and 5 Egyptian Ministries. The project is funded by the Spanish MDG Achievements Funds.

The aim of this joint program (JP) is to help Egypt align its climate risk management and human development efforts in pursuing the achievement of the Millennium Development Goals (MDGs) in the face of climate change and its predicted serious threats to the country. A special attention is given to the vulnerable poorest populations of Egypt through two complementary approaches which are:

- Mainstreaming GHG mitigation into national policy and investment frameworks, including increased CDM financing opportunities
- Enhancing the country's capacity to adapt to climate change.

The Forecasting, and Integrated Water Resources Management (F & IRWM) component is a collaboration between the Ministry of Water Resources and Irrigation (MWRI), the National Water Research Center (NWRC), and UN agencies (UNDP, UNEP and UNESCO) to spearhead adaptation efforts related to water resources and coastal zones. These partners support, amongst several other activities, building of a Regional Circulation Model (RCM) for the River Nile to predict the impact of climate change on rainfall patterns and Nile flood. The UNESCO Cairo Office is a main partner of the Ministry of Water Resources and Irrigation of Egypt in implementing the activities of the Integrated Water Resources Management and Forecasting Component.

Adaptation to current and future climate change is imperative, and therefore water management plans must respond to the forecasted resource scenarios. Supporting adaptation efforts will increase Egypt's capacity to protect its water supplies from the possible threats of climate change. By helping Egypt adapt its water resources management, the CCRMP is ensuring that the MDGs will be achieved, and that Egypt will effectively combat poverty, and provide social protection and economic growth. Changes in sea level will increase coastal erosion, sea water intrusion, and flooding of wetlands and lowlands in the delta. It will also have a significant impact on the availability of freshwater:

• groundwater resources in coastal plains are potentially vulnerable to salinization from rising sea levels, due to their low elevation and hydraulic gradient;

• salt water intrusion in the lower reaches of the deltas will be exacerbated by predicted rises in sea levels; and

• reduced protective capacity against extreme storms and floods, as higher sea levels provide a higher base for storm surges.

This book is organized as follows. Chapter 2 provides a background on environmental concerns in Egypt due to climate changes. The impacts of climate change on the Nile Basin are reviewed in Chapter 3. Chapter 4 presents the improvements in the estimation of Sea Level Rise flooding impacts on the Nile Delta using a flow routing model. Assessments of the potential economic and social Impact on Water Resources (costs of climate change on Egypt) are discussed in Chapter 5. Finally, climate change policy recommendations are presented in Chapter 6.

CHAPTER 2

ENVIRONMENTAL CONCERNS DUE TO CLIMATE CHANGE IMPACTS

2. ENVIRONMENTAL CONCERNS DUE TO CLIMATE CHANGE IMPACTS

Egypt can be categorized as a water-stressed country. Climate change is projected to cause sea level rise, more extreme weather events, decreased precipitation and, ultimately, less surface and ground water availability, all contributing to even greater water stress throughout the country, with severe environmental, economic, political and security implications. The lack of water threatens water security, as well as human health and economic development, and can lead to additional environmental stress. A lack of an adequate, safe, clean water supply constrains the society's opportunities for economic development, and thus endangers political stability within the country, and beyond as Egypt shares water resources across political boundaries with 10 other countries. The current water availability in Egypt is inadequate to address each internal agricultural, domestic and other requirement, where transboundary water agreements commitments do exist. For a region that already possesses some of the greatest political tensions in the world, the climate crisis is likely to exacerbate this cross-border political instability. Climate change provides both challenges, and opportunities for cross-border cooperation to ameliorate and prevent the problems that are already occurring and are projected to further intensify.

Egypt is located between 22° to 32° North and 24° to 37° East. It is bordered to the west by Libya, to the north by the Mediterranean Sea, to the south by Sudan, and to the east by the Gaza Strip and the Red Sea (Figure 1). Its coastline stretches for more than 3,500 km along the Mediterranean Sea and the Red Sea. The Nile delta coast, which extends for about 300 km, hosts a number of highly populated cities such as Alexandria, Port-Said, Rosetta, and Damietta.

Egypt's climate is arid, characterized by hot dry summers, moderate winters, and very little rainfall. The country has areas with strong wind, especially along the Red Sea and Mediterranean coasts. Sites with an annual average wind speed of 8.0-10.0 m/sec have been identified along the Red Sea coast and about 6.0-6.5 m/sec along the Mediterranean coast.

Egypt is fairly unique in the distribution of its population, land-use and agriculture, and economic activity which makes it extremely vulnerable to any potential impacts on its water

Figure 1: Egypt Map

resources and coastal zones. Despite being a large rectangular shaped country with an area of about a million square kilometers, its lifelines are constrained along a narrow T-shaped strip of land (which constitutes less than 5% of its land area) along the Nile and its delta (Figure 2). The Nile supplies 95% of the country's total water needs, including water intensive irrigated agriculture along its banks and delta. Agriculture is quite critical to the national economy as it employs 30% of the work force and contributes 15% to the GNP. Major urban centers, commerce, and industrial activity are also confined to the narrow corridor along the Nile and its delta. The rest of the country is desert and does not support much population or economic activity except for a narrow strip along the Suez Canal and Red sea Coast and a few oases in the Western desert.

Estimates of the predicted impacts of climate change vary, with assessments of future global temperatures differing between 1.4 and 5.8 degrees Celsius. Despite the large variation, even the minimum predicted shifts in climate for the 21st century are likely to be significant and disruptive, while changes at the higher end of the spectrum could be catastrophic. If climate change continues unabated, it threatens to impose severe environmental devastation upon Egypt. The vast majority of the Egyptian population lives in the Nile Delta and along the thin strip of the Nile Valley while the large expanses of territory that make up the rest of the country remain almost entirely uninhabited.

Egypt was among the first Arab countries to join the cooperative global efforts to confront climate change. Since the Rio de Janeiro Earth Summit in 1992, it has ratified the United Nations Framework Convention on Climate Change (UNFCCC) in 1994 and signed the Kyoto Protocol in 1999. Its First National Communication to the UNFCCC was published in 1999. The report pays extensive attention to the risks facing the country due to climate change and sea-level rise, mainly in relation to agriculture, water resources, human health, and the coastal zone (particularly the Nile Delta stretch). It also includes economic loss estimates for sea level rise in several coastal cities. Moreover, a large range of adaptation options are identified; most of them are “no-regrets”.

Reports and strategies relating to other environmental conventions, such as the Ramsar Convention on Wetlands, the UN Convention on Biodiversity and the UN Convention to Combat Desertification pay very little attention to climate change, even though they nominally mention cooperation between the environmental conventions. At the same time, some of their action plans do contain elements that could also be part of an adaptation strategy for Egypt. For instance, measures to alleviate desertification or conserve coastal ecosystems are likely to make the country more resilient to climate change.

Climate change could exacerbate the food security issues that Egypt is currently facing. Egypt’s report to the UNFCCC states that “climate change may bring about substantial reductions in the national grain production”. Grain is only one of Egypt’s food sources endangered by unmitigated climate change. Even without climate change, by 2020 Egypt is projected to import 300-360 thousand metric tons of fish, which is a third of its projected domestic production. However, climate change could drastically increase Egypt’s trade imbalance in fish products while simultaneously tightening the global fish market. As the sea level rises, salt water will infiltrate the North Egyptian lakes where 60% of Egypt’s fisheries arelocated.

Figure 2: The Satellite image of Egypt

As lake water becomes saltier, the aquatic plants that protect the marine life by filtering the contaminated wastewater drained to the lakes from Egypt’s industry will die off. The shallow nature of Egypt’s lakes will provide little protection from temperature increases that could disrupt the marine ecosystems. As Egypt’s domestic fisheries face increased risks, Egypt will be forced to import more fish from other nations whose own fisheries will be facing decline.

Disruptions in Egypt’s food supply could impose starvation and economic stress, likely leading to unrest. Food scarcity has a history of provoking instability in Egypt: the only mass popular uprising in Egypt in the past half-century" occurred in 1977 when there was an attempt to eliminate subsidies for bread.

The satellite image of Egypt (Figure 2) shows two characteristics of the country: the proportion of the country that is comprised of the Sahara Desert and the location of the Nile River. Egypt covers an area of about 1,010,000 square kilometers (390,000 sq mi). Egypt is one of the most populous countries in Africa (behind Nigeria and Ethiopia) and the most populous in the Middle East. About 96% of Egypt's total area is comprised of desert. The great majority of its 85 million people live in an area of about 40,000 square kilometers (15,000 sq mi) along the banks of the Nile River. This area is the only arable land (that is, land that can be used for growing crops) found in the country. This geographic profile, while culturally and historically significant, creates many environmental challenges that will ultimately transcend in significance, the political energies being experienced today. Excerpts from the symposium: Water, Energy and Climate Change Nexus for Egypt held in 2008 that provided the framework for understanding these challenges are:

- With 95 percent of Egypt's fresh water needs supplied from the Nile River, the country's vulnerability increases with any changes in rainfall patterns throughout the Nile Basin. Climatic changes will also impact agricultural productivity and fisheries, thus influencing the country's food supply. The Nile, as a transboundary water system, extends Egypt's hydrological interdependence across its national frontiers, linking users in different countries within a shared water system.
- Water and energy are extremely interdependent and their demand/supply balance is already critical. It is estimated that this critical balance will be aggravated by the demographic expansion and the climate change impacts. While Egypt's demand for water is increasing, the country's annual share of Nile water is almost constant. Different climate change scenarios expect an important decrease on the river's water yield originated in the Nile resources catchment areas.
- The rights of the coming new generations are primarily tied to the sustainability of both water and energy resources.
    - Today, most of Egypt's hydropower potential has been exploited.
    - Energy needs for water will greatly increase.

Egypt has already been struggling with existing water stress from pressures such as irrigation demands, industrial pollution and water borne sewerage. These pressures will be significantly exacerbated by climate change, which for many regions will result in reduced availability of water for drinking, household use, agriculture and industry. As the competition among these demands intensify under climate change, effective governance for balancing water demands will become essential, particularly in the face of strong pressures to prioritize industrial uses over other uses such as drinking supplies.

The quality of existing water supplies will become a further concern in some Egyptian regions. Water acquires most of its geochemical and biochemical substance during its cycle from clouds to rivers, through the biosphere, soils and geological layers. Changes in the amounts or patterns of precipitation will change the route/residence time of water in the watershed, thereby affecting its quality. As a result, regardless of quantity, water could become unsuitable as a resource if newly-acquired qualities make it unfit for the required use. For example, in areas with relatively high water tables, or under intensive irrigation, increased evaporation due to higher temperatures will raise the concentration of dissolved salts. Further, increased flooding could raise water tables to the point where agrochemicals/industrial wastes from the soil could leach into the groundwater aquifer. Likewise, higher Sea levels will lead to salt water intrusion in coastal groundwater supplies threatening the quality and quantity of freshwater access to large populations.

The high increase in the population and the rapid spread of urbanisation in Egypt are causes for concern due to the resultant increase in air and water pollution. Population growth requires increased sewage

services. The rise in temperature is expected to further exacerbate the dearth in drinking water, increase pressure on land resources, and lead to a rise in the incidence of sand and dust storms. Increased usage of fertilizers and pesticides is also expected to exacerbate water and food pollution.

There are conflicting projections of the future availability of Nile water as a result of climate change. While some simulation studies foresee an increase in Nile water levels by 25 per cent over current yearly levels, a larger number of studies project declines reaching up to 20 per cent. The variation in results indicates that more robust studies are needed to provide a more solid base for the design of public policy. However, the most plausible projections seem to point to less availability of Nile water for Egypt in the future.

Furthermore, the global rise in sea water levels by eight to 59 centimetres, added to expected local land subsidence (a result of tectonic movements and continued pumping of petroleum and ground water, estimated at another 30 centimetres within the next 100 years), will lead to a loss of a many low-lying coastal areas and to salt water intrusion into a number of coastal wells. The combined effect will also lead to a rise in the water table in coastal regions that would ruin the agricultural productivity of low-lying areas.

The adverse effects of climate change also include an increase in the frequency and severity of sandstorms, and longer periods of drought followed by more intense flooding. This is expected to lead to public health problems, including the spread of epidemics, especially in poorer regions. More generally, national income will decline and will in turn result in the spread of social and political problems.

Climate changes will reshape the main habitats in Egypt (El-Bagori, 2004) which must be maintained to safeguard biodiversity. Although wild species will react differently to climate change, negative impacts are expected in areas adjacent to the Egyptian Northern lakes, Eastern desert habitats, marine habitats, marginal pasture in Sinai, and natural mangrove vegetation in the Red Sea coasts. In the Western desert and the Southern valley habitats, the expected increase in temperature will increase the water requirements of field and horticulture crops. A substantial number of the currently endangered species might be lost as coastal habitats are lost and native communities invaded by competitors.

Red Sea coral reefs are among the most spectacular in the world, supporting a high level of biodiversity with over 1000 named species and many more yet to be identified. These are especially sensitive to variation in sea surface temperatures, and when physiologically stressed, corals may lose symbiotic algae, which supply nutrients and colors. At this stage, corals appear white and are referred to as bleached. In 2006, two phenomena of coral reefs bleaching had been monitored in Egypt. The first occurred in the extreme low tide exposing coral reefs to direct air causing a loss of vitality. This phenomenon continued for a few days during spring season, where some areas remained affected and has not recovered till now. Biological diversity has many benefits for human beings, its different kinds and species contribute in providing agricultural, fishing and livestock services, scientific research and cultural heritage. Some flora and fauna species with their genetic components help in developing medical, agricultural and industrial products. Additionally, it provides daily essential needs for the life of many local communities and supports ecotourism with its great economic potential.

Climate change is expected to have adverse impacts on human health in Egypt, which will be aggravated by high population densities. These may include increased prevalence and/or severity of asthma, infectious diseases, vector borne diseases, physiological disorders, skin cancer, eye cataracts, respiratory ailments, and heat strokes weakening public health infrastructure as well as extra deaths from cardiovascular and respiratory illness, diarrhea and dysenteric infections, and increased children mortality rates and malnutrition. However, comprehensive studies that contain detailed estimations and correlations between climate change and human health are still lacking in Egypt.

Many areas along the Egyptian coasts are at risk from natural and man-made impacts, created by geological (e.g. land subsidence) and meteorological disturbances of sea surface and human interventions to coast. These risks are of two kinds (i) short term risks associated with storms, swells, reclamation pollution, etc., and (ii) long-term risks related to climate change, sea level rise, damming of the river, coastal protection measures, etc. Often, it is a mixture of these two effects that is most potent. There are basically two responses to such threats at Nile delta coast; natural and man-made, a gradual rise in sea level will enhance landward penetration of surges, swells and storm waves in-addition to the deficiency of sediment supply because of construction of dams, these bring a morphologic change as we have in the Nile delta retreat during this century.

On the other hand, one of the man-made responses to the disturbance at Nile delta is to "out engineer" them, by the construction of protection measures (sea walls, jetties, breakwaters, barriers, etc.). These measures could be solution to a lot of problems along the delta coast such as erosion of some adjacent beaches (e.g. Ras El Bar beach), sedimentation processes (e.g. Dammieta harbor), inlets siltation (e.g. Burullus and Idku inlets), and a further alternative may be to offset sea level rise by transferring large volumes of seawater on to land, (e.g. Manzalla lake, eastern harbour at Alexandria, and Qattara depression).

Crop production in Egypt will be affected in at least three ways by climate change. First, higher temperatures will change yields and water demand. Table 1 from EEAA (2010) displays projected changes in yields. Yield for all crops is projected to decrease except for Cotton. This is mainly the result of higher temperatures because all crops are irrigated. The IPCC stated that by 2050, rice yields in Egypt could decrease by 11% and soybean yields by 28% (Boko et al., 2007).

Table 1: Projected changes in crop production of some major crops in Egypt under climate change conditions

Crop	Change %		Reference[a]
	2050s	2100s	
Wheat	-15b	-36c	Abou-Hadid, 2006
Rice	-11		Eid and El-Marsafawy, 2002
Maize	-19		Eid et al., 1997
	-14	-20	Hassanein and Medany, 2007
Soybeans	-28		Eid and EL-Marsafawy, 2002
Barley	-20		Eid et al., 1997
Cotton	+17a	+31b	Eid et al., 1997
Potato	-0.9 to -2.3	+0.2 to +2.3	Medany and Hassanein, 2006
a. Information on these studies can be found in EEAA, 2010. b. Temperature increase by 2°C. c. Temperature increase by 4°C. Source: EEAA, 2010.			

Change in irrigation water is the second way by which climate change may affect crop yields. Higher temperatures will likely increase the demand for water by crops [although higher atmospheric concentrations of carbon dioxide (CO_2) without a change in climate will reduce water demand by crops]. The SNC cited several studies that project a 5 to 13% increase in irrigation requirements by Egyptian crops (EEAA, 2010). If flows of the Nile decrease, it is possible that, in the long term, deliveries of water for irrigation could be reduced. Even if the Nile River's flow does not change, higher population levels could result in a shift of available water supplies from agriculture to domestic and industrial uses.

The third way climate change could affect agriculture is through sea level rise. A rise in sea levels could inundate low-lying and unprotected agricultural lands along the Mediterranean change, negative impacts are expected in areas adjacent to the Egyptian Northern lakes, Eastern desert habitats, marine habitats, marginal pasture in Sinai, and natural mangrove vegetation in the Red Sea coasts. In the Western desert and the Southern valley habitats, the expected increase in temperature will increase the water requirements of field and horticulture crops. A substantial number of the currently endangered species might be lost as coastal habitats are lost and native communities invaded by competitors.

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Table 2: Areas vulnerable to sea level rise in the Nile Delta

	With Mohamed Ali Sea Wall	Without Mohamed Ali Sea Wall
Area (km2) 2025 % of Nile Delta	152.9 0.6	701 2.8
Area (km2) 2025 % of Nile Delta	450 1.9	3,010.6 12.0
Source: EEAA, 2010.		

Sea level rise would threaten coastal development, agriculture in the Delta, and other areas. The IPCC cited a 1997 study by El-Raey (1997) that a 50-cm sea level rise would threaten 2 million people in Alexandria alone (Nicholls et al., 2007).

Climate change is expected to have adverse impacts on human health in Egypt, which will be aggravated by high population densities. These may include increased prevalence and/or severity of asthma, infectious diseases, vector borne diseases, physiological disorders, skin cancer, eye cataracts, respiratory ailments, and heat strokes weakening public health infrastructure as well as extra deaths from cardiovascular and respiratory illness, diarrhea and dysenteric infections, and increased children mortality rates and malnutrition. However, comprehensive studies that contain detailed estimations and correlations between climate change and human health are still lacking in Egypt.

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EEAA (2010) suggests that many current health issues in Egypt could be exacerbated by climate change. Higher temperatures could increase heat stress, particularly in urban areas such as Cairo and Alexandria. Higher temperatures and changes in precipitation could also affect the distribution of diseases such as malaria. To be sure, if the climate gets hotter and drier, the range of many diseases could be restricted.
A decrease in crop production, which could result from climate change, could result in an increase in malnutrition. If the use of irrigation increases, there could be more breeding ground for infectious and waterborne disease. EEAA (2010) notes that increased irrigation could result in more cases of schistosomiasis.
EEAA (2010) points out those cardiovascular and respiratory diseases are already a major concern in Egypt. As noted by the World Bank (2002), this may be the result of high current levels of air pollution. Increased temperatures and drier conditions could increase pollution levels. In addition, an increase in particulate matter (PM) may be of concern.
Higher temperatures can also reduce water quality by, for example, reducing dissolved oxygen levels. A decrease in precipitation can result in lower flow in rivers, which can concentrate pollutants. An overall drier climate punctuated by less frequent, but more intense rain events, as projected by Tebaldi et al. (2006), could result in more runoff of pollutants into water bodies. Finally, sea level rise will increase salinity levels and degrade water supplies in coastal areas.
Cantin et al. (2010) found that warming and increased acidification of seawater will slow coral reef growth in the Red Sea. They estimated that ocean acidification will increase the frequency of coral bleaching by 80% when atmospheric CO2 concentrations reach 550 ppm – around 2060 under the A1B scenario. They also projected that coral reef growth will decline by 5% for each 0.2oC increase in water temperature above 30.5oC and that growth has already decreased by 30% (recreational expenditures on Red Sea coral were $472 million (2.6 billion EGP) in 2000).
coast. The low-lying Nile Delta is Egypt's most productive agricultural region. The associated increase in sea water intrusion in the coastal aquifer could result in reduction of soil fertility as well as reduction in groundwater availability affecting crop production negatively.

There are other direct and indirect ways that climate change could affect crop production in Egypt. A change in climate could affect pests and disease. For example, a warmer climate may enable some

pests and diseases to migrate into Egypt, but a warmer climate may also make it too warm for some pests and diseases to survive. Wetter conditions could enhance migration of pests and disease, whereas drier conditions could limit migration of some pests and disease but perhaps make it possible for others to migrate into agricultural areas in Egypt (Easterling et al., 2007). The balance is thus uncertain.

Change in global supply and demand for certain crops could also affect production in Egypt. On average, warmer temperatures will increase relative yields of grain crops such as wheat in higher latitudes and will decrease relative yields in lower latitudes. This could shift the competitive advantage to growing areas at higher latitude (Easterling et al., 2007), putting Egypt at a competitive disadvantage, decreasing exports and increasing imports.

There is limited information on how livestock in Egypt could be affected by climate change. Higher temperatures can decrease livestock productivity; extreme hot and dry conditions can be fatal to livestock. The SNC notes that bluetongue and Rift Valley fever have recently emerged in Egypt and this emergence may be related to climate factors. Another risk to livestock from climate change is decreased fodder production resulting from climate change. Higher temperatures will also increase water demands by livestock, and these additional demands may not be easily satisfied given the mentioned competition between domestic, industrial, and agricultural uses.
In general, higher water temperatures will affect fish production. In addition, higher salinity levels could limit production of freshwater fish.

Egypt's long coasts, particularly the Nile Delta, are exposed and vulnerable to sea level rise. Table 2 displays the potential loss of land due to sea level rise in 2025 and 2075 as reported in the SNC. The presence of the Mohamed Ali Sea Wall substantially reduces potential loss of land to sea level rise. These estimates are based on the IPCC's (Trenberth et al., 2007) projections of sea level rise. Some studies have found that those projections are low because they do not adequately account for the risk of accelerated sea level rise from the melting of major ice sheets such as those in Greenland and Antarctica (e.g., Oppenheimer et al., 2007; Vermeer and Rahmstorf, 2009).

There are large uncertainties in predicting climatic changes over the Nile basin and their impacts on its flows. This complicates the development of water resources plans in basin countries. Di Baldassarre et al. (2011) reviewed some of the recent studies that investigated the impacts of climate change on the Nile river basin and its flow regime. These studies utilized different approaches ranging from simple statistical downscaling such as the delta change approach of Githui et al. (2009) to complicated regional climate modeling (e.g. Soliman et al., 2009) through statistical bias correction downscaling (e.g. Elshamy et al., 2009c). Downscaling applications in the Nile basin are relatively new as earlier studies (e.g. Conway and Hulme, 1996; Strzepek et al., 2001; Strzepek et al., 1996; e.g. Yates and Strzepek, 1998a) used GCM outputs directly. The results of these studies are discussed in the following section.

Due to lack of computational capacity, regional climate models (RCMs) were not widely used earlier. Apart from the short-span studies of the Sudd by Mohamed et al. (2005a) using RACMO and of the Sobat/Blue Nile using RegCM3 by Soliman et al. (2008), RCMs have not been applied to explore the climate change impacts on the basin. The "Climate Change Risk Management (CCRM)" programme, thus, represents a breakthrough in this regard as one of its component, namely the Forecasting and Integrated Water Resources Management (F&IWRM), assessed the impacts of climate change on the water resources of the basin using the PRECIS regional climate modeling software of the UK Meteorological Office (UKMO). The results of that study are being published in a separate report. This chapter compares those results to the direct use of results of GCMs, i.e. without downscaling in order to investigate the added value of using an RCM as a downscaling methodology over using GCM outputs directly. This provides a way to assess the usefulness of using RCMs versus the added computational resources to run them.

3.2 Previous studies

Climate fluctuations have dramatically changed both the structure and the regime of the River Nile, and it is only within "recent" times that the Nile has taken on its current hydrologic characteristics and its connectivity between Equatorial Africa and the Mediterranean Sea (Said, 1993). A number of researchers have looked at the implications of fluctuations in Nile discharge for water resources in Egypt, particularly since the prolonged drought period of 1978-1987 (e.g. Abu-Zeid and Biswas, 1991; Conway and Hulme, 1993). The historical fluctuations in Nile River discharge have also been reviewed by Shahin(1985), Evans (1990), Sutcliffe and Lazenby(1990) and Sutcliffe and Parks (1999). Other studies have attempted to evaluate the sensitivity of the Nile discharge to changes in temperature and precipitation and the impacts of future climate change on runoff in the Nile Basin. A number of studies have actually propagated the climatic scenarios produced by GCMs to generated flow scenarios for the river and few of these took this further to estimate its economic impacts on Egypt. The following sections display the findings of the different studies subdivided into climate variability and sensitivity studies and climate impact studies.

CHAPTER 3

IMPACTS OF CLIMATE CHANGE ON THE NILE BASIN

(using an Ensemble of Regional Climate Model Simulations)

3. IMPACTS OF CLIMATE CHANGE ON THE NILE BASIN (using an Ensemble of Regional Climate Model Simulations)

3.1 Introduction

The Nile River Basin, generally regarded as one of the longest rivers in the world, is shared by 11 river basin countries (Burundi, the Democratic Republic of Congo (DRC), Egypt, Eritrea, Ethiopia, Kenya, Rwanda, Southern Sudan, Sudan, Tanzania and Uganda). The river is the main source of water in the North Eastern region of Africa. This basin represents one of the most critical and perhaps most important shared water basins in Africa. The river basin area is estimated to be 2.9 Mkm2, about 10% of the continental landmass but it supports more than 25% of the continent's population. Nearly 350 million people, approximately half of Africa's Population, live in the 11 riparian states of whom some 190 million live within the basin itself(Nile Basin Initiative, 2006). However, the Nile has the lowest specific discharge (0.98 l/s/km2) of all world rivers with a basin area exceeding 1 Mkm2. This is due to the varying climate and topography which make the Nile Basin one of the most complex river basins. In addition, the region is facing rising levels of water scarcity, high population growth rates, watershed degradation, and loss of environmental services.

The available water resources in the Nile basin are under immense pressure due to rapidly growing population demand for water for development and urbanization. Egypt is currently water stressed and water is becoming a limiting factor for agriculture expansion to meet the rising food demands. Other riparian countries face periods of floods and droughts hindering the development and prosperity in general. The Nile countries have different water management requirements depending on their demands for hydropower, crop irrigation, and flood protection. Egypt, in particular, has a long tradition of using irrigation since the times of the pharaohs. Nevertheless, this is changing as municipal and industrial demands are on the rise. Therefore, any future changes in the water quantity and quality and their distribution in space and time are likely to have significant impacts on the local and basin wide economies and environment.

It is widely accepted that Global Circulation Models (GCMs) are the best available tools for exploring the impact of climate change. They reproduce the global and continental scale climate fairly well (e.g. Hewitson and Crane, 1996), however, despite the continuous advancements made, they still fail to simulate regional climate features required by hydrological (catchment scale) and national (country scale) impact studies. The main reason for this gap, between the spatial scale of GCM output and that needed for impact studies, is the coarse spatial resolution of GCMs which restricts their usefulness at the grid-size scale and smaller (Wilby and Wigley, 1997). This necessitates downscaling of GCM output either statistically or dynamically before it can be used in hydrological impact studies.

There are large uncertainties in predicting climatic changes over the Nile basin and their impacts on its flows. This complicates the development of water resources plans in basin countries. Di Baldassarre et al. (2011) reviewed some of the recent studies that investigated the impacts of climate change on the Nile river basin and its flow regime. These studies utilized different approaches ranging from simple statistical downscaling such as the delta change approach of Githui et al. (2009) to complicated regional climate modeling (e.g. Soliman et al., 2009) through statistical bias correction downscaling (e.g. Elshamy et al., 2009c). Downscaling applications in the Nile basin are relatively new as earlier studies (e.g. Conway and Hulme, 1996; Strzepek et al., 2001; Strzepek et al., 1996; e.g. Yates and Strzepek, 1998a) used GCM outputs directly. The results of these studies are discussed in the following section.

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3.2.1 Sensitivity Studies

A number of studies have attempted to evaluate the sensitivity of the Nile discharge to changes in temperature and precipitation and the impacts of future climate change on runoff in the Nile Basin. Probably, the first of these studies was that of Kite and Waititu (1981) who looked at the Nzoia River, a tributary of Lake Victoria and found that a 10% increase in precipitation brought about 40% increase in runoff and that the relationship is non-linear. Compared to precipitation, runoff was found less sensitive to changes in potential evapotranspiration (PET) but still, a change of 6% in PET brought more than 10% change in runoff.

Conway &Hulme (1996) applied a range of hypothetical changes in PET and precipitation to drive sub-basin models of the Blue Nile and Lake Victoria to examine their sensitivity. PET was changed by ±4% (corresponding to ± 1°C temperature change) and precipitation was changed in 5% steps from -25% to +25%. Changes in precipitation produced larger changes in runoff than changes in PET. The runoff response was greater than the precipitation anomaly: a 10% increase in precipitation caused a 34% increase in runoff in the Blue Nile while a 4% decrease in PET causes an 8%increase in runoff. In contrast, for Lake Victoriaa 10% increase in precipitation causes a 31% increase in runoff and a 4% increase in PET caused an 11% decrease in runoff.

Sene et al (2001)studied the sensitivity of the water balance of the White Nile to climate change, using both observed and stochastic time series to drive simple water balance models. A simple analytical model for Lake Victoria is used to illustrate the very slow lake's likely response covering many years. Assuming 1% change in the net basin supply components (rainfall less evaporation plus tributary inflow), the change in equilibrium flows at the end of an adjustment period (1-2 decades) is in the order of 7–10%, illustrating the extreme sensitivity to variations in the headwaters of the Lake Victoria region. Previously, Sene (2000) suggested that a 1% increase in rainfall alone is sufficient to cause a 4–7% increase in flows throughout the basin, and a 7–11% increase in the area of the Sudd swamps.

Sayed (2004) also studied the sensitivity the of different Nile sub-basins to uniform changes in rainfall using a distributed hydrological model (The Nile Forecast System, NFS - Nile Forecast Center, 2002). For Lake Victoria basin, he found that a 10% increase in rainfall would result in 5.7% increase in Lake outflows indicating a relatively low sensitivity, which contradicts with previous studies. On the other hand, a 10% increase in rainfall over the upper Blue Nile and Atbara sub-basins would cause increases of 34% and 32% respectively, indicating that these sub-basins are much more sensitive to climatic changes than Lake Victoria sub-basin. Reductions of 10% in rainfall would result in reductions of outflows of 24%, 24% and 4% for the Atabra, Blue Nile and Lake Victoria sub-basins respectively. The balance of these changes at Dongola gives changes of 30% (-25%) in mean annual flow for a 10% increase (reduction) of rainfall over the whole Nile basin because of the dominance of the Ethiopian plateau flows (through Atbara and Blue Nile).

Elshamy et al. (2009a) presented a sensitivity study for 3 sub-basins of various sizes and characteristics and reported that the degree of sensitivity is larger to rainfall than to temperature and increases with the aridity of the basin.

3.2.2 Climate Impact Studies

So far, the above-mentioned studies looked at the sensitivity of runoff to climatic drivers. The following sections review the studies that addressed the impacts of climate change on the water resources of the Nile categorized into three types: studies relying directly on GCM results to construct the climate scenarios; and studies that used statistical downscaling techniques to obtain finer detailed climatic scenarios; and finally those using dynamic techniques to construct the scenarios.

Direct Use of GCM Scenarios

The first, and probably most famous, impact study was carried out by Strzepek et al. (1995)who undertook an economic analysis of potential impacts of climate change in Egypt. Their projections indicated a decline in self-sufficiency (agricultural and non-agricultural) and that climate change had a number of potentially negative effects. Their analysis incorporated climatically induced changes in Nile supply which showed a very wide range of changes (-77% to +30%). They relied on the results of 3GCMs (CO_2 doubling experiments) without downscaling.

Yates (1996) used 3 equilibrium experiments (of CO_2 doubling) and one transient experiment and showed also a wide range of changes for Nile inflows. While three of the models indicated increases in natural river flow at Aswan of more than 50%, the fourth model showed a 12% reduction. Temperature rise will result in increasing evaporation losses from Lake Nasser as well as increasing irrigation water demands. Considering such losses in addition to possible increases in Sudan abstractions, the study predicts changes in water availability ranging between –11% to +61%. They indicated that such changes would have huge implications for the Egyptian economy as depicted in Yates' study and in the earlier study of Strzepek et al. (1995).

Conway and Hulme (1996) used GCMs at a grid scale of 2.5º to 3.75º and estimated changes for the 2025. They suggested that, the anticipated changes in atmospheric concentrations of CO_2, at the time of the study, would lead to a temperature increase of about 1ºC across the Nile Basin by 2025, leading to increased evaporation losses and a slight increase (2%) in rainfall in the Blue Nile basin and a slightly larger increase (5%) over the Equatorial Lakes region, spread fairly evenly throughout both wet and dry seasons. They used these changes to construct scenarios from a number of first generation GCM equilibrium experiments to derive estimates of future Nile discharge. Changes in mean annual Nile flows for 2025rangedbetween –9% to +12%.Dividing the Nile yield according to the 1959 Nile Waters Agreement, they estimated a mean annual flow for the Egyptian Nile varying between 50 and 65 BCM, compared to the current share of 55.5 BCM.

Yates and Strzepek (1998a) applied a monthly water balance model of the Nile River basin (WBNILE) for assessing potential climatic change impacts on Nile runoff. The WBNILE model divides the Nile into 12 sub-catchments, including characterization of the lakes region of equatorial Africa and the Sudd swamp. The model uses mean monthly climate variables of precipitation, temperature, relative humidity, and sunshine hours, and each basin is calibrated from observed monthly averaged discharge. Areally averaged temperature and precipitation changes from five GCMs were imposed on each sub basin for assessing climate change impacts on runoff. Results showed the sensitivity of the basin to climate fluctuations, because four of five GCMs predicted significantly larger flows in equatorial Africa and the expansion of the Sudd swamps, whereas there was a range of results for the Ethiopian highlands of the Blue Nile and Atbara basins depending on the GCM scenario. In a later study, Yates and Strzepek (1998b) found that five out of six climate models with a doubling of CO_2(expected to occur in 2060) produced an increases in Nile flows at Aswan, with only one showing a relatively small reduction (-15%).

Arnell(1999a) studied changes in global runoff using a macro-scale hydrological model (0.5° resolution) fed with scenarios from HadCM2 and HadCM3 GCMs. He focused on the 2050s and showed that precipitation will generally increase over the Nile basin but the resulting increase in runoff will be offset by increases in evaporation losses due to temperature rise. Thus, he expects little change in the mean Nile flows by 2050. During model development and calibration (Arnell, 1999b), he tested three methods (Penman, Penman-Monteith, and Priestley–Taylor) to calculate potential evaporation and found that the latter two outperformed the former while neither of these two was consistently better than the other. He did not downscale the output of GCMs to run the hydrological model but rather re-gridded (using bi-linear interpolation) GCM outputs to fit the resolution of the hydrological model.

Strzepeket al. (2001)updated their studies with greater emphasis on developing methodologies for designing what they termed as 'not implausible' climate and economic scenarios and for assessing and evaluating adaptation strategies. They used a purpose-designed software system to produce a sample population of climate change scenarios for the basin that incorporate uncertainties due to differences between climate models, a range of climate sensitivity estimates, emission pathways for greenhouse gases and sulphate aerosols and the effects of sulphate aerosols. They selected nine representative scenarios from the full range which were translated into future Nile flow scenarios using a suite of water balance models. The results showed a propensity for lower Nile flows (in eight out of nine scenarios), in contrast to their earlier study, in which five out of six scenarios produced an increase in Nile flows.

A more recent assessment of climate change impacts on Lake Victoria was performed by Tate et al. (2004) using 2 transient GCM scenarios from HadCM3 based on the recent IPCC SRES storylines (IPCC, 2000). The resultant change in outflow showed a reduction of 2.6-4.2% by the 2050s followed by an increase between 6.3% and 9.7% in the 2080s with respect to the 1961-90 baseline. The ranges correspond to the different climate scenarios and two baselines (observed and simulated) used. The earlier study of Conway and Hulme (1996) presented the results from 3 GCM equilibrium scenarios with rainfall changes between -1% and +5% of the 1961-90 mean resulting in runoff changes between -9% to +12% for Lake Victoria by 2025.

Sayed (2004) suggested a positive relation between rainfall and temperature in the Blue Nile basin based on a comparison of temperature and Mean Areal Precipitation between 1977 and 2003. In the White Nile region this relation was weaker. He used results from 4 GCMs and based on this he expects that the change in rainfall in the Blue Nile would be between 2 and 11% for 2030, while rainfall in the White Nile would increase between 1 and 10% for the same year. The associated range of changes in inflow to Lake Nasser is between -14% and 32%.

Statistically Downscaled Scenarios

Elshamy et al. (2009b) and Nawaz et al. (2010) used a statistical downscaling approach developed with the framework of the Lake Nasser Flood and Drought Control project to assess the impacts of climate change on the main Nile flow at Dongola and the Blue Nile flow at Diem respectively. This approach downscales monthly coarse spatial resolution output from 3 GCMs and two emission scenarios (A2 and B2) into daily fine resolution (20 km) output using a spatio-temporal weather generator. The output is used to drive the Nile Forecast System (NFS) to translate the generated rainfall and PET scenarios into flow scenarios. The weather generator has a stochastic component and a number of realizations is generated (Elshamy et al. (2009b) used 10 while Nawaz et al. (2010) used 50). Results for both the whole Nile and Blue Nile were divergent but showed that the uncertainty across GCMs was larger than that across emission scenarios especially till 2050. The range of differences between the scenarios was found to be GCM dependent and time dependent. The uncertainty due to downscaling was found to be also large and to be proportional to the flow.

Elshamy et al. (2009c) applied a bias correction downscaling approach to downscale the output of 17 general circulation models (GCMs) included in the 4th IPCC assessment report using the A1B emission scenario. Downscaled precipitation scenarios for the 2081–2098 period were constructed for the upper Blue Nile basin using a distribution mapping approach to correct the intensity of daily precipitation outputs of GCMs (Ines and Hansen, 2006). To bias-correct future PET scenarios, monthly gridded correction factors have been calculated as ratios of the observed climatology and GCM climatology for the baseline period. These factors were then applied to the future monthly PET climatology. The downscaled rainfall and PET were used to drive the NFS hydrological model to assess their impacts on the flows of the upper Blue Nile at Diem. The study found no consensus among the GCMs on the direction of precipitation change. Changes in total annual precipitation ranged between −15% to +14%. For no change in rainfall, increasing PET thus leads to a reduced wet season runoff coefficient. The ensemble mean runoff coefficient (about 20% for baseline simulations) is reduced by about 3.5% in the future. Assuming no change or moderate changes in rainfall, the simulations indicated that the water balance of the upper Blue Nile basin may become more moisture constrained in the future. The predicted ensemble mean annual flow at Diem is reduced by 15% compared to the baseline within a range of -60% to 45%.

Beyene et al. (2010) examined changes in the precipitation for the summer (JJA) and winter (DJF) seasons in the Ethiopian Highlands based on the 2007 IPCC scenarios using the VIC macro-scale hydrological model. Model inputs are bias corrected and spatially downscaled from
11 GCMs under two global emissions scenarios (A2 and B1) obtained from the IPCC Fourth Assessment Report (AR4) archive. Their analysis of the ensemble means show strong increases in both seasons for the period 2010-2039. Predicted increases in the important JJA precipitation are predicted for the Blue Nile that may be related to increased intensity in the Ethiopian Highlands. Under the current climate the Blue Nile, where it reaches Khartoum contributes some 65% of the Nile flow. This would suggest increases in the precipitation which might result in increases in inflows to HAD. Beyene et al. (2010) have also simulated the annual hydropower production at the HAD under the A2 and B1 global emission scenarios. They find that while much of the average mandated power requirement is met for the period 2010-2039, beyond this, these targets would not be met mainly due to inflow reductions to the HAD. They also found shortfalls in irrigation water from Lake Nasser compared to the historical average by the middle of the 21st century due to reductions in precipitation, increase in evapotranspiration generally and increase in evaporation from the Sudd swamps and Lake Nasser itself.

Dynamically Downscaled Scenarios

The first application of a regional climate model to the Nile basin was carried out by Mohamed et al. (2005b)who modified RACMO (the limited area model used by KNMI – The Royal Netherlands Meteorological Institute) include routing of the Nile flood over the Sudd. The impact of the wetland on the Nile hydro climatology was studied by comparing two model scenarios: the present climatology, and a drained Sudd scenario (building the Jonglei canal). The results indicate that draining the entire Sudd has negligible impact on the regional water cycle owing to the relatively small area covered by the wetland. However, the impacts for the local climate are considerable. Earlier, Mohamed et al. (2005a) presented a validation study for a 6-year period for the same model applied to the whole of the Nile basin.

The second application of RCMs to the Nile Basin was carried out by Soliman et al. (2008) who configured and validated RegCM3 over a domain covering two important stream flow-generating regions of the Nile Basin: the Sobat and Blue Nile Sub-basins. Using the output of RegCM3, the NFS was used to convert precipitation predictions into flow predictions for the Blue Nile at Diem with sufficient accuracy. Soliman et al. (2008) found that the spatial pattern of precipitation was generally well captured by the model both in the rainy and dry seasons but the model is biased towards warmer conditions (2-6°C) over the whole studied domain in all seasons although it captured the spatial and temporal patterns sufficiently. The multi-year flow simulation using NFS utilizing RegCM3 output showed good performance in capturing the seasonality of flows for the Blue Nile (RMSE = 0.80), but was poor for the Sobat (RMSE = 0.30) due to erroneously predicted extreme flows by the NFS (probably due to improper calibration of the NFS over the Sobat) in addition to some high spots of rainfall predicted by RegCM3.Solimanet al. (2009) followed by using RegCM3 to downscale ECHAM5 RCM for the A1B scenario. The model estimated future increases in Blue Nile flow at Diem of about 1.5% annually However, the estimated increase of flow was larger during the beginning of the flood season (+10%), whereas the flow was predicted to decrease towards the end of the rainy season in October and November, as well as in the dry season.

These studies indicate the wide range of uncertainty in the climate projections which becomes even wider when translated to changes in river flow. This motivated the use of dynamic downscaling techniques (i.e., RCMs) in an attempt to reduce the uncertainty range to help taking important decisions regarding the required adaptation strategies. The CCRM programme applied the methodology outlined below utilizing the PRECIS regional climate model to assess the impacts of climate change on the Nile Basin. The results are documented in a separate report while this chapter focuses on the differences between using GCM outputs directly and those obtained through dynamic downscaling using PRECIS.

3.3 Methodology

In the next sections, the study methodology is described showing the models and data used with possible improvements in future research.

3.3.1 Global Climate Modeling

Climate projections are inherently uncertain. Common sources of uncertainty that are widely recognized (Stainforth et al., 2007) include the natural variability of the climate system due to its chaotic nature, the uncertainty associated with estimating future anthropogenic emissions and the uncertainty resulting from our incomplete understanding of the climate system and the associated difficulties in attempting to represent the important processes in climate models.

Research that systematically analyses and quantifies the uncertainties in climate projections is a relatively new discipline. Recent EU research projects; PRUDENCE(Christensen and Christensen, 2007) and ENSEMBLES (Hewitt, 2005) provide the foundation for this type of research in a European context. In the UK, systematic analysis of uncertainties in climate change impacts began back in the 1990s and here the field is more mature. Indeed, the UK Met Office Hadley Center, (Murphy et al., 2004), pioneered the use of climate model ensembles to explore uncertainties in the climate projections in the QUMP (Quantifying Uncertainty in Model Predictions) project. They examined the impacts of uncertainties associated with the choice of parameters in the model, greenhouse gas emissions, and the internal variability of the system. QUMP generated 17 GCM ensemble members from the HadCM3 GCM using different parameterizations of the unresolved (sub-grid) physical processes (e.g. cloud formation, convection, and radiation). This was also reflected in the release of the most recent United Kingdom Climate Projections (UKCP09 - Murphy et al., 2009) which represents one of the first, if not the first, systematic evaluation of the uncertainty associated with climate projections and the corresponding assessment of uncertainty in impact studies.

It is worth noting that in assessing the uncertainties in predicted climate impacts, that the uncertainty in climate projections represents only a part, albeit significant, of the total uncertainty, (Buontempo et al., 2010). The extent of hydrological impacts due to climate change will depend on the dominant hydrological processes and also on the feedbacks between the hydrological system and the atmosphere. The impact uncertainty must also consider the uncertainties in hydrological models used for impact projections, and in the observed data used to calibrate them.
Rather than using all possible GCM ensemble members a simpler but robust procedure was adopted. van Roosmalen et al., (2010) conclude that “In general, it would be most beneficial for impact studies if the uncertainties in the climate change data were expressed quantitatively using a probabilistic approach, which is however very labor-intensive and requires a large number of climate model runs”.

Therefore it is of interest to find less computationally intensive methods to capture the uncertainties. In this work, the 17 QUMP ensemble members were ranked according to their predictive skill of the current climate. Skill was assessed against 4 criteria; namely their ability to represent accurately (1) precipitation across East Africa, (2) precipitation across West Africa, (3) the Indian monsoon and (4) temperature over the Nile Basin. All GCM ensemble members were ranked using the root mean square error against observations. One approach for selecting a subset could then be to select the models with the best total performance. However as one of the goals was to represent contributions to the uncertainty in climate projections, an alternative selection was made where five ensemble members were selected capture the full range of variability within the ensembles, thus, 2 members at each of the two extreme ends were selected as well as two median ones.

3.3.2 Regional Climate Modeling

A regional climate model (RCM) covering the entire Nile Basin has been configured. The regional model used is the UK Met Office Hadley Centre PRECIS, a modified version of the Met Office Hadley Centre’s regional model HadRM3, designed to run on PCs (Jones et al., 2004). Using a regional climate model (RCM) as opposed to global climate models (GCM) clearly provides better resolution of the future patterns of climate change; see Figures 3 to 6. The coarse resolution provided by GCMs is deemed insufficient for water resources impact studies, where local effects such as orographic rainfall enhancement can be very significant. The regional model boundaries have been defined to ensure they include the important moisture sources for the Nile basin (the Indian Ocean and the Gulf of Guinea). That is why the selected domain extends well beyond the boundaries of the Nile basin. The domain consists of 142 x 150 cells at 50 km resolution. This has the advantage that the results can be applied not only to the Nile Basin countries but also to other countries in the region. The same domain is covered by z x y cells at 2.5° x 3.75° for the parent GCM.
This chapter considers uncertainties in the regional climate response to global climate change, but not those arising from different emissions scenarios. Results from the GCM were derived for one emission scenario (SRES A1B) as previous studies (e.g. Elshamy et al., 2009b) indicated that the uncertainty across climate models is much larger than that across emission scenarios, at least till the 2050s. The UK Met Office regional climate model, PRECIS, was run using boundary conditions from 6 of the 17 QUMP ensemble members at 50 km resolution for the period 1950-2050.

3.3.3. Bias Correction

In order to avoid the bias in RCM results, which partly stems from that of the parent GCM, the delta change methodology is applied. Typically, a 30 year baseline period (Jones et al., 1997), is used to capture long-term mean of the climate. Monthly delta change factors (DCFs) were calculated for rainfall (ratios), temperature (differences) and evapotranspiration (ratios) from the baseline period (1970-1999) and the future period (2020-2049). DCFs were also calculated from the GCM output directly (the same QUMP members) at its original resolution (2.5° x 3.75°).
Although the GCM/RCM outputs actual evapotranspiration, it cannot be used for hydrological modeling because most hydrological models require potential evapotranspiration. Therefore, potential evapotranspiration (PET) for each of the ensemble members was calculated using the Penman-Monteith method (Allen et al., 1998) using the outputs of temperature, humidity, surface wind speed, and shortwave radiation from the GCM/RCM at their respective resolutions. This was done on a monthly basis for the above-mentioned baseline and future periods and then the resulting maps were used to derive DCFs for PET. These were used together with those for rainfall in the hydrological modeling exercise described in the following section.

3.3.4 Hydrological Modeling

The impact of climate change on future inflows into the High Aswan Dam is obtained using a basin-wide operational hydrologic model, the Nile Forecasting System (NFS), with the perturbed daily time series of rainfall using the DCFs derived above for GCM and RCM ensemble members. The NFS is a real-time distributed hydro-meteorological forecast system designed for forecasting Nile flows at designated key points within the Nile. Of major interest is the inflow of the Nile into the High Aswan Dam, Egypt. The system is hosted at the Nile Forecast Center (NFC) of the Ministry of Water Resources and Irrigation (MWRI), Giza, Egypt. NFS version 5.1 (Nile Forecast Center, 2007)was used for this study.

The core of the NFS is a conceptual distributed hydrological model of the whole Nile system including soil moisture accounting, hill slope and river routing, lakes, wetlands, and man-made reservoirs within the basin. This model is defined on the quasi-rectangular grid of the METEOSAT satellite from which the system receives imagery to estimate rainfall. Each grid cell (pixel) imitates a small basin with generalized hill slopes and stream channels. Inputs to each grid cell are precipitation and potential evaporation. This input is applied to a two-layer soil moisture accounting (water balance) model of the pixel. The upper layer is thin to represent the short-term detention of storm water. This layer receives precipitation inputs and evapotranspiration occurs at the potential rate. All rainfall is assumed to infiltrate the upper layer. Excess rainfall percolates to the lower layer which has a larger moisture capacity. If the evaporative demand is not met from the upper layer, water is extracted from the lower layer at rate which varies linearly with the current moisture capacity. Subsurface runoff is calculated as a non-linear function of the relative moisture content of the lower layer (anon-linear reservoir).
Surface runoff is calculated as a fraction of the excess rainfall which depends on the amount of the lower layer deficit.

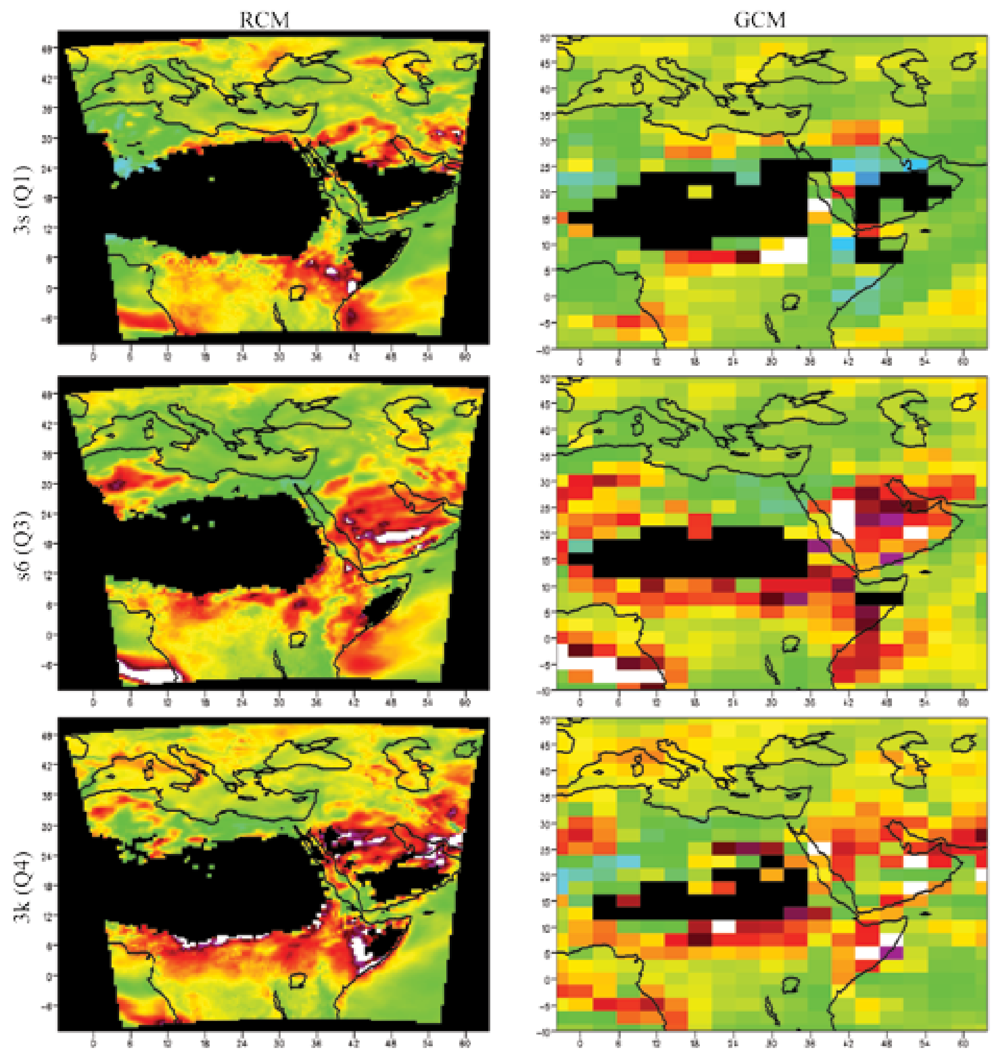
Surface and subsurface runoffs are subsequently input to the pixel's hill slope routing model, simulating the transfer of water towards the main channel. Generated runoff is then routed through this channel to the downstream pixel according to a pre-defined connectivity sequence (established via GIS). Sayed and Saad (2002) evaluated the daily performance NFS in daily simulations and found that it could explain 93% of the observed daily variance of the Diem flows over the period 1997-2002. Elshamy (2008) evaluated the long-term performance of the NFS and found that it could explain 79% of the observed monthly variance of Diem flows over the period 1940-1999 with errors related to the quality of rainfall data. For more details about the NFSrefer to Nile Forecast Center (1999) and Elshamy(2006).
For each month, and for each member in the two ensembles, the multiplicative change factors for rainfall were then used to modify present day daily time series for the period 1989-2007 and consequently generate perturbed time series representative of future conditions. This is period was selected as it has the most reliable daily rainfall in the NFS database. For PET, the NFS uses monthly climatological (long-term average) fields and these were perturbed accordingly. The NFS was then run using the modified time-series as an input. These estimates of Nile runoff were then compared with those predicted by NFS under present day conditions to determine the impact of climate change on the flow at key locations along the river. The following sections display and discuss the resulting changes in rainfall, temperature, evaportranspiration over the basin and flows at selected stations focusing on the main sources of the Nile: the Blue Nile, and the White Nile.

3.4 Results and Analysis

The following sections display the results of the study in terms of DCFs obtained for the most important climatic variables; rainfall and temperature. The resulting patterns from GCM and RCM results are inter-compared. This is followed by analysis of PET projections and future flows of the Atbara at Atbara Town, the Upper Blue Nile at Diem, the White Nile at Malakal and the main Nile at Dongola as estimated by the NFS. The focus is on comparing the range of results from direct use of GCM output to those downscaled using PRECIS. However, the results from each ensemble are also inter-compared.

3.4.1 Rainfall

Figure 3 and Figure 4 show that spatial patterns of rainfall change (for the months of January and August respectively) for the 2 ensembles (RCM & GCM) are generally similar with some differences between the ensemble members and the two ensembles over some regions. The largest relative changes occur over the drier areas where the baseline is originally small and thus relative changes are amplified but they are mostly insignificant in terms of rainfall rates. The GCM ensemble has larger white areas (DCF > 3.0) than the RCM ensemble. The GCM ensemble also seems to wetter in general over the Horn of Africa and the Equatorial Lakes. The difference in resolution and detail does not need to be mentioned.



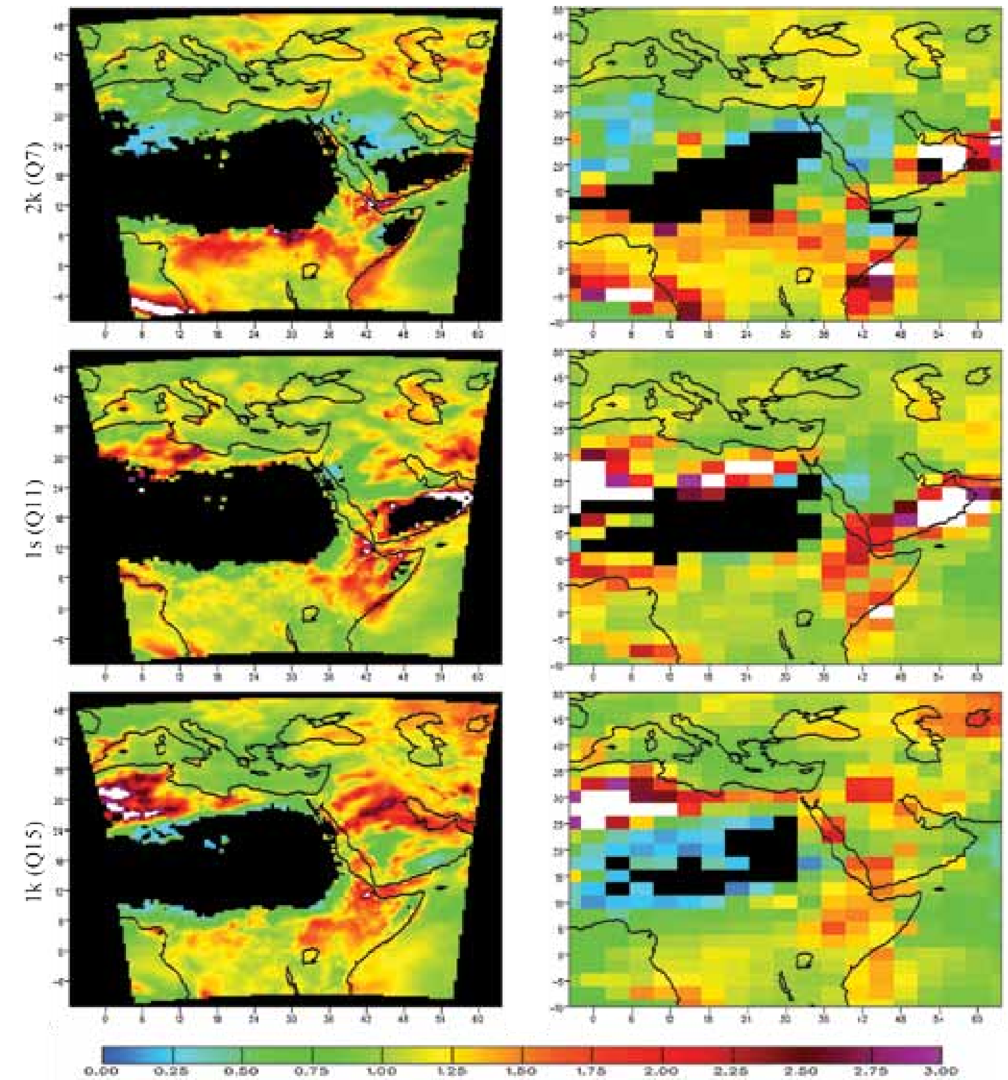
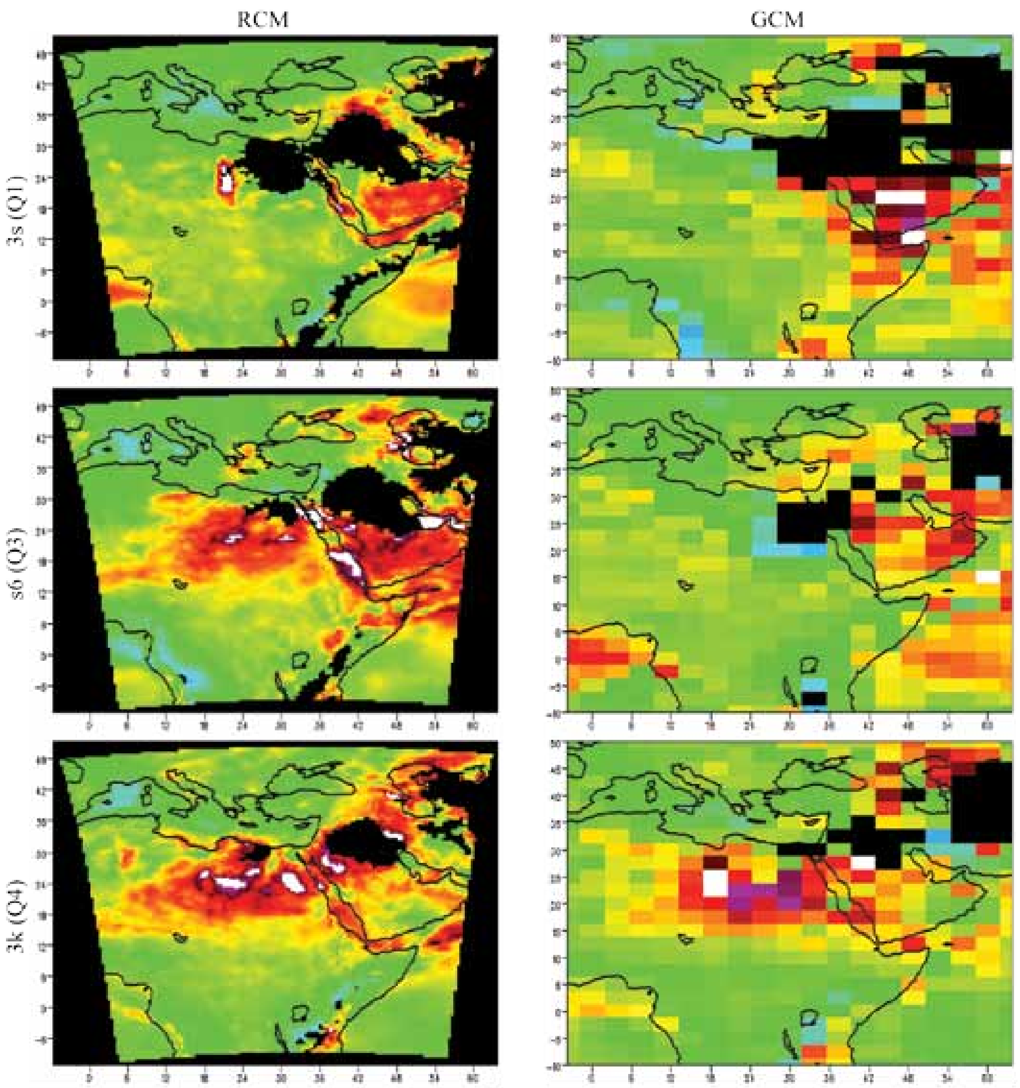


Figure 3:
Precipitation DCFs over the Nile Basin Domain for January from by the RCM and GCM Ensembles
Black areas are excluded from the calculations because baseline precipitation is almost zero
White areas are off the scale (DCF > 3). DCF around 1 indicate no change

Looking at the future projected mean seasonal distributions (Figure 5) over the four selected sub-catchments, it becomes clear that most of the ensemble members predict rainfall increases for the Blue Nile and the Atbara compared to the baseline while the signal is mixed for the White Nile. The RCM ensemble has a much smaller range than the GCM ensemble (note that graph scales are different). The GCM ensemble is also characterized by different shifts for the peak across the different members, which reflects the lack of consistency due to the coarser resolution of the GCM.



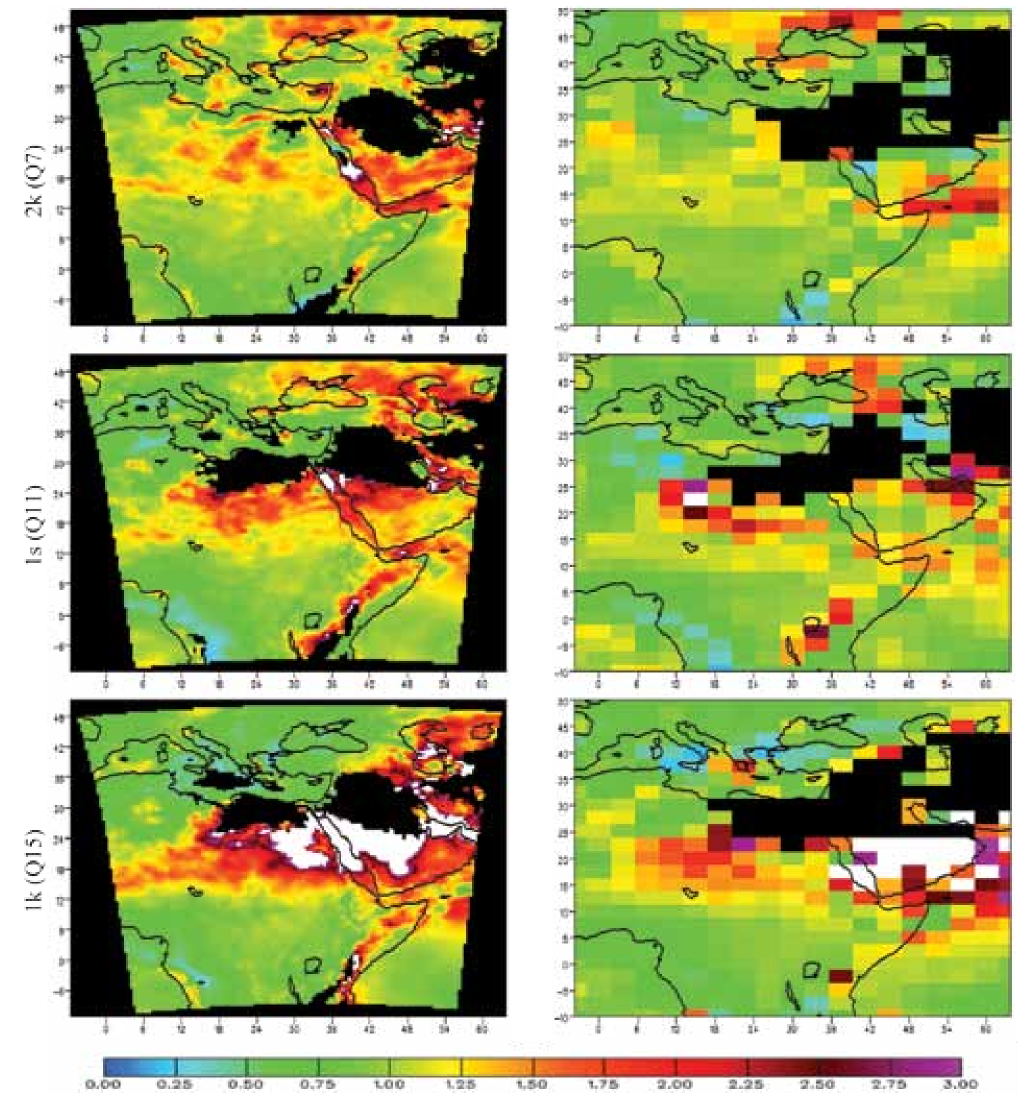


Figure 4:
Precipitation DCFs over the Nile Basin Domain for August from by the RCM and GCM Ensembles

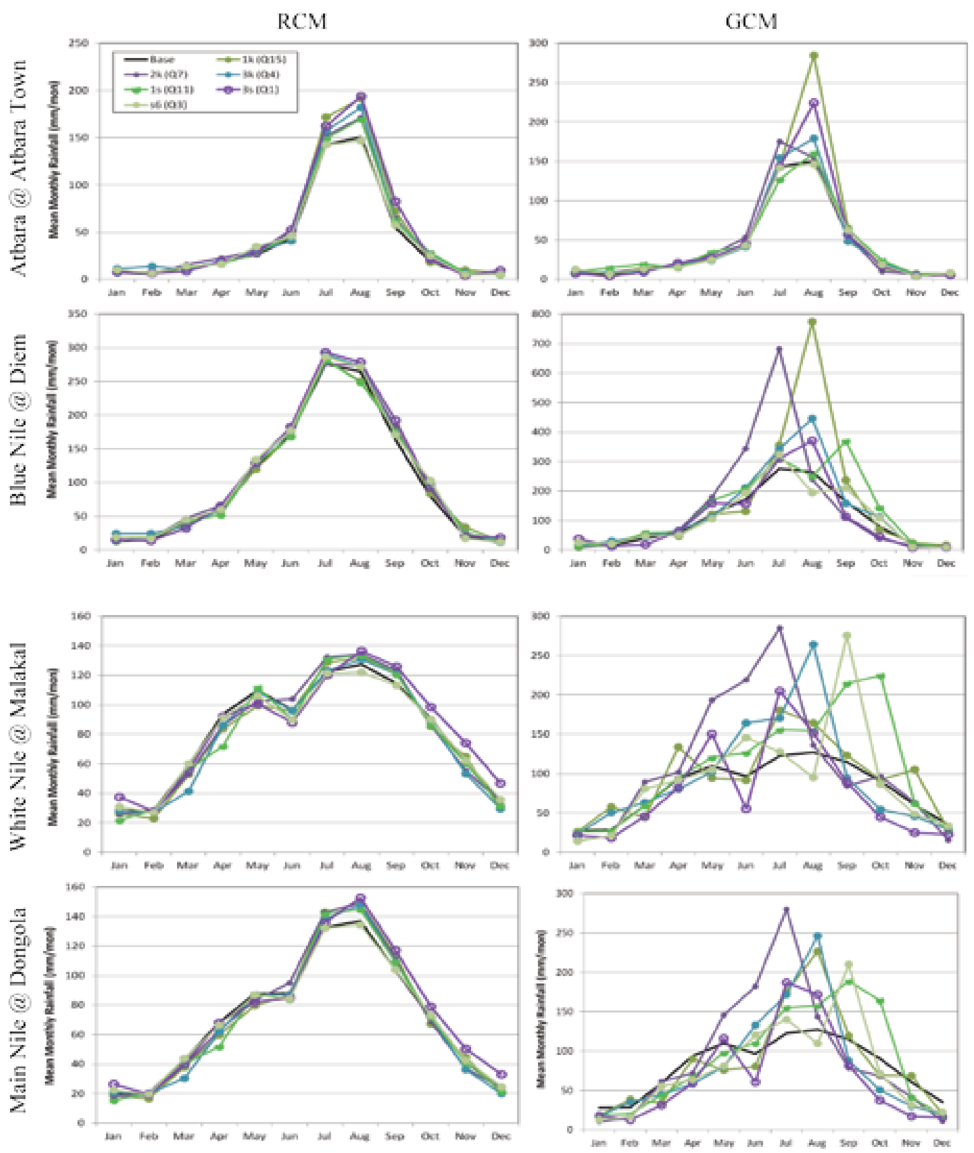
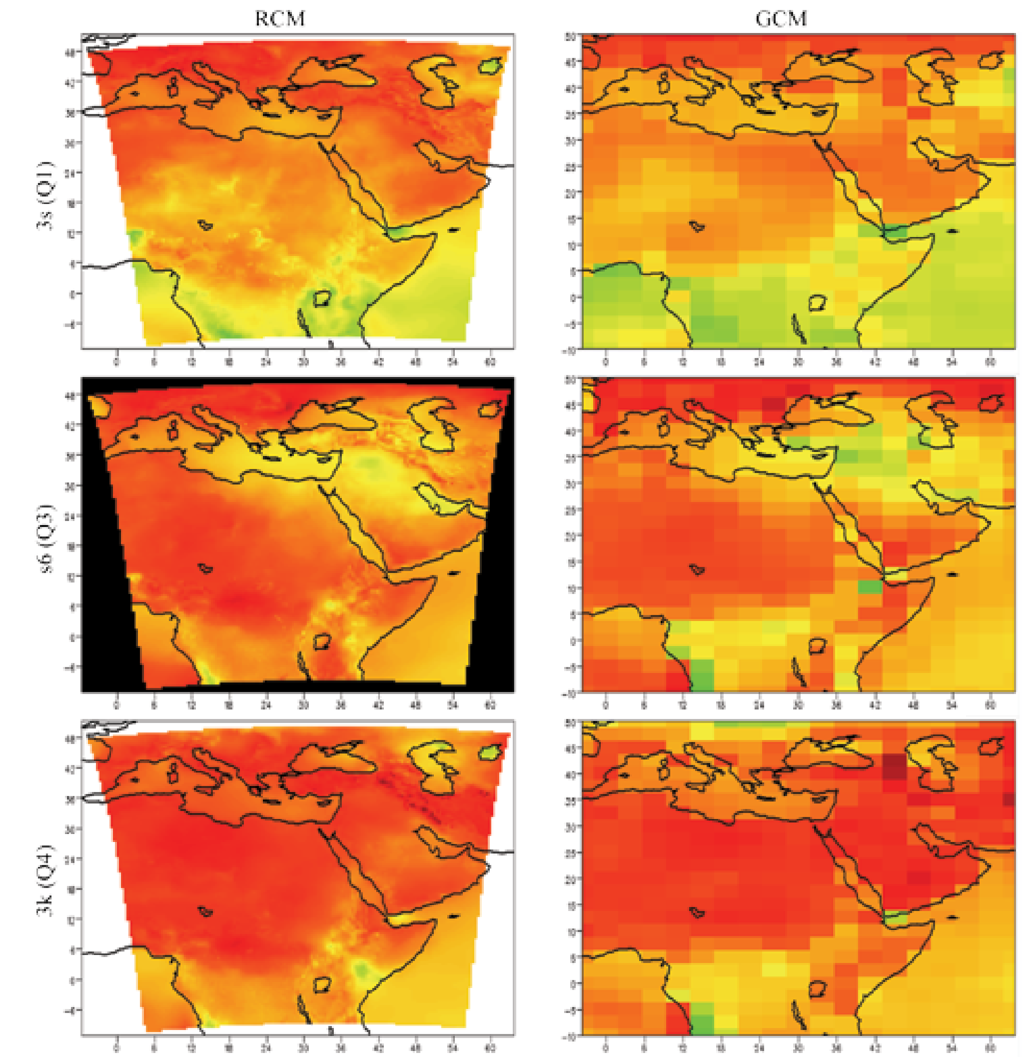
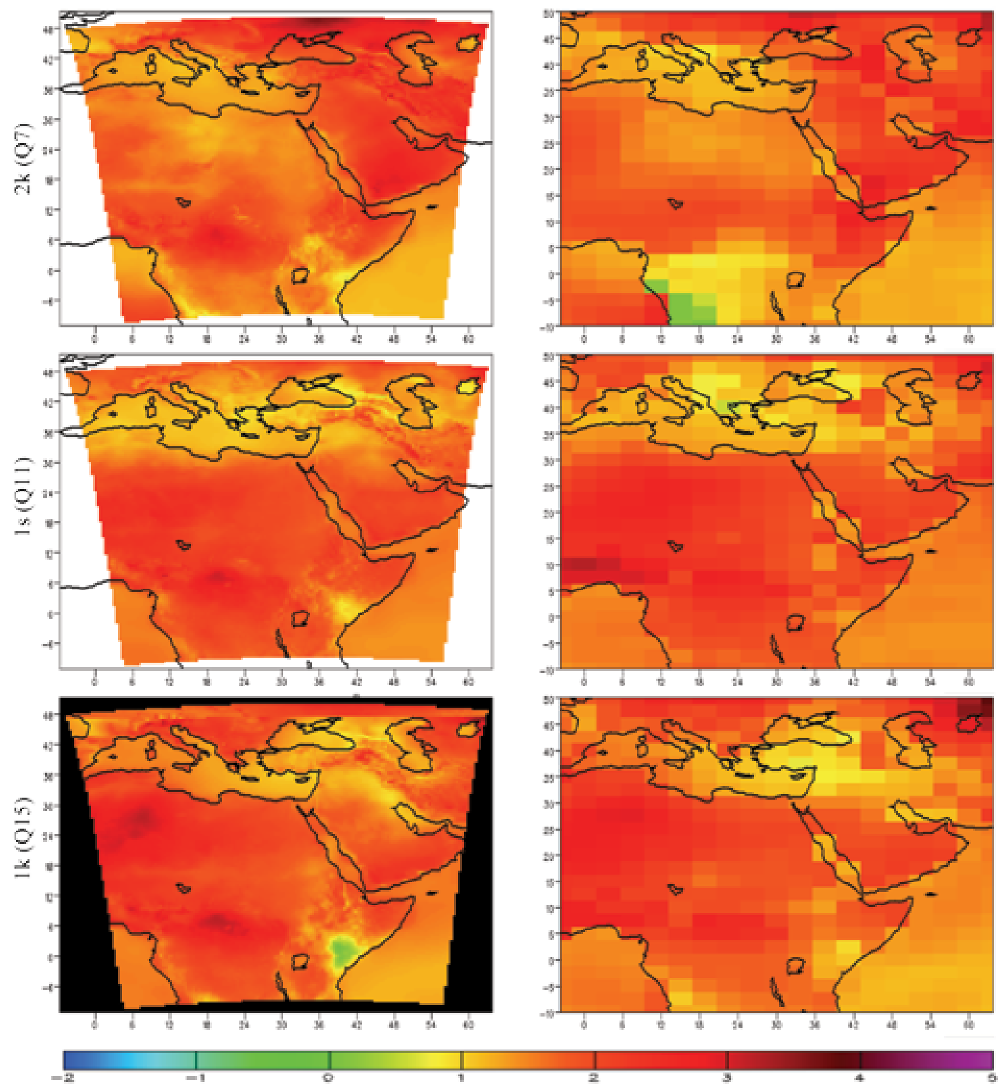


Figure 5:
Seasonal Precipitation Distributions for Key Nile sub-Basins from the RCM and GCM Ensembles

3.4.2 Temperature

Figure 6 and Figure 7 indicates some agreement amongst the different ensemble members regarding the warming/cooling patterns within the study domain of the months of January and August respectively. For the month of August, the ensemble members agree on a degree of warming for the Sahara desert followed by a cooling or a relatively smaller warming in the region of 16-20°N latitude followed by some warming around the equator of up to 2°C.





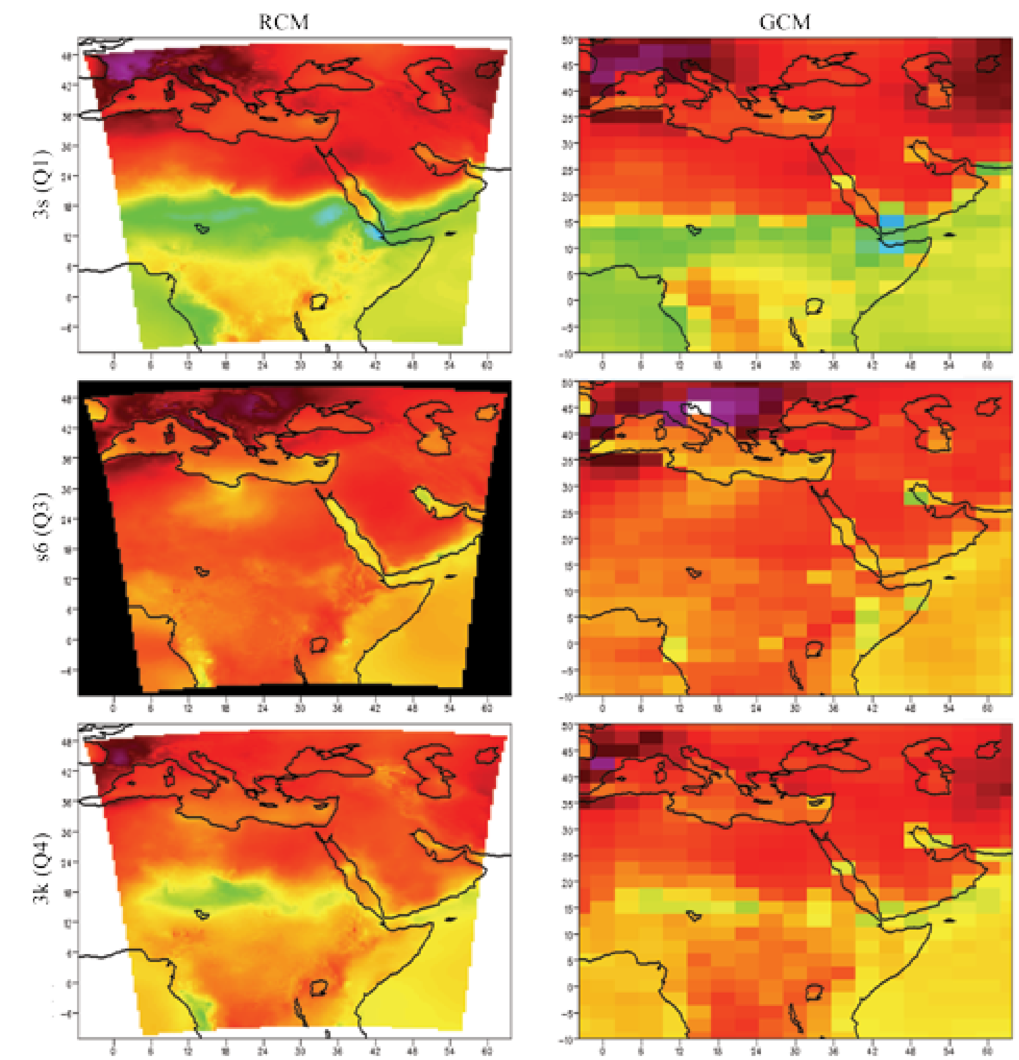


Figure 6:
Temperature DCFs over the Nile Basin Domain for January from by the RCM and GCM Ensembles White areas are off the scale; DCF around 0 indicate no change

Although the patterns are similar, the ensemble members show different absolute values for the warming trend (e.g. 1k projects higher temperature rise for the Sahara of over 4°C while 3k shows temperature rise of around 2.5°C for the same region. For most of the source areas of the Nile basin, the temperature rise is within 2°C. The evolution of climate in the RCM from that of the GCM reduces the change in some areas and increase them in others but the patterns remain broadly similar. The GCM patters are closer to those downscaled using the RCM for temperature than those shown above for precipitation reflecting the difficulty of the evolution of precipitation generation mechanisms.

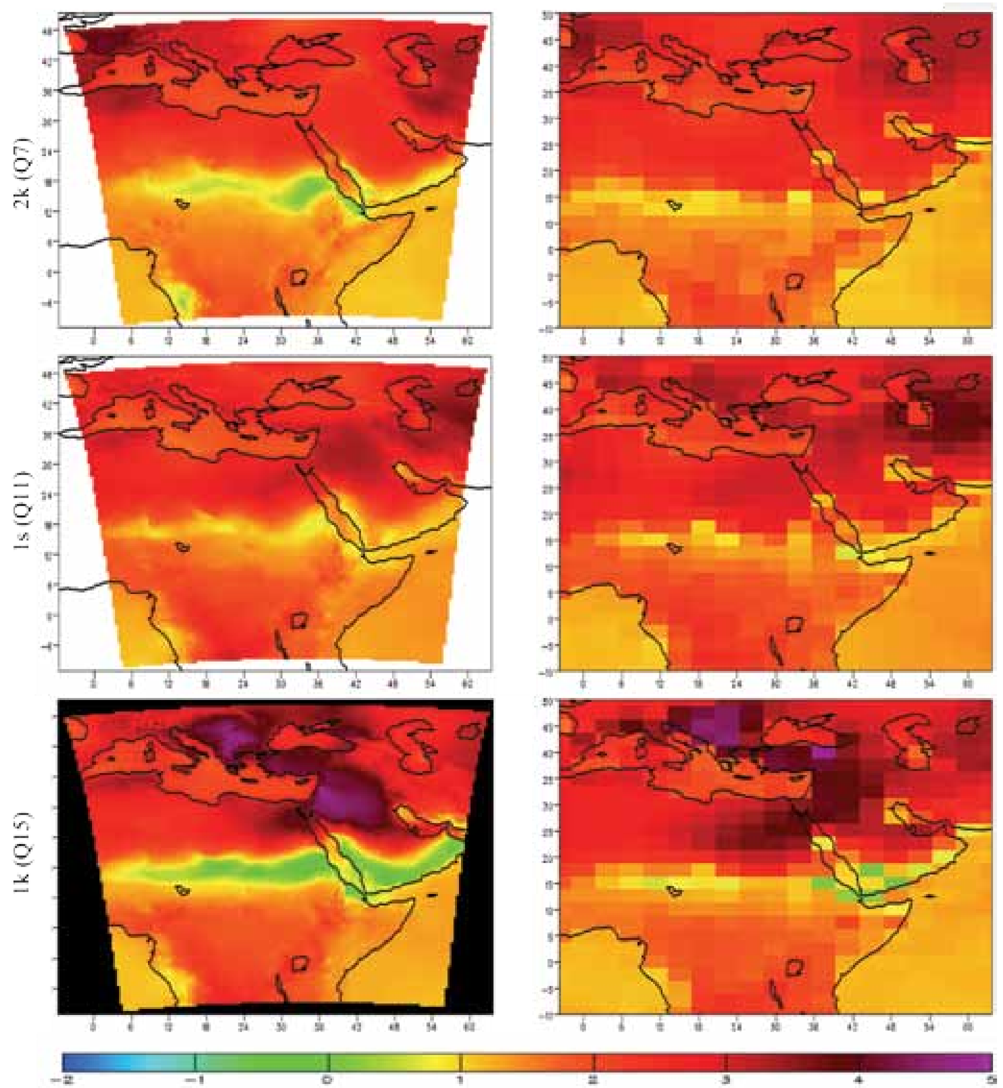


Figure 7:
Temperature DCFs over the Nile Basin Domain for August from the RCM and GCM Ensembles
White areas are off the scale; DCF around 0 indicate no change

3.4.3 Evapotranspiration

As mentioned above, evapotranspiration has been calculated using the Penman-Monteith method for the baseline and future periods to calculate the DCFs which are used to perturb the monthly fields of the NFS. Despite the agreement on the temperature rise, it seems the expected increase of cloudiness associated with the increase in rainfall, in addition to changes in other PET variables resulted in PET reduction in some areas. Figure 8 and Figure 9 compare the PET patterns for the different members of the RCM and GCM ensembles for the months of January and August respectively interpolated to the resolution of the NFS (20km). Despite the common interpolation, the GCM patters still show less detail as they come from coarser resolution fields. Most changes are modest (DCFs between 0.75 and 1.25, 1 means no change) but the patterns across the different ensemble members seem to be closer to each other than to their respective members for RCM and GCM. The projected precipitation change patterns for the GCM show wide variations as mentioned above and this may have affected the PET patterns.

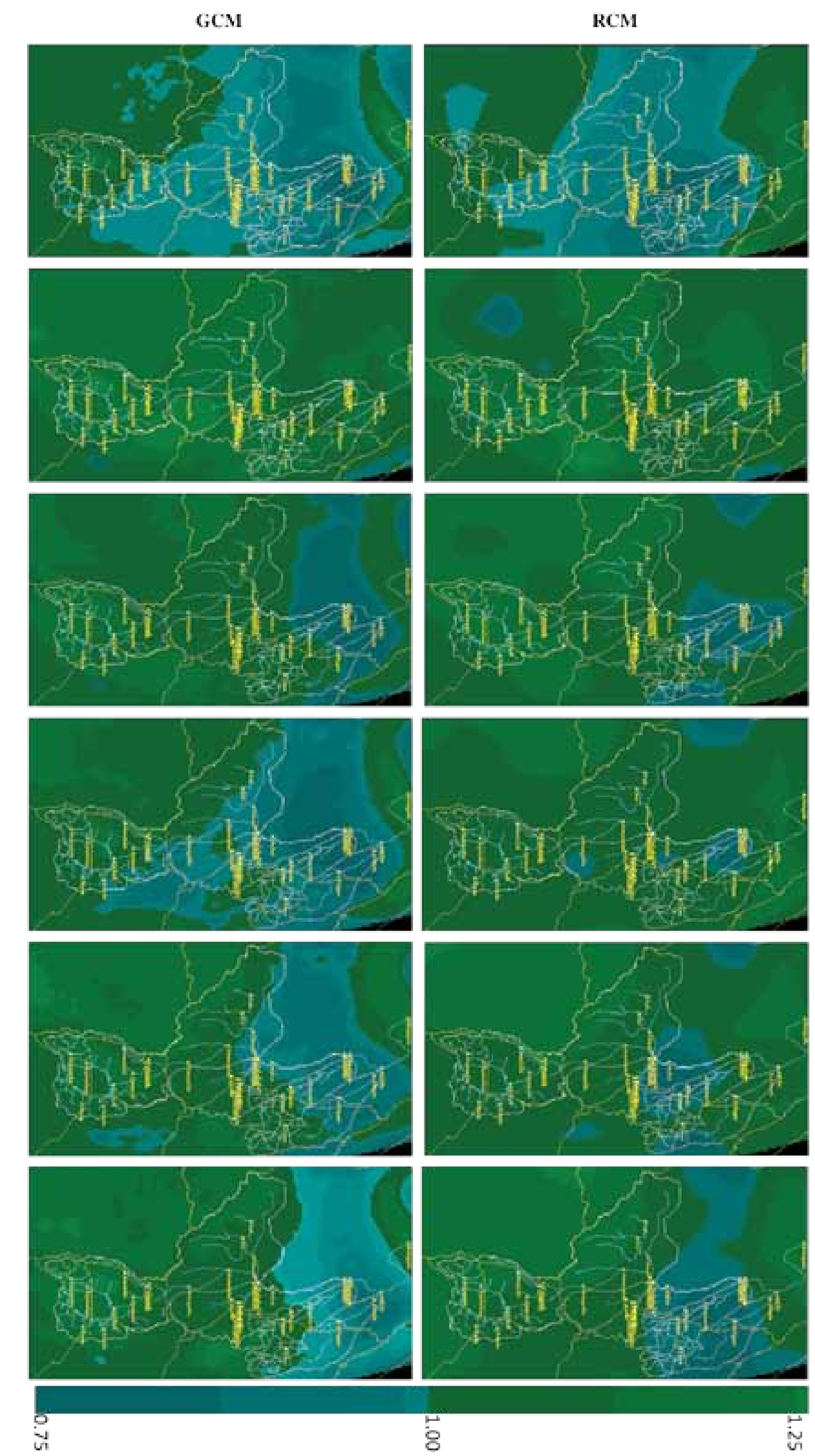


Figure 8:
PET DCFs over the Nile Basin for January from the RCM and GCM ensembles (Inte polated to the NFS resolution of 20km)

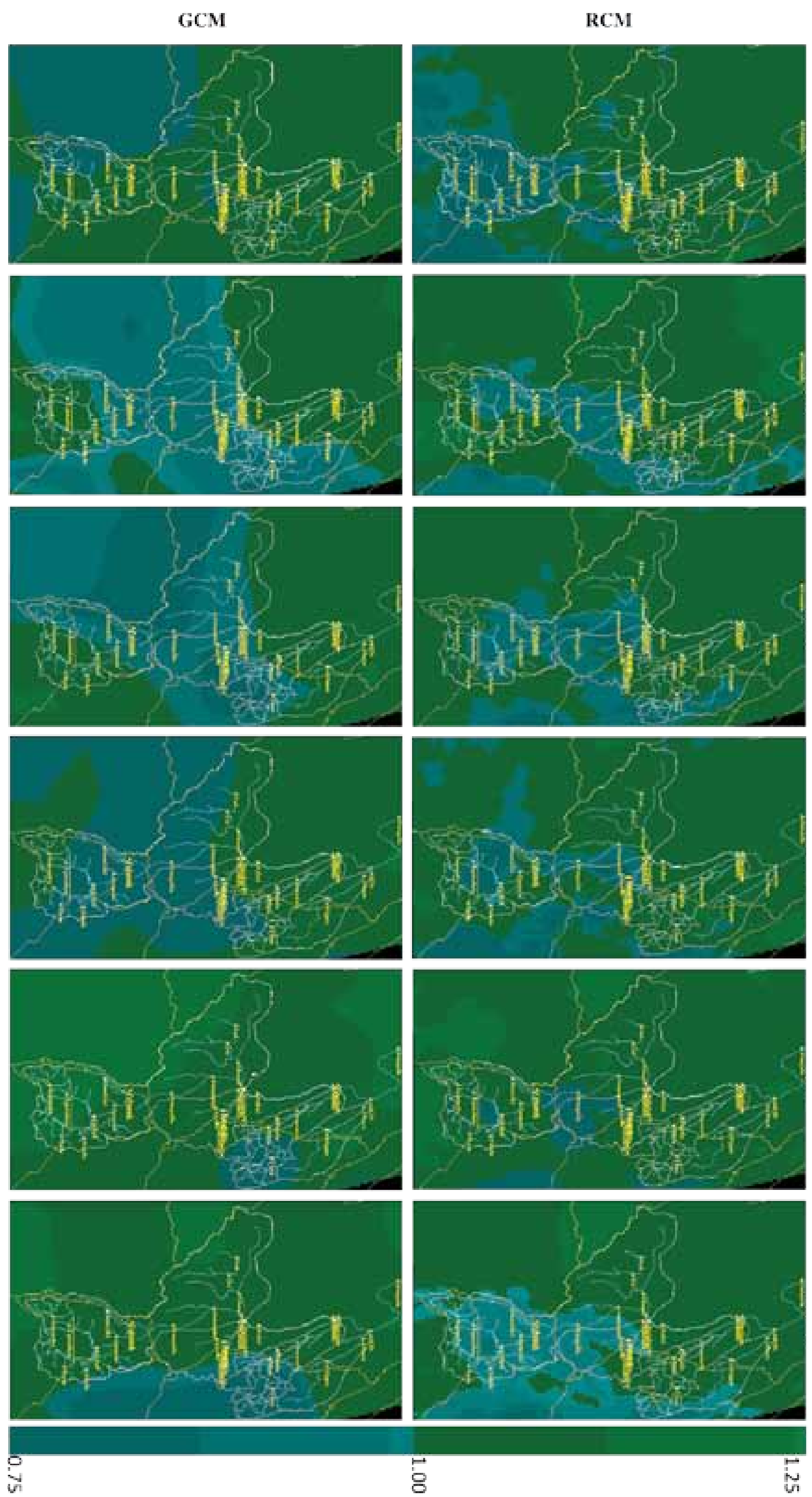


Figure 9:
PET DCFs over the Nile Basin for August from the RCM and GCM ensembles (Interpolated to the NFS resolution of 20km

3.4.4 Discharges

For the RCM ensemble, changes in rainfall and PET are generally modest, and therefore the changes in flows are generally modest as well, in comparison with the results of previous studies. However, the small changes in rainfall are amplified for the Blue Nile and the Atbara basins (Figure 10). For the Blue Nile, 4 members of the ensemble predict increases of up to 29% (3s) in the annual flow, while 2 of the ensemble members report reduction of up to 6% (1s) with a flattening of the peak. For the Atbara, all ensemble members predict increases ranging between 2% (s6) and 83% (3s). It should be noted the NFS underestimates the flow of the Atbara for the baseline period by about 13%, thus the changes may be underestimated. The NFS may need some calibration to overcome this problem. The Atbara is more sensitive than the Blue Nile as it has a more arid climate which resulted in a near-triangular shape of the hydrograph with a long dry period when the river has zero flow for most years. For both the Blue Nile and the Atbara sub-basins, changes occur during the period July – October where most of the flow occurs in response to the changes in rainfall. The GCM ensemble shows much larger changes with peak shifts that are correlated to changes in rainfall patterns (see Figure 5 above).

For the White Nile, the NFS overestimates the flow at Malakal especially at the peak which is also predicted earlier (September instead of October/November). Thus, the NFS needs improvement in modeling this complex region which includes several lakes and swamps. Considering only the changes between the baseline and the ensemble members, changes projected by the RCM are generally small (between -12% to +10% for the annual total). The ensemble members disagree on the direction of the change as 4 members predict reductions while 2 predict increases. The projected increase of PET over the Sudd by most ensemble members counterbalances the projected increases in rainfall for some members. As the case for the Blue Nile and the Atbara, the GCM ensemble shows a much larger range for changes where all changes are positive and range between 157% and 450% which correspond to the large increases in rainfall (see Figure 5 above). These changes need to be verified as the effect of downscaling is not expected to have such an order of magnitude.

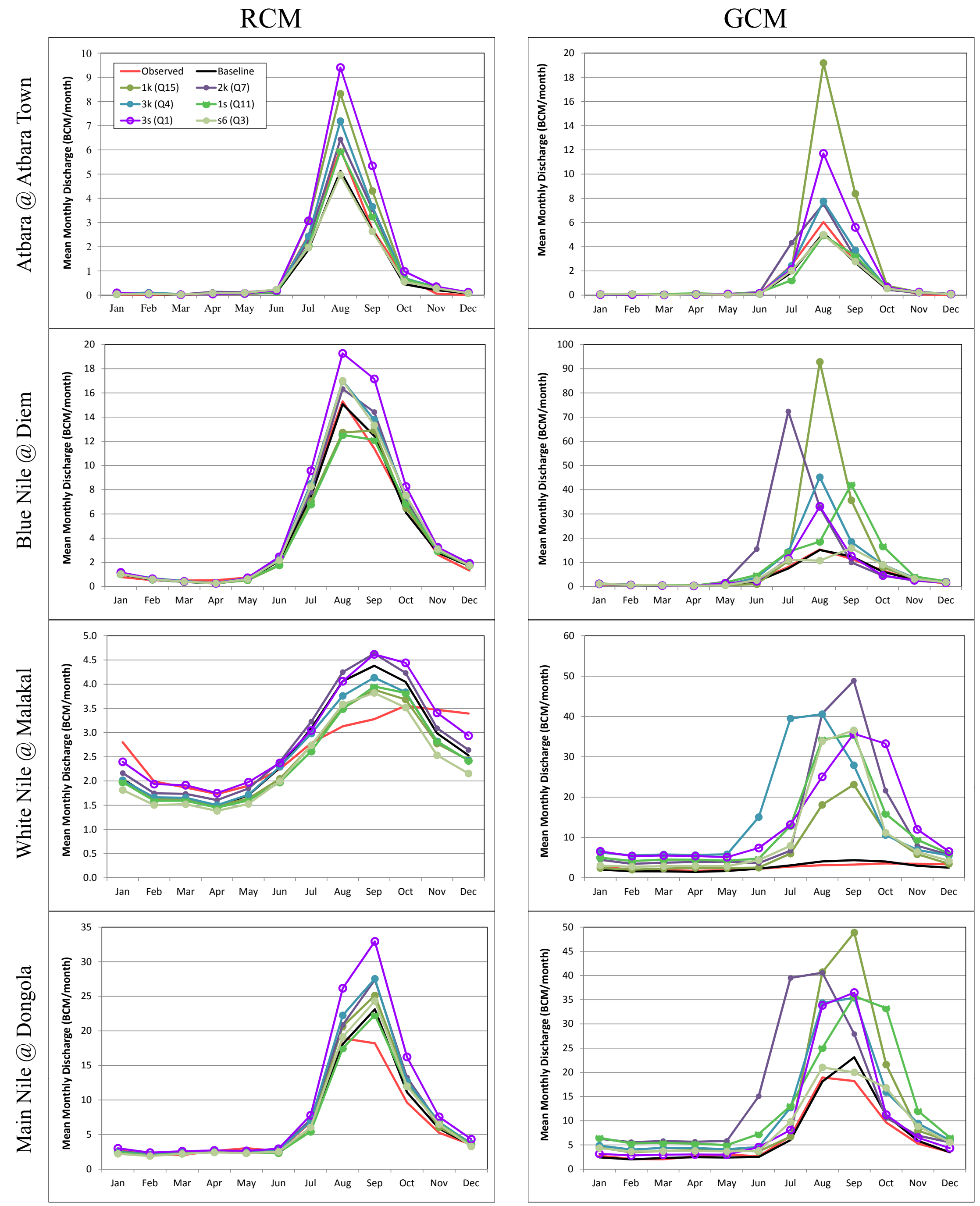


Figure 10:
Seasonal Flow Changes at Key Nile Stations from the RCM and GCM Ensembles

For Dongola, the NFS overestimates the flows for the second half of the year (August – December). Looking at the relative values of change from the RCM ensemble, the future simulations show increases in the annual total flow for 5 members between 4-36% while the last ensemble member (1s) shows almost no change in the mean annual total (0.5% reduction). The GCM based ensemble shows a much wider range with increases coming from all three sub-basins (28% to 114%) and different shift in the peak for the different members.

3.5 Discussion and Conclusions

The available water resources in the Nile Basin are under immense pressure from rapidly growing populations and demand for water in the region.Climate change adds more pressure on the current stressed situation. Therefore improved knowledge concerning the extent to which potential impacts of climate change will exacerbate this situation is important for decision-makers.

The UK Met Office PRECIS regional climate model was configured for a large window covering the Nile basin and the sources of moisture feeding the region. Thus, the boundaries of RCM extend far beyond the River Nile Basin and therefore the results obtained are applicable to other parts of the region as well. PRECIS was driven by an ensemble of 6 GCM experiments selected from a larger set of 17 HadCM3 ensemble members produced though perturbation of the unresolved physics for the QUMP project. The performance of the seventeen GCM ensemble members was assessed against 4 criteria; their ability to represent accurately (1) precipitation across East Africa, (2) precipitation across West Africa, (3) the Indian monsoon and 4) temperature over the Nile Basin. The 6 GCM ensemble members were selected to obtain a good representation of the variability with just a few ensemble members. The purpose for that is to reduce the number of RCM ensemble members to reduce the computational resources required to run these simulations. The NFS basin-wide hydrological model was then used to assess changes in flows of the Nile at important stations on the outlets of the Blue Nile, the Atbara, White Nile, and the main Nile at Dongola based on the climate signal obtained from the RCM in terms of delta change factors (DCFs). In addition, the original output of the same 6 QUMP members was used to calculate DCFs at the coarser resolution on the GCM.
The results indicated that the RCM ensemble has a smaller range of uncertainty compared to previous studies with modest changes in rainfall and PET. The GCM ensemble showed a much wider range than obtained from the RCM and what was reported in previous studies. The resulting changes in flows as projected by the RCM ranged between -6% to 29% for the Blue Nile at Diem and -12% to +10% for the White Nile at Malakal. Larger and positive changes were reported for the Atbara sub-basin. The resultant changes for the main Nile at Dongola, just upstream of Lake Nasser, shows a positive signal between -0.5% and 36%. The GCM based results (i.e. without downscaling) showed much larger changes in rainfall and flow with shifts in peak times at the different locations. The patterns of change for temperature were broadly similar between the GCM and RCM ensembles but the rainfall patters were less consistent and this resulted in large ranges that have been reflected in even larger changes for flows.

The joint use of a selected ensemble of GCM runs downscaled using an RCM and a hydrological model represents an affordable and practical approach for climate change impact assessments that also provides an estimate of the confidence level associated with the predictions. Without downscaling, GCM results have a much wider range of uncertainty. This emphasizes the need to downscale the results before being used in climate impact studies. Downscaling does not only provide finer details for change patterns but also reduces the range of uncertainty that is mainly caused by the coarse resolution of the GCM.

CHAPTER 4

IMPROVING THE ESTIMATION OF SEA LEVEL RISE FLOODING IMPACTS ON THE NILE DELTA USING A FLOW ROUTING MODEL

IMPROVING THE ESTIMATION OF SEA LEVEL RISE FLOODING IMPACTS ON THE NILE DELTA USING A FLOW ROUTING MODEL

4.1 Introduction

The Nile Delta is the delta formed in Northern Egypt (Lower Egypt) where the Nile River spreads out and drains into the Mediterranean Sea. It is one of the world's largest river deltas—from Alexandria in the west to Port Said in the east, it covers some 240 km of Mediterranean coastline—and is a rich agricultural region (Wikipedia). About half of Egypt's population lives in the Nile Delta region. Population density in the delta averages 1,000 persons/km² or more (Wikipedia). It is one of the most heavily populated and intensely cultivated areas in the world. This makes it extremely vulnerable to impacts of climate change and sea level rise. In particular, sea level rise could destroy or weaken the protection provided by sea defenses and sand dunes along the Mediterranean coast. This eventually could lead to severe flooding, loss of live and economic damages.
Given the importance of the Nile Delta, a number of studies looked at these potential damages to estimate the consequences of sea level rise on the Egyptian livelihoods and economy. In general, these studies have used simplified analysis methodologies to achieve this goal such as the use of GIS techniques to estimate the flooded areas in the Nile Delta. These GIS techniques have shortcomings and could lead to an overestimation of the sea level impacts on the Nile Delta due to flooding.

4.2 Objective

The main objective of this Chapter is to compare the estimation of the flooded areas due to the anticipated sea level rise using GIS and flow modelling techniques. Within this study, flow modelling techniques will be used – for the first time in Egypt - to estimate the flooded areas in the Delta and assess their capabilities to overcome shortcomings of the GIS techniques and improve the estimation of the sea level rise impacts in terms of the area and location. Therefore, more accurately estimate the social and economic impacts.

4.3 Chapter structure

This Chapter comprises the following sections:
Section 1 gives an introduction to study, its objectives and the Chapter structure.
Section 2 gives a presentation of the study area.
Section 3 describes the methodologies that will be used within this study.
Section 4 presents the results of the study
Section 5 concludes the Chapter with a number of conclusions and recommendations that are based on the study results.
Section 6 shows a list of references used or identified during this study.

4.4 Study area

The Nile Delta is located in the middle part of the Northern coast line in Egypt along the Mediterranean, between Alexandria in the west and Port-Said in the east with a total length of approximately 240 km (See Figure 110). Two promontories - Rosetta and Damietta - and three brackish lakes connected to the sea - Idku, Al-Burullus, and Al-Manzalla - exist along the shoreline of the study area.

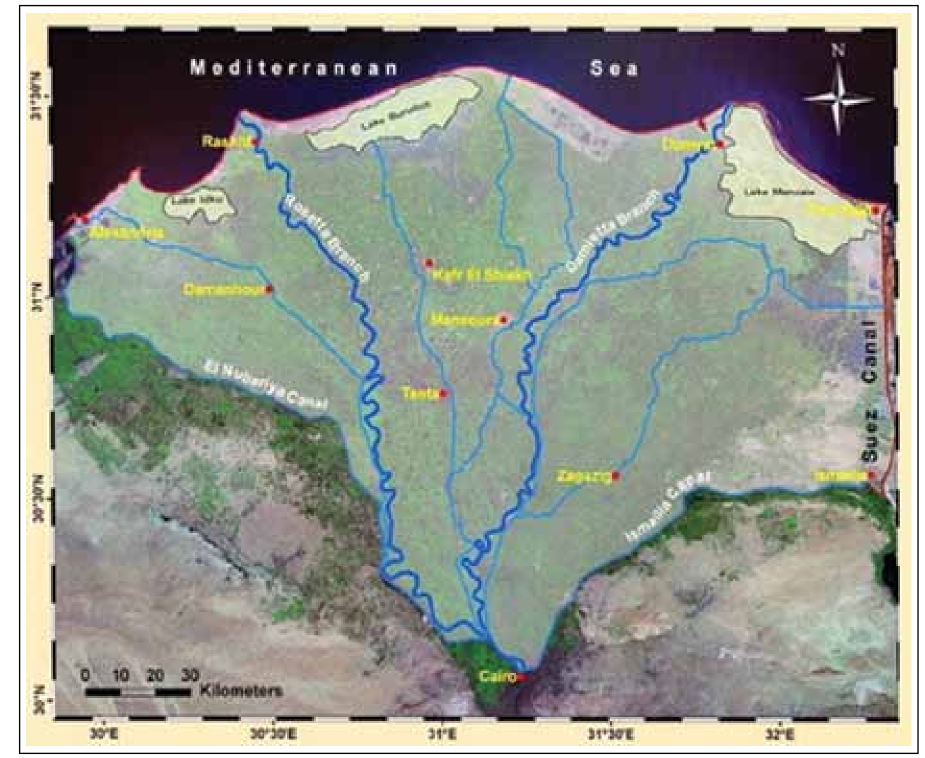


Figure 11: The Nile Delta (Sherif et al, 2012)".

The coastal area of the Nile Delta is subjected to severe coastal erosion, even without accelerated sea level rise. Some parts along the Nile Delta coast have been protected by hard structures such as the city of Alexandria and Rosetta as well as artificial nourishment that have been applied at some locations such as RasElbar (CoRI, 2008).
The population density in the Nile Delta is 1,000 persons/km² or more (Wikipedia). This is likely to increase given that the current population growth rate is about 2 percent per year in Egypt.

4.5 Methodology

To estimate the damages due to flooding resulting from sea level rise, the extent of flooding has to be established first. The flood extents can be determined using a number of techniques that include - but are not limited to - GIS and flow modelling. The two techniques have their own strengths and weaknesses. Depending on the application under investigation, a choice is made balancing the application goals, the strengths of the method and the available resources. For example, to assess the impacts of climate change at the global scale the GIS techniques are more suitable as the flow modelling techniques would need extensive human and computing resources to achieve the goal. Alternatively, at a local scale where a higher accuracy and more details are needed the flow modelling techniques are more appropriate.
This section gives a description of the GIS and flow modelling techniques showing the advantages and disadvantages of each technique and also shows the specific techniques that will be used within this study.

4.5.1 GIS techniques

The GIS techniques have been frequently used to estimate the sea level rise impacts on global and local scales. Examples of these are Nicholls et al. (1999), Nicholls (2002) and (2004), and Nicholls and Tol (2006) who examined the potential impacts of global sea level rise on coastal flooding. Weiss et al (2011) also mapped susceptible areas globally and Dasgupta et al. (2007) reported the impacts of sea level rises on 84 developing counties (Li et al, 2009).
The slicing technique is the simplest GIS technique that can be used to determine the flood extent. In this technique a flood water level is projected over the ground elevation and all areas below that water level is considered as flooded (Figure 12a). The slicing method is improved using the GIS connectivity and neighborhood functions to remove misclassified areas as shown in Figure 12b.

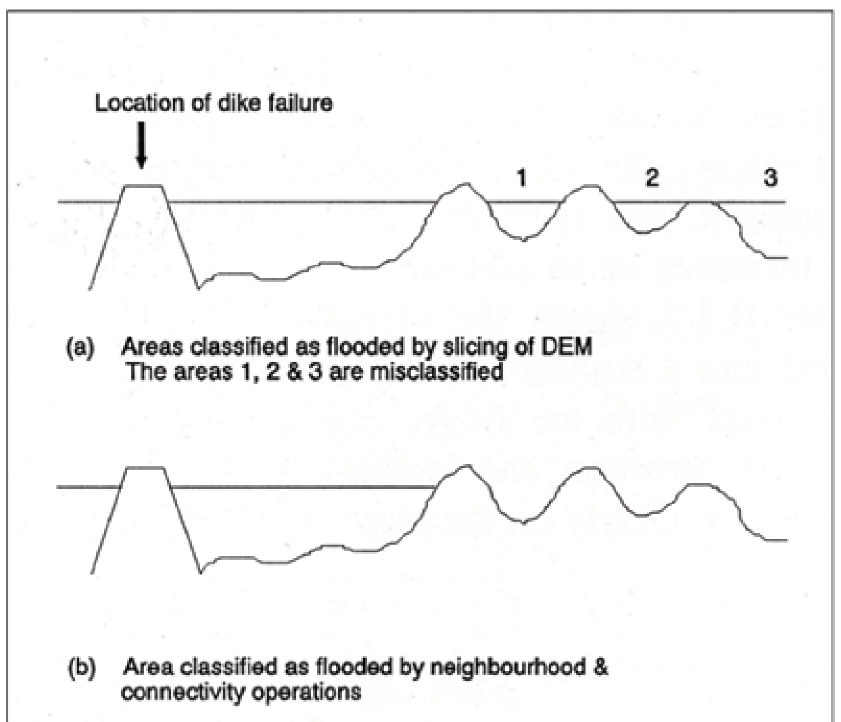


Figure 12: GIS techniques

Advantages
The main advantages of the GIS techniques are that they are simple to set up and quick to get the results which make them very attractive specially when determining flood extents on global scale.

Disadvantages
A potential problem with the GIS techniques is that no flood maintains a constant elevation all the time (i.e. projected water level). Therefore their estimation of the flood extents is always prone to overestimation which leads to inaccurate calculations of the impacts of sea level rise.

Selected technique for this study
The method that is used within this study is implemented as the following steps in a GIS raster analysis framework:
1. Select the Digital Elevation Model (DEM) cells with an elevation below a projected sea level rise.
2. Select the regions that are connected to the source of water.
3. Identify contiguous regions from the selected cells in Step 1.
4. Remove misclassified regions.
5. Remove water body areas.

4.5.2 Flow modeling techniques

There is a number of modeling packages that could be used to estimate the flood extent due to see level rise. These include:
TELEMAC 2D: a system developed to simulate physical processes associated with rivers, estuaries and coastal waters. It is based on a finite element technique applied to unstructured triangular grid, allowing realistic representations of complicated coastlines and bathymetries.
TUFLOW: is a computational engine that provides two-dimensional (2D) and one- dimensional (1D) solutions of the free-surface flow equations to simulate flood and tidal wave propagation. It is specifically beneficial where the hydrodynamic behaviour in coastal waters, estuaries, rivers, floodplains and urban drainage environments have complex 2D flow patterns that would be difficult to represent using traditional 1D network models.
MDSF LISFLOOD FP: a quasi-2D general tool for simulating fluvial or coastal flood spreading. The model assumes that flood spreading over low-lying topography is a function of gravity, friction and topography.
ISIS Flow: a 1D tool used for modeling steady and unsteady flows in networks of open channels and flood plains. Free surface flow is represented by the Saint Venant equations for unsteady flow in open channels.

Advantages
The main advantage of the flow modeling techniques is that they simulate the actual physical process to estimate the flood extents conserving the volume of water and momentum. Therefore, it is very unlikely that an excessive overestimation of flood extent would occur.

Disadvantages
Contrary to GIS techniques, the flow modeling techniques require more computing recourses that increase exponentially with the increase of the size of the study area.
Selected flow modeling technique for this study
A recent study by the Environment Agency in the UK (2004) involved an investigation of the most appropriate modeling approaches to estimate the flood extents in the Thames estuary (See Figure 13). The 4 above mentioned models were all compared within this study.

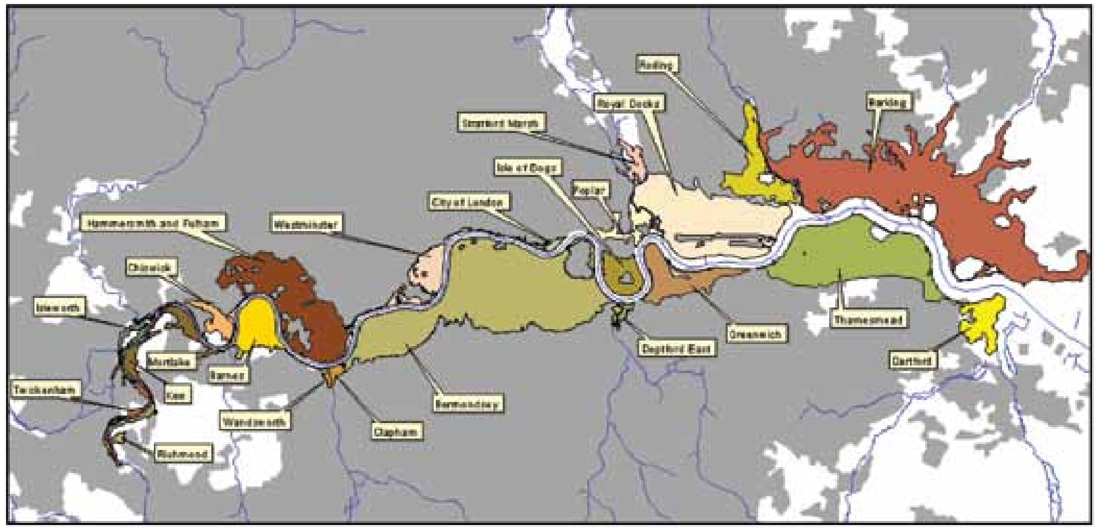


Figure 13: Thames estuary

The study concluded that the most appropriate modeling approach is the TUFLOW model (Syme, 2001). Based upon that, the TUFLOW model was used in this study at a grid size of 90 m.

4.5.3 Comparison criteria

It is important to specify the comparison criteria between the two techniques that are used within this study. It is also essential that the criteria can be easily measured. Thus the following two criteria have been selected for the purpose of the comparison:

- Area flooded in (Km2)
- Location of the area flooded (visually compared)

4.6 Results

Various runs have been undertaken using the GIS and flow modeling techniques. The Shuttle Radar Topography Mission (SRTM) elevation data was used to represent to ground elevation in the delta. The SRTM resolution is 90 m. The elevation data was not modified at the coastal defenses level assuming that they have deteriorated and do not offer enough protection. This was assumed to present the worst case scenario.

As this paper focuses on the assessment of the GIS and flow modeling techniques, a one meter increase in sea level rise was assumed for the purpose of comparison. In the next sections, the results of the runs are presented.

4.6.1 GIS results

The steps described in section 0 have been undertaken to estimate the extent of a sea level rise of 1 meter. Figure 14 shows the results after undertaking step 1. It is clear that the extent is overestimated as there areas that are not connected to sea yet still flooded.

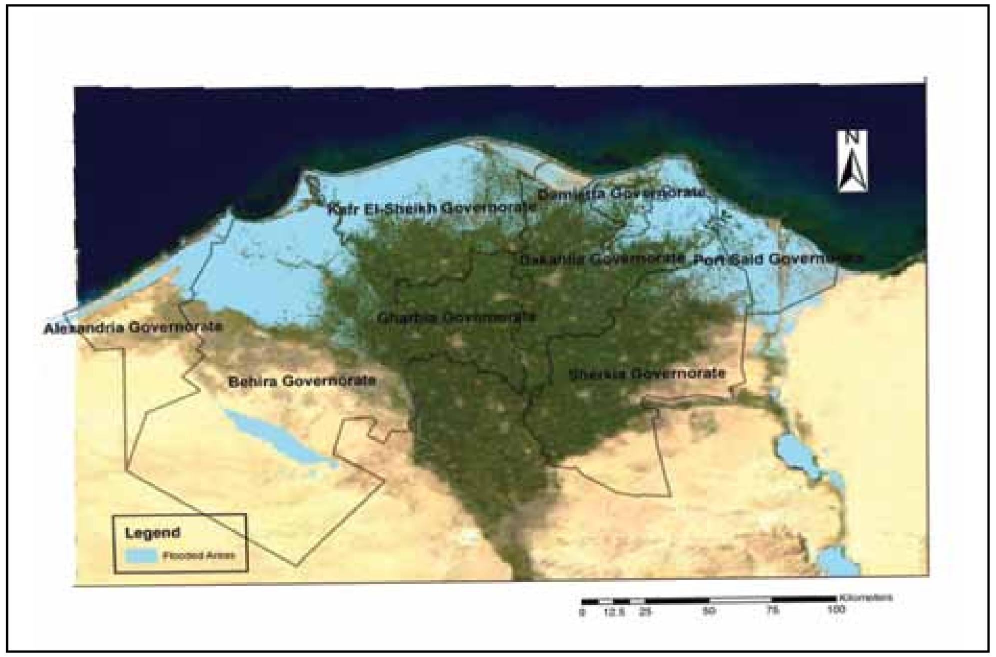


Figure 14: GIS results of step 1

Steps 2, 3 and 4 were therefore undertaken to correct this. A neighborhood function in GIS was used to remove noncontiguous flooded areas from the map. Figure 15 show the results of steps 2, 3 and 4 in which all of the noncontiguous flooded areas was removed from the map. This is quite clear in the Behira governorate where the flooded area in the south was removed. Although steps 2, 3 and 4 shows a significant improvement over step1, there were still other areas that are not going to be flooded along the Nile and Suez canal due to the existence of hydraulic structures along the water way. These had to be removed manually as shown in Figure 16

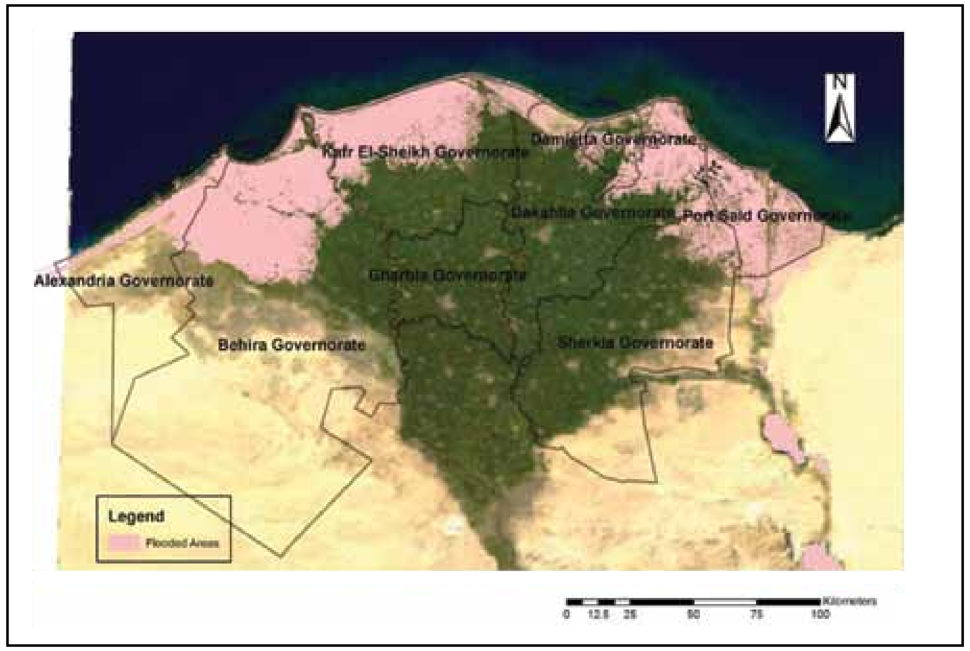


Figure 15: GIS results of step 2, 3 and 4

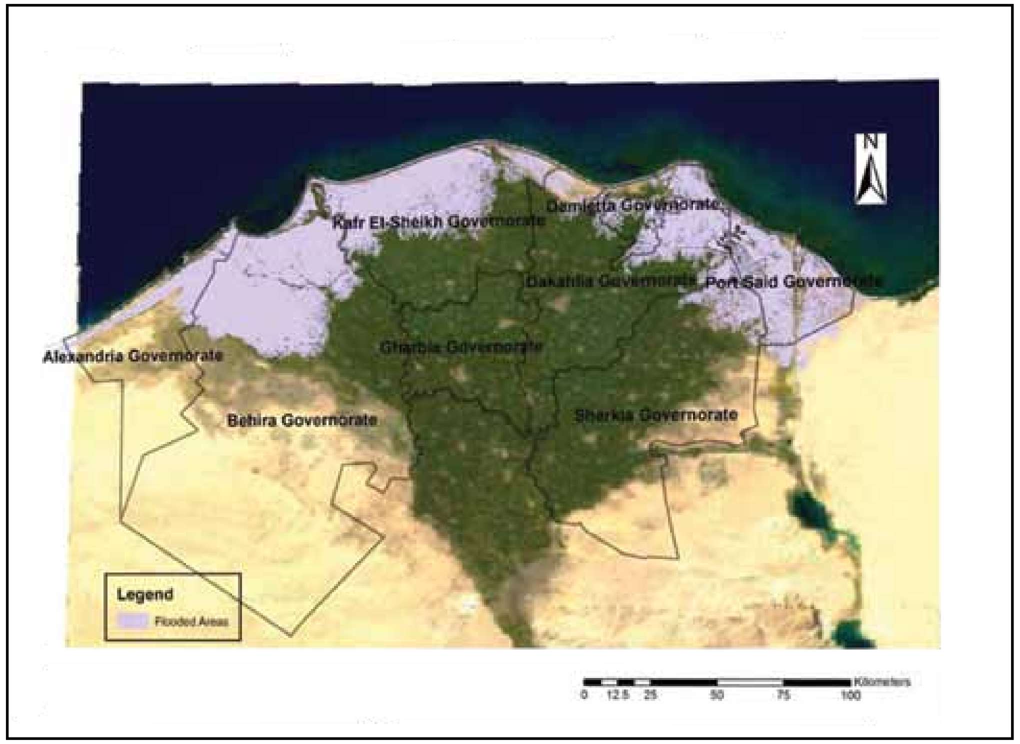


Figure 16: GIS results of the manual step

Table 3 shows the extent of flooding of the previous steps and step 5 in which the water body area were removed. The table shows clearly that the flooded areas were overestimated by 30-60 percent. The shows the importance of undertaking step 2-5 when using GIS techniques.

Table 3: Flooded area using GIS techniques

GIS step(s)	Flooded Area (km2)	% over estimation (compared to Step 5)
1	8711	60
2, 3 and 4	7551	39
Manua1	7111	31
Step 5	5436	----

4.6.2 Flow modeling results

The TUFLOW model was used to estimate the flood extents due to sea level rise in the Nile Delta. A triangular boundary condition as shown in Figure 17 was used to simulate the 1.0 m sea level rise. Wave overtopping was assumed to be insignificant compared to the overflowing of the sea water level and therefore was not included in the modelling. The simulation time was assumed to be 24 hours.

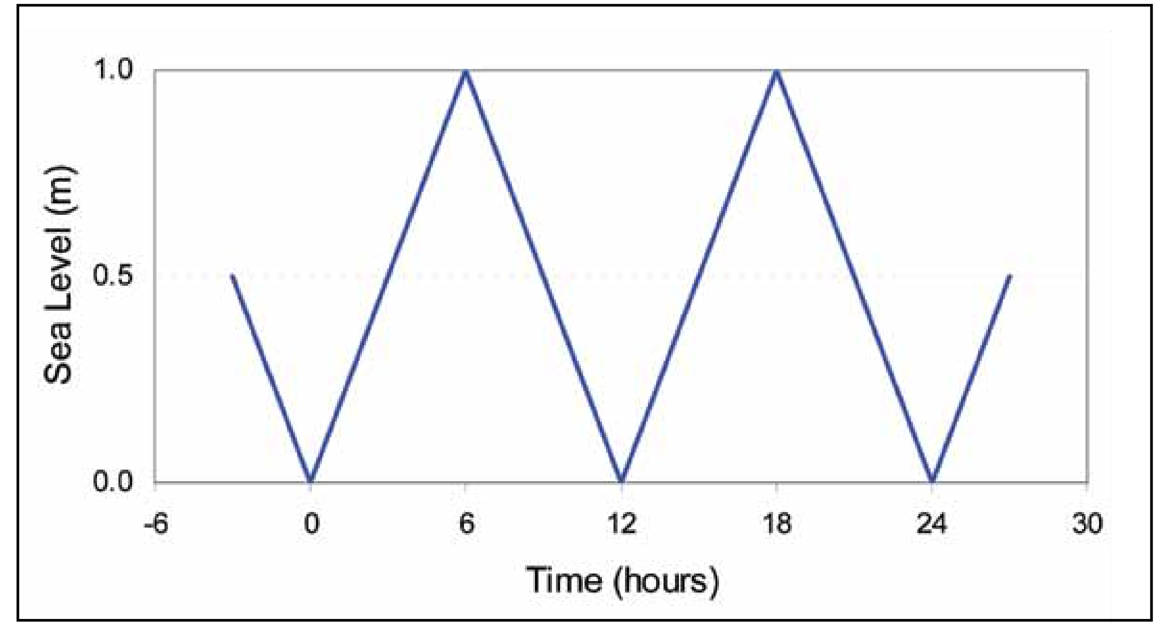


Figure 17: TUFLOW sea boundary condition

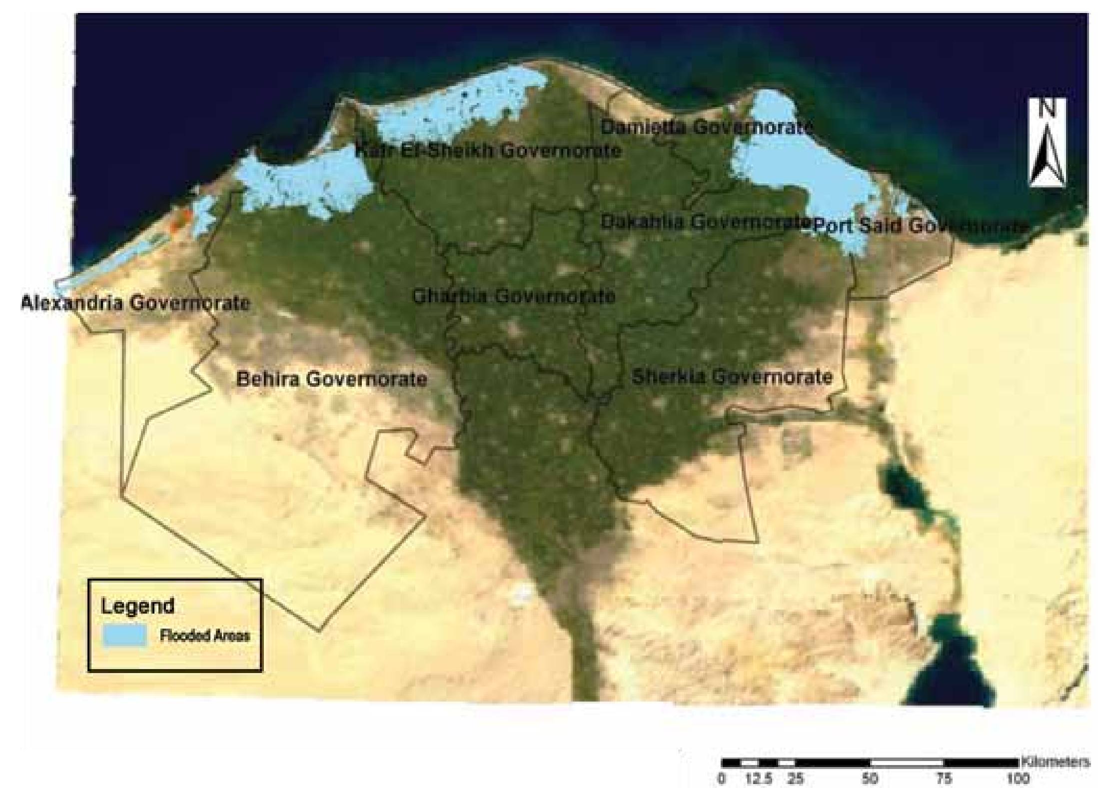


Figure 18 shows the flood extents estimated by TUFLOW including water body areas

The results of the TUFLOW model show a significant reduction in the estimated flood extent. The area flooded was estimated to be 2841 km2 including water body areas and 1166 km2 excluding

4.6.3 Comparison

The quantitative and visual comparison between the results of the GIS and flow modeling techniques show that the best estimate of the GIS technique used in this study overestimates the flood extents. This is approximately 4.7 times more than what is estimated by the used flow modeling technique. This has a substantial implication when estimating damages and loss of life in the flooded areas. This raises questions on the accuracy of the studies that have been using the GIS techniques to estimate the potential damages due to sea level rise as these damages will be overestimated based upon the GIS techniques results.
In terms of the location of flooded areas, the results show that a small area (approximately 2.5 km2) was only flooded using the flow modeling technique. This shows that for the delta region, the GIS techniques were able to detect the correct flow routes although the flood extents were overestimated.

4.7 Conclusions and Recommendations

Based upon the results of this study, the following conclusions and recommendations can be made.

4.7.1 Conclusions

• The GIS and flow modeling techniques are useful tools in assessing the impacts of sea level rise

• The selection of which technique to be used depends upon the study area under investigation, the required accuracy and the available man and computational power.

• The basic projection of sea level rise over ground elevation significantly overestimates the flooding extent. In this study, the overestimation was approximately 60 %

• Undertaking basic GIS neighborhood functions and manual removal of unlikely flooded areas improves the GIS technique results. In this study the improvement was approximately 30 %.

• Using the flow modeling techniques has further improved the accuracy of the estimation of the flooding extents. This was due to the conservation of mass and momentum that is a part of the equations used in this technique. In this study, the improvement was approximately 470 %.

• For the Nile Delta, the GIS and flow modeling techniques detected the same flow routes of flooding.

4.7.2 Recommendations

• To accurately estimate the flooding impacts of sea level rise, flow modeling techniques are recommended as their estimate of flood extents is more accurate than the GIS techniques.

• In the absence of flow modeling techniques, GIS techniques can still be used provided the steps described in this chapter are followed.

• The limited accuracy of the ground elevation data in the Nile Delta remains an issue that needs resolving to further improve the accuracy of the estimation of the flooding impacts of sea level rise.

• The damages estimated in the Nile Delta by previous studies that used GIS techniques should be used with caution as they are likely to be significantly conservative.

• The analysis undertaken within this study should be expanded to cover a number sea level scenario and their impacts on people, agriculture land, and properties in the Nile Delta.

CHAPTER 5

AN ASSESSMENT OF THE POTENTIAL ECONOMIC AND SOCIAL IMPACT ON WATER AND COASTAL RESOURCES

(COSTS OF CLIMATE CHANGE ON EGYPT)

AN ASSESSMENT OF THE POTENTIAL ECONOMIC AND SOCIAL IMPACT ON WATER AND COASTAL RESOURCES (COSTS OF CLIMATE CHANGE ON EGYPT)

Egypt is highly dependent on shared water sources and on other nations to meet 95 percent of its water needs. The Nile River Basin runs through ten riparian states and has been one of the most disputed basins in the world. The 1959 Nile Waters Agreement between Egypt and Sudan allocated about 66 percent of Nile River waters to Egypt, 22 percent to Sudan and 10percent to losses. As upstream countries required more water, the potential for conflict increased. This situation served as the basis for the Nile Basin Initiative to try to facilitate cooperation, rather than conflict, over this critical Basin.

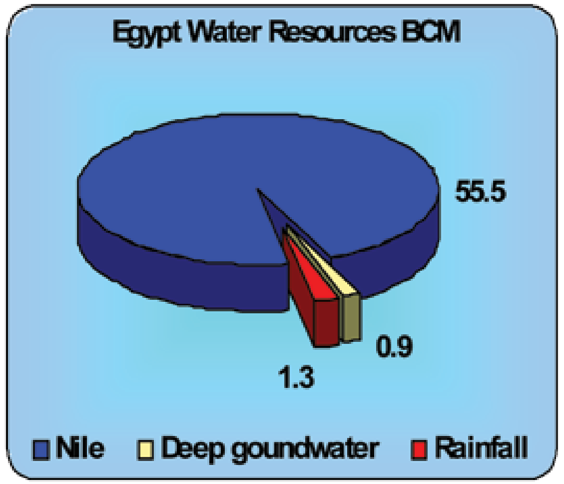


Figure 19:
Egypt's water resources

The Nile delta coast is situated along Egypt's northern boundary with the Mediterranean Sea extends for a distance of 450km from Alexandria in the west to Port Said in the east, (Figure 19). The coastline has two main promontories, which were produced by the sediment delivered by the Rossetta and Dammieta branches of the Nile River. There are two other positive features of lesser prominence (Burullus and Manzala), situated at older river outlets. This leads to a series of coastal cells on the open coast (Fanos et al., 1995).
Within the activities of the CCRMP, three studies were conducted in collaboration with the international and national consulting offices, used estimates of change in water supplies, coastal inundation, and crop yields previously published by Egyptian researchers, to estimate the potential impacts of climate change on Egypt's agriculture economy in 2030 and 2060 and the value of property that could be damaged due to sea level rise. The Remote Sensing and GIS Techniques were used to map the characteristics and land use of the coastal areas of the Nile delta. This include, human settlements (villages, towns, cities, etc.) and urban centers ;Industrial areas, if officially declared; agricultural areas; fish farming areas and main natural features such as lakes, sand dunes, and manmade establishments and infrastructure facilities such as canals, sea walls, main roads, etc. In addition a socio-economic valuation of the vulnerable land was carried out to estimate the value of human settlements, agriculture lands and other main economic activities that are vulnerable to inundation by sea level rise or sea water intrusion at the Nile delta during different IPCC scenarios with functioning and failure of natural and manmade sea defense systems. Based on the analysis and results of three studies, the following subchapters elaborate the potential impact of the predicated climate changes on the Egyptian water and coastal resources. In addition, a tentative estimate for the cost of damage, resulted from the climate changes, is also discussed.

5.1 Land Use on the Nile Delta Coastal Zone

The Nile delta coast is situated along Egypt's northern boundary with the Mediterranean Sea extends for a distance of 450km from Alexandria in the west to Port said in the east, (Figure 20). The coastline has two main promontories, which were produced by the sediment delivered by the Rossetta and Dammieta branches of the Nile River. There are two other positive features of lesser prominence (Burullus and Manzala), situated at older river outlets. This leads to a series of coastal cells on the open coast (Fanos et al., 1995).
The delta contains four lagoons connected to the sea: Mariute, Idku, Burullus, and Manzalla. These lagoons are internationally recognised overwintering grounds for migratory Paleo-arctic birds; they are furthermore important because of their endemic floral and faunal diversity and extensive fisheries resources (Mullie&Meininger, 1983; Bishai& Khalil, 1990; Ahmed &Frihy, 2000). There is a closed lake near Alexandria, Mariute Lake and another brackish lake at Port Fouad, which was formed during the construction of the Suez Canal by the fragmentation of the Manzalla lagoon.
Four channels empty into the sea, in addition to the two Nile distributaries and drains at Kitchiner and Gamasa. These no longer carry fresh water and sediments from the Nile and predominantly carry polluted agricultural runoff and industrial-municipal wastewater into lagoons and coastal waters. The three major harbors of Alexandria, new Dammieta and Port Said are also located on the coast, while the Suez-Canal ensures extensive shipping within the delta coastal area. Except near Alexandria where there are rocky shores, the otherwise uninterrupted yet sedimentologically dynamic coastline is generally composed of fine sandy beaches that are increasingly the focus of tourist activity.
The coastline is sandy in nature. The sea at the Nile delta is almost tidless and semidiurnal, however, the effects of seasonal fluctuation in sea level are so dramatic in coastal erosion. Summer swells (NNW Direction) during June, July and August cause rising of sea level up to twice the mean of sea level, which subsequently lead to accelerate the erosion in some localities particularly in the central part of the delta coast. Moreover, water level is also found to be magnified under the storm surges in winter (Hamed and El Gindy, 1988). The winter surges attack the coast with a frequency of about 14 per year, with 35 Knots wind speed and pressure lowered to 1002 mb.

A net population growth rate in Egypt of roughly 1 million people every 9 months (1.89% per annum) overshadows Egypt's growing economy and poses significant challenges both to the agricultural production sector and the environment (Factbook, World Bank, 1998). Pressures on the Nile delta system and the sustainability of its coastal resources are likely to increase substantially in the 21st Century given trends of exponential, highly concentrated population growth, the national population is 67 million at 2000 and expected to exceed 100 million by 2025 (UN, 1991).

Inland lies the Nile delta plain characterised by the Nile River and the large network of irrigation canals serving the 11,561km2 of associated fertile lands. Much of Egypt's 35,200 km2 of inhabitable and productive land (less than 4% and 1% of the country's area respectively) is closely associated with the Nile delta. This region is thus home to the majority of Egypt's population of about 50 million, with its sprawling and densely populated urban centres at Cairo, Alexandria, Damietta and Port Said. It is the focus of most of the nation's agricultural and economic activity, the livelihood of the Egyptian people thus being intimately linked to the stability and health of the delta system, (Abu Zeid and Dayem, 1991).

Many areas along the Egyptian coasts at risk from natural and man-made impacts, created by Geological, Meteorological disturbances of sea surface and human interventions to coast. These risks are of two kinds (i) short term risks associated with storms, swells, reclamation pollution, etc., and (ii) long-term risks related to climate change, sea level rise, damming the river, coastal protection measures, etc., often, it is a mixture of these two effects that most potent; There are basically two responses to such threats at Nile delta coast; natural and manmade, a gradual rise in sea level will enhance landward penetration of surges, swells and storm waves in-addition to the deficiency of sediment supply because of construction of dams, these bring a morphologic change as we have in the Nile delta reshaping during this century.

Figure (20), shows the present situation to problems face the delta coast, primary physical responses, direct and indirect effects on the changing of environmental conditions along delta coast. These effects cloud talks place at short or/and long-term scales. It should become evident that an amalgam of planning, engineering ecological, economic, informational and social skills are required to operate management of this kind. By nature, any integrated plan will vary according to the type and severity of the perceived hazard. Thus to protect against damage on the delta coast needs a different approach to that required on other Egyptian coast, where the greatest risks are from a slowly rising sea level. So, the protection management can be focused on specific at risk zones. In this case, engineering solutions are more acceptable and beneficial (at least in economic terms).

The next example is discussed the long term impact of sea level rise (1m) on the Nile delta coastal zone under 1m contour elevation. Dividing the delta coast into three cells starting from the western side of delta (Cell I) from Abu Quir to east Rossetta, then (Cell II) from east Rossetta to west Burullus at the central part of the delta and (Cell III) from west Burullus to east Dammieta at the eastern side of the delta. It is found that these cells located under 1m contour elevation with averaging distances from shoreline varies from 20km at cell (I), 31.5 km for cell (II) and 12 km for cell (III) (Stanly & Warne, 1998).

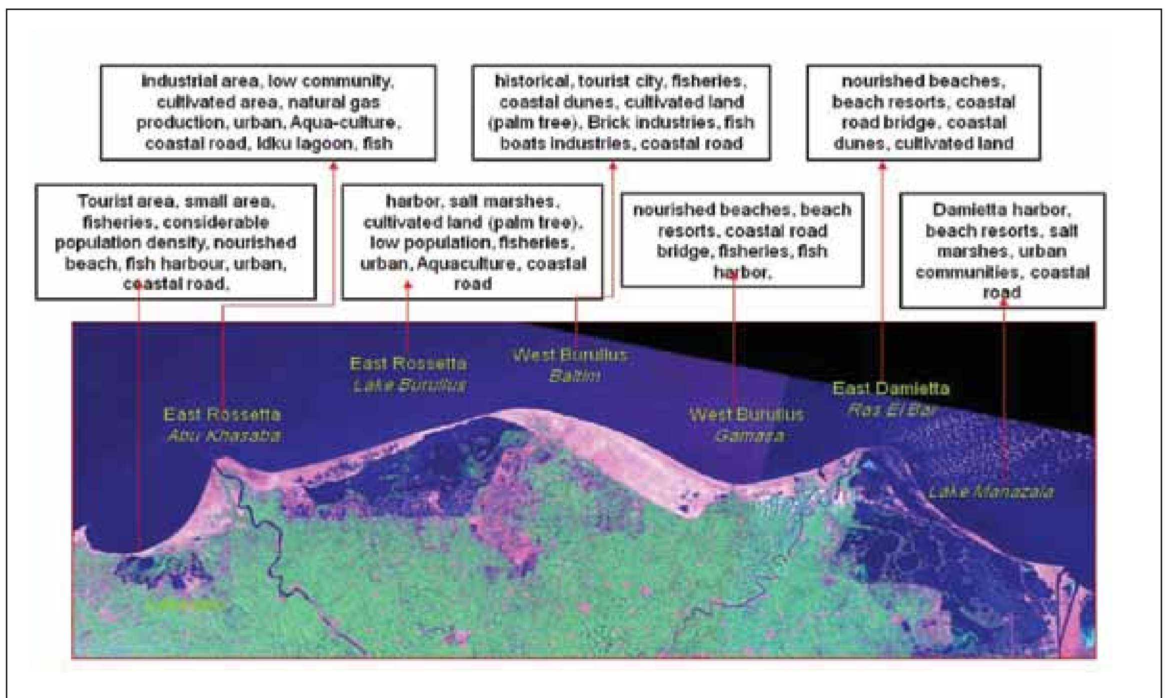


Figure 20: Main human and natural activities along the Nile delta coast

5.1.1 Eastern Zone of Nile Delta

The Abu Kir area contains important industrial and governmental activities centered on the Abu Kir Bay; among the industries are fertilizer complexes, a natural gas processing plant, an electrical generating section. There is no significant residential development at Abu Kir Bay due to the presence of Mohamed Ali Sea wall except on the western segment of the bay. The vicinity of the fishing village of Maadia is located at the inlet to Lake Idku, which is used for fishing industry. At about 13 km west of Lake Idku inlet at Maadia is the town of Idku. The population of Idku is engaged in farming and in fishing activity. Idku is not presently threatened by coastal erosion. However, maintenance of the inlet to the lake at Maadia is a matter of economic consequence to the Idku population because of the importance of fishing to the local population. At the tip of the Rossetta promontory, just north of the town of Rossetta", exists a small beachfront community. This community has suffered extensively due to erosion.

The city of Rossetta is not located directly on the Mediterranean coast, but rather on the west bank of the Nile, 10 km from the mouth. Thus the city is presently not directly threatened by coastal erosion. However there are several economic factors for the city, which are affected by the severe erosion which is taking place along the Rossetta coast. Those factors are: the effect of the loss of tourism mentioned earlier, effect upon the Rossetta fishing fleet, which suffers from a reduction of Sardine fishery, in addition, the shoaling of the river also, has eliminated the use of Rossetta as a port for ocean freight and other vessels.

Those factors were affected by coastal erosion of this particular zone, are clearly represents long-term change of available land at Rosetta. The eastern zone has a significant agricultural, industrial and aquaculture activity, on the eastern bank of the Rossetta Nile branch, is the Motobus District. (1) There are four small towns at Motobus District: Burg Meghaiyd, El-Ghezera El-Khodra, Wakf North and Wakf South, (2) Two recent small spits are being formed at the river entrance causing shoaling and subsequent navigation hazards and (3) The new Rossetta breakwater, just completed in 1990, constructed on the west and east sides to minimize beach erosion. It contains about half of the population of the district. Many industries activities are found along the eastern zone started from the west at Abu Kir paper industry, electrical industry, etc to the east of Rosetta.

5.1.2 Middle Zone of Nile Delta

This zone started from east of the Rossetta mouth is the coastal barrier forming the environs of Lake Burullus. This lake runs about 60 km and terminates at the inlet to the lake opposite the closely sited towns of El-Burg and Burullus, which together comprise the most important settlement bordering the lake. About 10 km from the inlet along the shore is the town of Baltim, in turn serviced by Baltim Beach on the Mediterranean coast. Lake Burullus area contains about 5% of the total population of the governorate where the fishing and agriculture are considered the main sources for living.

The western part of the Burullus inlet would be flooded more easily. The high-risk stretch is 1.5 km long, west of El-Burg outlet; it is low and narrow. Baltim beach is experiencing erosion, especially to the western area near the lighthouse. Erosion is also taking place along different locations of the beach. Artificial sand feeding would be the only sensible way to control the Baltim sea resort stretch.

The eastern coast of Lake Burullus extends from Baltim to Ras El- Bar with a length of 9.2 km. It takes a curved shape as it bends concavely towards the southern east to look like a Peninsula. The eastern coast is characterized by the predominance of mud over which extends massive amounts of aquatic plants. The sloping angle of the coast is between 0.5 and 2 especially at the northern edges of the eastern coast. This coast is from the moorland coasts extending 500 m inside the lake basin. The creation of these marshes was connected and developed with the circumstances prevailing in the lake and affected with the fluctuations of the water level. The marshes are affected with sand dunes near Baltim, which is the main source for the deposits forming the marshes surfaces. These deposits are characterized with its red color in some sites due to very few iron impurities. The marshes are silty-sand. They contain mainly small layers of organic matter especially in shallow zones.

The Productivity of fishing boats has been estimated. It fluctuated between a minimum (4.023 tons/boat) in 1988 and a maximum limit (8.112 tons/boat) in 1990 and dropped to 7.987 Tons/boat in 1999. It should be mentioned that the fluctuation in fish Productivity can be attributed to fluctuation in gross production, open water area and number of fishing boats operating in lake Burullus.

5.1.3 Western Zone of Nile Delta

The area from Ras El-Bar to Damietta mouth is a site for economic activities especially for the port of Damietta The port has a wide scope of economic activity. A new town development will have significant economic impacts upon this coastal region. Growth of industry and agriculture is expected as a result of the new port development as well as implications for population growth and employment. The old Damietta City lies along the Nile River, which has been affected by the shoaling of the entrance channel. Ras El Bar beach is located just east of the entrance of Damietta beach. This popular resort has declined seriously over the past 20 years due to severe erosion. Many hectares of beachfront promontory have been lost and erosion continues, in addition-shoaling is occurring in the river mouth, with adverse effect upon the fishing fleet at Damietta. From the eastern shore of the Damietta mouth of the Nile, for a distance of 50 km, a coastal barrier separates the Mediterranean from Lake Manzalla. Continual erosion has destroyed the road and a new highway, constructed some 10-km inland from shoreline.

Spatial patterns and temporal dynamics in marine populations are known to result from the coupling of processes over a range of space and time scales (Steele & Henderson, 1994). The problem of scale is thus in part one of contingent ecological understanding. Additionally, however, mismatches are often present between the scales over which ecological studies are conducted and the scales to which resultant theory or recommendations are applied for management purposes (e.g. Alexandria), (Nasr et al., 1997). Scale effects thus complicate the extrapolation of scientific management advice from better-described components to the system as a whole. Conclusions from applied ecological studies are thus now increasingly based on formal multi-scale analyses conducted on data collected with a variety of sampling platforms over a range of spatio-temporal scales.

Natural Factors

•Low-lying littoral deltaic regions are highly vulnerable to even minor changes in sea level, particularly because most deltas are actively subsiding. Moreover, predicted global warming may accelerate sea-level rise, which would have a pronounced impact on low-lying deltas all over the world. In particular, the Egyptian Nile delta coast is expected to be severely affected by sea-level rise (Stanley, 1988; El Fishawi and Fanos, 1989; Frihy, 1992; Ahmed, 1991). Sea level rise could have serious impact on the lagoon ecosystem and the fertile land that

has been reclaimed from the lagoon. Sea-level rise might affect the ecosystem of the Burullus lagoon by eroding the lake barriers that protect the lagoon from the sea and hence altering its water quality (Frihy et al, 1991).

•Coastal lakes inlets are capable of changing their cross-sectional dimensions (depth/width) quickly, migrating rapidly along the shore, and even closing completely (Leathrman, 1991). In Egypt, siltation problems of the Burullus lagoon inlets generally takes place as a result of the combination of sand transport in the long shore and cross-shore directions (Fanos et al., 1995). Siltation causes shoaling or closing the lagoon inlets resulting in navigation hazards, decreasing water flow in and out in the inlet channel, as well as negative implications on fishing activities. Keeping the inlet open is important for the fishery to keep the salinity down and to allow migratory movements.

•The sand barriers of Burullus lagoon are being subjected to severe beach erosion. This erosion is mainly due to the effect of prevailing dynamic processes of waves and currents, and the absence of the sediment supply resulted from the construction of the High Aswan Dam in 1964. This problem causes shoreline retreat of the lagoon barrier and hence reducing its function as a nature protective line from sea invasion (Orlova and Zenkovitch, 1974; Fanos et al., 1995; Ahmed et al., 2000).

•The human response to these long-term types of changes can be small-scale and tactical, rather than large scale and strategic responses, which would be move successful. A large-scale response demands considering that delta system as a whole as well as the natural subdivisions (e.g. coastal cells) which exist. Understanding these large-scale changes is fundamental to predicting the smaller scale changes that we often required as the coastal management problem. Such efforts are quite consistent with emerging ideas on large-scale coastal behaviour which recognize large-scale changes the boundary conditions for changes at smaller-scale. Further adaptation is often seemed as implementation of specific measures (e.g. building seawall). (Klein et al., 1999) argued that adaptation is a more complex process involving problem recognition, planning and design, implementation and evaluation. The plan proposed here is fundamental to all these steps, including recognizing and understands the problem; the first step to adaptation it has been argued that the minimum response to the threat of climate change is monitoring (Townend, et al., 1996; Capobianco, et al., 1999).

5.2 Valuation of Vulnerable Land to Sea Level Rise at the Nile Delta

For the area of five governorates namely; Damietta, Dakahlyia, Kafr El Sheikh, Behaira and Alexandria a projection of the population size of the inundated area at locality level were undertaken. Those rural governorates are subdivided into smaller administrative sections called Markaz and consequently each Markaz, which should have one urban settlement at least, is subdivided into localities. Each of these localities includes a number of main and satellite villages. Meanwhile, urban governorates are divided into districts or Hai. Each district or Hai is subdivided into a number of sections, which are subdivided into localities or Sheyakha. The six governorates of North Nile Delta consist of 66 districts, which are further subdivided into 1342 localities (Figure21). On the basis of the current demographic trends and their development in the future, two scenarios were developed to estimate the population size of various localities within the study area until 2030 and 2060. The scenario A (Pessimistic Scenario) assumes that current population growth would continue in the future. Therefore, various localities will experience high population growth. While, scenario B (Optimistic Scenario) assumes moderate population growth, with considerable decrease in fertility rate is expected to be prevailed in the study area. Therefore, various localities will experience moderate population growth.

An identification of the affected localities within the six governorates has been done based on the illustration of spatial extent of area vulnerable to SLR in 2025, 2050, 2075 and 2100. An adaption of the years 2030 and 2060 according to three different scenarios were used to fit with the modeling results. The scenarios are based on the expected impact of SLR on the coastal zone according to tide gauges measurements carried out by CoRI over the last three decades, (CoRI scenario assuming same increase rate of air temperature till 2100), the expected impact of SLR according to IPCC B1 scenario, and the expected impact of SLR according to IPCC A1F1 scenario.

A geo database for the inundated area was developed included mainly six feature classes illustrating the localities vulnerable to inundation due to SLR according to the three scenarios at two different point of time; 2030 and 2060. The developed geodatabase was employed to quantify roughly the magnitude of inundation impacts in the vulnerable area according to different three scenarios (Figures 22, 23 and 24).

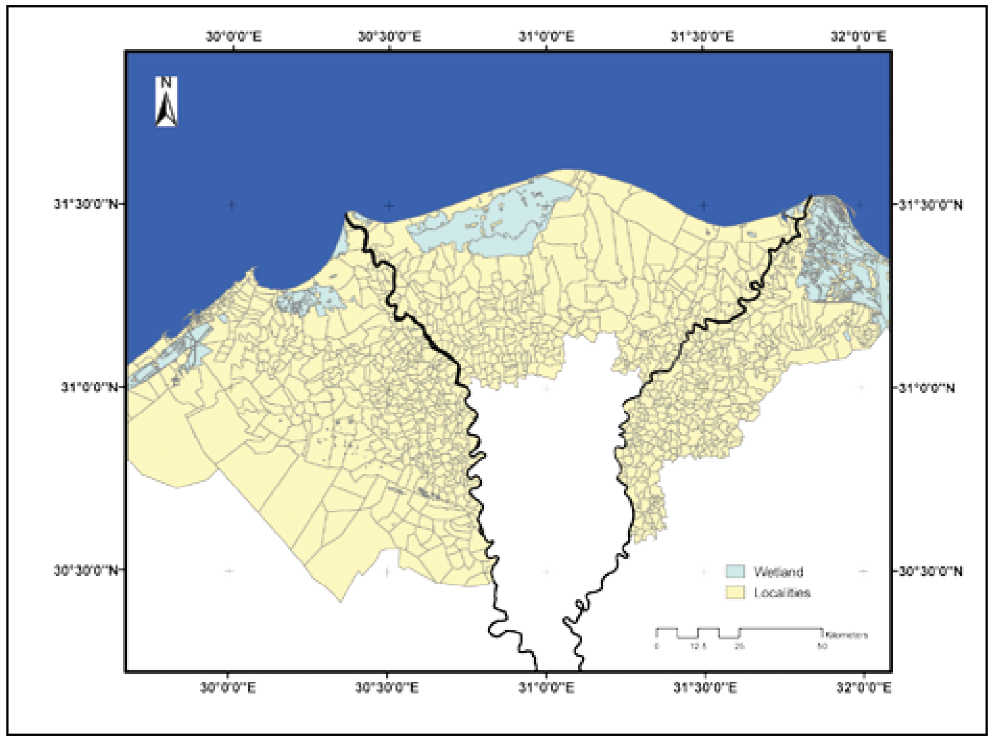


Figure 21: Administrative subdivisions of the impacted area

The Three scenarios differed widely in terms of spatial extent and consequently the no of localities will be affected by inundation. Meanwhile, no significant difference was noticed either in no of localities or inundated area between 2030 and 2060 (Table 4).

Table 4: No of localities and inundated area up to 2030 and 2060 according to different scenarios

Scenarios	2030		2060	
	No. of localities	Area (KM2)	No. of localities	Area (KM2)
CoRI	73	3408.5	81	3466.4
B1	79	3600.0	97	3661.5
A1FI	82	3611.4	254	6945.9

Similarly, the number of housing units in the area vulnerable to inundation varied widely among various scenarios (Table 5).

Table 5: Current number of housing units in the area vulnerable to inundation

Scenario	No. of housing units	
	2030	2060
CoRI	260505	273118
B1	276748	338178
A1FI	281905	1110793

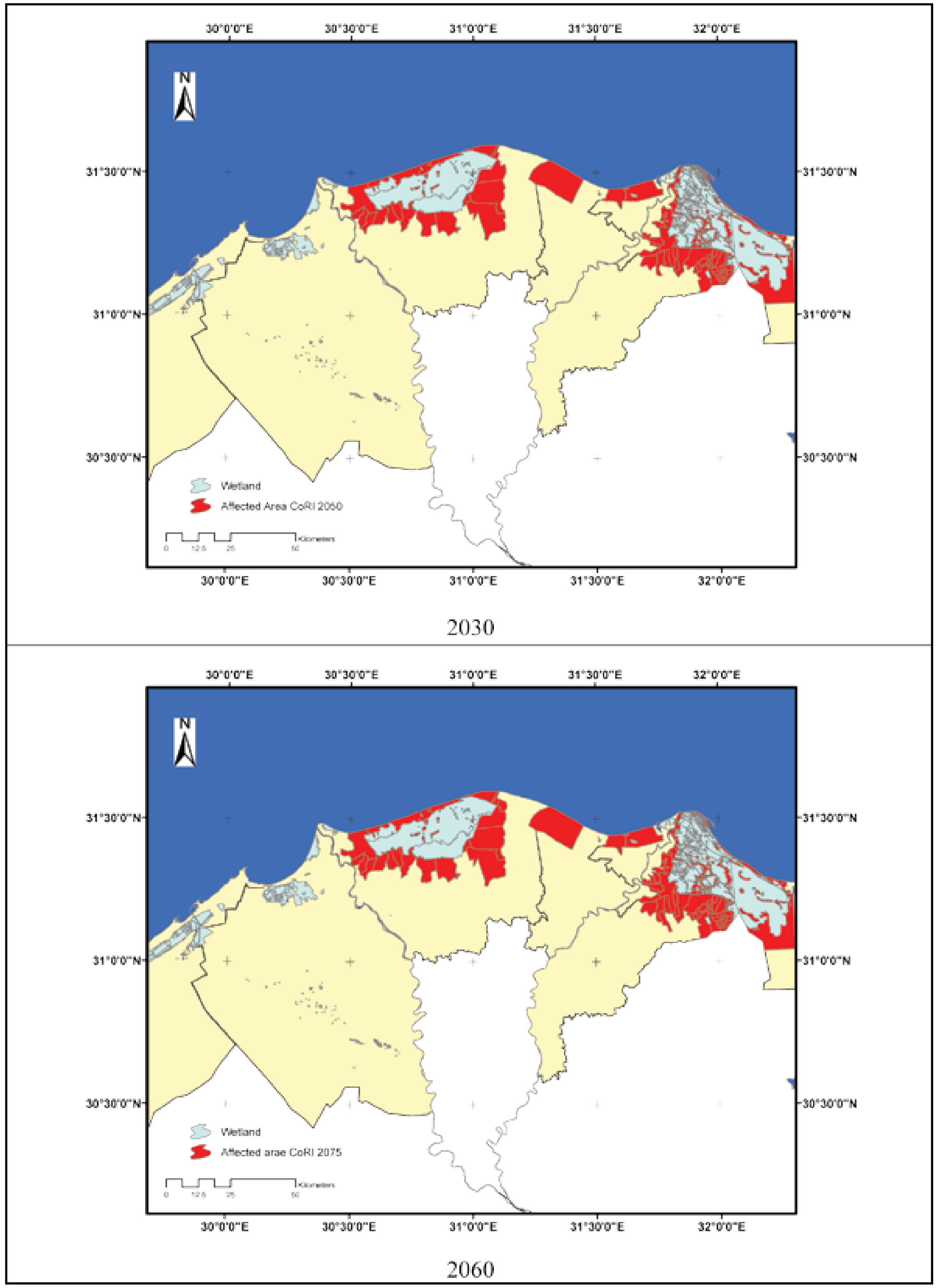


Figure 22: Inundated localities by 2030 and 2060 according to CoRI Scenario

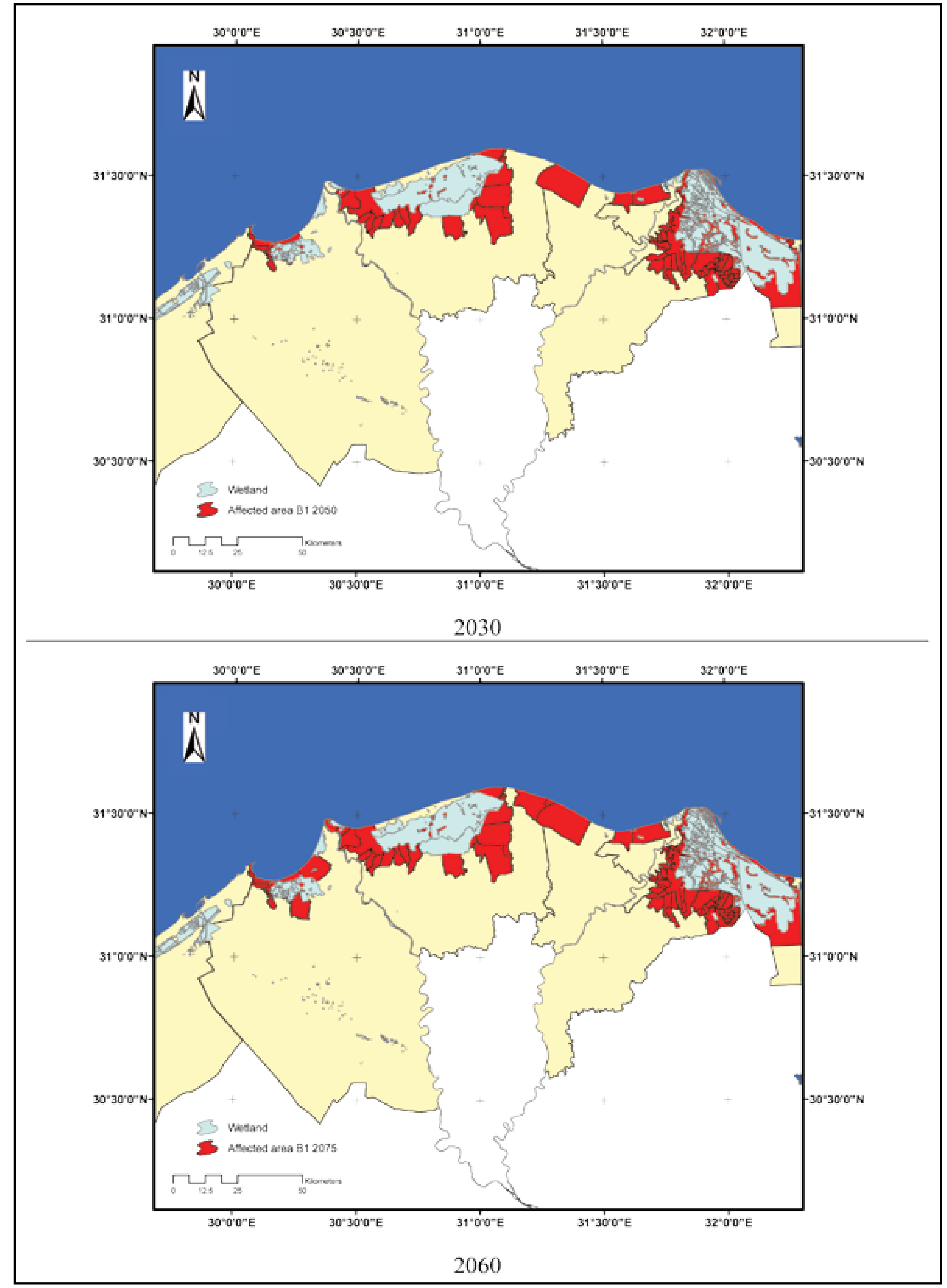


Figure 23: Inundated localities by 2030 and 2060 according to B1 Scenario

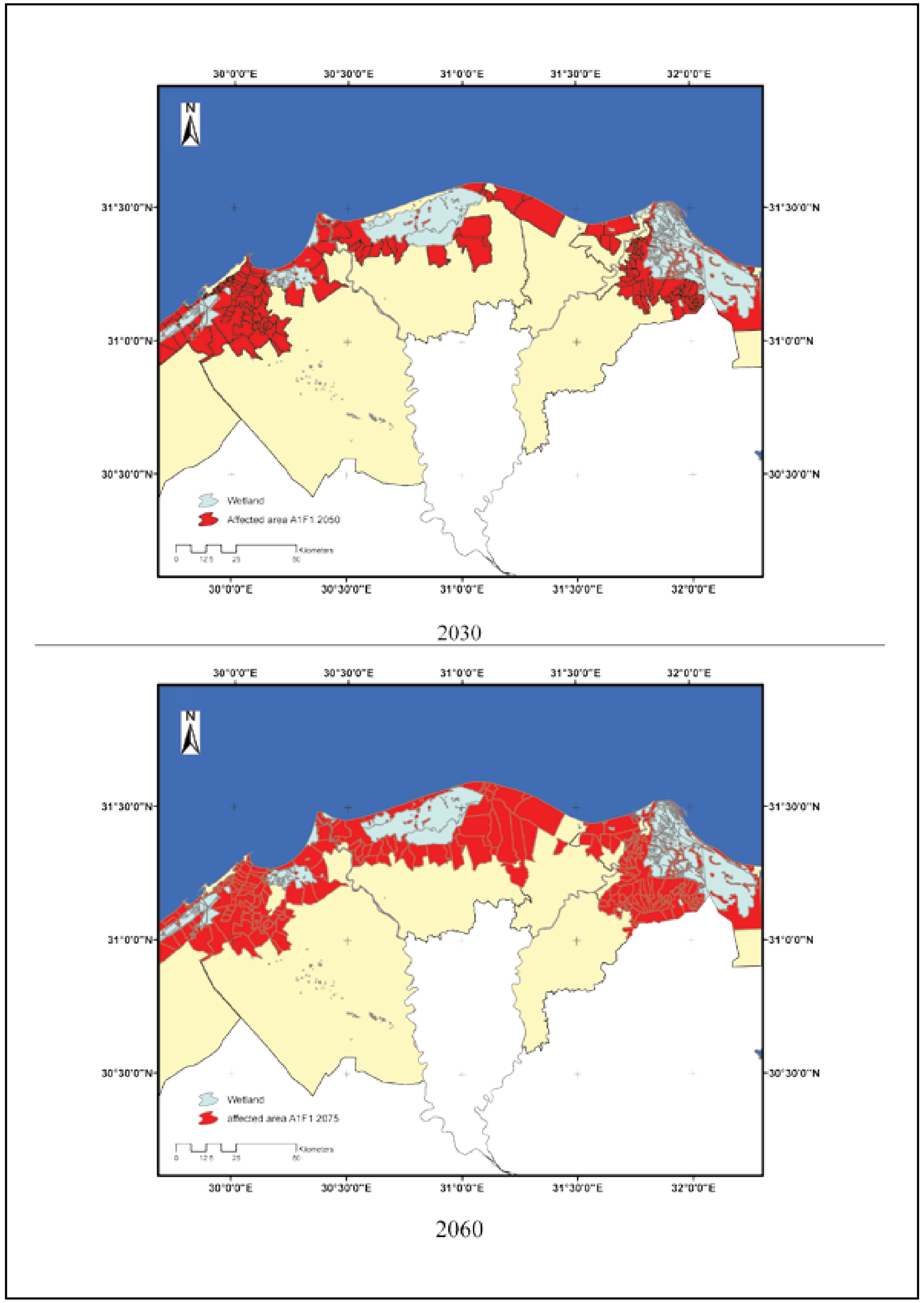


Figure 24: Inundated localities by 2030 and 2060 according to A1FI Scenario

Also, the area of current cultivated land that is vulnerable to inundation was varied among various scenarios. This is mainly due to the varied spatial extent of vulnerability to inundation according to various scenarios (Table 6).

Table 6: Current Area of cultivated land in the area vulnerable to inundation

Scenario	**Cultivated land (Km2)**	
	2030	2060
CoRI	1351.3	1418.7
B1	1431.7	1615.4
A1FI	1442.2	3957.9

The population size in each locality of the inundated area was estimated for each of these two scenarios. Table (7) illustrates the total projected population size in the study area at various point of time up to 2030 and 2060.

Table 7: Current and projected population size of the area vulnerable to inundation

Scenario	**Population size**				
		2030		2060	
		Scenarios A	Scenario B	Scenarios A	Scenario B
CoRI	1224622	2448584	1317515	31451328	1568977
B1	1312973	2584856	1422030	31686161	1798217
A1FI	1340657	2627781	1450614	31761332	1826908

The length of various types of roads in each locality within the area vulnerable to inundation was estimated. Table 8 summarizes the total length of roads in affected area according to the three developed scenarios.

Table 8: The length of roads in the area vulnerable to inundation

Scenario	**Length of various type of roads (Km)**	
	2030	2060
CoRI	3179.5	3259.4
B1	3359.7	3459.8
A1FI	3386.3	8890.9

The length of channels and drainage in each locality within the area vulnerable to inundation were estimated. Table 9 summarizes the total length of channels and drainages in affected area according to the three developed scenarios.

Table 9: The length of irrigation channels and drainages in the area vulnerable to inundation

Scenarios	2030		2060	
	Channels (Km)	Drainage (Km)	Channels (Km)	Drainage (Km)
CoRI	1525.2	1387.1	1587.5	1411.9
B1	1622.4	1495.9	1747.0	1559.1
A1FI	1640.6	1499.6	4235.9	3643.9

5.3 Potential Impacts of Climate Change on the Egyptian Economy

The effects of minor levels of climate change are already being felt in Egypt, with impacts across many economic sectors. Most of the impacts will be negative, and gains and losses will not be evenly distributed. For example: rising global temperatures will lead to an intensification of the hydrological cycle,resulting in dryer dry seasons and subsequently heightened risks of more extreme and frequent drought. Changing climate will also have significant impacts on the availability of water, as well as the quality and quantity of water that is available and accessible. Declining crop yields are likely to decrease the ability to produce or purchase sufficient food supplies. Changing temperatures will cause ecosystems to shift as land types and plant species will dieback in some areas as temperatures rise. Higher temperatures expand the range of some dangerous vector-borne diseases such as malaria. Further, heat waves associated with climate change and increases in water borne diseases, will result in increased health problem. Melting ice and thermal expansion of oceans are the key factors driving sea level rise. In addition to exposing coastlines, where the human population live, to greater erosion and flooding pressures, rising sea levels will also lead to salt water contamination of groundwater supplies, threatening the quality and quantity of climate change and water resources freshwater access to large percentages of the population.

Egypt faces an existential threat from climate change. In part, Egypt is vulnerable to sea level rise, which threatens the fertile Nile Delta. Perhaps more significant for Egypt are potential changes in water supply. The Nile River is Egypt's life source. Currently, Per capita water use is 750 m3/capita and is expected to significantly decline as population continues to grow. A reduction in average flow of the Nile could seriously threaten Egypt's water supplies and the well-being of its citizens.

Egypt's Nile Delta Mediterranean coastline is one of the areas that will be most affected by the rise in sea levels, as a large portion of it is itself below sea level and is subsiding. Within the Delta itself, or close to it, lie some of the most important Egyptian cities, such as Alexandria, Rosetta and Port Said. Further west, on the coastline, are Marina and Marsa Matrouh.

Climate change will harm Egypt's tourism sector through sea level rises and ocean acidification. The Nile Delta is home to much of Egypt's tourism, and for cities like Alexandria or Matrouh City, the threat of a rising sea level will reduce both their capability to sustain tourism as well as the desire of tourists to visit them. High levels of carbon dioxide in the atmosphere will result in ocean acidification, destroying coral reefs. The bleaching of the coral reefs is not just the loss of an important ecosystem but also the elimination of a prime tourist attraction. Disruption to the Egyptian tourism sector could have broader societal implications, as 20% of Egypt's foreign currency earnings are from tourism and according to Egypt's Minister of Tourism, 12.6% of the workforce depends upon the travel industry. The dangers climate change poses to Egypt's tourism sector and economy as a whole should not be underestimated.

Egypt's climate is hot and dry. The average daily temperature ranges from 17 to 20̊C along the Mediterranean to more than 25oC in Upper Egypt along the Nile (EEAA, 2010). Figure 25 displays average annual temperatures across Egypt.

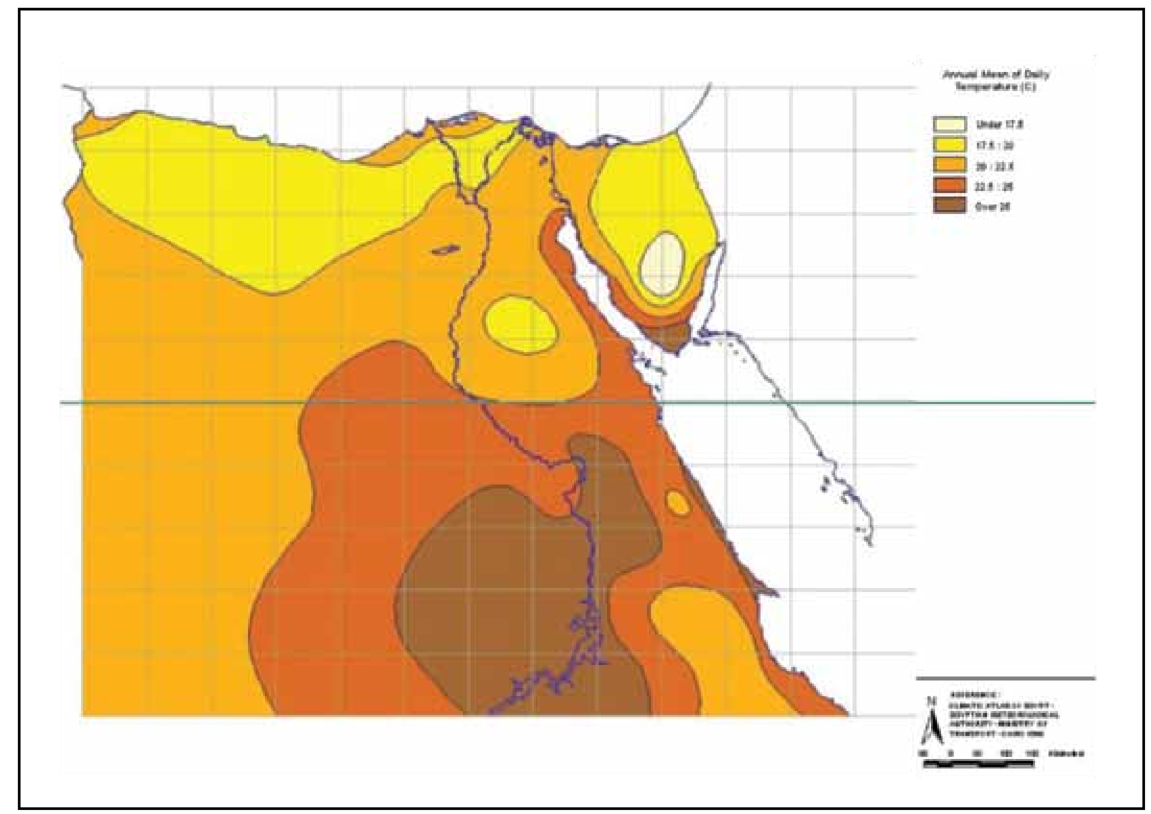


Figure 25: Average annual temperatures (̊C) in Egypt, Source: EEAA, 2010.

Figure 26 shows average annual precipitation across the country. Thus, most of Egypt is a desert and can be classified as arid. The exception is the slightly wetter Mediterranean coast, which can be considered semi-arid. Generally, the small amount of rain that does fall comes in the winter, and hence Egypt has a Mediterranean climate.

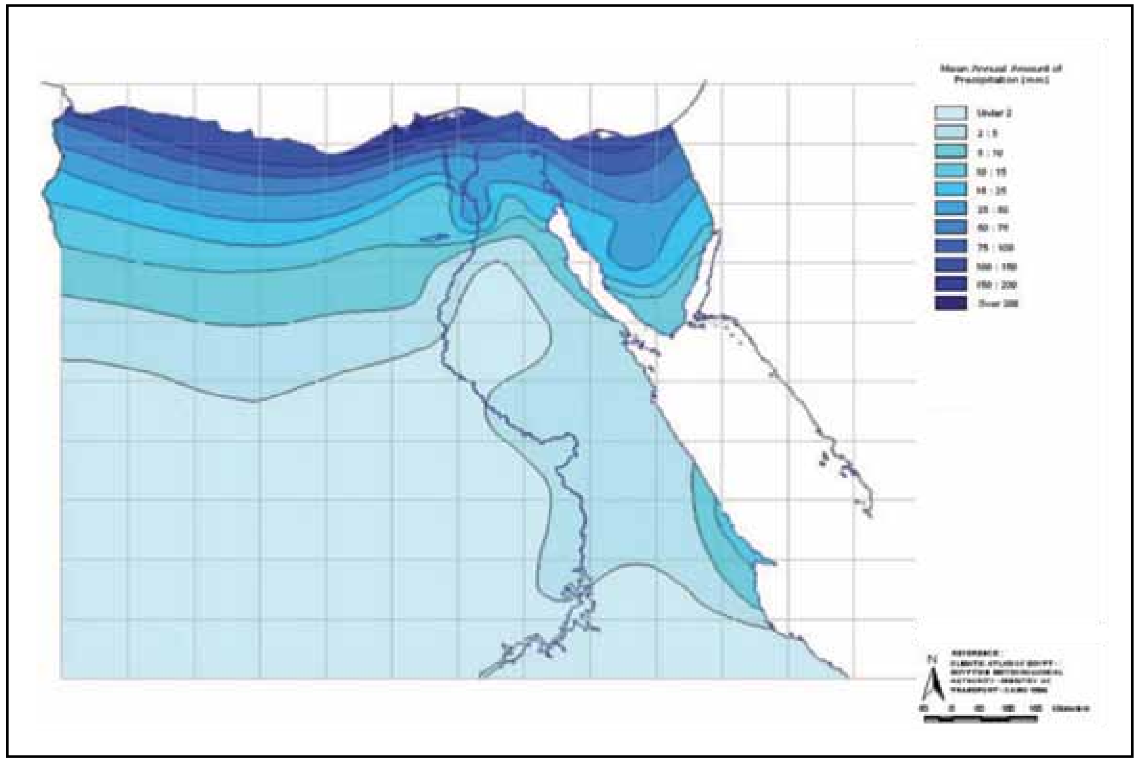


Figure 25: Average annual precipitation in Egypt (mm/yr), Source: EEAA, 2010.

5.3.1 Socioeconomic Conditions

Egypt's population in 2010 was approximately 80 million and had increased 2.3% per year over the last 10 years (EEAA, 2010). Egypt is a developing country with a growing population and a growing economy. Its real economy (adjusted for inflation) has grown an average of 5.1% per year since 2000 (World Bank, 2011a). Thus, per capita income has increased by more than 3% per year. If sustained, such a level of growth would result in a doubling of average per capita income in less than a quarter century (note we do not have data on the effect of the February Revolution on economic growth; Handoussa, 2010).

Although incomes on average have increased, there is widespread poverty in Egypt. Egypt has reduced extreme poverty, total poverty has increased in recent years. The extreme poverty rate of the population (which is close to $1.25/day in personal income) went from 8.2% in 1990 to 3.4% in 2008/2009. However, all of those in poverty (which is income less than $2/day) went from 24.2% in 1990 to 21.6% in 2008/2009. The upper poverty line ($2.50/day) remained at around 40% of the population. So, it is not surprising that the Gini coefficient, which measures income inequality, increased by 2 percentage points from 2005 to 30.46 in 2008 (Handoussa, 2010, p. 51). UNDP (2011) reports that the Gini coefficient had increased yet again to 32.1 by 2010. Nonetheless, Egypt's Human Development Index, which considers income, health, and education, rose from the same level as all Arab countries in 1990 to the world average in 2000 and has continued to increase.

Egypt is still mostly rural, with 57% of its population living in rural areas (Handoussa, 2010). Seven of 10 in poverty live in rural areas. Even within rural areas there are geographic disparities, with two-thirds of the extreme poor living in upper Egypt.

Thus, although Egypt is growing economically, the growth is not equal. Poverty is being reduced but not across the board. Income in urban areas appears to be increasing faster than in rural areas, and overall income inequality is increasing. Climate change risks, which are often borne disproportionately by the poor, could exacerbate the inequality.

In the following sections, brief review events in food and water resources sectors that will be affected by climate change are presented.

Food

Agriculture is one of the largest sectors of the economy, comprising 13.7% of gross domestic product (GDP; CAPMAS, 2010). Agriculture employs more Egyptians than any other sector, providing 30% of all employment (CAPMAS, 2010; Handoussa, 2010). Although manufacturing is a slightly larger share of GDP, it employs far fewer people than agriculture. Thus, agriculture is the largest employer in the Egyptian economy. With virtually all agriculture jobs located in rural areas, agriculture employs about half of the working population in those rural areas.

Total land dedicated to agriculture has increased in recent decades. Cropped areas have increased from 11.1 million feddans in 1980 to 15.2 million feddans in 2007. In addition, Handoussa (2010) reports that the quality of this land has decreased.

The increase in the number of people employed in agriculture has led to the unfortunate consequence of average landholdings for agriculture shrinking, even with the increase in total cropped land. Average agriculture holdings have gone from 6.3 feddans in 1950 to 2.1 feddans today, with 43% of farmers farming 1 feddan or less. This is an increase from 1950 when 24% of the farms were that small. These increase in the number of farmers on small farms will likely result in a decrease in the capacity of agriculture to adapt to climate change. It is generally thought that larger, well-capitalized farms will have a higher capacity to adapt to climate change than smaller, less well-capitalized farms.

Agricultural production in Egypt could be slowing. Handoussa (2010) reports that crop yields slowed significantly after the 1980s. From 1990 to 2000, yields increased 1% per year for maize and rice and 0.5% per year for wheat. Although this is a doubling of production for these three crops, the increase was primarily the result of expanding agricultural land. Importantly, one possible method for adaptation to climate change is to increase yields.

Egyptian fish production has almost quintupled in the last three decades, rising from 243,000 MT in 1980 to 970,000 MT in 2007. Three-fifths of fish production is from aquaculture, with a majority of fish production located in the northern Nile Delta. Handoussa (2010) reports that total fish production is expected to rise to 1.5 million MT by 2015.

Water resources

Egypt is heavily dependent on the Nile River for its water supplies. Egypt is particularly vulnerable to climate change because the Nile River's sources are more than 1,000 km south of Egypt's border. . Three-fifths of the Nile's flow is from the Blue Nile, which originates in the Ethiopian Highlands. The White Nile originates in the Equatorial Lakes region of East Africa.

According to MWRI (2005, p. 2-10), the 10 billion cubic meters (BCM) evaporation loss from the surface of the High Aswan Dam (HAD) is part of their net allocation of 55.5 BCM/yr to HAD from the 1959 Agreement. Figure 19 shows the currently available water for agricultural consumption which is 44.7 BCM/yr. The actual withdrawal for agriculture water is approximately 62 BCM/yr. This value exceeds the natural inflows because of return flows from municipal and industrial (M&I) users and reuse of irrigation drainage water. As the IPCC noted, Egypt and Libya are the only countries in Africa that consume more than 90% of their total available water resources (Boko et al., 2007). Most M&I returns or wastewater flows are untreated. Figure 19 in MWRI (2005) shows only 1.4 BCM/yr of municipal wastewater. This analysis assumes that such treated and untreated flows remain suitable for irrigation in the future. Otherwise, treatment costs must be added to the costs.

Egypt's water supplies are extremely limited and projected to become even more limited. Water use per capita has decreased from 2,500 m3/capita/yr in the 1950s to 750 m3/capita/yr today. Water use per capita is projected to be only 250 m3/capita/yr in 2050. Handoussa (2010) reports that countries with less than 1,000 m3/capita/yr are considered to be in water poverty.

The government is seeking ways to improve water supply and in particular to increase access to potable water. Since about 2005, the government has completed 1,669 water sanitation projects. The goal is to have all inhabitants within a 15-minute walk of clean water. Drinking water supplies have increased by 8 million m3/day to 27 million m3/day. The number of people receiving sanitary drinking water increased from 75% in 2006 to 88% in 2010. Handoussa (2010) reports that there will be 100% coverage when Egypt's current projects are completed.

Studies on climate change impacts have shown the potential for very significant changes in the flow of the Nile. Conway and Hulme (1996) estimate that flow in the Blue Nile in 2025 could range from an increase of 15% to a decrease of 9%. Strzepek et al. (2001) estimate that by 2020, the flow coming into the HAD could decrease by 10 to 50%. More recently, Elshamy et al. (2009) used bias-corrected statistical downscaling of 17 GCMs to estimate an average reduction in flow of the Blue Nile of 15% by the end of the century and a range of change from a decrease of 60% to an increase of 45%

The SNC notes that lower flows in the Nile would negatively affect Egypt's economy through impacts on agriculture, industry, tourism, hydropower generation, navigation, fish farming, and the environment. High flows, while increasing the total supply of water resources, would also necessitate more expenditure on infrastructure for increased water storage and conveyance and to control flood.

5.3.2 Socioeconomic and Climate Change Scenarios

Two sets of socioeconomic and climate change scenarios for 2030 and 2060 were developed in addition to optimistic and pessimistic projections to reflect a range of future conditions.

The identification of the change in per capita income was projected from IPCC's Special Report on Emissions Scenarios (SRES) projections (Nakićenovic et al., 2000). Combining per capita income changes and population projections yielded projections of total income.The population projections are displayed in Table 10.

Table 10: Optimistic and pessimistic population assumptions

	2009	2020	2030	2040	2050	2060
Optimistic	80	92	104	110	112	113
Pessimistic	80	98	117	134	149	162

The projections of GDP and GDP per capita are displayed in Table 11.

Table 11: Projections of GDP and GDP per capita

	2009	2030	2050	2060
GDP in EGP (mil)				
Optimistic	990,212	2,993,208	7,200,060	9,298,978
Pessimistic	990,212	2,287,141	4,501,023	5,907,201
GDP/capita in EGP				
Optimistic	12,378	28,781	64,286	82,292
Pessimistic	12,378	19,548	30,208	36,464

Three climate models were selected to cover the projected wettest and driest conditions in the Blue Nile basin and intermediate conditions. "SimCLIM" (CLIMSystems, 2011) is used to develop estimates of change in temperature and precipitation for Cairo and the HAD.The estimates of changes in flow at HAD are displayed in Table 12.

Table 12: Projected change in mean annual flow into the HAD (BCM)

GCM	2000 Egypt allocation	2030	2060
MIROC-medium	55.5	63.1	70.6
ECHAM	55.5	52.3	49.1
CGCM63	55.5	45.5	35.6

The changes in potential evapotranspiration for the three GCMs are displayed in Table 13.

Table 13: GCM estimated changes in PET and precipitation for the Blue Nile

GCM	PET % change	Precipitation % change
CGCM63	14	-15
ECHAM	14	2
MIROC-M	6	14

M&I use of water is projected to increase with population growth and to be further affected by climate change. An assumption of2.5% increase under climate change is used. The same assumption was used for all scenarios.

The inundated agricultural layers were categorized into three regions of the Nile Delta (east, central, and west) based upon an analysis of satellite imagery. The projected rates of sea level rise for the B1 and A1FI SRES scenarios using the IPCC (Solomon et al., 2007) projections are displayed in Table 14.

Table 14: Projected (low and high) average annual sea level rise (cm) relative to year 2000 sea level

City	Scenario	2025	2050	2075	2100
Port Said	B1	18.12	39.5	64.3	72.5
	A1FI	27.9	68.8	109.6	144.0
Al-Burullus	B1	8.75	19.5	32.25	35.0
	A1FI	14.75	37.5	60.3	79.0
Alexandria	B1	7.0	16.0	27.0	28.0
	A1FI	13.0	34.0	55.0	72.0
Source: Elshinnawy, 2008.					

Table 15 displays the sea level rise assumptions used for 2030 and 2060.

Table 15: Sea level rise scenarios used in this study (cm) relative to 2000

City	Scenario	2030	2060
Port Said	B1	18.12	64.3
	A1F1	27.9	109.6
Al-Burullus	B1	8.75	32.25
	A1F1	14.75	60.3
Alexandria	B1	7.0	27.0
	A1F1	13.0	55.0

The value of property was estimated by gathering data on population size, number of housing units, manpower and unemployment rate, and current price of housing units and agricultural land in five governorates on the Nile Delta: Damietta, Dakahlyia, Kafr El Sheikh, Behaira, and Alexandria.
An integration of population projections (to estimate change in demand for food and labor), the water resources forecast (to estimate change in availability of water for irrigation), delta inundation assessment (to estimate loss of agricultural land to sea level rise) and changes in crop yields (Egypt SNC) were used to estimate change in agricultural production using the so called Agriculture Sector Model of Egypt (ASME).

5.3.3 The analysis of the potential socioeconomic impacts

The estimated loss of low lying agricultural lands in the northern Nile Delta is displayed in Table 16.

Table 17 lists the value of housing units and roads at risk from sea level rise. The first section of the table displays current values. The second and third sections show increased values based on the optimistic and pessimistic scenarios for change in per capita income. The final section calculates an annual impact assuming all the housing units and roads are inundated and the value is completely amortized over 30 years. The losses would be between 1 and 2 billion EGP in 2030 and between 2 and 16 billion EGP in 2060.

Table 16: Percentage loss of agricultural lands in the northern Nile Delta

Scenario sea level	Northeast Delta		North Middle Delta		West Delta	
	km2	%	km2	%	km2	%
A1FI 2030 protected	11.4	0.7	13.4	0.2	0.0	0.0
A1FI 2060 protected	25.8	1.8	137.2	2.7	15.0	0.3
A1FI 2030 unprotected	379.3	25.7	84.3	1.6	6.0	0.1
A1FI 2060 unprotected	774.3	52.7	523.9	10.4	625.6	13.2
B1 2030 protected	2.6	0.0	7.8	0.2	0.0	0.0
B1 2060 protected	4.8	0.4	31.2	0.6	0.0	0.0
B1 2030 unprotected	2.6	0.0	7.8	0.2	0.0	0.0
B1 2060 unprotected	449.3	30.6	129.5	2.5	10.6	0.2

Table 17: Current value of lost housing units and roads (billion EGP)

Scenario	Housing units		Roads		Total	
	2030	2060	2030	2060	2030	2060
CoRI	16.4	17.5	2.2	2.3	18.6	19.7
B1	17.5	22.2	2.4	2.6	19.9	24.8
A1FI	18.0	65.6	2.4	8.0	20.4	73.5
Adjusted for increase in per capita income (billion EGP, pessimistic)						
CoRI	25.9	51.4	3.5	6.7	29.3	58.2
B1	27.7	65.4	3.7	7.7	31.4	73.1
A1FI	28.4	193.2	3.8	23.5	32.2	216.7
Adjusted for increase in per capita income (billion EGP, optimistic)						
CoRI	38.1	116.0	5.1	15.2	43.2	131.3
B1	40.8	147.6	5.5	17.4	46.3	165.0
A1FI	41.8	436.0	5.6	53.0	47.4	489.0
Annual impacts		**Pessimistic**		**Optimistic**		
CoRI		1.0	1.9	1.4	4.4	
B1		1.0	2.4	1.5	5.5	
A1FI		1.1	7.2	1.6	16.3	

The scenario that assumes pessimistic population and economic growth, the ECHAM change in Nile flow (a decrease of just over 10% by 2060), the A1 crop and sea level rise scenarios, and no protection from sea level rise is chosen to present the impacts of climate change on Egyptian agriculture. Under this scenario, by 2030, agriculture production decreases

12% and prices rise 16%; ultimately, Egyptian consumers would pay more for fewer goods. Indeed, imports of agricultural goods would increase 39% to make up for the reduced production. Meanwhile, the amount of land dedicated to agriculture is reduced by 1% and there are 2.5% fewer labor hours. Note however, that farmers who are able to plant a crop may gain from higher prices. Agriculture value of production, as measured by GDP, rises by 12%, but welfare is reduced by 2.5%, primarily because consumers have to spend more for food and divert income from other consumption and investment. In summary, agricultural output is reduced, fewer people are employed in agriculture, and consumers pay more for food. Such a scenario would almost certainly cause increased malnutrition and poverty. The nonagricultural populace in Egypt would be worse off because of the reduction in agricultural production. While farmers would gain, on the whole, Egypt would be worse off.

By 2060 under the same assumptions, conditions would be significantly worse. Production drops 27% and prices increase by 40%, which could cause malnutrition to increase. Imports of agricultural goods rise by 14%. By this time, land dedicated to agriculture is down 12% and the level of employment is reduced by 18%. With a much larger population, this could be a significant increase in unemployment. Agriculture GDP raises by more than 15%, but welfare drops by 6%. Income per capita would be substantially higher in 2060 compared to today. If there is more income equality, the risk of malnutrition would be lower than if significant inequities in income remain or increase.

CHAPTER 6

CONCLUSIONS & RECOMMENDATIONS

CONCLUSIONS and RECOMMENDATIONS

6.1 Introduction

There are two possible ways to tackle the problem of anthropogenic climate change; mitigation and adaptation. Mitigation aims to undermine the roots of the problem by stabilizing, and if possible decreasing, the concentrations of greenhouse gases in the atmosphere through reductions of emissions.On the other hand, adaptation aims to reduce the adverse impacts of climate change and utilize the beneficial impacts of climate change (IPCC, 2001a). Both mitigation and adaptation are costly but it is generally agreed that acting sooner will be less costly than acting later.

Mitigation is not an easy option for Egypt since, unfortunately, international efforts to control emissions of greenhouse gases have had limited success. Even an ambitious greenhouse gas control program will not prevent significant climate change. Thus, it is imperative that Egypt prepares for the inevitable risks that climate change is expected to bring. Therefore, a focus on the adaptation policies and measures that can be undertaken to reduce the impacts of Climate Change on Egypt is given here. This agrees with the findings of the 2006 Stern Report that stressed the importance of the provision of speedy assistance by the international community to developing countries seriously affected by adverse climate change impacts to help them in their adaptation efforts. The report also pointed to the fact that poorer countries will be the most affected despite the fact that they are not as responsible for emitting the greenhouse gases. It also stressed that while addressing climate change today would cost one per cent of national income, waiting for the adverse effects in the future would represent a yearly loss of 10 per cent of national income.

Adaptation starts with identifying and assessing the vulnerabilities of various sectors to potential climate change impacts. It then involves determining and assessing available options to deal with those impacts through a shift in public policies and/or the construction of protective structures such as embankments or defenses. Egypt's Second National Communication Project (SNC) developed a comprehensive study on climate change impact on Egypt (started in June, 2006 and completed in June, 2009) is one step forward in this direction. This was followed by a strategy that was prepared to adapt to potential changes in agriculture, water resources, irrigation, health, and coastal zone in the light of SNC outputs.

In general, measures to adapt to climate change can be hard or soft and some of them can be decided upon locally, while others need a regional approval. This book chapter attempts to address cross-cutting adaptation policies and to some extent measures within the water, coastal, and, partially, the agricultural sectors.

6.2 Water Resources

The available water resources in the Nile Basin are under immense pressure from rapidly growing populations and demand for water in the region. Climate change adds more pressure on the current stressed situation. Therefore, improved knowledge concerning the extent to which potential impacts of climate change will exacerbate this situation is important for decision-makers.

The UK Met Office PRECIS regional climate model was configured for a large window covering the Nile basin and the sources of moisture feeding the region. PRECIS was driven by an ensemble of 6 GCM experiments selected from a larger set of 17 HadCM3 ensemble members produced through perturbation of the unresolved physics for the QUMP project. Based on the output from the PRECIS simulations, delta change factors based on changes from baseline period (1970-1999) and the future (2020-2049) has been estimated for temperature, precipitation and potential evapotranspiration in order to assess the climate change over the Nile Basin. Predictions of large drying and warming over the Mediterranean in the summer are consistent with projections of most climate models, which provide some confirmation of this trend in the region. Similarly the increase in winter precipitation over the Horn of Africa is another robust feature of CMIP3 models that is captured by the RCM simulations.

The most important possible impacts of climate change on the water resources in Egypt are related to the rainfall patterns over the Nile Basin and evaporation rates over open water bodies and in particular wetlands. Precipitation changes along the western edge of the Ethiopian Plateau, where both the Blue Nile and the Atbara River have their sources, are the most critical for freshwater resources in Egypt. There is a consensus among the regional climate projections performed here indicating a general increase in precipitation during the main rainy season (JJAS) in this area. No other significant model agreement was found for other seasons and in spring a slight decline in precipitation can be identified. In contrast to the Blue Nile all the RCM simulations, in the Nile Equatorial Lakes region where the Nile has it sources, indicate a significant drying during the northern hemisphere summer (JJAS). The opposite appears to happen during the winter months when, in fact, most of the models predict a general increase in precipitation for the region. Very little consensus exists during the other seasons. Southern Sudan is another key region controlling the amount of water that flows in the main Nile as the evaporation losses from the Sudd plays a key role in the water balance of the river. Of the three key regions this is the one showing the least agreement between ensemble members. No clear signal appears to emerge for most of the months, the exception being the autumn when an increase in rainfall is apparent in most of the simulations.

The Nile Forecast Center (NFS) basin-wide hydrological model was then used to assess changes in flows of the Nile at important stations on the outlets of the Blue Nile, the Atbara, White Nile, and the main Nile at Dongola based on the climate signal obtained from the RCM in terms of delta change factors (DCFs). In addition, the original output of the same 6 QUMP members was used to calculate DCFs at the coarser resolution on the GCM to assess the added value of dynamical downscaling using PRECIS.

The projected changes in the annual inflow to the High Aswan Dam for the future period range from 0.5% to +36.2%. In fact, with the exception of a single ensemble member, the annual inflows for the future period are expected to increase due primarily to increases in flow during the period July to November, and in particular the months of August and September over the Ethiopian Plateau. This is a result of that fact that this period shows both that highest percentage changes (increases) and the largest inflows to HAD. The resulting changes in flows as projected by the RCM ranged between -6% to 29% for the Blue Nile at Diem and -12% to +10% for the White Nile at Malakal. Larger and positive changes were reported for the Atbara sub-basin. The results indicate reductions in rainfall and flows in the Lake Victoria region upstream of Jinja for this period. The major changes to HAD inflows arise from increases in rainfall and flows in the upper Blue Nile and Atbara. While there is a strong consensus in this regional analysis towards increasing inflows, the significant uncertainties in climate projections mean that there is still a risk of flow reduction that cannot be neglected. Furthermore water demands are expected to rise with the more certain population increase in all riparian countries including Egypt. The hydrological analysis also confirms the high sensitivity of the Nile to changes in precipitation and evaporation. Therefore Egypt should adopt climate adaptation measures that are robust to uncertainties in both the direction and magnitude of flows under climate change.

Although mean changes for rainfall and flow are positive, apart the White Nile basin, mean changes for PET are also positive, reducing the impact of rainfall increases. The uncertainty is rather high for flow in all basins and given the fact that this is only part of the total uncertainty (other sources include: uncertainty represented by the different emission scenarios, structural uncertainty in the models, hydrological model uncertainty, etc.), the results should be treated with caution. Even though there is some consensus towards flow increases, the possibility of flow reductions cannot be excluded especially given the fact that other GCM models show different precipitation trends over the region.

The hydro-meteorological regime of the Nile Basin is characterized by large variability in rainfall and river flow and therefore the Nile Basin countries have long had to manage water resources under this variability. Nevertheless improvement in water resources management in the Nile Basin is desirable as the region has a history of large flood and drought damage including famines and loss of lives and homes. The current water management practices within the basin need to be improved to accommodate potential changes in the not only in the mean flow as projected by the RCM ensemble but also the variability. This study did not attempt to assess the impacts on the inter-annual variability but there is a general consensus that climate change is likely to increase the variability of flows which needs to be accounted for when developing adaptation strategies. Although there is some consensus on positive changes, the associated uncertainty is large. This suggests the possibility of more extremes as other studies have shown but which was not assessed here.

The results also indicate that the RCM ensemble has a smaller range of uncertainty compared to previous studies with modest changes in rainfall and PET. The GCM ensemble showed a much wider range than obtained from the RCM and what was reported in previous studies. The GCM

based results (i.e. without downscaling) showed much larger changes in rainfall and flow with shifts in peak times at the different locations. The patterns of change for temperature were broadly similar between the GCM and RCM ensembles but the rainfall patters were less consistent and this resulted in large ranges that have been reflected in even larger changes for flows. This surely indicates the value added through the use of an RCM to downscale GCM results.

As pointed out earlier, regional climate modelling is expected to better represent changes at a finer scale, which in turn is expected to better reflect patterns of change in the Nile. Therefore the results of this study and how they compare to previous GCM studies is of considerable interest. The results are in agreement with some of the latest GCM studies (Beyene et al., 2009; Elshamy et al., 2009) which show that while the IPCC GCMs agree with respect to the direction of temperature changes, there is considerable variability in the magnitude, direction, and seasonality of projected precipitation changes. The simulations of Beyene et al. (2009) averaged over 11 IPCC GCMs also show early increases in the flows in the period 2010-2039 in full agreement with our the above findings. They find that further into the future flows decline as a result of increased evaporative demand and declines in precipitation. This should be further investigated using this regional climate model.

The joint use of a selected ensemble of GCM runs downscaled using an RCM and a hydrological model represents an affordable and practical approach for climate change impact assessments that also provides an estimate of the confidence level associated with the predictions. Without downscaling, GCM results have a much wider range of uncertainty. This emphasizes the need to downscale the results before being used in climate impact studies. Downscaling does not only provide finer details for change patterns but also reduces the range of uncertainty that is mainly caused by the coarse resolution of the GCM.

In order to carry out an adaptation assessment, potential adaptation measures are identified and evaluated in terms of their applicability, efficiency, effectiveness, and feasibility. The analysis presented below attempts to identify the available adaptation options of the Egyptian water resources system. In terms of evaluation, enormous resources are required to fully conduct an adaptation assessment that evaluates all available options and prioritize them. This is attempted in Section 6.4.

6.3 Coastal Zones

The Coastal zones in Egypt are likely to be impacted by sea level rise which could destroy or weaken the protection provided by existing natural and manmade defenses. This eventually could lead to severe flooding, loss of lives, salt water intrusion, and economic damages. In order to assess those impacts, an accurate method is needed to identify the likely impacted areas.
Currently, those areas are, typically, identified using GIS techniques which have advantages of being easier to setup and obtain results than other methods. However, they are prone to overestimation which leads to inaccurate calculations of the impacts of sea level rise. Therefore, an attempt has been made within this book to find a more accurate method to assess those impacts. A two dimensional flow model have been used to simulate the impacts of a sea level rise of 1m on the Nile Delta in Egypt. In the past, the use of such models was not advisable as they were not east to setup and required high computing recourses. With the recent improvements of model user interfaces and computing power, these are no more obstacles.
The results of the two dimensional flow model were then compared to their corresponding GIS results. The comparison revealed that the best estimate of the GIS techniques overestimates the flood extents by approximately 4.7 times more than what is estimated by the flow modelling technique. This astonishing difference will obviously have a substantial implication when estimating damages and loss of life in the flooded areas.
The above conclusion raises questions on the accuracy of the studies that have been using the GIS techniques to estimate the potential damages due to sea level rise, in particular at local scales, as these damages will be overestimated based upon the GIS techniques results.
Assuming a linear relation between impacted areas and damages would mean that also the damages are overestimated by approximately 4.7 times. This in turn will have a significant impact on the decision making and budget allocation to take necessary adaptation measures especially for developing countries where resources are limited and under extreme pressure.

6.4 Socio-Economic Aspects

The world's climate has been changing and this change is affecting Egypt. It is expected that climate change to continue and most likely accelerate (Solomon et al., 2007). A key uncertainty is the extent to which climate continues to change, not whether the climate will continue to change.
For that reason, it was difficult to forecast future socioeconomic conditions because it is not known how population, income, greenhouse gas emissions, climate, and many other important factors will change. In assessments such as this it is critical to communicate that there many uncertainties about future conditions. This is often done through the use of scenarios. A scenario is plausible combination of circumstances that reflect our current understanding of possible future conditions. A set of scenarios should capture a reasonably wide range of future conditions. In the study, this is done for two reasons. One is to show how conditions can change and to communicate what is known and not known about future conditions. When all scenarios show a variable such as population or temperature increasing, it is likely that the variable will increase in the future. When all scenarios show different changes in sign, that is, some scenarios show an increase in a variable and others show a decrease, there is uncertainty about whether the variable will increase or decrease.
Differences in magnitude of change are then demonstrated uncertainty about how a variable will change. For example, uncertainties about how much population will increase in the future can be

shown by scenarios with different levels of increase in population.
The second reason for using scenarios is to gain an understanding of how systems will be affected by future changes in conditions.
The study presented the time frame of the analysis, the socioeconomic scenarios, and the climate change scenarios. None of these scenarios should be interpreted as predictions. All are intended to be plausible possibilities of future conditions. It is not intended to assign any probabilities to these scenarios.

6.5 Recommendations

6.5.1 Policy Recommendations

Water Resources Adaptation

Assessment of climate change impacts and formulation of adaptation strategies is made complex by the uncertainty of water allocations and institutional arrangement for water sharing between the Nile basin riparians. For Egypt, flow increases are of course better than reductions as water can be stored in Lake Nasser in case of moderate increases. The High Aswan Dan allows Egypt to exploit any benefits from increases in Nile River flows for both irrigation and hydropower. For reductions in flow the picture is less clear. Previous studies suggest that Egypt could adapt to a 10 to 15% reduction in Nile flows (Conway and Hulme, 1993) while a reduction of 20% or more would have major social and economic impacts. To accommodate current and future climate variability, the current operating rules need to be adaptive to such changes in order to reduce the flood risk associated with those increases especially when flow reductions are also possible. The correct balance between flood risk and drought risk necessitates an adaptive management approach for the dam and Lake Nasser and requires multi-objective assessments of the flood risk, drought risk and hydropower requirements. The following sections attempt to elaborate on the possible adaptation strategies to climate change impacts on water resources.

Adaptation to Uncertainty

Despite the indicative results of a reduced uncertainty range from the RCM, the uncertainty is still high in determining the direction/value of climate change impact on the Nile flow necessitates higher flexibility operation and management of the water resources system including infrastructure and operation rules of reservoirs, barrages, etc. For example, for a moderately wet scenario, adaptation options would include operation of the HAD at lower levels to allow more room to receive higher floods. This option has already been studied during the LNFDC (Lake Nasser Flood and Drought Control) project which found that, under current conditions without climate change, it is probably beneficial to lower the 1st August level from 175m to 170m and even 165m with minor increases in drought risks and major benefits via reduction of losses by evaporation and spillage to Toshka. Increases in the irrigated area can be made taking advantage of such beneficial impact. In addition, to address the uncertainty, continuous monitoring of climate change trends and regular update of the impacts are required. Adaptation could include step-wise decision making that may define certain benchmark dates to review the strategies and update the decisions taken in light of updated information.

Adaptation to Inflow Increases

For a highly wet scenario, and in addition to the above measures, additional storage structures may be needed upstream of the HAD to reduce the risk of flooding downstream the dam (high discharges passing through the dam) or possible overtopping of the dam. As discussed earlier, Sayed (2004) showed that there is more than 6% chance that Lake Nasser level exceeds 183m under current operation conditions. Lowering the operating level (the 1st August level) may be sufficient in some cases but if the inflow increases considerably (especially if associated with increased variability as indicated by several studies), the capacity may be exhausted. Egypt Built reservoirs in other riparian countries in the past,

but the political situation is currently different. However, the Nile Basin Initiative can be a vehicle to take such bold decisions, especially if these reservoirs can have mutual benefits such as flood protection and hydropower production. Increasing water utilization in upstream riparians would not be of much interest under such a wet scenario.

Adaptation to Inflow Reduction

For a dryer scenario, irrespective of the level of inflow reduction, Egypt will have to face water shortage. Even without the impact of climate change, Egypt expects to face water shortages which will reduce the per capita share of water to less than 500 cubic meters per year by the year 2050. Therefore, Egypt's water policies have been formulated to face shortage (e.g. MWRI, 1997; NWRP, 2005) due to increases in demands and limited possibilities of augmenting the supplies. Climate change may exacerbate the problem but current water policies include several strategies that can serve as adaptations to water shortage whatever its reason may be. The following is a list of some of the strategies developed under the National Water Resources Plan (NWRP, 2005) which are categorized into three main directions: optimal use of available resources, development of new resources, and water quality preservation/ improvement.

Optimal Use of Available Resources

- Minimize Water Losses

One of the quickest ways of increasing the water availability is through improving the efficiency of water use by minimizing losses. The main losses of the irrigation system are the evaporation from canals and drains, deep percolation especially in new lands, evapotranspiration from weeds on waterways, and leakage from control structures. The main proposed strategies to minimize water losses include:

- The implementation of the Integrated Irrigation improvement Project (IIIP) to improve the irrigation efficiency in the old lands
- Improvement and upgrade of the traditional methods used to maintain the canal network
- Redesign of canal network to use the minimum cross-sections to minimize the total surface of water and reduce evaporation loss as well as land used by the network.
- Recovery of operation and maintenance costs and in some cases the transfer of the management responsibility to water users.
- Improvement of drainage conditions for better productivity. This will be integrated with the IIIP.
- Increasing water reuse from drainage and treated sewage. Care will be taken to avoid the use of polluted water. Instead of reusing water from large drains that receive untreated sewage, it is suggested to reuse water from intermediate drains which are less polluted.
- Reduction of irrigation supplies after rainfall

For municipal and industrial water use, demand management holds the potential for improving the efficiency of water use. Suggested demand management measures include:

- Water pricing for municipalities and industries.
- Public awareness campaigns.
- Improvement of the distribution system (pipelines, tanks, etc.) to reduce leakage.
- Reuse of treated wastewater

Cropping Pattern Changes

The agricultural sector is considered the main user for water that consumes about 85% of the High Aswan Dam release. Although this percentage will decrease in the future due to the high rate of future growth in other demands, it will represent for a long time the major consumer of water. Economic analyses showed that there are substantial differences in the total economic returns to different crops grown in Egypt. Productivity of resources is a central development indicator. In fact, development is frequently reviewed and defined as "The increase of productivity". It was indicated that water productivity in some regions is low according to the high water consumptive crops that has low value added. Cotton has the highest economic return both per feddan and per unit of water. Wheat is the second most attractive crop in terms of value per unit of water, despite its relatively low returns per feddan. If water becomes scarce, and one objective is to maximize the economic returns from the available water, these two crops should increase in area cultivated. Therefore, the following policies are proposed to reduce the agriculture water consumption:

- Replace crops having high consumption (e.g. Sugar Cane and Rice) with those having lower consumption (Sugar Beet and Maize).
- Develop new crop varieties that consume less water (shorter growing season, lower requirements, etc.)

Development of New (Re)sources

Nile Waters

Possibilities to increase the Nile yield are limited to conservation projects in the upper Nile countries such as the age-old Jonglei canal, Machar, and Bahr El-Ghazal projects. Other new projects that may be beneficial to Egypt from a water resource perspective include the Baro-Akobo scheme. These projects were suggested more than 50 years ago and have to be re-evaluated in terms of their hydrological and environmental impacts taking into consideration climate change. Under wet scenarios, these projects may not be as feasible as thought previously. Under dry conditions, they may not provide the water quantities envisaged and therefore may not be as beneficial. Other developments in the upper Nile countries (especially Ethiopia and Sudan) may reduce the inflow to Lake Nasser. However, they provide additional storage so that the operation of Lake Nasser may be adapted to reduce evaporation and spillage losses. In addition, these reservoirs will redistribute the flow which will benefit Sudan and Egypt in low years.

Groundwater

Deserts cover more than 95% of Egypt's total area. Groundwater is considered the main resource to provide adequate water supply for sustainable development in these desert areas. That is because it would be so hard or even impossible to transfer NileRiver water to those areas. The aquifers in the WesternDesert hold huge quantities of fossil non-renewable water. The total abstraction potential is about 3.5 BCM/year. Most of the development will take place in East Oweinat and the Farafra and Dakhla oases. Some 200-300 and 50-100 MCM/year are potentially available in Sinai and the Eastern desert respectively.

The groundwater policy aims to encourage the agriculture development in the desert areas. These areas will be the basis for initiating new communities that can absorb part of the highly concentrated population in the Nile valley and Delta. Such approach will increase the future demands for groundwater, which consequently will necessitate continuous monitoring and evaluation of the groundwater aquifers to avoid any possible deterioration in these aquifers due to misuse. Future strategies for Groundwater development should take into consideration that abstractions from non-renewable aquifers must be within the safe yield and the area of the proposed development projects should be limited to this allowable level of abstraction. Otherwise, these aquifers would be depleted due to over pumping which threatens the sustainability of any existing projects utilizing these aquifers. Cropping patterns should be carefully selected to suit the climatological condition and to provide high revenues as well.

In addition, there are vast amounts of unpolluted brackish groundwater of varying salinity (3000-12000 ppm) in the Nubian sandstone and Mughra aquifers. Potential use of this resource includes aquaculture, salt tolerant cropping, and industry. Brackish water can be desalinated at relatively lower costs than that required for sea water and used for cultivating cash crops or even for municipal uses in remote areas. Renewable energy such as solar or wind energy can be used in this respect to reduce the desalination costs. This source can be used as a supplementary source to rainfall water to increase land productivity by cultivating two crops per year instead of one.

Groundwater in the Nile valley and Delta region cannot be considered an independent resource as it gets recharged only from seepage losses from the Nile main river, canal and drainage networks, and from deep percolation losses of irrigated lands. There are some considerations for using this resource such as:

- These aquifers could be used as storage reservoirs along the Nile River system. It could be used to meet part of the water demands during peak periods and then left to get recharged again during the minimum demands. It can be considered as a storage reservoir with the advantage of no water losses due to evaporation.
- Use of modern irrigation methods in the new lands (sprinkler or trickle) that uses groundwater as the source of water to prevent water logging and keep the groundwater table far from the root zone. Moreover, this water has good quality and free from suspended matters, which is suitable for such methods.
- To increase the agricultural productivity, it is highly recommended to use of vertical wells as a modern drainage system in Upper Egypt. This will prevent the groundwater table from reaching the root zone and avoid any possibility of water logging at the agriculture lands.
- Groundwater could be used as a source of water for artificial fish fields as it has consistent and steady temperature and good quality.
- It is recommended to reuse the seepage water losses to the groundwater aquifers through pumping back to satisfy a part of the agricultural demands and conserve a portion of the surface water to reclaim new lands.
- At tail ends of long mesqas where water shortage is experienced, groundwater may be pumped from low capacity private wells to augment the canal water supply.

Shallow groundwater in coastal aquifers can sustain small-scale exploitation of thin freshwater lens through shallow wells and galleries (skimming). However, potential abstraction is small due to the presence of saline water underneath. Locally, there may be some potential to increase abstractions but care must be taken not to disturb the salt balance.

Rainfall Harvesting

• Flash floods are considered a natural hazard that occurred due to very heavy storms in a short period of time. The velocity of water is very high and it can make damages in the infrastructure and properties. These types of floods occur in southern Sinai and in the Red Sea plateau where the topography is very steep. Up till now, there are not enough studies about flash floods risk assessment and how to change this natural phenomenon from a hazard into a useful source of water. Estimates show a possibility to conserve about 2.0 BCM/year from flash floods.

• Use of modern technologies in remote sensing and GIS to study the basic characteristics of the stream network that contribute in flash floods. This would include the study and analysis of surface runoff, the definition of basin streamlines characteristics, and soil type.
• Avoid hazards from flash floods by implementing risk zone maps for major bottlenecks on the basin streamlines and identifying areas that lie in risk zones to take proper precautions to avoid any possible hazards.
• Construct small reservoirs for storage and utilization of water and to provide flood protection.
• For the northern coast, rainfall harvesting techniques may be used to assist rain-fed agriculture. The interception of surface runoff and its storage in the soil profile requires simple and low cost techniques that can be implemented by farmers and thus holds some potential in coastal areas.

Desalination

Egypt has 1000s of kilometers of shorelines and therefore sea water in abundant. Small desalination plants are implemented for drinking in some distant resorts where other sources are too costly to obtain. However, the cost of desalination of sea water is still too high to render agriculture economically infeasible. Research in new desalination technology is required to reduce the costs, especially with the use of non-conventional energy sources such as wind and solar energy, and even nuclear energy. As mentioned above, desalination of brackish water can improve the economics of such projects.

Water Quality Management

One of the major issues facing Egypt is the accelerated decline of water quality. Water quality has a direct effect on the quantity available for a specific use. As the quality of water gets worse, its scope of use narrows, thereby, reducing supplies and intensifying shortages. Therefore, the MPWWR, in coordination with other involved ministries and authorities, aims to implement a long-term strategy to prevent the different sources of pollutants from discharging to the NileRiver and other water bodies. Improvement of water quality requires prevention of pollution, treatment of polluted water, and if neither is possible, control of pollution.

Preventive Measures

For industry:

• Financial incentives (taxes and subsidies of products and inputs) to promote clean technology
• Public disclosure pollution program aiming at forcing incompliant industries to shut down or to adjust due to public pressure.
• Compliance action plans for industries
• Public awareness campaigns
• Moving industries away from vital waterways towards new cities
• Load-based discharge levies (charges)
• Monitoring and control
For agriculture
• Encouragement of environment friendly cultivation practices including environment friendly agrochemicals (developed through research)
• Control the use of agrochemicals (pesticides, herbicides, fertilizers)
• Control the use of organic fertilizers

Treatment

The capacity of urban wastewater treatment plants need to be increased rapidly in order to control pollution and prevent polluted water from reaching drains. Given the high cost involved, cost recovery of urban water treatment and sanitation is required but this should be accompanied by metering and should be implemented gradually. For rural areas, sanitation coverage is generally too low and local action plans need to be formulated using low cost technologies depending on the locality and involving the community.
Treatment of industrial waste should be the responsibility of the industry. Industrial effluents are generally very different from domestic ones and therefore require different types of treatment. Separating the collection of the two types can help reduce the treatment costs. Introducing load-based charges can stimulate industries to treat their effluents before discharging them to the collection network. Public and private sector awareness is always important in this respect.

Control

For pollution that cannot be treated nor prevented, control is the only option. This is mainly done through legal and institutional measures such as:

- Defining functions of waterways with each having its water quality standards based on these functions
- Reducing contact with pollutants and incorporating these into local action plans
- Diversion of pollution away from coastal lakes
- Protection of groundwater wells
- Provision of on-site sanitation system and safe disposal sites for distant areas disconnected from collection systems
- Monitoring of water quality and dissemination of information
- Coordination of investments on the local and national levels
- Training and capacity building of involved stakeholders

Adaptation to Coastal Zones

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. Options of adaptations are generally site-dependent and necessarily involve multicriterial analysis to assess levels of technology, maintenance, impact assessment and cost (El Raey et al., 2000).
The following adaptation measures on the local scale are under considerations (El Shennawy, 2008):
• Creating wetlands in areas vulnerable to the impacts of sea level rise in low lying deltas. Lake Manzala and Lake Burullus are two examples of such areas eligible for such adaptation processes;
• Progressing with protecting and fixing natural sand dunes systems which constitute an important natural protection;
The Shore Protection Authority is considering protection and enforcement of Mohamed Ali Wall as a first line of defense of the low lands south of Abu-Qir Bay;
• Reinforcing the international road along the Mediterranean coast to act as a second line of defense for the protection of the northern zone of the Delta. In this respect, the northern side of this road should be reinforced so as to act as a sea wall;
• Possibly using Al-Salam Canal banks as protection, as they rise 2 m above Lake Manzala water level;
• Activating the National Coastal Zone Management Committee which should formulate an integrated coastal zone management plan.

Climate variability and/or climate change -together with other stresses on the coastal environment of the delta coastal zone brought about by existing management practices- produce actual or potential impacts. These impacts trigger efforts of mitigation to remove the cause of the impacts, or adaptation to modify the impacts. Policy criteria and coastal development objectives that interact with existing management practices condition the process of adaptation.

Adaptation to Socio-Economic

Among the possible government roles in facilitating agriculture adaptation are:

- Supporting a more efficient irrigation system. The SNC states that the goal of the current national plan is to reduce water use by 50 to 75%. The government should review progress in implementing this plan and determine how successful the plan has been so far. In order to measure success, milestones and metrics are needed so that success or failure can be measured. Do such milestones or metrics exist? If not, they should be established.
- Support research and development of heat-resistant, drought-resistant, and salinity-resistant crops. As noted above, it may be most effective for Egypt to participate in international research efforts. Egypt should ensure that its needs are being addressed.
- Enable or otherwise support crop insurance. Insurance can help farmers cope with poor production years. As noted in the coastal section above, the insurance industry can also help improve farming practices. In addition, private sector funding should be encouraged. There could be a role for the public sector in removing institutional barriers and possibly providing some financial support for insurance.

6.5.2 Recommendations

It is important to note that many, if not all, of the adaptations for water resources and other sectors can be justified without consideration of climate change. Egypt's extremely limited water supplies combined with growing demand make more efficient use of water and enhancement of supplies imperative. Climate change presents yet another reason for making these investments and may shorten the time when these investments need to be made.

Reuse can be implemented in order to enhance existing water supplies. Water used for irrigation does need not need to meet the same standards as drinking water. Water that has been used for municipal, industrial, or even agriculture uses can be treated to certain levels and used for certain domestic uses and irrigation or to maintain instream flow (of course, it should be treated to a level that supports aquatic ecosystems). A rule of thumb is that water reuse can be applied for $0.30/m3 (1.65 EGP/m3; World Bank, 2009).Also, the reconsideration of the impact assessments of drainage water storage in northern lakes is needed.

Desalination is already being pursued in Egypt and may need to be enhanced because of climate change. Costs of desalination have been decreasing, making it more competitive. However, desalination requires more energy and probably only is justifiable for providing water to coastal areas. The use of wind and solar energy for water desalination must be promoted and adequate financing for scientific research in these areas must be provided.

A drought management plan is needed to account not only for increased demand and population growth, but also for the possibility of more intense and frequent droughts should Egypt's climate become hotter and drier. Local human resource skills in the field of mathematical regional circulation models must be developed so as to allow future projections with the high degree of accuracy required for policy formulation.
The SNC mentions additional rainwater harvesting. This option could be useful along the Mediterranean coast. Studies should be undertaken to determine the possible adaptation choices for the water and agriculture sectors that would make use of simple and low cost technologies.

There are uncertainties involved in predicting future climate change and that existing planning processes and hydrologic methodologies need to be improved to deal with such challenges. Update of the development of Regional Climate Models capable of predicting the impact of climate change on the local (Egypt) and regional (Nile Basin) water resources is recommended.

Unfortunately information was unavailable for the upper Nile flows at the key locations. This requires the following actions to be undertaken:
Encouraging exchange of data and information between Nile Basin countries.
Enhancing precipitation measurement networks in upstream countries of the Nile Basin as well as the installation of modern early warning systems.

Environmental laws should be firmly enforced and environmental assessments of projects must be made mandatory. National projects should take into consideration expected climate change effects. Strengthening the current institutions that study climate change and its impacts (e.g. the Institute of Environment and Climate Change of the Ministry of Public Work and Water Resources) is essential.
It is important to involve stakeholders in adaptation planning. If adaptations are not developed and implemented with the active cooperation of stakeholders who are at risk from climate change and whose involvement is need to ensure the adaptations are adopted and implemented, then adaptation efforts are

prone to failure. Stakeholder involvement in adaptation planning is needed at multiple levels including the community level, sub-governorate level, governorate level, and national level.

Government adaptation appears to be most successful when there is a strong and coherent call for action that sends a clear signal across the government that adaptation is important and that cooperation is needed. It is clear that a number of important economic and commercial centres in Egypt will be exposed to the adverse effects of climate change, with the coastal cities of the Nile Delta, in particular, being most affected. It is urgent that strategic adaptation policies and plans are put in place and strong institutions and systems of supervision to enforce environmental laws, are established.

A comprehensive institutional mechanism for the protection of coastal areas must be established with the aim of coordinating the efforts of the research community and implementation agencies.

Non-governmental organisations should be encouraged to raise awareness among decision makers and the public on the dangers posed by climate change and the necessity for reducing over-consumption. Public awareness campaigns on water shortages or surpluses caused by climate change are also needed.

6.5.3 Way Forward

This section concludes the book with a more global vision of how the world could deal with Climate Change. A 2007 report on climate change was subtitled "Avoiding the Unmanageable and Managing the Unavoidable". The phrase reflects one of the bitter ironies of climate change and that its impacts will be felt mostly by poor countries that have contributed the least to the problem. For them the challenge will be to manage the unavoidable (e.g. drought, flooding, disease, and the effects of weather on their economies and political stability). To be effective, their national strategies for economic development and poverty alleviation must now include increased resilience to the impacts of climate change.

Even for the rich countries, the threats from climate change to their people, economy, security, and humanitarian interests justify immediate action. Managing the climate crisis requires new forms of international cooperation to reduce global emissions and assist vulnerable societies in adapting. All countries need to work together to help to solve the climate crisis, but they must act now and do so in concert. This will require political resolve, creative negotiating, innovative policy mechanisms, stronger global institutions, and additional financial resources (Wirth, 2008). But, it is our obligation as inhabitants of the Earth.

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ANNEXES

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The total population found along the coastal vulnerable areas are about 1,850,000 person, (Sestini, 1992), located on a total area with about 4400 km2, beside the area of three delta lagoon, this is represented on table (I). Table (II) lists the main activities and prevail present problems of the Nile delta coast.

Table (I): Socio-economic parameters of the three vulnerable cells located below 1 m. contour along the Nile delta coast and gradually affected by SLR.

Cell Code	Cell Name	Area (km2)	Average Dist. From Shore-line to 1m Cont. (km)	Total Population	% National Population	% Dry land at loss	% Wetland at loss
I	Abu Quir East Rossetta	1,100	20		1.145	0.11	0.003
II	East Rossetta West Burullus (Baltim)	2,150	31.5	710,000	1.202	0.215	0.041
III	West Burullus (Baltim) East Damietta	1,150	12	745,000	0.63	0.115	0.1
	Total	4,400		395,000	2.977	0.44	0.144

Table (II): Lists the main activities and prevail present problems of the Nile delta coast.

Cells Names	Main Activities	Present Problems	Large-scale Causes
Abu Quir El-Maadia	Touristic area, small area, fisheries, considerable population density, nourished beach, fish harbour, urban, coastal road,	Erosion, Pollution Wave actions	General causes 1.Large scale of landform change 2.Relative sea level rise
Lake Idku	industrial area, low community, cultivated area, natural gas production, urban, Aquaculture, coastal road, Idku lagoon, fish	Pollution, Lagoon reclamation, Over fishing	1.Cross shore processes 2.Human modification
East Rossetta Abu Khasaba	harbour, salt marshes, cultivated land (palm tree), low population, fisheries, urban, Aquaculture, coastal road	Erosion, Siltation, Pollution soil salinisation	1.Water Quality 2.Lack of fresh water 1.Building coastal measures
East Rossetta Lake Burullus	historical, tourist city, fisheries, coastal dunes, cultivated land (palm tree), Brick industries, fish boats industries, coastal road	Erosion, Pollution soil salinisation Sand dunes movement	
West Burullus Baltim	nourished beaches, beach resorts, coastal road bridge, fisheries, fish harbor,	Erosion, Pollution Siltation, soil salinisation Sand dunes movement	
West Burullus Gamasa	nourished beaches, beach resorts, coastal road bridge, coastal dunes, cultivated land	Soil salinisation Sand dunes movement	
East Damietta Ras El Bar Lake Manazala	Damietta harbor, beach resorts, salt marshes, urban communities, coastal road	Erosion, Siltation Reclamation, Pollution	