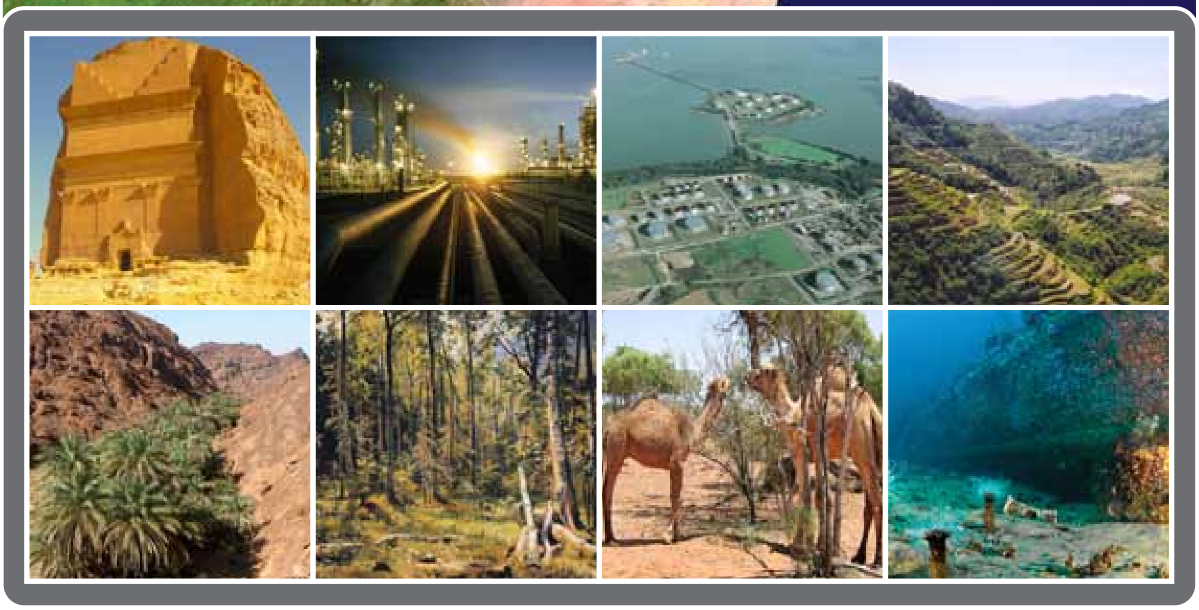
SECOND NATIONAL COMMUNICATION

KINGDOM OF SAUDI ARABIA



Submitted to:

The United Nations Framework Convention on Climate Change (UNFCCC)

2011

Second National Communication

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Foreword

This report is a result of dedicated and hard work by a team of national experts and scientists in different disciplines as well as close cooperation among relevant sector ministries and organizations coordinated by the Presidency of Meteorology and Environment. This report emphasizes more on regulatory framework to deal with the impacts of climate change and adaptation efforts. In addition to Vulnerability, Assessment and Adaptation of marine ecosystem, water resources, socio-economic analysis, desertification and biodiversity, there are two new chapters added to this report dealing with the 'Steps Taken to Address Article 12.1 (b) of UNFCCC and "Current Status of the Technology Development and Transfer in the Kingdom of Saudi Arabia". The report has been prepared in accordance with the methodologies and guidelines of the Intergovernmental Panel on Climate Change (IPCC) and the Conference of Parties (COP).

I would like to emphasize that this National Communication has been prepared ensuring highest standards and has been extensively peer reviewed. While this exercise has resulted in the development of a National Team of scientists and researchers, however, certain constraints and gaps have also been identified. These gaps and constraints would be addressed during the process of preparation of future communications. I would like to express my gratitude and thanks to the relevant ministries, government agencies, organizations, research institutes and academic institutions and universities for their cooperation in providing necessary and updated data and information. I would to appreciate all scientists and experts of the National Team for their commendable work.

We also thankfully acknowledge the support provided by UNDP-GEF during the course of the preparation of this report.

Turki Bin Nasser Bin Abdulaziz
President
Presidency of Meteorology and Environment (PME)

Preface

This report ‘the Second National Communication” of Saudi Arabia has been prepared by a group of committed National Experts, Academicians, Researchers and International Consultants after a tireless work of more than two years.

The report has been prepared using methodologies and guidelines provided by the Intergovernmental Panel on Climate Change (IPCC) and Conference of Parties (COP). This report has emphasized on the existing institutional and legal frameworks in the Kingdom of Saudi Arabia dealing with Climate Change, sustainable development and environmental issues. The data used was the latest and best available at the time of writing this report. The report has some deficiencies and gaps which would be addressed in the next communication.

During the course of this project, several national and regional workshops, attended by many international experts, were conducted. Representatives from relevant ministries and organizations, research centers, academic institutions, and universities took part in these workshops. The main focus of these workshops was to enhance public awareness about climate change issues; (i) promoting understanding on the need of energy efficiency and renewable energy in particular solar energy (ii) developing strategies for adaptation of the Kingdom to climate change impacts (iii) assess its vulnerability both to climate change impacts and impact of climate change response measures on the Kingdom and (iv) capacity building such as training of the Saudi and GCC scientists to use and run regional climate scenario models where our scientist successfully carried out analysis of the run presented in this report.

The highlights of the report was a significant effort to gather data and information on the renewable energy potential of the Kingdom in addition to technology development and transfer, steps taken to address Article 12.1 (b) of UNFCCC and analysis of socioeconomic impacts of Annex 1 response measures.

The authors of the report are thankful to all relevant sector ministries, organizations, research institutes, universities and academic institutions for providing their timely and valuable inputs, data and information.

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The following provided a significant contribution and support:

- Dr. Mohamed S. Al Sabban – Senior Economic Advisor, Ministry of Petroleum and Mineral Resources
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We also valued and appreciate the constructive support of the United Kingdom (UK) through:

- Hadley Center for Climate Prediction and Research, U.K.
- Oxford Institute
- Stockholm Institute
- AEA, A world leading energy & climate change consultancy

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SECTION - 1

Introduction

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Section 1:Introduction:

1.1 Background Information on Saudi Arabia:

Saudi Arabia, located between 16.5°N–32.5°N Latitude and 213.75°–236.25° Longitude, has an average annual rainfall of less than 150 mm in most parts of the Kingdom. It covers an area of approximately 2.15×10^6 km^2 and has a population of 28 million. Its maximum summer temperatures often exceed 45°C. High temperatures and low precipitation cause a concomitant increase in the Evapo-transpiration rate, a reduction in soil moisture and erosion of the soil, all of which adversely affect agricultural products and water resources, particularly in underground and surface water resources.

Saudi Arabia's geography extends from the western coastal region (Tihamah), where the land rises from sea level, to a peninsula-long mountain range (Jabal Al-Hejaz), beyond which lies the plateau of Nejd in the center. The southwestern 'Asir' region has mountains as high as 3,000 m (9,840 ft) and is known for the greenest and freshest climate in the entire Kingdom, one that attracts many Saudis to such resorts as Abha in the summer months. The east is primarily rocky or sandy lowland, which continues to the shores of the Arabian Gulf. The geographically hostile Rub Al Khali ("empty quarter") desert along the Kingdom's imprecisely defined southern borders contains almost no life.

Mostly uninhabited, much of the Kingdom's landmass consists of desert and semi-arid regions, with a dwindling traditional Bedouin population. In these parts of the Kingdom, vegetation is limited to weeds, xerophytic herbs, and shrubs. Less than 2% of the Kingdom's total area is arable land. Population centers are mainly located along the eastern and western coasts and in densely populated interior oases such as Hofuf and Buraydah. Some extended areas, primarily the Rub Al Khali and the Arabian Desert, are unpopulated, although the petroleum industry plans to construct communities there. Saudi Arabia has no permanent year-round rivers or lakes; however, its coastline extends 2,640 km along the Arabia Gulf and the Red Sea which harbors world-class coral reefs including the Gulf of Aqaba.

Native animals include ibex, wildcats, baboons, wolves and hyenas in the mountainous highlands. Small birds are found in the oases. The coastal area on the Red Sea with its coral reefs has a rich marine life.

1.1.1 Population and Water Consumption:

The population increased from 6.9 million in 1972 to 21 million by 2001. As a result, water consumption has increased significantly in the last three decades (Figure 1.1). As shown in this figure, extensive agricultural activities in the 1990s resulted in a high withdrawal of non-renewable water resources. A steady increase in water demand was also observed from 1997 to 2005 (Figure 1.2). The annual water demand in Saudi Arabia was 20,740 million cubic meters (MCM) in 2000 and increased to 22,480 MCM in 2005. This indicates an average yearly increase of 1.7% (Shareef et al., 2005; Chowdhury and Champagne, 2006). Based on this overall increase and trends in sector-wise demands from 2000 to 2005, water demands for 2100 have been estimated as 111,500 MCM (Table 1.1; Figure 1.1). At the current trend, approximately 5,250 billion cubic meters (BCM) of water will be needed in Saudi Arabia to meet the demands from 2010 to 2100, while the total estimated current reserves (non-renewable and renewable groundwater sources) and future contributions through recharges and surface water sources will be approximately 2,700 BCM (Abderrahman, 2001). However, estimates of water availability are also associated with a high degree of uncertainty and it is highly unlikely that all of the reserved water from non-renewable and renewable groundwater sources will be extractable (Abderrahman, 2001)

1.1.2 Climate:

Extreme heat and aridity are characteristic of most of Saudi Arabia. It is one of the few places in the world where summer temperatures above 50°C (122°F) have been recorded, with 51.1°C (124°F) the highest temperature ever recorded in Saudi Arabia at Dhahran in 1956. In winter, frost or snow can occur

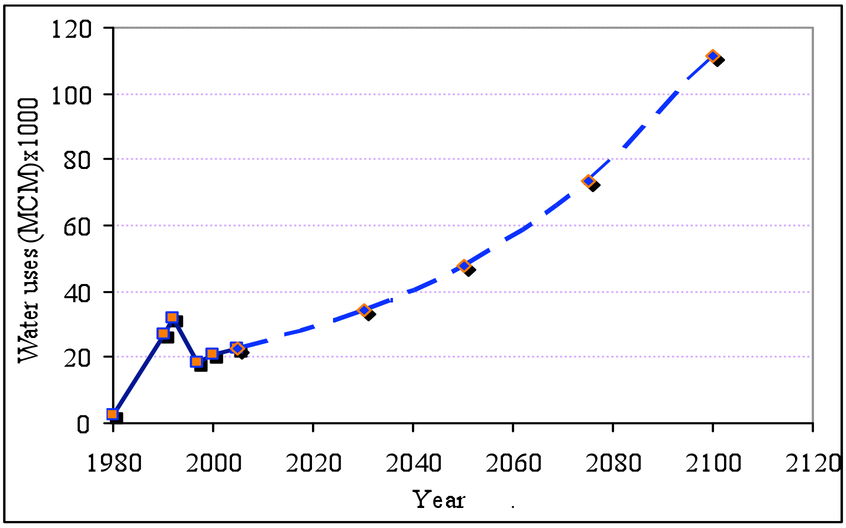

Figure 1.1 Past Water Uses and Future Prediction for Saudi Arabia

	2000		2005		2100 (Predicted)	
	Amount	(%)	Amount	(%)	Amount	(%)
Agricultural	18,540	89.4	19,850	88.3	78,050	70
Domestic	1,750	8.4	2030	9.0	22,300	20
Industrial	450	2.2	600	2.7	11,150	10
Total	20,740	100	22,480	100	111,500	100

Table 1.1 Sector-wise Water Demand (MCM) in Saudi Arabia

in the interior and on the higher mountains, although this only occurs once or twice in a decade. The lowest recorded temperature is -12.0°C (10.4°F) at Turaif. The average winter temperature ranges from 8° to 20°C (47°-68°F) in January in interior cities such as Riyadh and 19° to 29°C (66°-83°F) in Jeddah on the Red Sea coast. The average summer temperature range (in July) is 27° to 43°C (81°-109°F) in Riyadh and 27° to 38°C (80°-100°F) in Jeddah. Night time temperatures in the central deserts can be chilly even in summer, as the sand loses daytime heat rapidly once the sun sets. The annual precipitation is usually sparse (up to 100 mm or 4 in. in most regions), although sudden downpours can lead to violent flash floods in wadis. Riyadh's annual rainfall averages 100 mm (4 in), falling almost exclusively between January and May; Jeddah's average of 54 mm (2.1 in) occurs between November and January. Climate change is any long-term change in weather statistics over periods of time that range from decades to millions of years. It can be expressed as a change in the mean weather conditions, the probability of extreme conditions, or in any other aspect of the statistical distribution of weather. Climate change may occur in a specific region, or across the entire earth. In recent usage, especially in the context of environmental policy, climate change usually refers to changes in modern climate.

The Kingdom of Saudi Arabia ratified the UN Framework Convention on Climate Change (UNFCCC) in December 1994. This convention aims to stabilize the greenhouse gas (GHG) concentrations in the atmosphere at a level that would prevent significant potential changes to the global climate. Being a signatory to the UNFCCC, Saudi Arabia has agreed to develop and submit its National Communications to the Secretariat of the Convention. In continuation of this commitment, the Kingdom of Saudi Arabia has prepared the 'Second National Communication (SNC)' after submitting the "First National Communication" in 2005. This report is comprised of the following ten sections.

1. Introduction
2. Inventory of Greenhouse Gas Emissions for the Year 2000
3. Steps Taken to Address Article 12.1(b) of United Nations Framework Convention on Climate Change (UNFCCC)
4. Technology Development and Transfer in the Kingdom of Saudi Arabia: Current Structure and Trends
5. Analysis of Socioeconomic Impacts of Annex 1 Response Measures
6. Climate and Climate Change Scenarios
7. Vulnerability, Impact Assessment & Adaptation of Saudi Arabian Coastal Zone to Sea Level Rise
8. Vulnerability, Assessment and Adaptation of Water Resources to the Impacts of Climate Change on Saudi Arabia
9. Vulnerability, Assessment and Adaptation of Desert Ecosystem to the Impacts of Climate Change in the Kingdom of Saudi Arabia
10. Vulnerability, Assessment and Adaptation of Biodiversity to the Impacts of Climate Change on Saudi Arabia.

1.2 References:

Abderrahman, W.A. 2001. Water demand management in Saudi Arabia. In: N.I. Farukui, A.K. Biswas, and M.J. Bino (eds.). Water Management in Islam, The International Development Research Centre (IDRC), 68-78 pp.

Chowdhury, S. and P. Champagne. 2006. Use of treated wastewater: evaluation of wastewater minimization strategies using fuzzy technique. In: Proceedings of the Conference on Advanced Technology in the Environmental Field (ATEF), Spain, February 6-8.

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SECTION - 2

Inventory of Greenhouse Gas Emissions for the Year 2000

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Section 2: Inventory of Greenhouse Gas Emissions for the Year 2000

2.1 Introduction:

This section presents the National Inventory of Anthropogenic Emissions by Sources and Removal by Sinks of Greenhouse Gases not controlled by the Montreal Protocol for the year 2000. This inventory has been prepared in response to the Kingdom's commitment to the United Nations Framework Convention on Climate Change (UNFCCC) to submit its second National communication which would include national inventory of anthropogenic emissions and removals by sinks of greenhouse gases for Saudi Arabia according to the Revised 1996 Guidelines of the Intergovernmental Panel for Climate Change (IPCC, 1997).

The Kingdom of Saudi Arabia ratified the United Nations Framework Convention on Climate Change in December 1994. This convention aims to stabilize the greenhouse gas (GHG) concentrations in the atmosphere at a level that would prevent significant potential changes to the global climate. One effective option that has been adopted by various developed countries to obtain this objective is the stabilization of greenhouse gas emissions by the year 2000 at their 1990 levels. Being a signatory to the UNFCCC, Saudi Arabia has agreed to develop a national inventory of greenhouse gas emissions and sinks as part of its National Communication. Accordingly, the Kingdom submitted its First National Communication in 2005 (PME, 2005).

The 2000 national inventory of anthropogenic emissions of greenhouse gas emissions and removal by sinks for the Kingdom of Saudi Arabia was developed according to the Revised 1996 IPCC Guidelines. The major findings including a brief description of the inventory development process are presented in the following sub-sections.

2.2 Objectives:

As mentioned above the main objective of this section was to present a national inventory of anthropogenic emissions of greenhouse gases by sources and removal by sinks for Saudi Arabia addressing the three direct greenhouse gases i.e. CO_2, CH_4 and N_2O as an integral part of the Kingdom's Second National Communication (SNC) to the UNFCCC.

2.3 Inventory Development Process:

The inventory development process included the following major steps.

- Identification of the types of data to be collected from each emission source category and sub-sectors (under each category) as proposed in the Revised 1996 IPCC Guidelines;
- Preparation of a list of government ministries and departments, semi-government and private organizations that would be contacted to collect the required information (identification of the inventory data input sources);
- Development of questionnaires or forms to collect the required information from the selected ministries and organizations (development of questionnaires);
- Collection of inventory data from all the selected ministries and organizations (collection of information);
- Tabulation of the collected data in the IPCC prescribed format;
- Estimation of greenhouse gas emissions/sinks based on methodologies recommended by the Revised 1996 IPCC Guidelines; and
- Development of the national inventory report and summary of total anthropogenic emissions of greenhouse gases and their removals by sinks.

2.4 Data Collection, Emission Factors and Methodologies:

2.4.1 Preparation of Questionnaires:

The Revised 1996 IPCC Guidelines were utilized in the preparation of questionnaires. These Guidelines are in three volumes. Volume 1 consists of general reporting instructions and identifies sectors, sub-sectors and categories of activities that are considered in developing a greenhouse gas inventory of sources and sinks. The methodologies for estimating emissions are discussed in Volume 2 (Workbook) and Volume 3 (Reference Manual) elaborates on the scientific bases of the methodologies and default factors that are used in the calculations of greenhouse gas emissions.

The Revised 1996 IPCC Guidelines for preparing the greenhouse gas inventory were reviewed thoroughly to identify inventory input data requirements for each of the activities given in the documents. The workbook accompanying the Revised 1996 IPCC Guidelines was also checked thoroughly for additional and/or auxiliary information that may be required for calculating emissions of greenhouse gases. Custom-made questionnaires were developed for each targeted organization/company and forwarded to them for their input.

2.4.2 Selection of Target Organizations / Companies:

Based on the input data requirements for calculating greenhouse emissions for each sector and sub-sector given in the Revised 1996 IPCC Guidelines, a list of potential government departments, private organizations, and industrial companies, from which such information should be available/obtained, was prepared. All relevant information sources were consulted in preparation of this list.

2.4.3 Input Data Sources:

The basic information sources prepared during the development of the First National Communication for the Kingdom of Saudi Arabia (PME, 2005) was updated for selection of target organizations to obtain necessary data pertinent to direct greenhouse gas emission sources in the Kingdom. The custom-made questionnaires were prepared and mailed to each of the targeted organizations/companies. The inputs from these organizations/companies were carefully reviewed and analyzed for utilization in the calculations of greenhouse gas emissions. In addition to the questionnaires, various other sources of information were consulted.

2.4.4 Input Data Collection and Tabulation:

The data collected through questionnaires and from other accessible sources were sorted for individual activities for which direct greenhouse gas emissions were to be calculated. Information obtained from different sources for a specific activity was combined, as appropriate. Some of the information requested in the questionnaires was not provided by the respondents. In such cases, appropriate assumptions were made to estimate the missing data.

2.4.5 Selection of Emission Factors and Calculation Methodologies:

In addition to the basic inventory input data, emission factors were needed to calculate greenhouse gas emissions. These emission factors were adopted from the Revised 1996 IPCC Guidelines. Additionally, more accurate country-specific information was also adopted in this study. Calculation methodologies in the Revised 1996 IPCC Guidelines were followed in estimating greenhouse gas emissions in this study.

2.4.6 Uncertainties in Emissions Estimation:

Due to the unavailability of certain source specific input data including emission factors, uncertainties are unavoidable when any estimate of national emissions or removals is made. It is therefore important to establish and express uncertainties quantitatively and/or with the acceptable confidence interval or range. The Revised 1996 IPCC Guidelines provide a general table for relative uncertainties associated with emission factors and activity data, which is limited to CO_2 and CH_4 emissions only.

Uncertainties in emissions estimation basically come from three major sources: input data, assumptions used in selecting the emission factors and adopting extrapolated and/or averaged values in calculations. Uncertainties related to input data depend mainly on the size and quality of data collection and record keeping. Uncertainties involved in selection of emission factors come from the fact that the default values provided in the Revised IPCC Guidelines (1997) were established for a certain group of activities that comprises a number of processes. The nature of a group of activities in a particular country may differ from the generalized nature of the group considered in derivation/establishment of the default emission factors. Similar analogy applies to the variation in source and/or sink characteristics in different countries. Therefore, the default emission factors may not exactly represent and characterize the actual conditions of source/sink activities. In such cases, using these factors to calculate the greenhouse gas emissions would result in high uncertainties.

Uncertainties also appear when the unavailability of input data compels the use of extrapolated and/or averaged values for a particular set of data. Uncertainty of extrapolated or averaged data cannot be quantified precisely because the uncertainties associated with the interpolation and/or averaging procedures also depend on the quality of the relevant data including accuracy.

2.4.6.1 Input Data:

The raw data provided by the government organizations were considered to be accurate while the raw data supplied by the private sectors were considered to be accurate in some cases and the uncertainty of raw data were considered to vary within 5% to 10% in others. As mentioned above, the uncertainties involved in estimation of missing data were not quantified since it was not possible to establish uncertainty levels associated with the extrapolated and/or averaged values adopted in emissions calculations.

2.4.6.2 Emission Factors:

The uncertainties associated with the emission factors used in this study were taken from the IPCC Guidelines (1997) and ranged between 7 and 55%.

2.4.6.3 Overall Emissions Estimation:

The overall uncertainty of CO_2 and CH_4 emissions were estimated according to the Revised IPCC Guidelines (1997). Uncertainties in emission estimates for N_2O were not determined due to the unavailability of relevant data, and/or methodology in the IPCC Guidelines.

2.5 Summary of Overall Greenhouse Gas Emissions and Sinks:

2.5.1 Overview of National Greenhouse Gas Emissions and Sinks:

The 2000 greenhouse gas emission inventory for Saudi Arabia is summarized in Table 2.1. The details of estimated greenhouse gas emissions from various activities associated with sub-sectors in each sector are presented in Table 2.2. The inventory included the direct greenhouse gases; namely, carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Emissions of these gases were calculated for the energy, industrial processes, agriculture, land-use change and forestry, and waste sectors in the Kingdom. Greenhouse gas emissions from the various uses of paints and solvents have not been recommended by the Revised 1996 IPCC, thus, they were not included in this report. The major findings pertaining to individual greenhouse gases are summarized below.

- CO_2 emissions in Saudi Arabia in 2000 were 257,970 Gg and CO_2 sinks were 14,169 Gg. As shown in Table 2.1, the energy sector contributed 92.1% of the total CO_2 emissions, followed by the industrial processes sector (7.4%) and the agriculture sector (0.5%). The major source categories contributing to these CO_2 emissions (contributions $\geq$ 2% of the total emissions) were electricity generation (33%), road transport (21%), desalination (11%), petroleum refining (8%), agriculture (5%), cement production (4%), cement industry (3%), petrochemical industry (3%), fertilizer industry (3%) and iron and steel production (2%) (Figure 2.1).

Table 2.1 Summary of Direct Greenhouse Gas Emissions Inventory for Saudi Arabia

Source Sector	Quantity Emitted (Gg)		
	CO_2	CH_4	N_2O
Energy*	237,547 (92.1)**	345.61 (26.34)	1.44 (3.79)
Industrial processes	19,173 (7.4)	11.18 (0.85)	
Agriculture	1,250 (0.5)	89.70 (6.84)	33.70 (88.63)
Land-use change and forestry	-14,169*** (5.6)		
Waste		865.50 (65.97)	2.88 (7.58)
Total Emissions	**257,970**	**1,312**	**38**
Net Emissions******	**243,800**	**1,312**	**38**

* *As per the IPCC Guidelines, emissions from International Aviation & Navigation Bunkers were not included in Total Emission*
** *Numerals in brackets are percentages of Total Emissions;*
*** *Minus sign indicates sink*
**** *Total emissions minus sinks.*

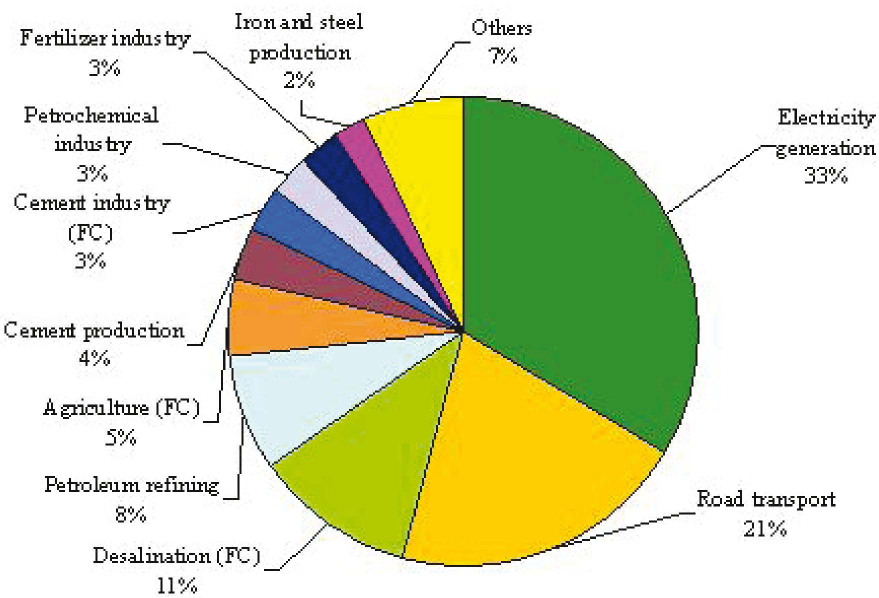

Figure 2.1 Relative Contributions of Major Source Categories to CO_2 Emissions of 257,970 Gg (Data From Table 2.3).

Table 2.2 Overview of National Direct Greenhouse Gas Emissions Inventory for Saudi Arabia.

SOURCE AND SINK CATEGORIES	CO_2 (Gg)	CH_4 (Gg)	N_2O (Gg)
Total National Emissions	**257,970.00**	**1,311.99**	**38.03**
Net National Emissions	**243,800.00**	**1,311.99**	**38.03**
1. Energy*	**237,547.00**	**345.61**	**1.44**
A. Fuel combustion	***233,680.00***	***18.49***	***1.44***
1. Energy industries	107,292.00	3.38	0.56
2. Manufacturing industries and construction	23,609.00	1.85	0.07
3. Transport	57,686.00	10.96	0.57
4. Other Sub-sectors	45,093.00	2.31	0.20
B. Fugitive emissions from fuels	***3,867.00***	***327.12***	-
2. Industrial processes	**19,173.00**	**11.18**	**0.00**
A. Mineral products	9,779.00	-	-
B. Chemical industry	3,554.00	11.18	-
C. Iron and steel production	5,840.00	-	-
3. Solvent and other product use**			
4. Agriculture	**1,250.00**	**89.70**	**33.71**
A. Enteric fermentation	-	74.64	-
B. Manure management	-	12.78	9.30
C. Agricultural soils	-	-	24,362.00
D. Field burning of agricultural residues	1,250.00	2.27	0.04
5. Land-use change and forestry	**-14,169.00**	**0.00**	**0.00**
A. Changes in forest and other woody biomass stocks	-5,694.50	-	-
B. Forest and grassland conversion	-4,004.00	-	-
C. Abandonment of managed lands***		-	-
D. CO_2 emissions and removal from soil	-4,470.00	-	-
6. Waste	**0.00**	**865.50**	**2.88**
A. Solid waste disposal on land	-	764.87	-
B. Wastewater handling	-	10.10	-
C. Human sewage	-	-	2.88
D. Industrial wastewater	-	90.53	

* *As per the IPCC Guidelines, emissions from international aviation and navigation bunkers were not included in energy total;*

* * *Estimation of greenhouse gas emissions from the various uses of paints and solvents have not been recommended by the Revised 1996 IPCC Guidelines.*

*** *No abandonment of managed lands in Saudi Arabia was assumed.*

Table 2.3 Carbon Dioxide (CO_2) Emissions from Major Source Categories.

Source Categories	CO_2 (Gg)	Percent of Total
Electricity generation	86,744.3	33
Road transport	53,070.8	21
Desalination (FC)*	28,482.3	11
Petroleum refining	20,547.7	8
Agriculture (FC)	13,877.8	5
Cement production	9,405.8	4
Cement industry (FC)	7,769.0	3
Petrochemical industry	7,090.2	3
Fertilizer industry	7,054.6	3
Iron and Steel production	5,840.0	2
Others **	18,087.2	7
Total	**257,970**	**100**

** Fuel Combustion [1] Fugitive Emission*

*** Others include the following source categories:*

Ammonia production (3,553.6 Gg)
Aviation –national (3,270.8 Gg)
Oil and gas transportation-FE[1] (2,997.5 Gg)
Residential (2,733.1 Gg)
Iron and steel production (1,490.3 Gg)
Navigation-national (1,295.9 Gg)
Field burning of crop residues (1,249.6 Gg)
Oil and gas production-FE (584.7 Gg)
Limestone use (352.7 Gg)
Oil refining-FE (250.9 Gg)
Other industries (205 Gg)
Railways (48.2 Gg)
Gas processing –FE (23.4 Gg)
Soda ash production and uses (21.2 Gg)
Oil and gas exploration-FE(10.4 Gg)

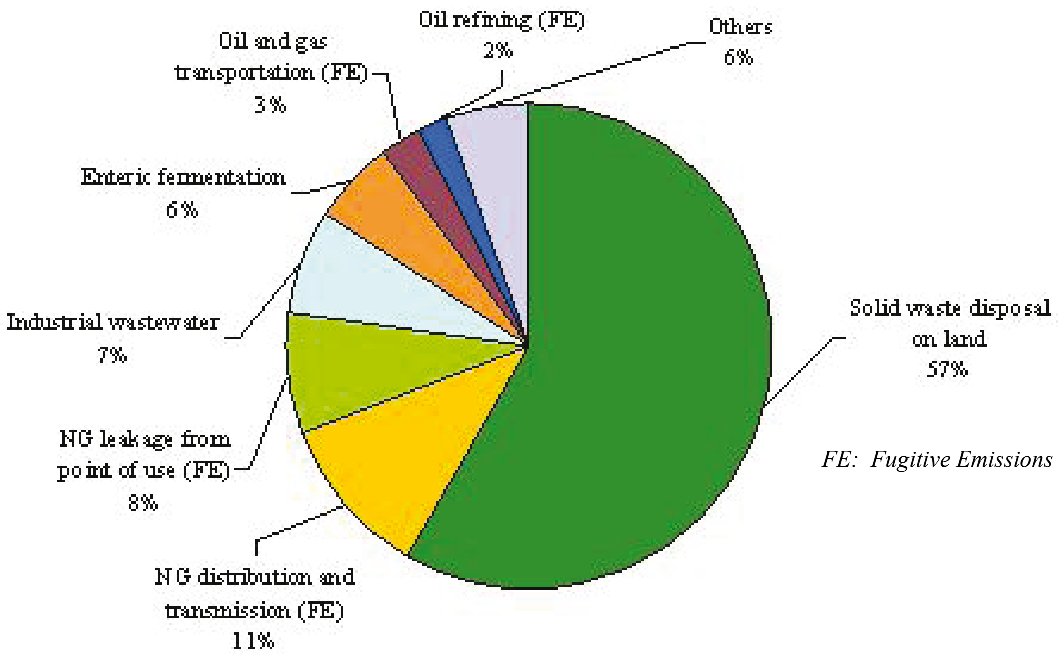

Figure 2.2 Relative Contributions of Major Source Categories to CH_4 Emissions of 1,312 Gg (Data from Table 2.4).

- CH_4 emissions were 1,312 Gg as shown in Table 2.1. The waste sector contributed 65.97% of the total CH_4 emissions followed by the energy (26.34%), agriculture (6.84%) and the industrial processes (0.85%) sectors. The major source categories contributing to CH_4 emissions (2% of the total emissions) are shown in Figure 2.2.
- N_2O emissions were 38 Gg as shown in Table 2.1. The agriculture sector was the major contributor with 88.63%, followed by the waste (7.58%) and energy (3.79%) sectors. Major source categories contributing to N_2O emission (2% of the total emissions) are shown in Figure 2.3.

Table 2.4 Methane (CH_4) Emissions from Major Source Categories.

Source Categories	CH_4 (ton)	Percent of Total
Solid waste disposal on land	764,871.4	57
NG distribution and transmission (FE)*	141,975.3	11
NG leakage from point of use (FE)	105,278	8
Industrial wastewater	90,526.0	7
Enteric fermentation	74,643.6	6
Oil and gas transportation (FE)	35,426.5	3
Oil refining (FE)	25,927.9	2
Others**	73,3338.2	6
Total	**1,311,987**	**100**

** Fugitive emission*

** *Others include the following source categories:*
Manure management(12,780.3 tons)
Chemicals production(11,181 tons)
Road transport(10,293.1 tons)
Wastewater handling(10,103 tons)
Oil and gas production (FE)(10,057.4 tons)
Gas processing (FE)(8,328.2 tons)
Electricity generation(2,958.4 tons)
Field burning of crop residues(2,272.1 tons)
Agriculture (FC)(1,892.6 tons)
Petrochemical industry(635.1 tons)
Fertilizer industry(631.9 tons)
Aviation-national(572.5 tons)
Cement industry (FC)(429.3 tons)
Petroleum refining(421 tons)
Residential (FC)(217.8 tons)
Desalination (FC)(201.5 tons)
Iron and steel industry(133.5 tons)
Oil and gas exploration (FE)(122 tons)
Navigation-national(86.4 tons)
Other industries(18 tons)
Railways(3.3 tons)

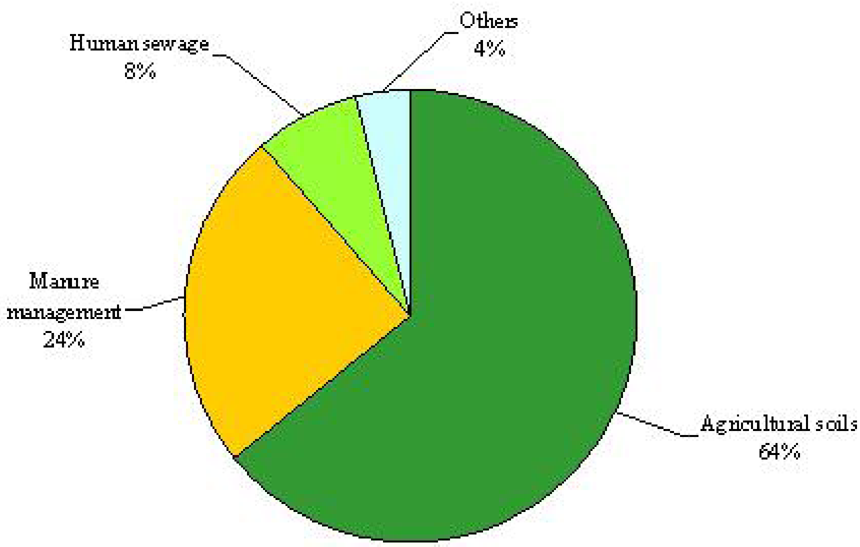

Figure 2.3 Relative Contributions of Major Source Categories to N_2O Emissions of 38 Gg (Data from Table 2.5).

Table 2.5 2000 Nitrous Oxide (N_2O) Emissions from Major Source Categories.

Source Categories	N_2O (ton)	Percent of Total
Agricultural soils	24,362.5	64
Manure management	9,303.7	24
Human sewage	2,882.8	8
Others*	1,479.8	4
Total	**38,029**	**100**

** Others include the following source categories:*
Electricity generation (545.7 tons)
Road transport (451.1 tons)
Agriculture (FC) (113.6 tons)
Aviation-national (107.6 tons)
Desalination (FC) (83.6 tons)
Petroleum refining (54.2 tons)
Cement industry (FC) (41.6 tons)
Field burning of crop residues (39 tons)
Petrochemical industry (12.7 tons)
Fertilizer industry (12.6 tons)
Navigation-national (10.4 tons)
Residential (FC) (4.4 tons)
Iron and steel industry (2.7 tons)
Other industries (0.4 tons)
Railways (0.4 tons)

2.5.2 Uncertainties in Greenhouse Gas Emission Estimations:

In this study, the raw data provided by the government organizations were considered to be accurate. However, the uncertainty of the raw data supplied by the private sectors was assumed to vary within 10%. The overall uncertainties of CO_2 and CH_4 emissions were estimated to be in the range of 7-15% and 25-60%, respectively (as per the IPCC Guidelines). Uncertainties in emission estimates for N_2O could not be determined due to the unavailability of methodology and/or the emission factors in the Revised 1996 IPCC Guidelines. Uncertainties involved in using extrapolated values, yearly averaged values, or both were not established. Uncertainties due to exclusion of some sources were also not assessed.

2.6 Contributions of Major Sectoral Activities to 2000 Greenhouse Gas Emissions:

The contributions of major activities associated with the energy, industrial processes, agriculture, land-use change and forestry, and waste sectors in the Kingdom to the 2000 greenhouse gas emission inventory for Saudi Arabia is presented in Table 2.2. The main findings pertaining to individual greenhouse gases are summarized below.

2.6.1 Energy Sector:

The energy sector is the most important contributor to greenhouse gas emissions, especially carbon dioxide (CO_2) emissions. Different activities considered in the energy sector are presented in Figure 2.4. Greenhouse gas emissions from energy-related stationary and mobile combustion source categories were considered in this sector. These sources included electricity generation, petroleum refining, manufacturing industries and construction, and transportation (road transport, civil aviation, navigation, and railways). Residential, desalination, agriculture and fisheries, and waste management activities were also accounted for. In addition to the combustion sources, fugitive emissions from fuels in the oil and gas industry, including venting and flaring, were considered.

The emissions of CO_2, CH_4 and N_2O from various activities in this sector were estimated and are summarized in Table 2.2. The total CO_2, CH_4 and N_2O emissions from this sector were 237,547 Gg, 345.61 Gg, and 1.44 Gg respectively.

2.6.1.1 Emissions from Fuel Combustion:

- Emissions from the **electricity generation** category were 86,744 Gg CO_2, 2.96 Gg CH_4 and 0.55 Gg N_2O. Crude oil combustion accounted for 35% of CO_2 emissions, followed by natural gas

(30%), diesel oil (27%) and residual fuel oil (8%). Combustion of crude oil, diesel oil, natural gas and residual fuel oil contributed 43%, 32%, 16% and 9% of CH_4 emissions, respectively. About 46% of N_2O emissions were contributed by the combustion of crude oil, followed by the combustion of diesel oil (35%), residual fuel oil (10%) and natural gas (8%).

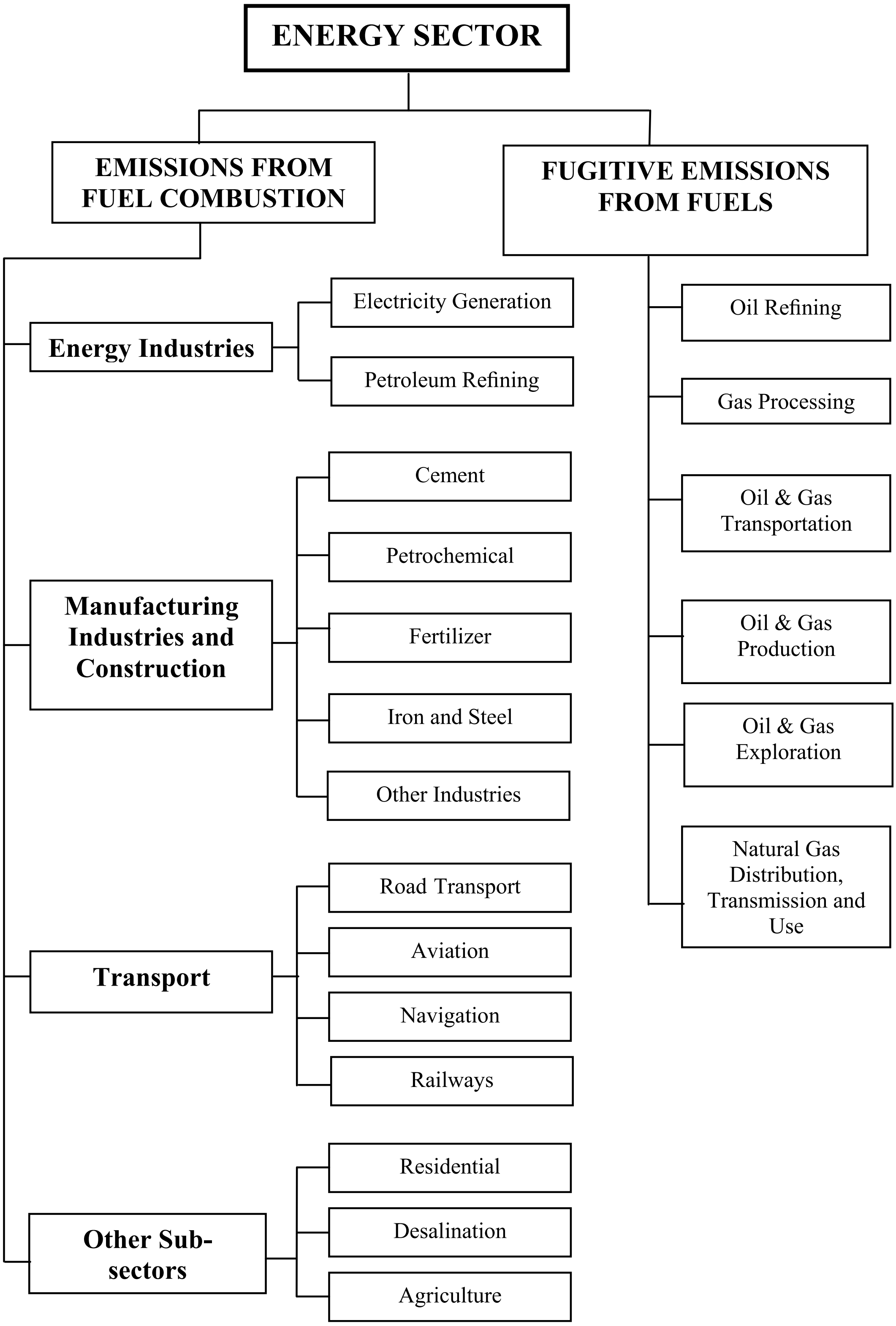

Figure 2.4 Activities Considered in the Energy Sector.

- The **petroleum refining** category encompasse s activities related to oil refining, gas processing, oil and gas production, oil and gas transportation, and oil and gas exploration. Emissions from petroleum refining were 20,547 Gg CO_2, 0.421 Gg CH_4, and 0.054 Gg N_2O. Fuel combustion associated with gas processing activities was the major contributor to CO_2 emissions, followed by those generated by the fuel combusted in the oil refining activities. The emissions of CH_4 and N_2O from different activities of petroleum refining followed the opposite trends to those of CO_2 emissions.
- The **manufacturing industries and construction** category consists of activities related to the cement industry, petrochemicals manufacturing, fertilizer production, iron and steel production, and other industries. Total emissions from fuel combustion in these activities were 23,609 Gg CO_2, 1.85 Gg CH_4, and 0.07 Gg N_2O. Activities related to the cement, petrochemical, and fertilizer industries were the largest contributors to CO_2 and N_2O emissions from the manufacturing industries and construction category.
- The **road transportation** category was one of the major sources of greenhouse gas emissions. Automobiles emitted 53,071 Gg CO_2, 10.29 Gg CH_4 and 0.45 Gg N_2O. Gasoline combustion was the major contributor to the emissions of three direct greenhouse gases.
- The **aviation** category was divided into national and international aviation combustion sources. The greenhouse gas emissions from national aviation combustion sources were 3,271 Gg CO_2, 0.57 Gg CH_4, and 0.11 Gg N_2O. The emissions from international aviation combustion sources were 2,964 Gg CO_2, 0.09 Gg CH_4 and 0.095 Gg N_2O. However, the emissions from the combustion for international aviation category were not included in the 2000 greenhouse gas emissions inventory as per the Revised 1996 IPCC Guidelines.
- The **navigation** category was divided into national and international bunker combustion sources. The emissions from national bunker combustion sources were 1,296 Gg CO_2, 0.09 Gg CH_4, and 0.01 Gg N_2O. The emissions from international bunker combustion sources were 4,427 Gg CO_2, 0.29 Gg CH_2, and 0.04 Gg N_2O. However, the emissions from the international combustion for navigation category were not included in the 2000 greenhouse gas emissions inventory as per the Revised 1996 IPCC Guidelines.
- The **residential activities** relate to the combustion of liquefied petroleum gas. Emissions from fuel combustion in the residential activities category were 2,733 Gg CO_2, 0.22 Gg CH_2 and <0.01 Gg N_2O.
- The **desalination** plants combust heavy fuel oil, crude oil, diesel oil, and natural gas. Emissions from fuel combustion in the desalination plants category were 28,482 Gg CO_2, 0.20 Gg CH_4 and 0.08 Gg N_2O.
- In the **agricultural** category, off-road vehicles (such as tractors, bulldozers etc.), irrigation, and the activities related to poultry and dairy farms were considered (from fuel combustion only). Emissions from the agricultural activities category were 13,878 Gg CO_2, 1.89 Gg CH_4 and 0.11 Gg N_2O.

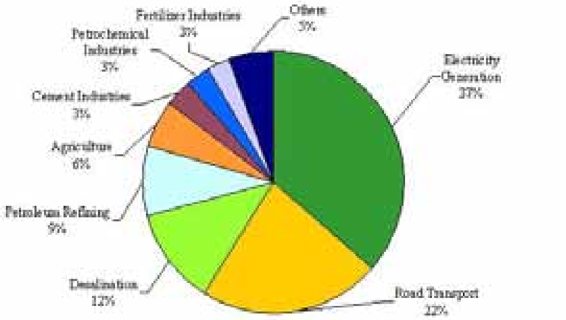

Figure 2.5 Relative Contributions of Major Activities to CO_2 Emissions from Energy Sector.

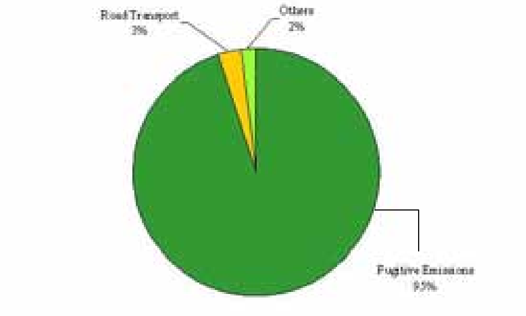

Figure 2.6 Relative Contributions of Major Activities to CH_4 Emissions from Energy Sector.

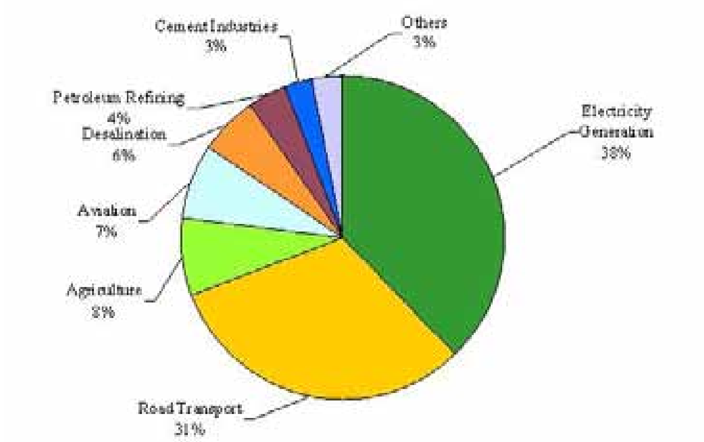

Figure 2.7 Relative Contributions of Major Activities to N_2O Emissions from Energy Sector.

2.6.1.2 Fugitive Emissions from Fuels:

The fugitive emissions (non-combustion and non-productive combustion emissions) were the major source of CH_4 in the energy sector (95%) and accounted for about 327.12 Gg CH_4. Oil refining, gas processing, oil and gas production, transportation, exploration, venting and flaring, and leakage from distribution, transmission and point of use were considered in the above estimate. Approximately 72% of CH_4 emissions in this sector were generated from leakage of natural gas during distribution, transmission and use. Oil and gas related activities including exploration, production, transportation, processing, oil refining activities, flaring and venting accounted for 24% of CH_4 emissions. All other activities accounted for about 4% of CH_4 emissions. Gas flaring from oil and gas related activities emitted 3,867 Gg of CO_2.

The relative contributions of the major activities (emitting ≥ 2% of the sectoral total) to CO_2, CH_4, and N_2O emissions in the energy sector are presented in Figures 2.5, 2.6 and 2.7 respectively.

2.6.2 Industrial Processes Sector:

Greenhouse gas emissions are produced from a variety of industrial activities which are not related to energy use. The main emission sources are industrial production processes, which chemically or physically transform materials to greenhouse gases. Cement production, limestone uses, soda ash uses, ammonia production, chemicals production and iron and steel manufacturing are some of the important activities of the Saudi industrial sector that are considered in this section. The major source categories in industrial processes from which greenhouse gas emissions have been estimated are presented in Figure 2.8.

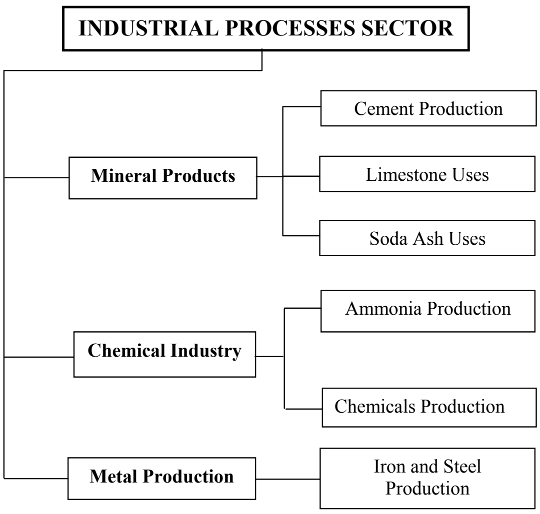

Figure 2.8 Activities Considered in the Industrial Processes Sector.

The emissions of CO_2, CH_4 and N_2O from various industrial processes were estimated and are summarized in Table 2.2. A total of 19,173 Gg of CO_2 was emitted from mineral products (51%), metal production (30%) and chemical industry (19%). Cement production emitted the highest amount of CO_2(49%) followed by iron and steel production (30%) and ammonia production (19%).

The chemicals production was the sole contributor to a total of 11.18 Gg of CH_4 emissions in this sector. No N_2O was emitted from this sector.

The relative contributions of the major activities (emitting ≥ 2% of the sectoral total) to CO_2 emission in the industrial processes sector is presented in Figure 2.9.

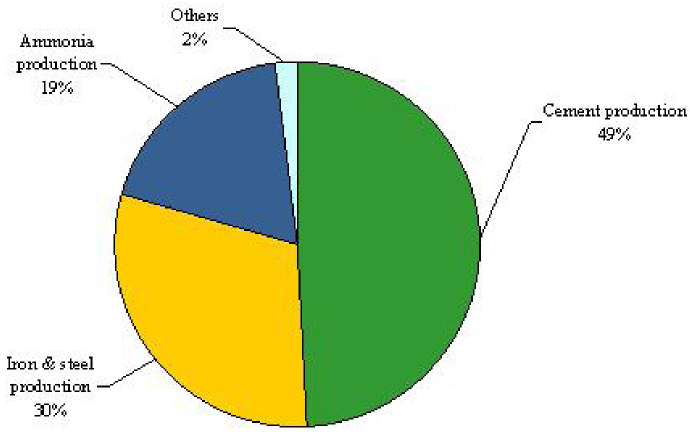

Figure 2.9 Relative Contributions of Major Activities to CO_2 Emissions from Industrial Processes Sector.

2.6.3 Agriculture Sector:

Saudi Arabia is a desert country where irrigation-based agriculture is neither well developed nor extensive. Shortage of good quality irrigation water is the foremost limitation. The Revised 1996 IPCC Guidelines recommended agricultural activities for estimating greenhouse gas emissions are presented in Figure 2.10.

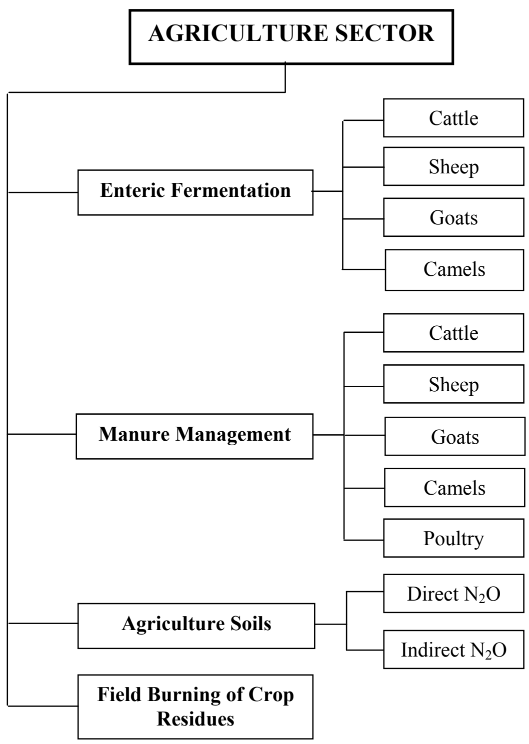

Figure 2.10 Activities Considered in the Agriculture Sector.

Greenhouse gas emissions from livestock (enteric fermentation and manure management), soils, and field burning of agricultural residues are considered in this section. Cattle, sheep, goats, camels and poultry constituted the livestock population in Saudi Arabia. CH_4 and N_2O emissions were the most important greenhouse gases emitted by the activities related to livestock. The estimated greenhouse gas emissions from the agricultural sectors are presented in Table 2.2. The total CO_2, CH_4 and N_2O emissions from various activities of agriculture sector were 1,250 Gg, 89.7 Gg and 33.7 Gg respectively.

The CH_4 emissions from enteric fermentation, manure management and field burning of crop residues were estimated at 74.64 Gg, 12.78 Gg, and 2.27 Gg, respectively. The N_2O emissions from manure management, agricultural soils (direct and indirect) and field burning of crop residues were estimated at 9.30 Gg, 24.36 Gg, and 0.04 Gg respectively. Field burning of crop residues also emitted 1,250 Gg CO_2. For agricultural soils, as per the IPCC Guidelines, only N_2O emissions were estimated.Enteric fermentation, manure management and field burning of crop residues contributed 83%, 14% and 3% to the total CH_4 emissions from the agriculture sector, respectively. Agricultural soils accounted for 72% of the total N_2O emissions in the agriculture sector followed by 28% from manure management. Field burning of crop residues was the sole source of CO_2 in the agriculture sector.

The relative contributions of the major activities (emitting ≥ 2% of the sectoral total) to CH_4, and N_2O emissions in the agriculture sector are presented in Figures 2.11 and 2.12 respectively.

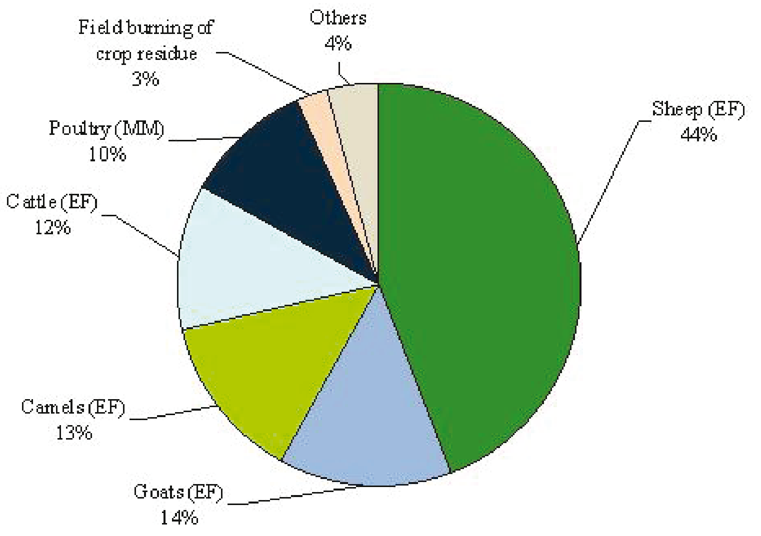

Figure 2.11 Relative Contributions of Major Activities to CH_4 Emissions from Agriculture Sector

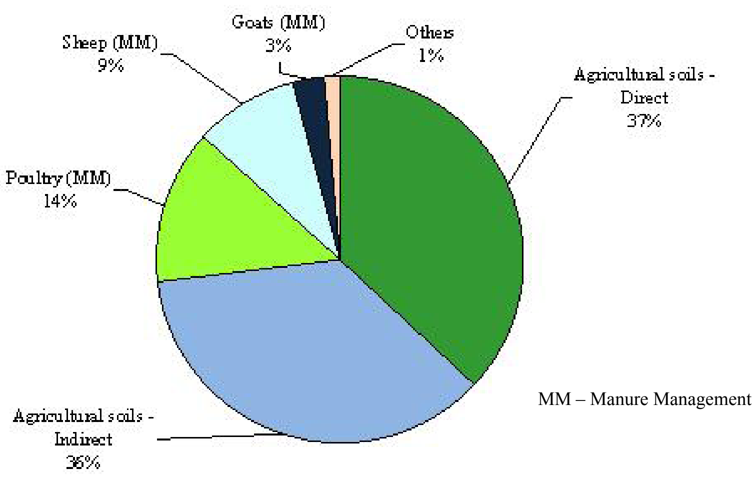

Figure 2.12 Relative Contributions of Major Activities to N_2O Emissions from Agriculture Sector.

2.6.4 Land-use Change and Forestry Sector:

Calculations of greenhouse gas emissions from land-use change and forestry focus upon four activities (Figure 2.13) that are sources or sinks of CO_2. Activities considered in this section include changes in forests and other woody biomass stocks, forest and grassland conversion, abandonment of managed lands, and uptake by soil from land-use change and management. The estimated greenhouse gas emissions from this sector are presented in Table 2.2. A total of 14,169 Gg of CO_2 sink was estimated from various activities related to this sector.

2.6.4.1 Sinks:

- Changes in the forest and other woody biomass provided a sink for 5,695 Gg of CO_2.
- Forest and grassland conversion to agricultural uses converted 4,004 Gg of atmospheric CO_2 to plant material (acting as a sink for CO_2).
- Due to land-use changes, agricultural soils accumulated (acted as sinks) 4,470 Gg of atmospheric CO_2.
- The total sink from the land-use change and forestry sector was 14,169 Gg of CO_2.
- In general, CO_2 exchange (uptake or release) by oceans are not anthropogenic. Therefore, marine sinks (the Arabian Gulf and the Red Sea) were not included in this inventory.

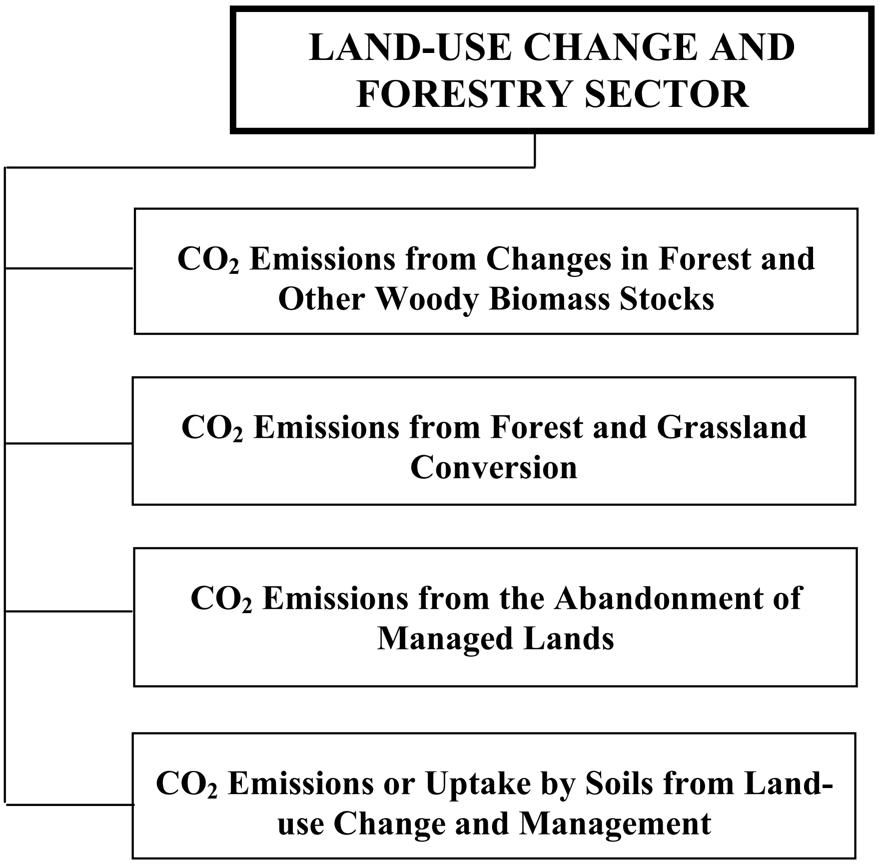

Figure 2.13 Activities Considered in the Land-Use Change and Forestry Sector.

2.6.4.2 Emissions:

No significant emissions of CO_2 from the land-use change and forestry sector is expected in Saudi Arabia considering that wood is not generally burned for fuel in the Kingdom.
The relative contributions of the major CO_2 sinks in the land-use change and forestry sector are presented in Figure 2.14.

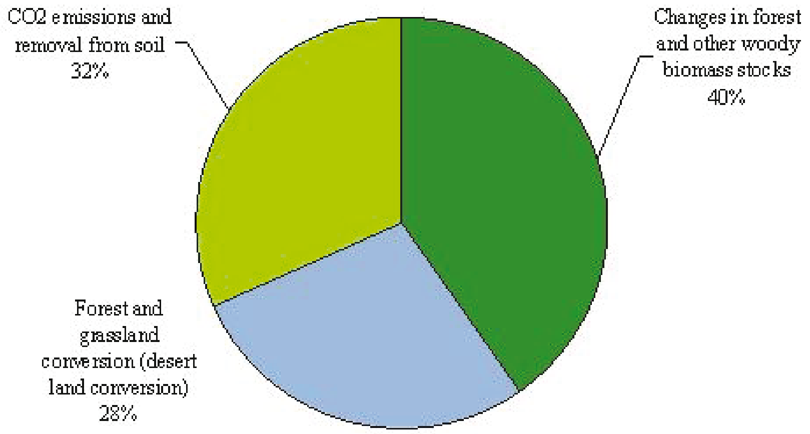

Figure 2.14 Relative Contributions of the Major Sinks to CO_2 Emissions from Land-Use Change and Forestry Sector.

2.6.5 Waste Sector:

The Revised 1996 IPCC Guidelines recommend consideration of greenhouse gas emissions from landfilling of solid wastes, treatment of liquid wastes (wastewater), and waste incineration activities. Waste incineration activities in Saudi Arabia are very limited and are not addressed. Solid wastes and wastewater disposal practices are considered in this section. The activities considered in the waste sector are shown in Figure 2.15. The emission estimations are summarized in Table 2.2. The total CH_4 and N_2O emissions from various activities of this sector were 865.5 Gg and 2.9 Gg, respectively.

Solid waste management practices emitted 765 Gg of CH_4. Municipal and industrial wastewater handling emitted 101 Gg of CH_4. N_2O emissions from human sewage were estimated to be 2.88 Gg. Solid waste disposal contributed more than 89% of total CH_4 in the waste sector followed by industrial wastewater handling (10%). The sole contributor to N_2O emission in the waste sector was human sewage.

The relative contributions of various activities to CH_4 emission in the waste sector are presented in Figure 2.16.

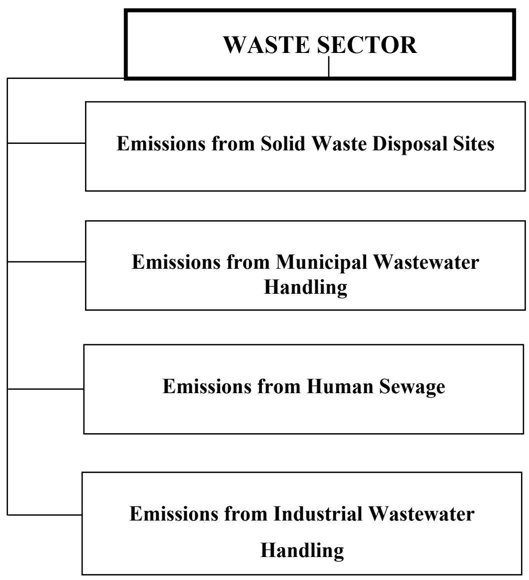

Figure 2.15 Activities Considered in the Waste Sector.

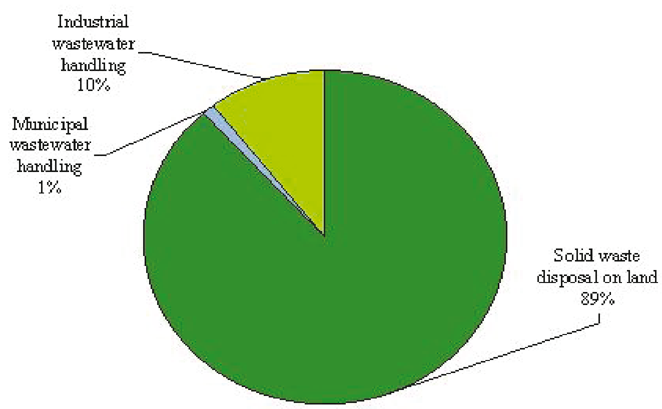

Figure 2.16 Relative Contributions of Various Activities to CH_4 Emissions from the Waste Sector.

2.7 References:

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- PME (2005). First National Communication for the Kingdom of Saudi Arabia – submitted to UNFCCC by the Presidency of Meteorology and Environment, Jeddah, Saudi Arabia.

SECTION - 3

Steps Taken to Address Article 12.1(B) of the United Nations Framework Convention on Climate Change (UNFCCC)

TABLE OF CONTENTS

Section 3: Steps Taken to Address Article 12.1(B) of the United Nations Framework Convention on Climate Change (UNFCCC)

3.1 Introduction:

In line with the Kingdom's strong commitment to sustainable development, the Kingdom ratified the United Nations Framework Convention on Climate Change (UNFCCC) and has accessed to the Kyoto Protocol (UNFCCC, 2005). Being a signatory, Saudi Arabia is required to address Article 12.1(b) of the UNFCCC.

The Kingdom is showing keen interest at the national level in the development of Renewable Energy Sources (RES) and Rational Use of Energy (RUE). It is expected that the use and development of RES and RUE can make a significant contribution to the improvement of environmental protection (Bertelsmann Foundation, 2002; Gelil and Kandil, 2004). The Kingdom adopted holistic approach by exerting its sincere efforts in almost all the sectors which affect the environment, to ensure sustainable environment for the present and future generations.

A brief description of various steps and initiatives of the Kingdom to achieve sustainable development and at the same time address Article 12.1(b) of UNFCCC follows.

3.2 Rational Use of Energy Initiatives:

- The Ministry of Water and Electricity (MOWE) has initiated several steps to implement energy conservation and to reduce peak load demand which include the formation of an Energy Conservation and Awareness Department, imposing limits to the maximum power that can be delivered to electricity consumers, establishing demand-side management actions, and rationalizing the use of electricity (Al-Ajlan et al., 2006). It is estimated that 871 MW peak load reductions were achieved by various sectors during 2001. Moreover, MOWE in collaboration with SEC has implemented procedures enabling the commercial, governmental, agricultural, and industrial sectors to reduce and shift peak loads and organized workshops and seminars to promote public awareness of energy conservation.
- An energy saving program known as National Energy Efficiency Program (NEEP) was launched nationwide to use all means to conserve the energy in all sectors right from a single house to an industry.
- Thermal Energy Storage (TES) offers a way of reducing the electrical demand in large commercial buildings (Hasnain et al., 1999a). TES appears to be a feasible option that favors the conditions and other aspects of cool storage applications in Saudi Arabia.

3.3 Renewable Energy Sources Conversion Initiatives:

3.3.1 Wind Energy Conversion Initiatives:

- Small and large wind energy conversion systems have been installed at Yanbu and Al-Wajh on the Red Sea coast, Dhahran on the Arabian Gulf coast and Qaisumah in the north east of the Kingdom as a part of feasibility study of wind energy utilization (Amin and El-Samanoudy, 1985).
- Saudi Aramco installed two wind turbines each of 6 kw at two different remote locations to generate power for the communication towers.
- A Center of Research Excellence in Renewable Energy at King Fahd University of Petroleum & Minerals (KFUPM) was established in the year 2007. The aim of the center is to further enhance the scientific/technological development in all the major areas of renewable energy.

3.3.2 Solar Energy Conversion Initiatives:

- The Solar Village designed and operated in late seventies and early eighties was aimed to produce solar energy to provide power to remote villages. (Huraib et al., 1996).

- A 350 kW solar hydrogen production demonstration plant was started in 1993 in solar village about 50 km North West of Riyadh (Huraib et al., 1996).
- A solar-powered seawater desalination pilot plant was completed in 1984 at the coastal city of Yanbu, which uses an indirect-contact heat-transfer freeze process to produce 200 m3 of potable water per day (Thompson, 1987).
- A PV-powered water pumping and R.O. desalination plant was installed in 1994 at Sadus Village near Riyadh with a capacity of 24 m3 per day (Alawaji, 2001).
- Saudi Atlas Project for the exact measurements of solar radiation in the Kingdom has been completed.
- The Solar Thermal Dish Project was aimed to produce 50 kw of electrical power from each thermal dish (Alawaji, 2001).
- PV systems have been used to power highway devices in remote locations. (Alawaji and Eugenion, 1993).
- 03 and 06 kw PV power systems were installed in the Solar Village in order to evaluate the climate effects on the efficiency and output of PV systems and their integration with the electric grid (Smiai et al., 1998).
- As part of rural areas school lighting, PV lighting systems were used for 20 government run schools scattered throughout rural areas of the Kingdom. (Hasnain et al., 1999b).
- Research studies have also been conducted to develop efficient systems for drying dates using solar energy (Alawaji, 2001).
- Studies have been conducted to design, fabricate and test solar water heating systems (SWHS) (Alawaji, 2001).
- A plant to produce 7,500 tons of poly-silicon will be fully operational in 2013. A solar desalination plant to serve 100,000 people is under development at Al Khafji to be completed in the year 2013.
- A 2MW solar park in King Abdullah University of Science and Technology (KAUST) which includes combining over 9,300 high-efficiency solar modules to provide 3,332 megawatt hours of clean energy annually. Saudi Arabia has two factories producing flat plate collectors (Doukas et al., 2006). Solar and Photo-voltaics Engineering Research Center at KAUST will actively contribute to student education, alternative energy awareness for decision makers and community, active engagement with industry and technology development. It will attempt to provide the foundation for innovation in efficient and low-cost disruptive PV foundational technologies.
- MIT and KFUPM are collaborating to conduct research on the technologies related to the production of fresh water and low-carbon energy.

3.3.3 Hybrid System Initiative:

- A wind-diesel hybrid system is developed for remote villages that are far away from the available grid (Alawaji, 1996).

3.3.4 Other Renewable Energy Conversion Initiatives:

- The Kingdom embarked on a massive agricultural experiment that can help in the assessment of the potential of utilization of biomass as a source of energy (Aljarboua, 2009).
- A study has been conducted for the use of geothermal energy which is recognized as a cost effective form of energy (Sharqawy et al. 2009).
- A program was initiated for hydrogen utilization for domestic, agriculture and industrial applications (Alawaji, 2001). R&D activities on Phosphoric Acid Fuel Cells (PAFC) were also initiated.

- Locally available internal combustion engines and ceramic mantle gas lamps have been modified to use hydrogen as a fuel for small-scale demonstration purposes (Alawaji, 2001). A commercial thermoelectric power generator, supposed to be fuelled by methane or propane, has been modified to operate using hydrogen.
- A Royal Decree was issued in April 2010 to establish King Abdullah City for Atomic and Renewable Energy (KACARE). It aims to contribute to achieving sustainable development in the Kingdom through exploring and exploiting science, research and industry of atomic and renewable energy for peaceful purposes.
- The researchers at KFUPM are actively participating in fuel cell research since 1980s. The efforts are directed to develop Proton Exchange Membrane (PEM) fuel cell system emphasizing three different aspects such as developing novel low cost proton conducting membranes, developing multifunctional catalyst system and development of hydrocarbon based fuel processing systems.

3.4 Carbon Capture and Management Initiatives:

- In line with the corporate commitment and part of environmental stewardship program, Saudi Aramco is participating in a number of research and technology programs with leading national and international organizations to address greenhouse gas emissions by improving combustion efficiency, reducing carbon dioxide emissions and implementing carbon management (CM).
- Saudi Aramco operates the world's largest single gas collection system (Master Gas Collection System) that reduced the flaring emission from oil-gas production activities by more than 99% during the period between 1997 and 2000.
- Saudi Aramco developed a CM technology roadmap which aims toward enhancing petroleum presence in global CM technological development, leveraging petroleum industry resources and know-how, and enhancing the value created from the carbon cycle.
- Saudi Aramco arranged first regional symposium on CM titled "Carbon management challenges and opportunities for the petroleum industry". It was held in Dhahran in May 2006.
- Saudi Aramco will design and implement the first CO_2-EOR demonstration project in Saudi Arabia. This project will be implemented in a small area at the Uthmaniyah field with the objective to assess the applicability to sequester CO_2 in depleted oil reservoir. However, it should be noted that the Kingdom of Saudi Arabia has abundant conventional oil reserves and EOR is not required at production scale for decades to come. The project will use 40 million standard cubic feet a day (MMscf/d) of CO_2 that will be captured and processed at Hawiyah NGL Recovery Plant and shipped to Uthmaniyah field. The design of the CO_2-EOR project is based on a reservoir simulation study and has a comprehensive monitoring and surveillance plan. It is estimated that up to 50% of the injected CO_2 will be sequestered permanently in the reservoir. The project design will be completed and CO_2 will be ready for injection by the mid 2013.
- Saudi Arabia was one of the four countries signed up to the "Four Kingdoms" initiative. It aims to explore the environmental viability of carbon capture and storage (CCS) technology (Arab News, October 2, 2010).
- Saudi Arabia established its Designated National Authority (DNA) required by the Kyoto Protocol for the Clean Development Mechanism (CDM) in June 2008. The DNA is an important step to promote CDM projects nationwide.

3.5 Solid Waste Management Initiatives:

- The Presidency of Meteorology and Environment (PME) prohibited the practice of waste management using fossil fuel by regulations in the Kingdom.
- The strategic plans of major cities are getting inspired by the concept of waste minimization. For

example, the strategic plan of Jeddah initiated in 2005 emphasized on reducing landfill requirements by employing waste reduction technologies including composting.

3.6 Sustainable Urban Development and Green Building Initiatives:

- Jeddah city has initiated a number of plantation and forestation projects. Planting a total of half a million trees in a total area of eight million square meters; a 2.5-million-square-meter forestation program; a garbage separation and recycling plant at landfill site and other greenery projects including a national park, a safari park and many other entertainment facilities covering an area of 100 million square meters.
- The National Spatial Strategy (NSS) provides principles and guidance on ways to support development and address the social and environmental consequences of growth, including ways to integrate low-emissions approaches to urban planning.
- In Yanbu, as part of city greening campaign, 9 km^2 area has been planted with trees and floweing plants. Fairouz Gardens in Yanbu covering an area of 72,300 square meters has been opened.
- Saudi Green Building Forum which is a key milestone in the Kingdom's on-going efforts to raise awareness and promote sustainability was established in 2010.

3.7 Transportation Related Initiatives:

- The Kingdom has initiated the North-South Railway (NSR) project, a 2,400 km passenger and freight rail line originating in the capital city Riyadh to Al Haditha, near the border with Jordan, which is the world's largest railway construction and the longest route to adopt the European train control system (ETCS) to date.
- The Al Mashaaer Al Mugaddassah, a 20 km long metro line constructed connecting the holy cities of Mecca, Arafat, Muzdalifa and Mina started operation during the Hajj pilgrimage of 2010.

3.8 Awareness Campaign:

- National Energy Efficiency Program (NEEP) objectives includes awareness program to let the masses know about the importance of energy conservation and ways and means to implement these including pamphlet distribution, advertisements in electronic and print media and seminars.
- Considerable public awareness has been developed in the Kingdom for development of renewable energy by emphasizing on solar-energy education programs, conducting seminars and workshops, supporting and developing awareness regarding the climate change and energy related exhibitions.
- PME is currently working on development of a suitable national strategy for environmental awareness that will support environmental legislation in the country.

3.9 Recent R & D Efforts in the Kingdom for Climate Change:

The Kingdom has realized the essential role of research and development to provide promising solutions to the challenging issues facing the national development such as climate change. These research and development efforts cover four key areas, namely solar energy, clean fuel production, emission reduction, and water resources.

3.9.1 Solar Energy:

3.9.1.1 Research and Development:

A number of research and development projects have been carried out with the application of the latest solar energy technologies in different activity aspects which, in turn, have enhanced the national capacity in advancing and applying solar energy technologies in the following areas:

- Producing electricity, desalinated water, refrigeration, and air conditioning.
- Producing hydrogen gas and building reference laboratories to transfer hydrogen and fuel cells

storage and use technologies.
- Developing water heating systems and agricultural dryers.
- Securing electricity for communication systems and protecting oil pipelines from corrosion.
- Operating traffic and warning signals and lighting of tunnels in remote and mountainous areas.
- Photovoltaic link with the main electricity grid aiming at reducing electric loads on the main grid during peak periods.
- Pumping and desalinating water projects for some remote regions.
- Designing cost-effective solar collectors for hot water systems.
- Designing and implementing solar dryers for drying dates in the areas with high humidity to help reducing loss of dates as a result of high humidity.
- Source of thermal energy needed to run air conditioning systems through the absorption cooling system which has been proven to be technically and economically practical to reduce air conditioning loads during the summer season.

3.9.1.2 Future Trends:

The Kingdom has undertaken and implemented integrated programs aimed at developing solar energy based technologies, supporting the industrial base for such promising technologies and achieving the leadership in solar technologies. The following are some of the important future trends that the Kingdom intends to achieve in the field of solar energy.

- **Pilot projects for solar energy applications:**
  - Water desalination pilot plant using solar thermal energy.
  - Power generation plants in remote areas using photovoltaic cells.
  - Power generation plant using photovoltaic cells connected to the general electricity grid to reduce electricity loads.
  - Pilot plant to use solar energy in refrigeration and air conditioning.
- **Projects to strengthen the industrial base for solar energy systems components:**
  - Manufacturing silicon cells with a production capacity of 30-100 MW.
  - Manufacturing PV micro inverter to convert the generated energy from solar panels.
  - Manufacturing protection and control systems and smart grid software to connect solar energy systems to the general electricity grid.
  - Manufacturing solar thermal system components.
- **Research and development projects and technology transfer of solar energy:**
  - Developing and transferring solar cooling technologies.
  - Developing and transferring cost-effective solar-grade silicon technologies from white sand to provide raw materials for solar cells.
  - Developing and transferring advanced technologies such as nanotechnology in the field of solar energy in collaboration with international centers.
  - Developing an integrated photovoltaic system with concentration capacity of more than 1,500 sun and increasing the efficiency of photovoltaic solar cells to higher rates compared to the conventional cells.
  - Producing and improving the efficiency of organic-based solar cells using nanotechnologies.
  - Developing low-cost solar cells using nano fingerprint.
  - Producing nano materials for the use in energy applications such as manufacturing of fuel cells and photovoltaic cell components.
  - Producing nano scale carbon tubes using chemical vapor deposition technology.
  - Building a nano metric powder pilot plant using plasma technology.

3.9.2 Clean Fuel Production:

3.9.2.1 Research and Development:

A number of research and development projects have been pursued to enhance the capacity of the Kingdom in clean fuels production discipline, among which are the following projects:

- **Oxy-fuel Carbon Capture in a Boiler Model Furnace:**

  Oxy-fuel technology provides a promising option for CO2 capture and storage, applicable in power and steam generation systems.

- **Development of Nano-catalyst to Produce Clean Fuel:**

  This aims to develop supported nano-catalyst with high activity for dimerization mono-olefins or groups of olefins to improve the combustion properties of fuels; clean fuel components in the range of gasoline, jet fuel and diesel free of sulphur, nitrogen and aromatic compounds.

- **Nanocatalysts for Deep Hydrodesulphurization of Diesel Fuel:**

  This project aimed at developing new hydrodesulphurization (HDS) catalysts to produce clean fuels. The catalysts were characterized and subsequently tested in HDS of sulphur compounds. The obtained results show that the HDS activity of the prepared nano-catalysts is considerably higher than the activity of the traditional catalysts in removing the sulphur compounds from fuels.

- **Microbial Enhanced Oil Recovery and Clean Fuel Technology:**

  This project aimed at studying the possibility of using the ability of micro-organisms to enhance the quality and quantity of oil recovery (microbial enhanced oil recovery) and/or to improve the quality of produced oil (clean fuel technology) by:
  - Cultivating new microbial strains using innovative isolation methods under aerobic and anaerobic conditions.
  - Improving extracting oil methods under different conditions of the reservoir.
  - Converting the remains of oil residue to methane, and improve energy recovery from marginal wells.
  - Cloning and increasing gene expression and quantitative propagation for sulfur compounds analytical enzymes.

- **Nanotechnology Applications:**

  The Kingdom has set up various cooperative projects with eminent companies and universities aimed at transferring nano technologies to the Kingdom and building the capacity of the national human resources in educational institutions and industry.

3.9.2.2 Future Trends:

The national future R&D trends in clean fuel production include the followings:

- Production of high octane compounds.
- Transformation of heavy fuel oil to high-quality hydrocarbons,
- Development of catalysts for refining processes, clean fuel additives, and the desulfurization of crude oil.
- Development of fuel cell technologies using nano carbon tubes.
- Improvement of the clean fuel production using biotechnology.

3.9.3 Emission Reduction:

3.9.3.1 Research and Development:

A number of research and development projects in the area of reducing emissions have been conducted, most important of which include:

- **Carbon Capture and Storage:**

  The project contributes to the protection of the environment from pollution and aims to capture and store carbon dioxide emitted from industrial sources and other human-induced activities such as power plants, in an attempt to reduce the increasing rates of carbon dioxide emissions. This project studies the potential of isolating carbon dioxide at production, transportation and storage facilities, and studies the possible geological formations to determine the most suitable geological sites for carbon storage. The outcome of this project will play a substantial role in the future in-depth studies covering the economic feasibility of injecting carbon dioxide for storage and to enhance production of oil and gas from productive aquifers.

- **Disclosing and assessing the methane gas emission sources in Saudi Arabia and its related control and utilization technologies:**

  This project is a joint funded R&D effort between the UK government and the Kingdom aimed at exploring and assessing the methane gas emission sources in the Kingdom and developing win-win technologies that would help the Kingdom to tackle, control, and utilize the methane gas emissions from the key sources, mainly, from wastes and agriculture sectors. The project has successfully developed baseline data for the targeted sources based on the IPCC guidelines 2006, established geographical mapping for methane emission sources, evaluated the economic potential of mitigating methane gas emission, and proto typing environmentally-sound and cost-effective technologies and products.

- **Assessment and prevention of underground fuel storage tanks pollution:**

  The primary objective of this project is to assess the environmental damage caused by leakage of NAPL from an underground storage tank and loss of fuel.

- **Assessing environmental impacts of mining activities in Saudi Arabia:**

  The project is aimed at developing a methodology to assess environmental impacts of mining activities compatible with Kingdom of Saudi Arabia environment guidelines. The methodology addressed the important issues impacted from mining activities such as air, water, soil and socio-economics.

- **Recycling of waste plastics:**

  This project is aimed at recycling post-consumer-plastic (PCP) wastes. PCP wastes were collected, sorted, classified according to plastic type, and tested by several equipment such as extruder. Finally, some useful materials were successfully made out of the PCP stream such as tiles.

  - Tile glass production used to manufacture filters to reduce pollution from vehicle exhaust.

3.9.4 Water Resources:

3.9.4.1 Research and Development:

A number of research and development projects have been pursued and have successfully developed advanced technologies for water desalination and treatment at competitive costs including the following technologies:

- Hydrophobic membrane preparation for membrane contactors application which is concerned with the development of advanced membranes for drinking water purification.
- Tile glass production used to manufacture water purifying filters.
- A pilot project to produce new high-efficiency nano membranes for water desalination using reverse osmosis methods. This new membrane has the potential to prevent the deposition of salts, to prevent accumulation of pollutants at different pressures, to increase the production capacity of the membranes, and to reduce membrane fouling compared to traditional membranes.

Deliverables of both pilot projects have been integrated to take advantage of them in water desalination, instead of using fossil fuels, which will have a great impact in maintaining the integrity of the environment, and ensure the continuity of desalinated water at lower costs.

3.9.4.2 Future Trends:

A considerable number of future R&D trends have been adopted in water technology and its role in preservation of the environment including the following:

- Novel process for heavy metal removal from waste streams.
- CNT-RO and NF membranes for water treatment and desalination.
- Recovery of waste organic solvents by Zeolite membranes.
- Developing a new system for saline water desalination and electric power generation using ionic liquids and locally synthesizing the ionic liquids.
- Direct-Contact membrane distillation, osmotic distillation and membrane crystallization.
- Development of small-scale brackish water solar desalination units for remote arid regions which fall within the field of water desalination methods using solar energy.
- Development and application of adsorbent materials for heavy metals adsorption from industrial waste effluent.

3.10 International Treaty, Plan, Policy and Program Initiatives:

- In 2007, King Abdullah announced a US$ 300 million research fund for addressing climate change issues during a summit of Organization of the Petroleum Exporting Countries (OPEC) Heads of State in Riyadh.
- Saudi Arabia has taken initiatives to develop regulatory framework for the promotion of clean and renewable sources of energy to generate power in the Kingdom.
- Saudi Arabia agreed to the United Nations Framework Convention on Climate Change on 28 December 1994 and the Kyoto Protocol in 2005.
- The Kingdom has signed Montreal Protocol for phasing-out Ozone Depleting Substances (ODS) and within the framework of a national strategy industrial facilities/plants are have phased out the use of ozone depleting substances.
- The Gulf Cooperation Council (GCC) will establish a Centre of Excellence in Renewable Energy Research in Saudi Arabia. The centre is to be set up under auspices of United Nations Educational, Scientific and Cultural Organization (UNESCO) and the Islamic Educational, Scientific and Cultural Organization (ISESCO).
- UNDP and the Government of Saudi Arabia have launched a joint urban planning project that will help guide the shape and pace of urbanization.

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SECTION - 4

Technology Transfer and Development in the Kingdom of Saudi Arabia: Current Structure and Trends

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4.1 Introduction:

The Kingdom of Saudi Arabia, realizing the substantive role of science, technology and innovation to attain its ambitious future vision of joining the advanced knowledge-based economies by the year 2025, has embarked on a major effort to advance its position in science and technology in order to expand its economy, address problems of national importance and improve the quality of life. This effort is motivated by the desire to shift the economy of the Kingdom away from natural resource based to the one driven by innovation, with strong knowledge-based industries that develop and make use of the Kingdom's human talents. This effort involves setting up a comprehensive National Policy for Science and Technology that engages, among others, research and development, technology transfer and development, innovation, education, capacity building, financial resources, and institutional structures in a strategically coordinated and productive way.

4.2 Current Status of Technology Transfer and Development:

King AbdulAziz City for Science and Technology (KACST) was established in 1986 as an independent scientific organization entrusted with the responsibility to propose a national policy for the development of science and technology and to develop strategies and plans necessary to implement them, to support scientific research and technology development, to foster national innovation and technology transfer between research institutes and the industry, and to foster international cooperation in the field of science and technology.

The Kingdom has followed internationally recognized best practices and successful processes in technology transfer and development such as purchasing, transferring and localizing technologies by public and private sector institutions, streamlining expertise studies on selection of appropriate technologies suiting the future development in the Kingdom, building strategic international partnerships such as that with France in remote sensing, Taiwan in fish farming, Germany and the United States in renewable energy, and Japan in bio-technology. For its part, Saudi Aramco is endeavoring to transfer and indigenize oil technologies and has established two R&D centers for this purpose. In the petrochemicals industry, similar efforts have been made by Saudi Basic Industrial Corporation (SABIC), which has established a Riyadh-based research complex. The Kingdom, furthermore has capitalized building conducive environment needed to flourish scientific and technological advancement. Setting the National Policy for Science and Technology, establishing King Abdullah University for Science and Technology, initiating the National Innovation Eco-System, lunching the Research Centers of Excellence program and issuing the General Environmental Regulation and Rules for Implementation are among the visionary actions that have been taken by the Kingdom to built a robust conducive environment needed to flourish the scientific and technological advancement and to achieve the distinctive land mark for the Kingdom in the global scientific structure.

Accurate understanding of the current scientific and technological advancement had led the Kingdom to carry out massive studies to identify the key science and technology indicators including publication and patent data, intellectual property rights, international cooperation, institutional framework, development strategy, and future vision.

4.2.1 Publication and Patent Data:

The Kingdom is a significant player in the regional science and technology enterprises, but it is a modest player in the world. During the 1996-2006 time period, the Kingdom reserved the 4th largest producer of scientific publications in the Middle East region and the 48th among all countries, the 3rd largest regional affiliated researchers and the 51st globally in terms of publication impact as measured by the "h-index", and the second regional leader in technology development as measured by patents granted by the United States Patent and Trademark Office; with 164 patents from 1996-2006 (Table 4.1).

Table 4.1 Publication and Patent Indicators Summary (1996-2006 - SCImago 2007)

Regional Ranking	Global Ranking	Value	Indicator
4	48	20,700	Publications
3	51	67	h-index
2	43	164	Patents

Table 4.2 shows the activity index, implying the relative level of publication activities in a given field pertaining to climate change in the Kingdom compared to the world total. The activity index of energy, chemistry and environmental sciences are higher than 1, implying that the researchers publishing activities in those fields are higher as a proportion of the total activity in the Kingdom than in the rest of the world. However, the activity index of the other sciences is less than 1 indicating that these activities are lower as a proportion of the total than the global average

Table 4.2 Scientific Publication Fields in the Kingdom of Saudi Arabia (1996-2006 – SRI International)

Activity Index	Field share of global publications	Field share of KSA publications	Number of publications	Field
2.84	1.79%	5.07%	1,050	Energy
1.17	7.21%	8.43%	1,746	Chemistry
1.07	3.94%	4.21%	872	Environmental Science
0.86	4.3%	3.76%	778	Earth and Planetary Sciences
0.79	6.74%	5.34%	1,105	Agricultural and biological Sciences
0.63	10.62%	6.71%	1,390	Physics and Astronomy

A closer look at the Kingdom's collaboration patterns shows a trend towards diversification of the Kingdom's international relationships, with an increasing proportion of collaborative activity involving regional partners. This trend mirrors a global trend towards more decentralized collaboration networks with emerging regional hubs. The United States remains the Kingdom's most significant collaborative partner in terms of total co-authored publications, but since 2000, the USA's share of co-authored papers has dropped from 34% to 24.9% while regional collaborators such as Egypt, Pakistan, India and Algeria have emerged as more significant partners (Figure 4.1).

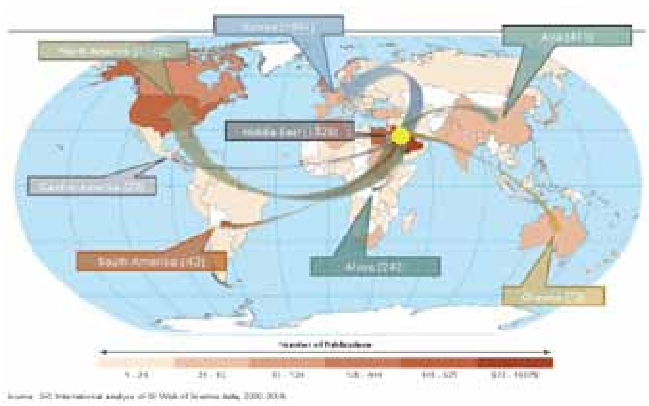

Figure 4.1 Saudi Arabia's International Collaboration Partners in Scientific Publications

4.2.2 Intellectual Property Rights:

The Kingdom started officially the follow up of patents in 1982 after its accession to the World Intellectual Property Organization (WIPO). The first “law of Patents” in the Kingdom was issued in 1989 and was phased out in 2005, by which the new law of patents entitled “Patent System Planning and Design of Integrated Circuits and Plant Varieties and Industrial Designs” was issued and became effective. The new law of patents aims to provide full protection within the Kingdom of Saudi Arabia for inventions, layout designs of integrated circuits, plant varieties and industrial designs. Around (1635) patents and (593) industrial design certificates were granted by the Saudi Arabian Industrial Property office during the time period 1989-2009.

4.2.3 International Collaboration:

Perceiving the significant and increasing role of international collaboration in scientific and technological advancement, the Kingdom has signed bilateral cooperation agreements with more than 45 countries in economic, scientific and technical fields, as well as for promotion and protection of investment in addition to agreements with several regional and international organizations in various fields. To intensify the joint industrial development programs, the Kingdom has utilized several means, such as the economic off-set program, research centers outside the Kingdom and direct cooperation between Saudi universities and R&D centers and their foreign counterparts (MEP).

Saudi-Japanese Joint Research and Development Program is among the largest programs of its kind in the Kingdom signed in 1997. This joint R&D program has focused on the practical application of advanced technologies in three major areas: (a) technology for the reuse of water, (b) technology for irrigation and water conservation and (c) technology for promoting greenery. Around sixteen research projects have been undertaken and concluded through this joint R&D program, which was fully funded by PEC (Petroleum Energy Center).

4.3 Institutional Framework:

In recognition of the crucial role of scientific and technological advancement in supporting comprehensive sustainable development, the Kingdom has promoted the national scientific and technological base to a level that would enable it to achieve the strategic objectives of socioeconomic development including economic diversification, enhancement of growth and human development.

4.3.1 Supporting Services:

Scientific and technological supporting services are among the most important components of the national science, technology and innovation system. These supporting services include the following (Alabdulkader et al., 2003):

- Providing scientific and technological information services through national libraries and databases.
- Providing internet services at an advanced level and high speed in the major independent libraries and libraries affiliated to academic and research institutes.
- Preparing standards and specifications for various materials, equipment and instruments in different fields
- Establishment of scientific societies and professional commissions to support and organize scientific and technological activities.
- Issuing the law of patent to provide full protection within the Kingdom of Saudi Arabia for inventions, layout designs of integrated circuits, plant varieties and industrial designs.
- Supporting the establishment and development of a creative environment and society so the talented and gifted individuals can harness and exploit their talents to serve the nation.
- Establishing and strengthening scientific and technological cooperation at all levels.

4.3.2 Creativity and Innovation Encouragement Activities:

In the past few years, a number of institutions concerned with promotion of creativity and innovation have been established. In addition to the prizes for scientific excellence offered by the universities, further encouragement of creativity and innovation is provided by a number of public and private prizes for scientific achievements; the most important of which are: the King Faisal International Prize, the Custodian of the Two Holy Mosques King Abdullah bin Abdul Aziz Prize for Scientific Research, prizes offered by regional princes for scientific excellence and innovation, the Al-Marai Prize for Scientific Innovation, the Faqih Center Prize for Research, and the Abdullatif Jamil Prize for Technological Innovation.

4.4 Development Strategy :

The Eighth Development Plan of the Kingdom of Saudi Arabia envisages the implementation of an integrated set of science and technology programs, through cooperation and coordination among the relevant sectors and agencies. These programs are classified into the following three categories:

- **Sector Programs:** These are programs adopted by each public or private sector to develop its own science and technology capabilities, guided by the national policy.
- **National Programs:** These are programs that seek to develop the functions of science and technology system at the national level, including education and training, R&D, technology transfer and indigenization, development and optimal utilization of technology. These programs will be implemented primarily by KACST, the higher education institutions and the public and private science and technology agencies.
- **National Initiatives:** these are aimed at indigenizing and capacity building in important and promising technologies such as oil, water desalination, petrochemicals, information and communications, electronics, genetic engineering and space sciences.
- The development strategy for science and technology aims at building a national science and technology base capable of innovation and creativity, adaptation of technology, development of information technologies and services to enhance efficiency of the Saudi economy and building an informed society and knowledge based economy.

4.4.1 Future Vision:

The future vision of the Kingdom in science and technology is to ***"join the advanced knowledge-based economies and becoming an international leader in science and technology".*** In the near term, the Kingdom must establish the infrastructure of manpower, equipment, policies and institutions that will provide the foundation for growth. In the longer term, the Kingdom needs to significantly increase investments in science and technology to become one of the leaders in the region and in Asia. To reach the goals, it will require an increasing portion of the Kingdom's population to be engaged in science and technology, and an increase in the effectiveness of the Kingdom's science and technology institutions (Figure 4.2). The future vision for science and technology rests upon implementing the national policy for science and technology. Expenditure on R&D is planned to amount to 2% of GDP by 2025, increasing by relatively low rates at the beginning but at higher rates as science and technology potential mounts and the system develops. The development plans shall estimate the required financial resources to be allocated for developing the science and technology system on the assumption that the targeted ratio to GDP will be achieved gradually by the end of 2025 (MEP Five Year Development Plan).

4.5 The National Policy for Science and Technology :

The Kingdom of Saudi Arabia has embarked on a major effort to advance its position in science and technology in order to expand its economy, address problems of national importance and improve the quality of life of its people. This effort is motivated by the desire to shift the economy of the Kingdom away from oil based to the one driven by innovation, with strong knowledge-based industries that develope

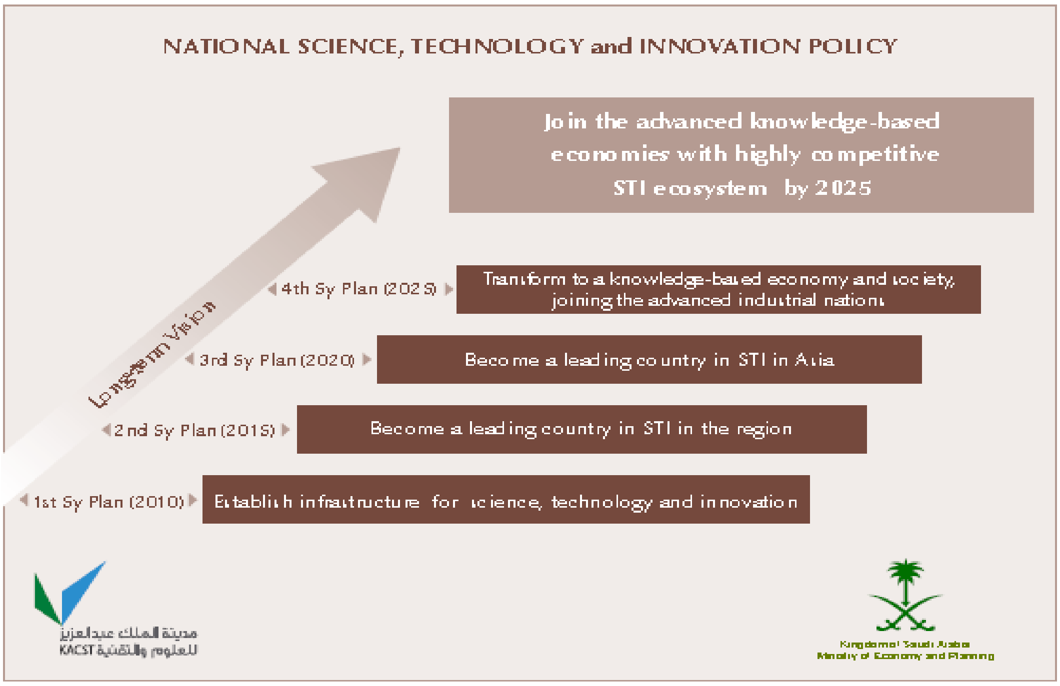

Figure 4.2 Long Term Science, Technology and Innovation Vision of the Kingdom of Saudi Arabia

and make use of the Kingdom's human talent. This effort involves establishing an effective national innovation system that engages research and development, education and economic institutions in a strategically coordinated and productive way.

In July 2002, the Council of Ministers approved the National Policy for Science and Technology (NPST), which spans the period 2001-2020. NPST drew up the broad lines and future direction of science, technology and innovation in the Kingdom, defining the role of key stakeholders including academia, government, industry, and society at large. The Policy will serve as a reference to ensure the continuation of the system development efforts and the enhancement of its performance in the way that achieves the objectives sought by the Kingdom in the long-term and will play a substantial role inter-linking the related national activities and ensuring the harmony and coherence among them (Table 4.3).

Table 4.3 National Initiatives/Activities in the Kingdom of Saudi Arabia. (Turki S.M. Al-Saud)

National Activities	Developer/ responsible agency
The Eighth National Development Plan	Ministry of Economy and Planning
King Abdullah University for Science and Technology	Saudi Aramco
Mawhiba Giftedness and Creative Plan	King Abdulaziz and His Companions Foundation for Giftedness and Creativity
Knowledge Based Industries Strategy	Saudi Arabia General Investment Authority
10X10 Competitiveness Project	Saudi Arabia General Investment Authority
AAFAQ Project	Ministry of Higher Education
The E-Government Program	Ministry of Communication and Information Technology
National Plan for Communication and Information Technology	Ministry of Communication and Information Technology
National Industrial Strategy	Ministry of Commerce and Industry

The Policy encompasses eight programs. These programs as shown in Figure 4.3 are as follows:

1. Strategic and advanced technologies
2. Scientific research and technical development capabilities
3. Transfer, development and localizing technology
4. Science, technology and society
5. Scientific and technical human resources
6. Diversifying financial support resources
7. Science, technology and innovation system
8. Institutional structures for science, technology and innovation

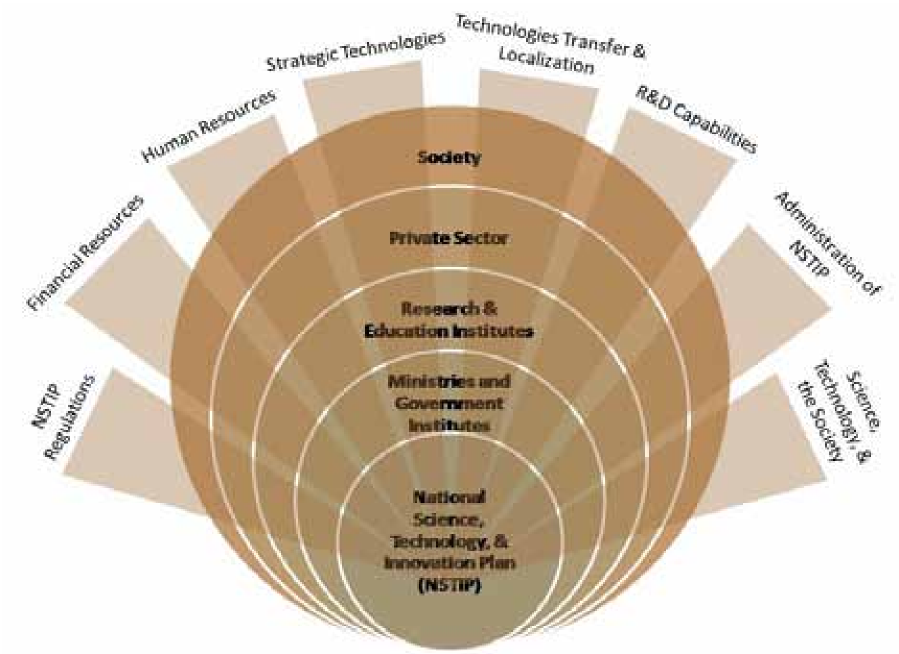

Figure 4.3 Key Programs and Players of the National Policy for Science and Technology in the Kingdom of Saudi Arabia

The strategic technologies defined in the policy are water, energy, oil & gas, petrochemicals, environment, nanotechnology, biotechnology, information technology, electronics, communications & photonics, space and aeronautics, advanced materials, mathematics and physics, medicine and health, agriculture and building and construction.

4.6 Strategic Priorities for Technology Transfer and Development:

The strategic priorities for technology transfer and development is the core deliverable of the Strategic and Advanced Technology Program in the Kingdom aiming at developing, transferring and localizing safe and sound technologies that suit the Kingdom's future development and respond to the international challenges. The following section summarizes the results of the national effort to develop plans and programs to enhance the Kingdom's position in some strategic technologies, namely water, oil and gas, petrochemical, energy, and environment technologies.

4.6.1 Water Technologies:

The Kingdom identified four technology target areas that will be the focus of the future R&D trends in water technologies.

- Water Desalination
- Drinking Water Treatment
- Wastewater Treatment
- Water Resources Management

The Kingdom established the following R&D centers to deal with the key areas of water technologies.

- Saline Water Conversion Corporation Research Center, Jubail:
- National Center for Water Technologies, Riyadh
- Center of Excellence in Desalination Technology, Jeddah

4.6.2 Oil and Gas Technologies :

Kingdom of Saudi Arabia has almost a quarter of the world's proven oil reserves and plays an important role supplying the energy needs around the globe. Accordingly, the Kingdom determined its long term needs of the advanced oil and gas technologies in alignment with the goals and objectives of the National Policy for Science and Technology as follows:

- Improved data availability, openness, visualization and access for research.
- Improved human resources quality, quantity and education.
- Improve oil recovery and proven reserves.
- Reduced exploration and production cost.
- Improve and increase efficiency of oil and natural gas exploration and drilling operations.
- Reduced well pollution and emission.
- Complete the geological information needed for oil and gas upstream R&D.
- Development and localization of technology services for oil and gas.

The Kingdom identified eight technology target areas of R&D in oil and gas technologies.

- An advanced and integrated database with high end visualization and communication tools for oil and gas information
- Completion of the petroleum geological information
- Enhanced oil recovery (EOR)
- Reservoir modeling, monitoring and management
- Improved oil and gas exploration success rates especially in the Rub Al Khali and the Red Sea
- Oil and natural gas production
- Improved drilling operations (quality and efficiency)
- Protecting the environment

4.6.3 Petrochemical Technologies :

The Kingdom determined its long term needs of the advanced petrochemical technologies in alignment with the goals and objectives of the National Policy for Science and Technology, which will support competitive local production and facilitate new investment opportunities and markets, pursuing a robust economic base, comprehensive development and efficient use of available resources in the field.

The strategic goals of this program are as follows:

- Support and develop domestic capacity in critical petrochemicals and refining technologies
- Optimizing the use of abundant available natural resources
- Supporting the local refining and petrochemicals industry with technology solutions that facilitate new product development, improve production efficiency, price/value efficiency, environmental protection and similar concerns
- Developing innovative high quality petrochemical technologies and applications to meet specialized industrial and commercial needs in the Kingdom such as in oil and gas
- Adapting and localize petrochemical technologies to support the development of national capability
- Supporting societal and cultural development towards optimal exploitation of technology and transformation from a consumption to a production culture
- Enhancing the Kingdom's competitiveness in regional manufacturing through transfer and development of advanced petrochemical technologies

- Improving the national ranking in science and technology capabilities.

4.6.4 Energy Technologies:

Energy technologies are of particular importance to the Kingdom of Saudi Arabia. Energy is a key driver of the country's development and economic growth. The following strategically-aligned goals are selected for the Kingdom to work out:

- Efficiently exploiting national energy resources
- Supporting national self dependence in critical energy technologies
- Supporting the local energy industry to attain development and growth with technology solutions that facilitate new product development, improve production efficiency, price/value efficiency, environmental protection, especially in view of the rapidly rising demands for electrical and other forms of energy due to population growth, industrialization and globalization
- Developing innovative technologies for special needs that cannot be satisfied efficiently or economically through existing systems. For example, utilization of renewable energy technologies for remote areas
- Transferring, adapting and developing technologies for local users and markets through business models that promote creation and maximization of employment and investment opportunities, as well as economic diversification and competitiveness
- Supporting societal and cultural development towards optimal exploitation of technology and transformation from consuming to producing culture
- Promoting the high level of national image and stature in science and technology.

The Kingdom identified seven technology target areas that will be the focus of the R&D trends in energy technologies as follows:

- Renewable Energy Generation
- Conventional Energy Generation
- Electricity Distribution and Transmission
- Energy Conservation and Management
- Energy Storage
- Fuel Cell and Hydrogen
- Combustion

4.6.5 Environmental Technologies:

Environmental technologies are particularly important in the Kingdom, where waste, pollution, air quality and degradation of natural resources have significant environmental implications. The importance of advanced environmental technologies is to protect the environment and maintain a high quality life within the Kingdom. The Kingdom defined its strategic goals for the advanced environmental technologies as follows:

- Establishing a national infrastructure for environmental technologies.
- Transferring, localizing and developing high quality environmental technologies to tackle national environmental issues.
- Promoting innovative research and development in environmental field.
- Contributing to the concept of advanced environmental technology industries to enhance the national economy.
- Developing national and international strategic partnerships.
- Providing scientific consultation in the field of environmental technologies.

The Kingdom identified five technology target areas that will be the focus of the R&D trends in environment technologies as follows:

- Municipal solid waste remediation technologies.

- Food contamination prevention technologies.
- Air pollution monitoring and assessment technologies.
- Greenhouse gases avoidance, monitoring and assessment technologies.
- Desertification monitoring and assessment technologies.

4.7 King Abdullah University of Science and Technology:

King Abdullah University of Science and Technology (KAUST) has been established in Saudi Arabia as an international, graduate-level research university dedicated to inspiring a new age of scientific achievement in the Kingdom that will also benefit the region and the world. KAUST is the realization of a decades-long vision of the Custodian of the Two Holy Mosques, King Abdullah bin Abdulaziz Al Saud. KAUST is governed by an independent, self-perpetuating Board of Trustees and supported by a multi-billion dollar endowment.

KAUST will pursue its R&D agenda through four strategic research thrusts that focus on areas of science and technology that are important to Saudi Arabia, the region, and the world:

- Resources, Energy and Environment;
- Biosciences and Bioengineering;
- Materials Science and Engineering;
- Applied Mathematics and Computational Science.

4.8 Technology Development Centers:

The Kingdom established a Technology Development Center (TDC) to strengthen and promote technology development and commercialization activities within the Kingdom. TDC is a key part under the National Policy for Science and Technology to promote the national scientific and technological base, thereby helping to realize the objectives of economic diversification, enhancement of growth and promotion of human development.

In partnership with government agencies, universities, and the industrial sector, TDC is responsible to prepare and implement programs related to the management of knowledge, as well as the acquisition, transfer, localization and development of technology, thus contributing to the creation of a fully functioning national system of innovation, including the following activities:

- Encouraging the networks among major parties involved with the development of technology (R&D centers, universities, technology importers, investors, and others)
- Setting up common research projects with beneficiaries.
- Suggesting research programs with KACST research institutes according to national need.
- Assisting in the creation of technology parks and incubators
- Helping to create technology development projects in industry
- Serving technology transfer operations throughout the innovation process, as well as developing and spreading technology
- Participating in setting standards and specifications and negotiating methods for technology transfer.

4.9 Technology Innovation Centers:

4.9.1 University-Affiliated Centers for Collaborative Research with Industry:

Given the importance of strong linkages among various elements of the NIE, notably between research-performing units in government, universities and industry, Technology Innovation Centers (TIC) program was initiated to create a series of university-based centers in carefully selected locations in the Kingdom. Collectively, these centers should:

- Promote university-industry research collaboration and technology transfer;
- Strengthen university research and engineering education;

- Address economic and social goals of the Kingdom; and
- Implement appropriate features of the structure, incentives, and requirements of successful programs in countries similar to Kingdom.

The TIC program is part of a three-tiered strategic concept. The concept consists of a fundamental research to support university-based basic and applied research aligned with the fifteen strategic technologies identified in the National Policy for Science and Technology; a Technology Innovation Centers (TIC) tier that will focus on university-industry collaborative applied research; and a third tier consisting of a system of incubators that support product development and business start-ups. The TIC Program will perform a critical role by linking knowledge outputs generated by university-based research to incubators and technology parks designed to identify commercially promising ideas, develop them and introduce them into the marketplace.

4.9.2 Research Centers of Excellence Program:

The Kingdom has sought to achieve the higher directions of the Eighth National Development Plan, which focused on the state of art to support and encourage scientific research and technical development to enhance the efficiency of the national economy, and keep up with the trends towards the knowledge economy, by setting the "research centers of excellence." program. The total number of research centers of excellence established within the program is thirteen (13) in various scientific disciplines. Table 4.4 highlights some of the more relevant centers for the scope of this report.

Table 4.4 Research Centers of Excellence in Saudi Arabia

Center Title	Research focus	Location	Establishment date
Center of excellence in environmental studies	Air pollution, water pollution, solid wastes	King Abdulaziz University	**2007**
Center of excellence in water desalination studies	Water desalination technologies		**2008**
Center of research excellence in petroleum refining and petrochemicals	Oil and petrochemical refining, catalysts, and polymers	King Fahad University for Petroleum and Minerals	**2007**
Center of excellence in renewable energy	Solar energy, fuel cell technology, energy storage, economics of renewable energy, electricity infrastructure		**2007**
Center of excellence in Biotechnology Research	Environment, food and agriculture, medicine, and pharmacy science.	King Saud University	**2007**
Center of excellence for research in engineering materials	Environment and energy, materials and manufacturing, electronics, medicine and healthcare, chemical, and computation		**2007**
Center of palms and dates research	Post harvesting date processing and manufacturing, economic evaluation, others	King Faisal University	**2007**

4.10 General Environmental Regulations and Rules for Implementation:

The Kingdom has paid a great attention to environmental protection and development of its resources. It has actively attempted to establish a balance between the environmental considerations and prerequisites, rationalization of the use of available resources and their development and advancement in various fields. Accordingly, the Kingdom, represented by the Presidency of Meteorology and Environment (PME), developed the “Environmental Regulations and it’s Rules of Implementation”, which aims essentially to enhance the balanced environmental activities to take care of the environment, conservation of natural resources and promoting environmental awareness in the society. The ultimate achievement is the implementation of sustainable development concept, which is a paramount goal for all nations, by all government sectors while preparing their overall development planning.

Article (6) of the General Environmental Regulations and Rules for Implementation stated the need to utilize the best available technologies and to use materials that cause least contamination to the environment.

Pursuant to Article VIII of the General Environmental Regulations, and without prejudice to the provisions of the regulations and directives, public agencies and persons shall undertake to:

- Develop conventional technologies and traditional systems compatible to the local and regional environmental conditions. Encourage and motivate scientific research centers and institutes to conduct scientific studies related to maintaining and developing traditional systems and nurturing environment friendly alternatives and to adopt the required policies to promote the use of such traditional technologies systems.
- Coordinate with the Competent Agency to carry out scientific studies and research related to pollution sources in traditional building materials and their effect on human beings and to encourage the application and implementation of the outcome of such studies
- Encourage institutes, scientific study and research centers to conduct scientific research related to the development of technologies, materials and traditional building design on developing traditional building technologies, material use and to adopt the required policies to encourage the use and development of such technologies.
- Coordinate to develop a national information dissemination plan emphasizing the importance of reuse of resources and its development and protection and encourage the organization of scientific and specialized workshops, forums and conferences related to recycling technologies and reuse of resources and development of inherited techniques.
- Encourage and support the use of the technologies and practices aimed at minimizing and rationalize the use of natural resources while maintaining or increasing production efficiency.

In addition, Article (12) stated among others that when burning any kind of fuel or other substances for any purpose, the concerned agencies and persons shall employ the most appropriate means, technologies and suitable alternatives to minimize adverse environmental impacts to the lowest level. Article (13) stated among others to employ the best available technologies and means and take the necessary precautions to avoid contamination of surface, ground and coastal waters and control and minimize pollution in accordance with the approved environmental criteria.

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SECTION - 5

Analysis of Socioeconomic Impacts of Annex 1 Countries Response Measures

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5.1 Objectives :

The purpose of this section is to illustrate the Saudi Arabian economy's potential vulnerability as a result of the implementation of Annex I response measures in order to mitigate greenhouse gas emissions. This vulnerability arises due to the fact that Saudi Arabia remains highly dependent on hydrocarbon exports while significant demographic pressures continue to tax the government's ability to provide for the needs of its population.

A remedy to this potential concern would be for Saudi Arabia to diversify its economy sufficiently to reduce its dependency on hydrocarbon to adapt to the implementation of these Annex I climate change policies. However, Annex I countries are obliged to fulfill the needs of vulnerable developing countries like Saudi Arabia in order to meet Annex I countries' commitments in the climate change convention and its legal instruments such as Kyoto Protocol and beyond. Therefore, assistance from Annex I countries to support Saudi Arabia's efforts in economic diversification can produce a win-win strategy and at the same time satisfy the requirements of the climate change convention.

5.2 Background:

In the 1980s, concerns emerged about potential links between human-induced greenhouse gas emissions with the risk of global climate change. As a result, certain governments voiced their concerns about this potential problem. This ultimately led to the creation of the United Nations Framework Convention on Climate Change (UNFCCC), which entered into force in 1994. The objective of this convention is the stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. This objective must also be accomplished in a way to give sufficient time for natural systems to adapt without affecting sustainable development.

Developing countries have raised concerns about the potential impacts of climate change related policies undertaken by developed countries to mitigate greenhouse gas emissions. As a result, Articles 4.8 and 4.10 of the UNFCCC as well as Articles 2.3 and 3.14 of the Kyoto Protocol stipulate that Annex I parties agree to meet specific needs of developing countries arising from the impact of the implementation of response measures.

The following paragraphs from the climate change convention and the Kyoto Protocol are relevant to the implementation of response measures and their potential socio-economic impacts on Saudi Arabia:

UNFCCC Article 4.8:

In the implementation of the commitments in this Article, the Parties shall give full consideration to what actions are necessary under the Convention, including actions related to funding, insurance and the transfer of technology, ***to meet the specific needs and concerns of developing country Parties arising from the adverse effects of climate change and/or the impact of the implementation of response measures****, especially on:*

(a) Small island countries;
(b) Countries with low-lying coastal areas;
(c) Countries with arid and semi-arid areas, forested areas and areas liable to forest decay;
(d) Countries with areas prone to natural disasters;
(e) Countries with areas liable to drought and desertification;
(f) Countries with areas of high urban atmospheric pollution;
(g) Countries with areas with fragile ecosystems, including mountainous ecosystems;
(h) Countries whose economies are highly dependent on income generated from the production,

processing and export, and/or on consumption of fossil fuels and associated energy-intensive products; and

(i) *Land-locked and transit countries.*

UNFCCC Article 4.10:

The Parties shall, in accordance with Article 10, take into consideration in the implementation of the commitments of the Convention the situation of Parties, particularly developing country Parties, with economies that are vulnerable to the adverse effects of the implementation of measures to respond to climate change. ***This applies notably to Parties with economies that are highly dependent on income generated from the production, processing and export, and/or consumption of fossil fuels and associated energy-intensive products and/or the use of fossil fuels for which such Parties have serious difficulties in switching to alternatives.***

Kyoto Protocol Article 2.3:

The Parties included in Annex I shall strive to implement policies and measures under this Article in such a way as ***to minimize adverse effects, including the adverse effects of climate change, effects on international trade, and social, environmental and economic impacts on other Parties, especially developing country Parties and in particular those identified in Article 4, paragraphs 8 and 9, of the Convention,*** taking into account Article 3 of the Convention. *The Conference of the Parties serving as the meeting of the Parties to this Protocol may take further action, as appropriate, to promote the implementation of the provisions of this paragraph.*

Kyoto Protocol Article 3.14:

Each Party included in Annex I shall strive to implement the commitments mentioned in paragraph 1 above in such a way as ***to minimize adverse social, environmental and economic impacts on developing country Parties, particularly those identified in Article 4, paragraphs 8 and 9, of the Convention.*** *In line with relevant decisions of the Conference of the Parties on the implementation of those paragraphs, the Conference of the Parties serving as the meeting of the Parties to this Protocol shall, at its first session,* ***consider what actions are necessary to minimize the adverse effects of climate change and/or the impacts of response measures on Parties referred to in those paragraphs. Among the issues to be considered shall be the establishment of funding, insurance and transfer of technology.*** *These provisions on impacts of response measures are also relevant for the current Post-Kyoto negotiations and should guide mitigation policies and measures under any future climate change agreement.*

5.3 Socioeconomic Trends and Key Vulnerabilities:

The implementation of greenhouse gas emissions mitigation policies by Annex I countries will undoubtedly impact the economies of oil-exporting nations. The extent of impacts will depend on the degree of vulnerability of the given oil economy to negative oil demand and price shocks. The Saudi economy is particularly vulnerable to such shocks because of high dependence on oil, strong demographic pressures, and limited scope for diversification outside the oil sector:

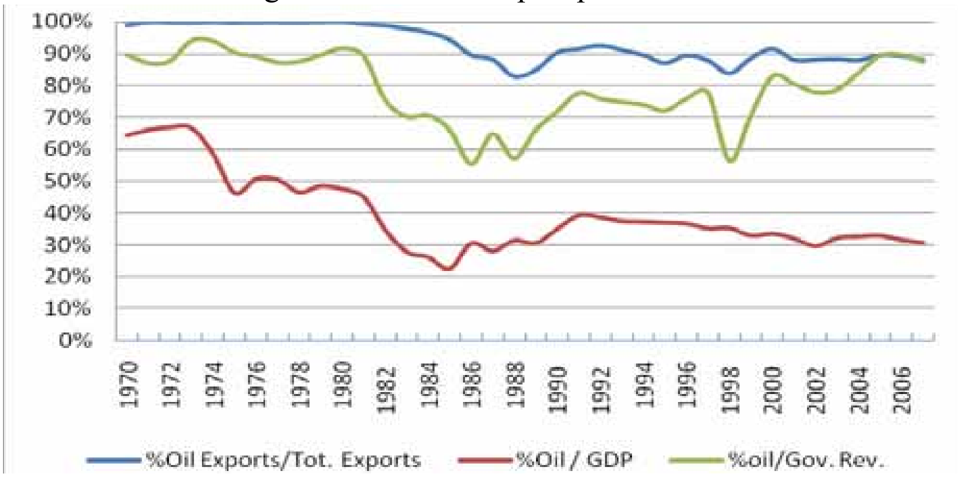
5.3.1 High Dependency on Oil:

The high dependency of the Kingdom's economy on oil is reflected by the contributions of the oil sector to GDP, exports, and to government budget. These contributions are graphically shown in Figure 5.1 for the period 1970-2007. The essential features summarized by the graph include:

- The dominance of the oil sector with average contributions of more than 30% to GDP, more than 70% to budget revenues, and more than 90% to export proceeds.
- Sharp fluctuations implying lack of consistent trends towards diversification, or diversification efforts being interrupted by oil market conditions.
- Clear trend of transformation towards non-oil economy with contribution of oil to GDP falling from above 60% in the 70s to around 30% during the 2000s. In contrast, there is very limited

or no diversification taking place with respect to budget revenues and exports, particularly after the mid 80s. This is an indication that diversification in GDP took place in sectors that have very little contribution to exports and budget revenues. These are mostly in the service sector and non-tradable or non-competitive manufacturing products.

Hence, despite apparent diversification in GDP composition, Saudi economy remains heavily dependent on the oil sector for both budget revenues and export proceeds.

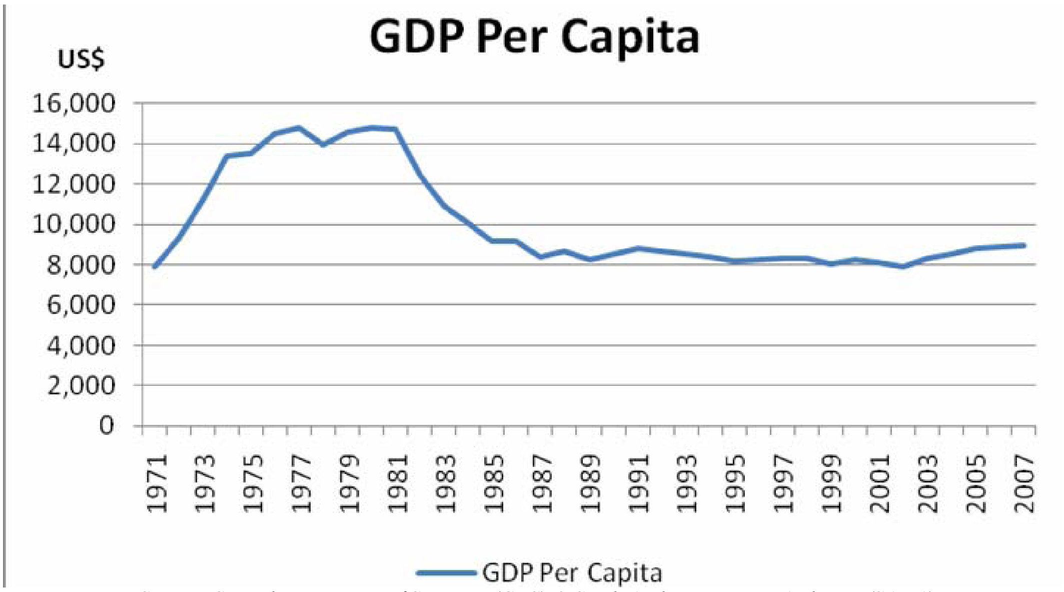


Source: Central Department of Statistics (CDS) & Saudi Arabia Monetary Authority (SAMA)

Figure 5.1Contributions of Oil to GDP, Exports and Gov. Revenues (1970-2007)

5.3.2 Strong Demographic Pressures:

Saudi Arabia has one of the highest rates of growth in population in the world. During the last four decades the average annual population growth rate was 3.8%. Such population pressure has led to deterioration in per capita incomes and living standards, even despite the recent upward trend in oil prices (see Figure 5.2). In turn, this further amplifies Saudi Arabia vulnerability to oil demand and price shocks and hence to the implementation of climate change response measures.



Source: Central Department of Statistics (CDS) & Saudi Arabia Monetary Authority (SAMA)

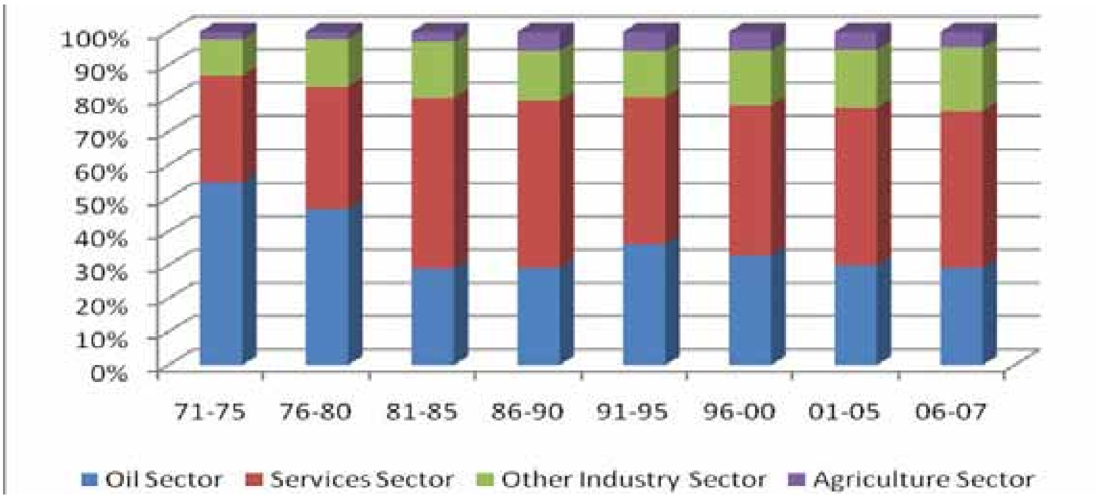
Figure 5.2 Per-Capita Real GDP (1971-2007)

5.3.3 Limited Diversification Potentials:

Efforts to diversify the Saudi economy away from oil have started very early and have resulted in a remarkable structural shift towards the services sector. Yet the potentials for structural transformation of the Saudi economy seemed to have been exhausted by mid 80s, after which the structure of the economy has remained stagnant except for slight trend towards manufacturing. These trends and structural shifts are graphically depicted in Figure 5.3 for the period 1970-2007. Two observations need to be noted that:

- The potentials for further diversification of the Saudi economy are limited. In particular the options in the low value added services and manufacturing activities and those based on comparative advantages are mostly exploited.
- Despite the remarkable shift away from oil, the Saudi economy remains heavily reliant on oil for export proceeds and budgetary revenues.

These two observations reveal the limited scope for diversification in the Saudi economy and further underscore its vulnerability. A successful and effective diversification has to generate substitutes for both government revenues and export proceeds. Such diversification must be towards dynamic, high-value added and competitive products and services, which would require enhanced knowhow and technology dissemination and transfer, in addition to market access.



Source: Central Department of Statistics (CDS) & Saudi Arabia Monetary Authority (SAMA)

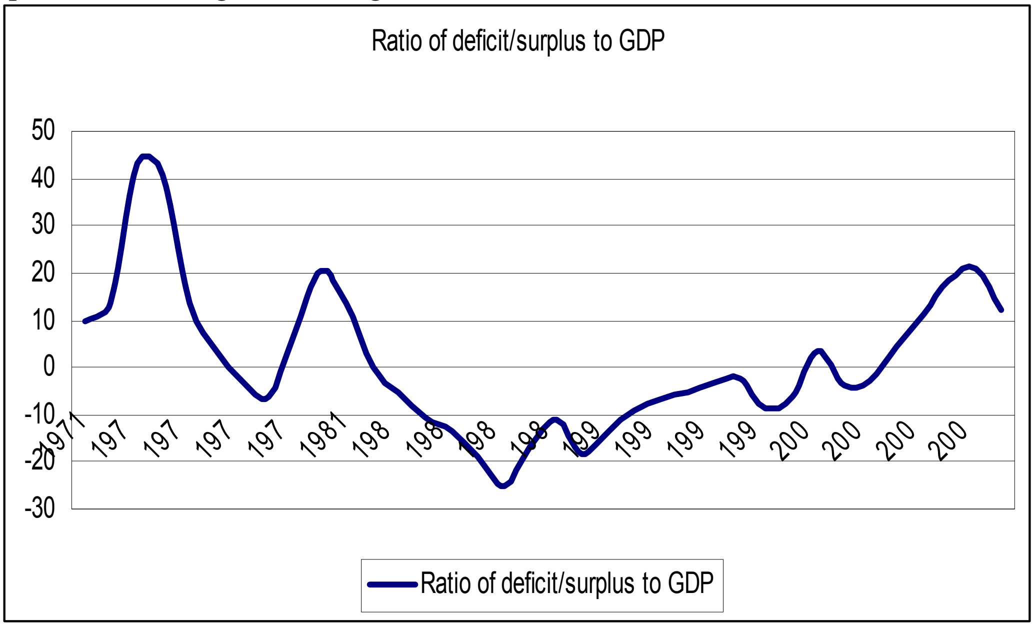
Figure 5.3 Structural Changes and GDP Composition (1971-2007)

5.4 The Budgetary Implications for an Oil-based Economy:

Oil revenues have historically had a direct impact on Saudi government spending and fiscal policy. The instability of the world oil markets contributed to the continued instability of the oil revenues and consequently the fiscal budget. While 1970's and early 1980's were the years of considerable budget surpluses from oil revenues, the national budget had been running in deficit for two consecutive decades (1983-2003), and only after the recent rally in oil prices does it show a surplus (Figure 5.4). The two decades, during which government expenditures have predominately outstripped government receipts, have resulted in the accumulation of a high domestic debt reaching as much as 100% of GDP in the late 1990s. It is then clear, in the absence of alternative fiscal means or non-oil revenues, that such pattern of annual budgetary deficits will be unavoidable would the oil sector be exposed to a significant risk such as the implementation of a climate change policies.

The loss of oil revenues, due to climate change policies, will be much more difficult to replace for specialized oil exporters like Saudi Arabia. This is due to the fact that the Kingdom's domestic industrial base for the production and export of non-oil based goods and services is very limited. Without expanding and diversifying the domestic industrial base, the economy will continue to be vulnerable to exogenous world oil demand and price shocks such as those expected from the implementation of climate change response measures and policies.

Even though Saudi Arabia has established robust downstream oil and petrochemical industries, the contribution of these industries to economic diversification remains far below the level needed to support the economy withstand shocks to the upstream crude sector. This lack of economic cushion certainly places Saudi Arabia's economic development at risk, especially if industrialized countries are to implement policies to curb greenhouse gas emissions.



Source: Central Department of Statistics (CDS) & Saudi Arabia Monetary Authority (SAMA)

Figure 5.4 Saudi Government Budgetary Balances (1971-2007)

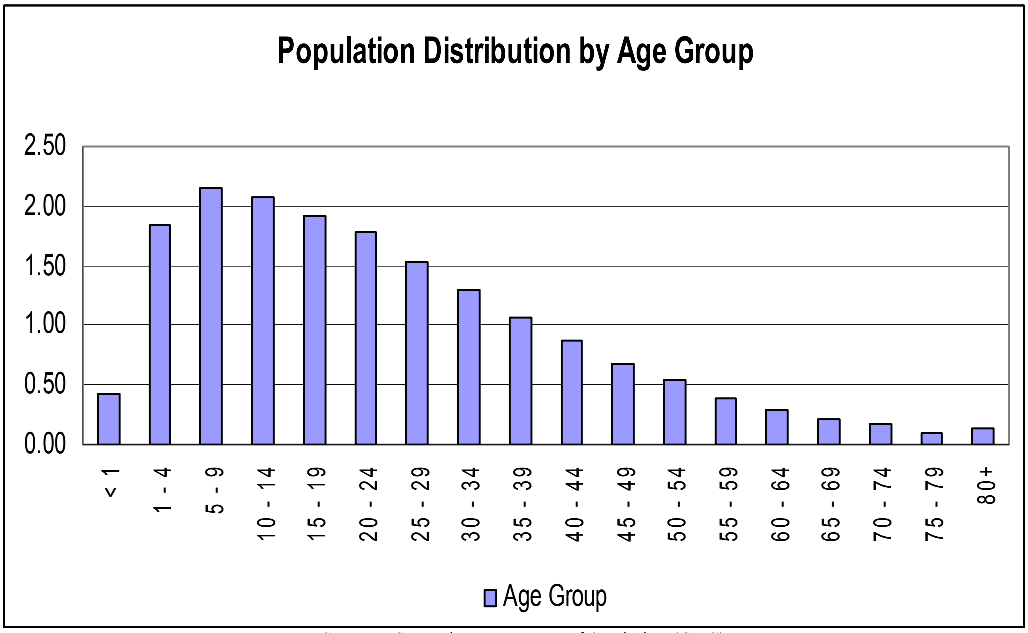
5.5 Population Dynamics:

Past and current patterns of population growth put ahead of Saudi planners significant future challenges and opportunities with respect to living standards and sustainable development. According to the 1992 census, the total population of Saudi Arabia was approximately 17 million. In 2007, Saudi Arabia's population exceeds 24 million of which Saudis make up 73% of the total. This was due to a major influx of expatriate workers and the high natural growth of the indigenous population. However, the projected population of Saudi Arabia by 2010 is estimated to reach 27 million, suggesting an annual average growth rate of 3.0%. Despite the declining trend in Saudi Arabia's population growth, it is still amongst the highest in the world compared to growth rates of 1.7% and 0.7%, respectively for developing and industrial country populations, in the 1990s.

High Saudi population growth can challenge the future economic development of Saudi Arabia and may have adverse implications on the government's ability to spend on physical and social infrastructure. Following the oil shocks of the 1970s, Saudi Arabia's economy expanded due to windfalls profits from surging oil prices resulting in the implementation of major domestic infrastructure projects. However, this situation continued to be vulnerable to changing conditions of the oil market. In addition, demographic pressures had become a major issue in the 1990s since population growth rates began to outstrip economic growth.

Concerns over the booming population and high Saudi unemployment in the 1990s have coincided with the slowdown of economic growth. This had become a serious concern for the government; namely, increasing financial burdens due to a growing population in the face of declining oil revenues. A major current concern is that 60% of the growing Saudi population is below the age of 25 (Figure 5.5), implying significant challenges ahead in terms of education and employment. Hence from an economic policy perspective, the challenge that the Saudi government currently is facing is whether the Saudi economy can generate sufficient employment opportunities within the next 10 years for this burgeoning labor force.

There is a need for enhancing the quality of this potential labor force through better training and reforming the education system. Economic diversification will require accelerated capacity building in cognitive skills and computer literacy for the Saudi workforce. The quality of education at all levels must be enhanced so that the Saudis can meet the demands of the 21st century. However, the successful implementation of this major realignment of the education system will require scientific laboratories and educational know-how, which means that additional resources need to be allocated to scientific institutions to accommodate the growing Saudi youth population.



Source: Central Department of Statistics (CDS)

Figure 5.5 Saudi Demographic Youth Bulge (2007)

5.6 Economic Impacts of Response Measures on the Saudi Economy:

5.6.1 Transmission Mechanisms:

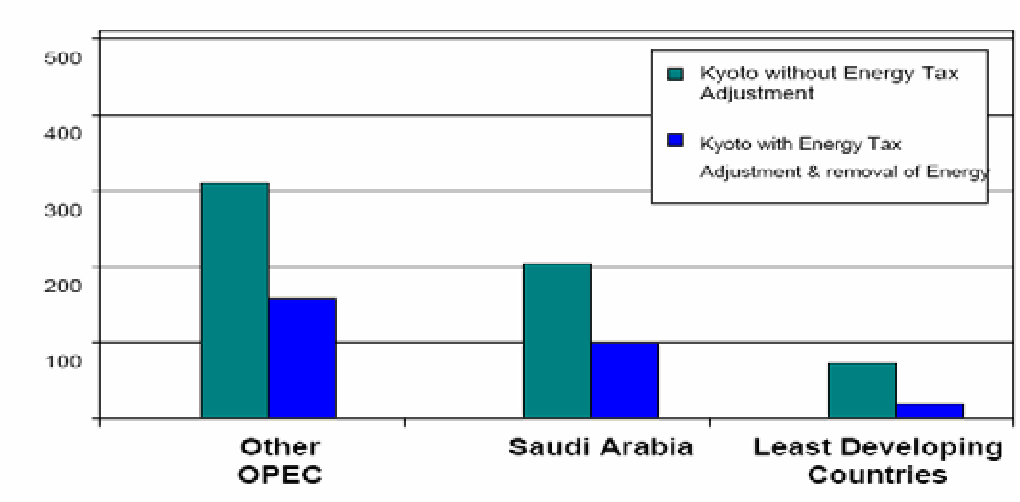
There are two channels through which climate change actions by Annex I countries adversely affect the economies of non-Annex I countries. These channels are demand for hydrocarbon (Direct) and terms of trade (Indirect). Mitigation of greenhouse emissions reduces demand for hydrocarbon and depresses their international prices, causing direct revenue losses for hydrocarbon exporters. Implementation of response measures can also induce spillover effects through the international trade channel. Restrictions on the use of hydrocarbon energy in Annex I countries, whether through prices and taxes or through direct control, increase production costs and hence prices of exportable goods and services. Provided that the majority of developing countries imports are from Annex I markets, the mitigation action of Annex I will effectively translate into an adverse movements in terms of trade for developing countries. Being a major oil exporter and a highly open economy, Saudi Arabia will be significantly impacted through both channels.

5.6.2 IPCC TAR & Earlier Assessments of Kyoto Impacts:

The IPCC Third Assessment Report (TAR) provided a detailed evaluation of the impacts of climate change response measures on non-Annex I countries for the original version of Kyoto (including the US). The studies and model comparisons cited in the report, e.g. Weyant et. al. (1999), have indicated that oil exporting countries will be negatively impacted by Annex I mitigation action and that the extent of the impacts on these countries would be greater than those to be experienced by Annex I countries themselves.

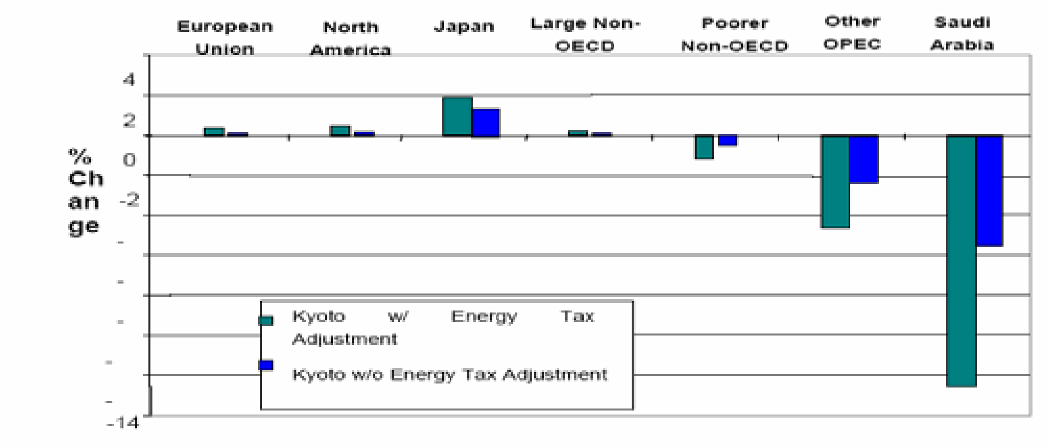
Climate change response measures will impact world oil demand by making hydrocarbon energy more expensive in Annex I countries, thus leading to a reduction in oil imports and a downward pressure on the international oil price. This will have negative economic impacts as well as adverse effects on Saudi Arabian welfare since lower incomes can lead to deteriorating socio-economic standards.

The Multi-Sector/Multi-Regional Trade (MS-MRT) model results indicate that it would require a present value lump-sum payment between $100-200 billion to offset the economic damage to Saudi Arabia during the period between 2000 and 2030 due to Annex I climate change response measures (Figure 5.6). The Intergovernmental Panel on Climate Change (IPCC) has also projected declines in oil demand and revenues for developing countries that are highly dependent on the export of hydrocarbon such as Saudi Arabia. These economic losses will vary; however, Saudi Arabia, being the largest oil-exporting economy, will experience disproportionate losses to its economic welfare compared to other developing countries. In addition, Saudi Arabia will also face disproportionate losses compared to those Annex I countries who are obligated by the UNFCCC and the Kyoto Protocol to take the lead in reducing their greenhouse gas emissions. The high welfare losses for Saudi Arabia and other oil exporting countries are not only because of revenue losses but also due to spillover effects caused by the adverse movement in their terms of trade (Figure 5.7), particularly given their dependence on the import of consumer and capital goods from Annex I markets.



Source: Charles River Associates (2000)

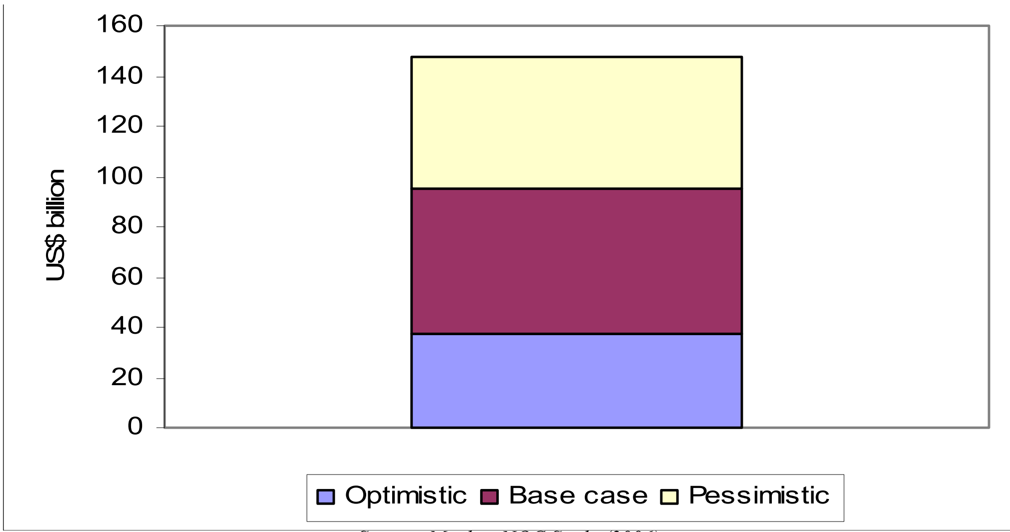
Figure 5.6 Net Present Value of Cash Compensation



Source: Charles River Associates

Figure 5.7 Percentage Changes in Terms of Trade in 2010

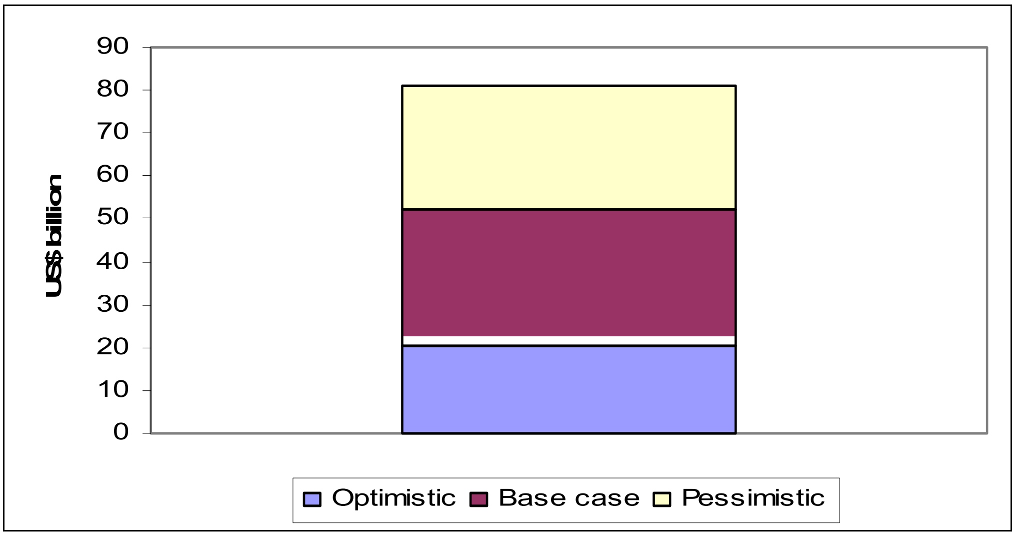
The Mackay Study (2006) assesses the impacts of Kyoto type policies on petroleum consumption and incomes of the National Oil Companies (NOC) along three scenarios: a base case, a pessimistic scenario, and an optimistic scenario. The results on lost oil consumption caused by Annex I climate change response measures under these scenarios based on 60$ per barrel are shown in Figure 5.8.



Source: Mackay NOC Study (2006)

Figure 5.8 Value of "Lost" Petroleum Consumption in 2015

These oil demand losses are expected to translate into significant revenue losses for the National Oil Companies and consequently Government revenues, estimates of which are shown in Figure 5.9 under the three scenarios.



Source: Mackay NOC Study (2006)

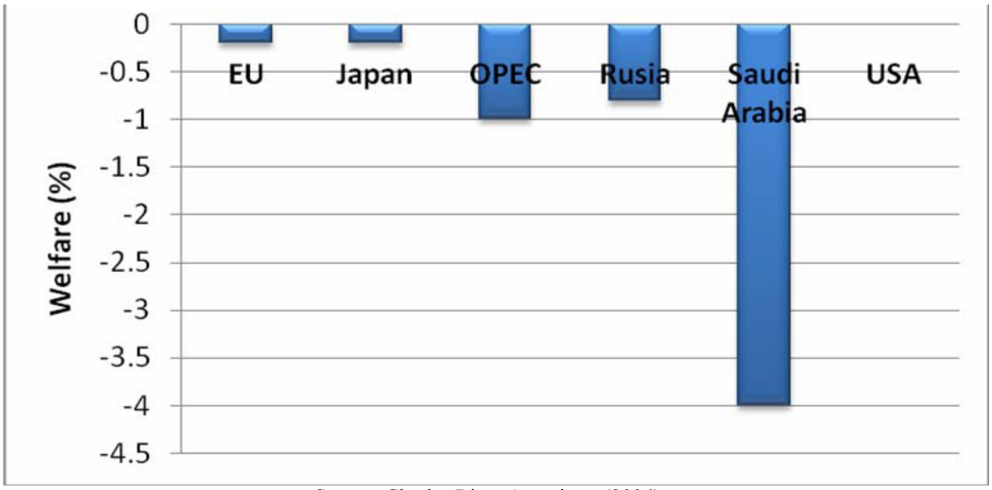
Figure 5.9 Value of "Lost" NOC's Revenues in 2015

5.6.3 AR4 & Later Assessments of Kyoto Impacts:

In its Fourth Assessment Report (AR4), the IPCC concluded that the literature since the publication of its Third Assessment Report confirms the earlier findings with respect to the impacts of Annex I response measures on non-Annex I. In particular, the report confirmed that hydrocarbon exporters would expect lower demand and prices and lower GDP growth due to Annex I mitigation policies.

It is understandable that, Entering force without the US, the Kyoto Protocol will yield both lower costs and lower climatic impacts than the original Kyoto setup. Nonetheless, the scope of spillover effects, the distributional impacts, and the direction of the adverse effects of Annex I mitigation actions on developing countries and oil exporters would be the same.

The Multi-Sector/Multi-Regional Trade (MS-MRT) model was again used to assess the impacts within the new Kyoto setting (i.e. without US). The model was updated to the most recent available data and used to simulate a policy scenario in which US implements a regulatory regime following the Bingaman Bill and the rest of Annex I countries follow Kyoto. The welfare impacts of the policy package are shown graphically in Figure 5.8. These results support the AR4 conclusions and the earlier TAR results that the Annex I mitigation action will have negative impacts on hydrocarbon exporters, particularly on Saudi Arabia, and as well confirm the finding in the literature that oil exporters would shoulder greater burden than Annex I countries themselves. Given its heavy dependence on oil, Saudi Arabia is seen to face even higher economic and welfare costs than the other oil exporters.



Source: Charles River Associates (2006)

Figure 5.10 Welfare Costs of Kyoto (with Bingaman Bill for US)

5.6.4 Assessments of Post-Kyoto Impacts:

In 2007, the Bali Action Plan set forth the negotiation stage for a post-Kyoto regime by laying out the essential concerns and aspects regarding mitigation, adaptation, technology transfer, and financing and by calling for a shared global vision. Following Bali, intense talks have taken place leading to an interim deal at COP15 in Copenhagen, Dec 2009.

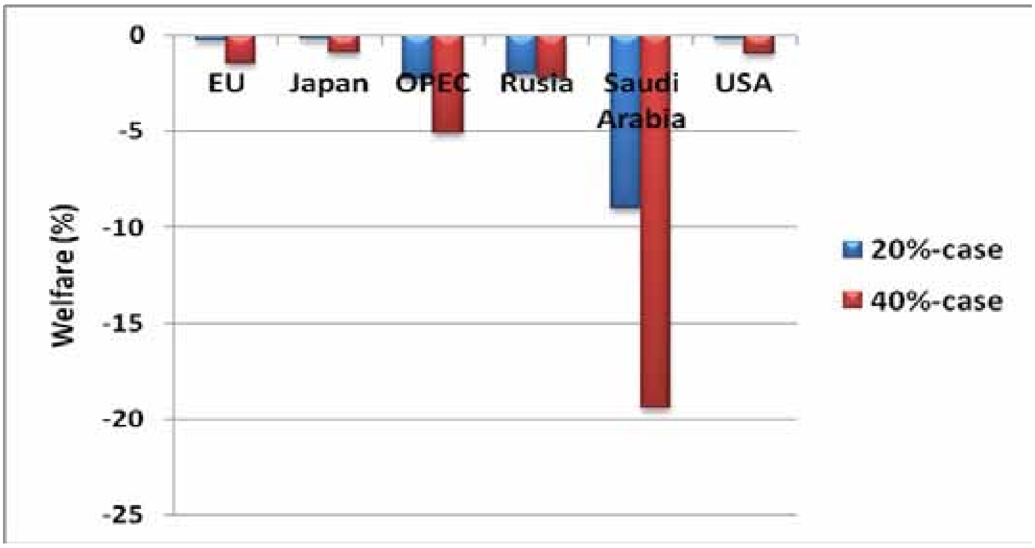
Though COP15 has provided some potential guidance for a future global agreement, the vast bulk of work is left for the upcoming years, with the end of 2010 summit in Mexico as the next step. Among its major provisions, the Copenhagen Accord stipulated that the rise in global temperatures be limited to two degrees, developed countries transfer significant funds to finance mitigation in developing nations, and that countries provide their unilaterally-offered emissions cutback pledges to the UN by the end of January 2010.

Different initiatives and proposals for post-Kyoto are so far on the table. The G8 countries have declared a goal of a 50% reduction in global emissions by 2050. The EU has a target of 20% reduction below 1990 by 2020 if no global agreement and 30% if there is a global agreement, and a global target of 50% below 1990 by 2050. Australia has declared a target of 5% below 1990 by 2020 if no global agreement and up to 15% if there is a global agreement. The US new administration has a target of reducing emissions to their 1990 level by 2020 and by 80% by 2050. Given the stringency of such global mitigation targets, their implications for the impacts of response measures on developing countries in general and oil exporters in particular would be critical. Unfortunately, there are yet only a few studies that have attempted to assess these implications.

Based on the G8 reduction goal, a recent MIT study (Jacoby et. al., 2008) simulates a scenario in which global greenhouse gas emissions are reduced gradually by 10% in 2015 to 50% in 2050 from their 2000 levels. The study has considered various allocation and burden sharing schemes, including the participation of developing countries and the impacts of response measures. The study concluded that the 50% global target is unachievable without the participation of developing countries and that, unless appropriately compensated, the bulk of the mitigation costs will fall on developing countries if they participate in the mitigation regime. Among developing counties, the oil exporters will be the most burdened with welfare costs for the Middle East ranging between 18% in 2020 and 51% in 2050 for the case of no compensations and between 5% in 2020 and 9% in 2050 when compensated for mitigation costs only (i.e., no compensation for the impacts of response measures). In contrast, the welfare cost in the latter case for US ranges between 1% and 7%, for Japan between 0.6% and 4%, and for EU between 2% in 2020 and 8.5% in 2050, confirming the higher burden on oil exporters and the legitimacy of the call for consideration of the impacts of response measures.

To inform on cost implications of more stringent post-Kyoto mitigation regimes, the Multi-Sector/ Multi-Regional Trade (MS-MRT) model was used to simulate cases with 20% and 40% reduction in Annex I emissions from their 1990 levels starting 2015. Consistent with the above results, the model reported life time welfare losses for Saudi Arabia of 9% and 19% for the 20% and 40% cases, respectively (Figure 5.11). Further, the results also confirm the difference in order of magnitudes of the impacts on oil exporters compared to those on Annex I, and therefore the more urgent the need to take measures to minimize the impacts of Annex I response measures.

A further dimension of impacts on oil producers not reflected in the cost of policy uncertainty on future investment decisions with respect to new developments and capacity expansions, which will negatively impact supply-demand balance and energy security.



Source: Charles River Associates (2006)

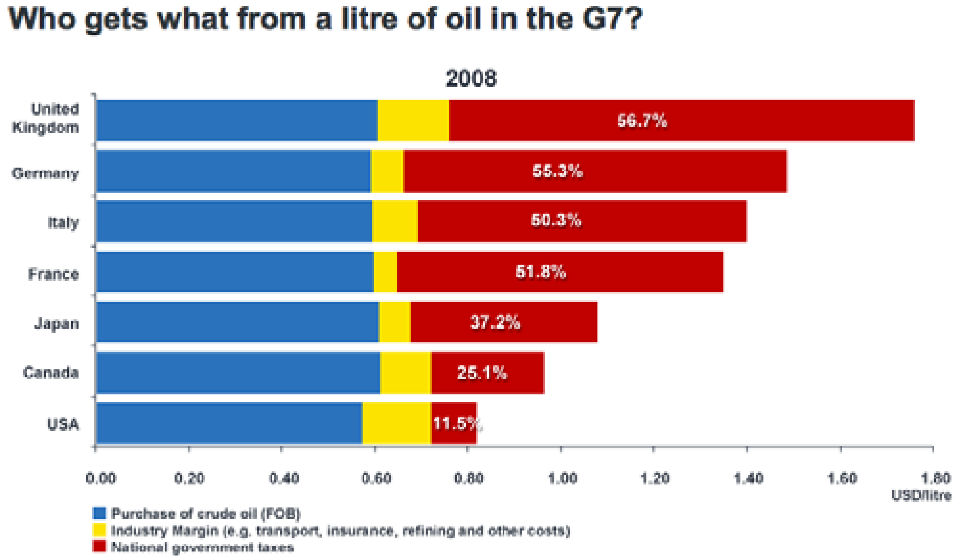
Figure 5.11 Welfare Costs of Post-Kyoto Regime

5.7 Implications of the Choice of Response Measures:

5.7.1 General Perspective:

Under the UNFCCC as well as Kyoto, Annex I countries have an obligation to minimize the impacts of their response measures on developing countries. The first step towards meeting that obligation would be to select policy measures with that objective in mind. In contrast to this, there is a profound concern among oil exporting countries that Annex I countries may strategically use their climate change policies to target the oil sector. Historically, developed countries have shown a trend of formulating policies and regulations that tend to target oil unfairly for environmental and energy security considerations. For example, the subsidization of coal and nuclear energy production as well as the relatively high and discriminate taxation on petroleum products (Figure 5.12) are both environmentally unfriendly and have adverse impacts on economic growth of developing countries, particularly oil exporting countries like Saudi Arabia. The continuation of such policies certainly contradicts the aim of assisting economic development and world sustainable growth and contravenes the requirements of Articles 4.8 and 4.10 of the Convention.

Reforming the existing fuel taxation system in OECD to be more geared towards curbing greenhouse emissions will be a necessary step. The use of carbon taxation based on carbon content as well as the removal of environmentally unfriendly subsidies (predominantly for the production of coal and nuclear power) in developed countries will result in reduced economic burdens on all countries, in particular oil exporting countries like Saudi Arabia. This can also yield global economic and environmental benefits.



Source OPEC Website (http://www.opec.org/opec_web/en/data_graphs/)

Figure 5.12 Oil Taxation in OECD

5.7.2 Climate Change Policy Architecture:

A good architecture should adequately accommodate the distribution, efficiency, and technology aspects of the policy design. On distribution and equity, mitigation policy and measures should aim at balancing costs vs. benefits, burden across sectors and regions, treatment of emission sources, and the treatment of the impacts on developing countries. On the efficiency front, policies and measures should employ instruments and implementation mechanisms that encourage emissions reduction from the least cost sources. On the technology front, good climate policy architecture should aim at availing a level-playing field for innovation and should encourage the development of technologies with large abatement potentials, such as Carbon Capture and Storage (CCS) technologies.

Provided these characteristics, climate change policies and measures that would likely have the least costs on oil-exporting developing countries, such as Saudi Arabia, would be:

- Broad and comprehensive rather than sector-specific measures.
- Use carbon-based rather than fuel-based policy instruments.
- Based on climate change concerns rather than inspired by energy security or energy independence objectives.
- Encourage maximum flexibilities across time, sources and location, including utilization of potentials from land use change, sinks, and non-CO_2 greenhouse gases and the broad use of Kyoto-type flexibility mechanisms (Trading, JI, and CDM).
- Take into account the full environmental impacts of the response measures, including their impacts on sustainable development.
- Facilitate trade of technology components (goods and service) and disseminate technology use without resorting to measures of protectionism that will result in disguised trade measures.

5.7.3 Policy Choice Makes a Difference:

Sector-specific policies in general and those targeting the oil or transport sectors in particular are damaging to oil-exporting countries and world economy. Taxonomy of some of the most affecting measures and policies for the oil exporting countries and where in particular Saudi Arabia is most vulnerable are:

- Fiscal policies involving direct or indirect taxes on petroleum and/or petroleum products. These measures are directly affecting the oil consumption and consequently global demand for oil, leading to lower export quantities from Saudi Arabia combined with lower prices. A simulation-run of MS-MRT with a border adjustment tax on carbon content of imports in the EU of US$ 25.00 per ton of carbon produced an 8% fall in the oil price and 15% loss of export revenues for Saudi Arabia.

- Fiscal policies involving subsidies to alternative fuels. Increasing subsidies by developed countries on low-carbon energy sources such as nuclear and hydro will negatively impact oil demand and oil exports.
- Mandatory fuel switching or fuel mixing in the transport sector has major effect on the economics of the transport sector that is reflected in less oil based fuel being consumed in this sector. Though such policies may have little impacts in the short run, their impacts on the environment and the world food supplies in the long run will be devastating.
- Unilateral measures applied by certain countries and/or groups of countries, such as policies initiated by the European Union or some of its members, although limited in nature but targeting specifically petroleum imports has a low effect on emission reduction but has a very high effect on the income of the exporting countries.

5.8 Saudi Arabia's Adaptation Requirements to cope with Climate Change Response Measures:

Annex I climate change mitigation actions will have adverse effects on Saudi government revenues and thus impede the government's ability to provide for the needs of its citizen. Therefore, minimizing the impact of climate change policies on developing countries that are heavily reliant on oil exports was recognized from the inception of the Climate Change Convention. Since these response measures will impact the economy of Saudi Arabia, it is imperative that Annex I countries meet their obligations of providing assistance to Saudi Arabia as an adaptation measure to offset the economic impacts of their climate change response measures. These requirements are stipulated in decision 5 CP.7 entitled "Implementation of Article 4, paragraph 8 and 9 of the convention" which specifically addressed the needs of developing countries to adapt to climate change as a result of the implementation of response measures from Annex I countries.

Annex I countries need to provide assistance to Saudi Arabia in its future endeavors to diversify its economy so that it can adapt to future climate change policies. If Saudi Arabia is not able to diversify its economy and its national budget sufficiently away from dependence on oil revenues, then Annex I countries will neither meet their commitments in Articles 4.8 and 4.10 in the climate change convention nor promote the United Nation's ultimate goals of sustainable development. This assistance can be achieved predominately through the diversification of the Saudi Arabian economy.

The diversification of the Saudi economy is not only in the best interest of Saudi Arabia, but may also be in the best interests of the global economy. If the Saudi economy continues to be dependent heavily on oil revenues and the concomitant increase in fiscal commitments due to its current population boom, then the only method the Kingdom has in its disposal to meet its domestic financial commitments is to increase its oil revenue through oil supply management. This will lead to higher global oil prices and may potentially have adverse effects on the global economy. In addition, lower national income per capita and an increase in the unemployment of a youthful Saudi population will reduce social standards which may increase the risk of future instability. Thus, these conditions will not be desirable for the global economy since Saudi Arabia is considered the world's "central bank of oil". Therefore, there are potential risks that may be faced by all countries in the absence of future economic diversification of Saudi Arabia.

Why is a well-diversified Saudi economy in the best interest of Annex I countries? Saudi Arabian economic diversification may be in the best interests of all parties for the following security, economic, and environmental considerations:

- A diversified economy tends to generate a healthy social society. Since 25% of the global oil reserves are in Saudi Arabia, stability in the region will have a global benefit it will help ensure global energy security.
- Diversification would help Saudi Arabia develop towards a post oil age over the next several decades and thus may lead to the reduction of greenhouse gas intensive nature of its economy.
- The marginal cost of greenhouse gas emissions abatement in Saudi Arabia is considerably low. Therefore, investment in modernization (creating a more energy efficient economy) will reduce overall environmental degradation.
- A diversified economy will lend itself to more global trade and thus a benefit to the global economy. Saudi Arabia exports oil while it imports manufactured goods, services and high tech equipment from certain Annex I countries. Since the oil based economy may not be sustainable in the long-term due to climate change policies, this will reduce Saudi Arabia's ability to purchase goods and services from developed countries.

An important criterion for a nation to undergo economic diversification is to undertake steps in liberalizing its economy. Saudi Arabia has taken these liberalization steps in the past several years in order to diversify its economy: These steps can be summarized as:

- Allowing for the first time foreign investors to participate in exploration and production of natural gas. This "gas initiative" has resulted in the restructuring of certain investment laws in the Kingdom.
- Privatization of certain industries; and
- Accession to the World Trade Organization.

The main areas in which Saudi Arabia would require technology transfer and dissemination as well as more investments from the Annex I parties in order to diversify its economy are the following: power generation, water resources, non energy use of hydrocarbon, research and development particularly of Carbon Capture and storage (CCS) and most importantly education.

5.8.1 Power Generation:

As the population of Saudi Arabia continues to grow, so does the demand for electricity. Annex I investments in this area would be of essence to provide power generation requirements through providing the best and more efficient ways to use Saudi Arabia's low cost energy resources for the purpose of producing electricity. Some of the areas that can be addressed are:

- Possessing one of the largest reserves of natural gas, tapping into this resource has the potential of producing less-greenhouse intensive power generation for Saudi citizens.
- Due to Saudi Arabia's low cost energy, technology transfer and dissemination into residual gasification through CDM projects can produce environmental friendly power.
- Technology transfer of renewable energy production for power generation would reduce dependence on oil, particularly, Solar and Wind technologies and applications.
- Co-generation technologies

5.8.2 Water Resources:

Water is the most precious resource in the world. Due to its enormous population growth, Saudi Arabia's ground water supplies will not be enough to meet this growing demand. Therefore, Saudi Arabia has resorted to highly expensive desalinization technology to provide this critical resource. Annex I parties can assist Saudi Arabia through transferring technology and dissemination and allowing this capital intensive process to be more economical. For example, nano-fibers can be used to make this process considerably less expensive.

Desalinization of seawater is not the only means of securing future water resources for Saudi Arabia. Capacity building through integrated water management would be another method for meeting the growing needs of Saudi Arabia in this area. This can be accomplished mainly through water conservation and the reuse of wastewater streams.

A third area for technical assistance is development of salinity-tolerant crops and agriculture.

5.8.3 Non-Energy Use:

Saudi Arabia is currently attempting to diversify its economy through the expansion of its domestic petrochemical industry. Saudi Arabia can offer Annex I countries inexpensive feedstock to produce petrochemicals. However, Saudi Arabia will need assistance in the following areas:

- Finance: The production of petrochemicals is a capital intensive industry; therefore, Saudi Arabia will require a considerable amount of foreign direct investment to expand this industry domestically.
- Technology transfer and dissemination: Consumer markets are quite demanding when it comes to the performance of certain plastic products; therefore, Saudi Arabia will need the latest in technological development in this field to produce modern products that are demanded by end users.
- Market Access: Saudi Arabia needs assistance from Annex I countries to remove certain trade and non-trade barriers in order for its end products to reach the desired markets. This is very critical because diversifying the economy without diversifying exports will not reduce the country dependence on oil for budget revenues and foreign currency.

5.8.4 Research & Development and Technology:

- CCS Technologies:
- Research, development, deployment, dissemination and scale up of technologies that can achieve significant reduction in CO2 capture costs.
- Gaining a better understanding of the science behind CO2-EOR for future use in Saudi Arabia.
- Develop appropriate actions for carbon storage in subsurface reservoirs, both aquifers and hydrocarbon traps.
- Work towards proofing the technology and its qualification as a CDM activity.
- Green Oil technologies:
- Develop technological solutions that reduce CO2 emissions from mobile sources.
- Identify and develop industrial applications for emitted CO2.
- Strengthen efficiency in upstream and downstream activities.
- Technological development of non-energy uses of hydrocarbon.

5.8.5 Education:

Saudi Arabia has a very large youth population. This can be seen as a potential burden if the economy is not able to create sufficient employment opportunities. However, a large young population can have considerable long-term benefits if this workforce has the sufficient skills required by the labor market. The suitable education for this young population is the key factor in building the future wealth of this nation; namely, through skilled labor and a competitive work force. This is the most important future challenge that Saudi Arabia must face; namely, building the proper skills of its workforce in order to effectively diversify its economy. Annex I countries can assist Saudi Arabia through a transfer and dissemination of technical know-how. This would be beneficial to educate the young population in order for this nation to generate a more competitive workforce. This will allow the Kingdom to build a wealth of knowledge in the long term.

5.9 Recommendations:

Articles 4.8 and 4.9 of the UNFCCC and articles 2.3 and 3.14 of the Kyoto Protocol have provided the foundation for the basic obligations and commitments of Annex I parties in relation to the impacts of their climate change response measures. A number of decisions followed to provide guidelines with respect to actions, implementation, and reporting related to these commitments, e.g. paragraphs 3 and 8 of decision 9/CP.7, decision 5/CP.7, decision 1/CP.10 (The Buenos Aires Program of Work on Adaptation

and Response Measures), decision 15/CMP.1, and paragraph 8 of decision 31/CMP.1. Unfortunately progress regarding compliance with these provisions and obligations remain to date unsatisfactory.
The following are some recommendations for improving compliance and for addressing the unfinished business with respect to the adverse impacts of response measures:

- Undertake a comprehensive review of current actions, as a platform for the process of implementation referred to in paragraph 1 of decision 9/CP.7.
- Develop methodologies and specify criteria/indicators to evaluate and account for adequacy of compliance. The specific criteria/ indicators are needed to measure the impacts of the implemented/proposed response measures, the impacts of the alternative measures that might be implemented, and to assess the adequacy and effectiveness of funding, insurance and technology transfer arrangements to minimize these impacts.
- Standardize reporting requirements on the impacts of policies and measures, creating a common template to be used as supplementary information submitted with national inventory reporting.
- Standardize reporting on support-type programs to reduce the impacts of response measures, based on the six actions spelled out in paragraph 8 of decision 9/CP.7. This also should feature as part of national inventory reporting.
- Require that the GEF report annually to the COP on programs undertaken that comply with the commitments spelled out in paragraphs 22-29 of decision 5/CP.7.
- Create guidance for the facilitative branch as to the nature, timing and substance of its responsibility to assess compliance with the basic obligations on response measures. This should be an annual assessment, and should be based on the reporting described above, as well as on a special technical report by either the IPCC or an expert modeling group of various policies and measures and their relative impacts.
- Commit to a future review of actions to decide what further actions might be needed. This would be based on inter alia, a best effort to model the impacts of past response measures.
- Create a special fund to support technology dissemination, transfer and economic diversification as methods for addressing the impacts of response measures.
- Create a forum or an expert group to discuss best practices on policies and measures that minimize the impacts on developing countries.

5.10 Conclusion:

The Saudi Arabian economy will undoubtedly be impacted by Annex I climate change response measures since these actions will be implemented as policy measures to reduce primarily CO2 emissions. This will reduce oil demand and affect negatively global oil prices. The implication of this for Saudi Arabia would be a reduction in crude oil exports and a decline in its oil export revenues which comprise a large portion of its GDP. However, Saudi Arabia may adapt to these response measures by diversifying its economy sufficiently away from its crude oil export sales. In order for Annex I countries to implement these response-measures, they must attend to the needs of developing countries as stipulated in climate change convention, the Kyoto Protocol and beyond.

Saudi Arabia will require assistance from Annex I countries to diversify its economy in order to adapt to potential climate change related policies. However, this will require a joint effort between Annex I countries and Saudi Arabia in order to implement solutions for Saudi economic diversification. This can be achieved by leveraging the Kingdom's potential assets (abundant and low cost energy resources as well as a large youth population) and providing investments as well as implementing technological know-how of Annex I countries. Therefore, Annex I countries can realize benefits when assisting the Kingdom in diversifying its economy. Not only will the best interests of the Kingdom be served, but also that of the world for this will be a global benefit to reliable energy availability, the global economy, and the environment.

SECTION - 6

Climate and Climate Change Scenarios

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Section 6: Climate and Climate Change Scenarios

6.1 Introduction:

Since the publication of the First National Communication report (FNC) of the Kingdom of Saudi Arabia in 2005, substantial progress has been made in scientific understanding of observed changes in the country's climate and its qualitative character and quantified range of possible future changes. This knowledge is being used to derive a variety of decisions in multiple areas of concern. However, user needs for information that is relevant and directly applicable to risk management issues at local to regional scales are not being met. Users need information at finer temporal and spatial scales than is commonly provided. Within the framework of the FNC, the climate change scenarios were elaborated on the basis of some selected and widely used GCMs. According to IPCC (2001), previous models of the Global Climate Change underestimated, to some extent, the predicted temperature increase for the coming 50-100 years. The most recent assessments of IPCC (2006) show that increasing global emissions of GHG will facilitate the increase of temperature between 2-6ºC depending on the intensity of emissions and geographical location of the region.

6.2 Activities Undertaken for Second National Communication Report (SNC):

In order to improve the conclusions obtained in the First National Communication Report (FNC), activities for the Second National Communication Report (SNC) were carried out along two main tracks, which can be summarized as follows:

- Elaboration on the baseline climate scenarios and
- Elaboration on the future climate change scenarios

6.2.1 Elaboration on the Baseline Climate Scenarios:

These climate scenarios can further be classified into the following categories:

6.2.1.1 Further analysis of some noticeable features of FNC results as related to the baseline climate:

- **Remarks on the temperature trends at the Western Coast of the Kingdom:**

  In the climate study part of the FNC, data from 26 meteorological stations for the period from 1978 to 2003 was used as the baseline climate for the country. In order to obtain the trends of the basic climate parameters, namely the temperature and rainfall, a "STEP-WISE" method was followed. The baseline period is divided into two equal parts of 13 years each (sub-periods). Trends were judged from the difference of the mean values corresponding to these two sub-periods for all stations.

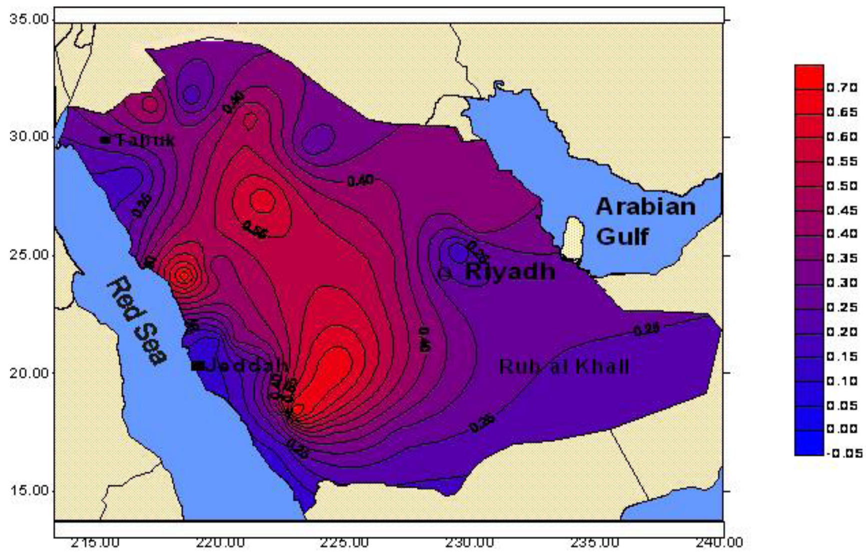


Figure 6.1 Spatial Distribution of Temperature Trends (1978 – 2003)

- Results were plotted for the changes of the mean annual values of temperature and precipitation to show their spatial distribution. Figure 6.1 shows the resulted chart for temperature from which it can be concluded that:
- Temperature trends are positive all over the country and large in the interior parts but small over the coasts (due to mixing with the maritime air), except in Yanbu at the western coast and Jubail at the eastern coast.
- Temperature trend in Yanbu is much higher than those estimated in Jeddah and Al-Wajh and even in Jazan far too the south. This is also clear from the plot of time series of mean annual temperatures for Jeddah, Yanbu and Al-Wajh (Figure 6.2). It is interesting to note that the annual mean temperature in Yanbu exceeded, for the first time in recorded period, that of Jeddah for the year 2001.

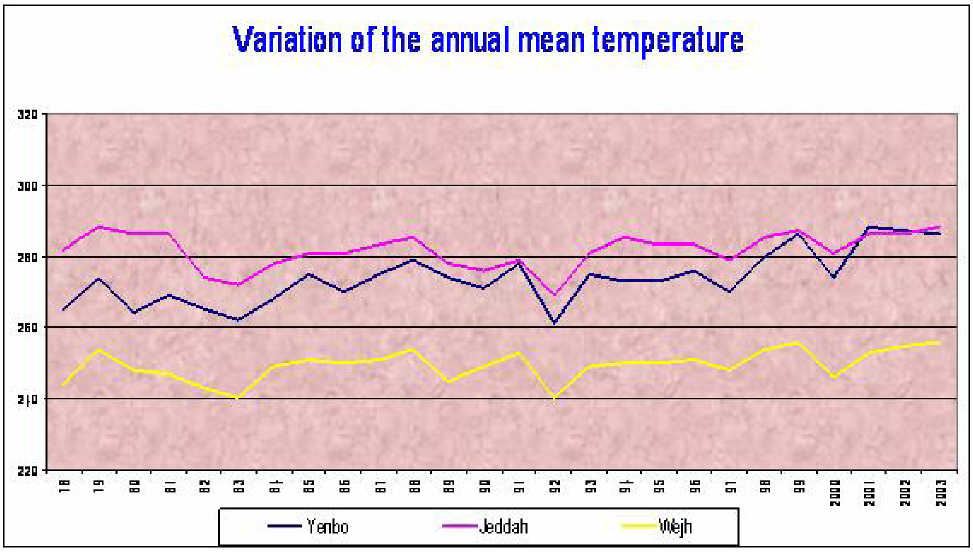


Figure 6.2 Annual Mean Temperature Time Series

It is suggested, based on the trend pattern and its strong correlation to the topographical features of the region, that the general warming during the last 26 years was mainly related to solar radiation. The excessive warming in Yanbu could be apparently due to the local GHG input by the heavy industries in this industrial area since 1982.

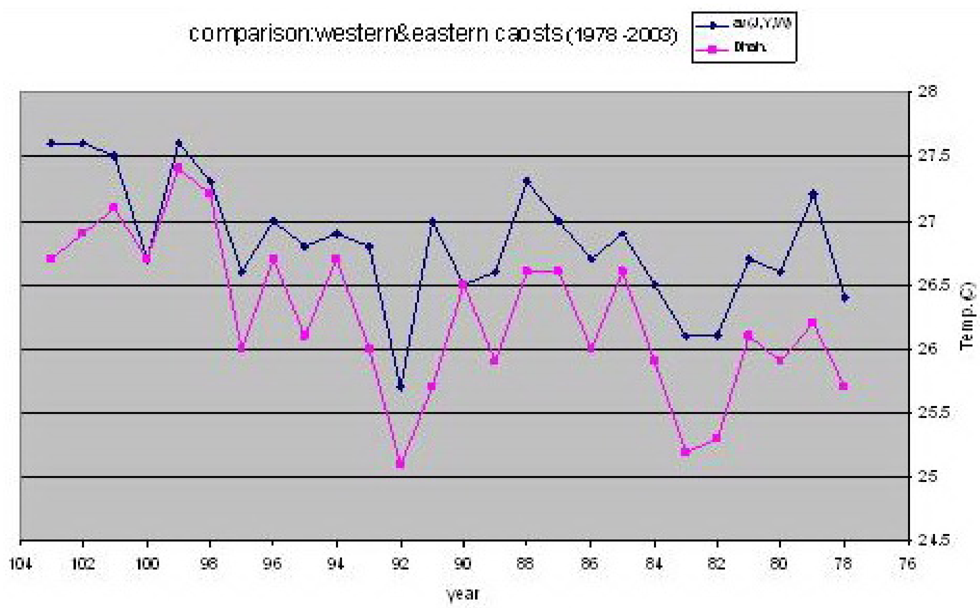


Figure 6.3 Comparisons of Western and Eastern Coast Temperatures

- **Thermal characteristics of years with extremely high or low annual mean temperature :**

Examination of the time series of the annual mean temperatures of various stations revealed a general consistency in their behaviour, (Figures 6.3 and 6.4). This calls for further analysis to shed some light on this common feature for certain selected years. In the recorded period, 1992 has been found to be the coolest year and 1999 the hottest year and have been further analysed.

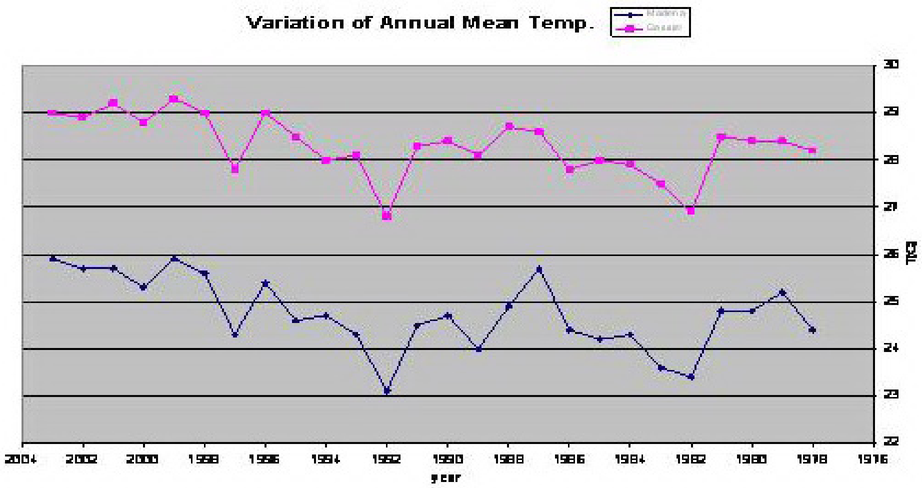


Figure 6.4 Comparison of Annual Mean Temperature of Madinah & Gassim

Coolest year 1992:

Table 6.1 shows the anomalies of the mean annual temperature of the coolest year from the corresponding baseline period mean at all synoptic stations. It has been noted that all anomalies are negative ranging in magnitude from -0.6 to -1.8ºC, showing that there was cooling all over the Kingdom with varying degree.

The excessive cooling occurred mainly in the northern and central areas of the Kingdom in association with a deep intrusion of the Siberian high to these areas in winter and early spring, (Table 6.1). Figure 6.5 shows the anomalies of the monthly mean temperature values of the year 1992 from the corresponding base line values for Gassim.

Table 6.1 Anomalies of the Coldest Year 1992

Station	26 Years Mean	1992 Mean	Anomalies
Turaif	19	17.3	-1.7
Arar	21.8	20.1	-1.7
Guriat	19.6	18.3	-1.3
Al-Jouf	21.9	20.2	-1.7
Rafha	23.2	21.5	-1.7
Qaisumah	25.1	23.6	-1.5
Tabuk	21.9	20.5	-1.4
Hail	22.2	20.8	-1.4
Wejh	24.9	24	-0.9
Gassim	24.8	23.1	-1.7
Dhahran	26.1	25.1	-1
Al-Ahsa	27.1	25.6	-1.5
Madinah	28.2	26.8	-1.4
Riyadh	26.3	25	-1.3
Yanbu	27.4	26.1	-1.3
Jeddah	28.1	26.9	-1.2
Makkah	30.7	29.1	-1.6
Taif	22.9	21.9	-1
Al-Baha	22.7	21.5	-1.2
Wadi Aldawasser	28.4	27.8	-0.6
Bisha	25.8	24	-1.8
Abha	18.5	17.7	-0.8
Khamis Mushait	19.2	18.6	-0.6
Najran	25.3	24.3	-1
Sharourah	28.6	27.9	-0.7
Jazan	30.2	29.5	-0.7

Month	26 yr aver.	1992 aver.	Anomalies
1	12.6	8.8	-3.8
2	14.8	11.8	-3
3	18.9	15.7	-3.2
4	24.7	22.9	-1.8
5	30.5	29.3	-1.2
6	33.6	33.2	-0.4
7	34.8	33.7	-1.1
8	34.7	34.2	-0.5
9	32	31.5	-0.5
10	26.6	25.1	-1.5
11	19.4	18.4	-1
12	14.4	12.6	-1.8

Table 6.2 1992 Monthly Mean Anomalies for Gassim

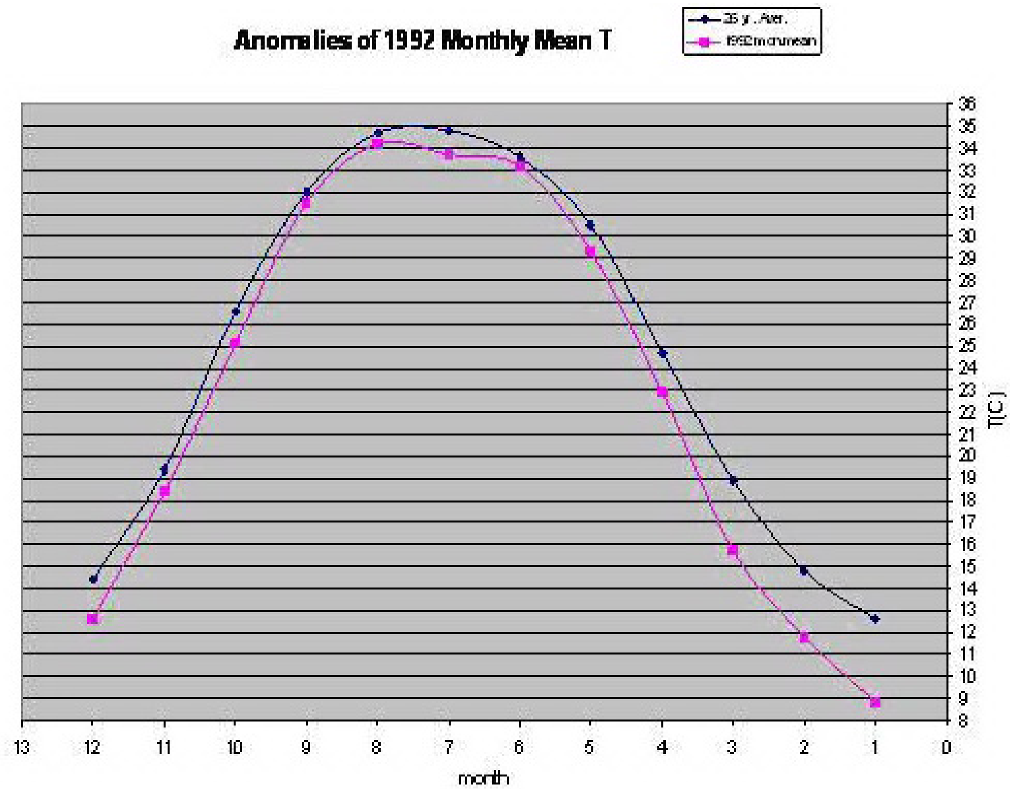


Figure 6.5 Anomalies of 1992 Monthly Mean Temperature for Gassim

Warmest year 1999

Table 6.3 shows the anomalies of the mean annual temperature of the warmest year from the corresponding baseline period mean at all synoptic stations. It has been noted that all anomalies are positive ranging from +0.2 to +1.5ºC, showing that there was warming all over the Kingdom with varying degree.

The excessive warming appeared to affect mostly the northeastern and eastern coasts and the central areas of the country, which may be attributed to an abnormally strong influence of the Indian monsoon extension to these areas during the summer and early autumn (as is clear from Table 6.3). Figure 6.6 shows the anomalies of the monthly mean temperature values of the year 1999 from the corresponding base line values.

Table 6.3 Anomalies of the Warmest Year (1999)

Station	26Years Mean	1999 Mean	Anomalies
Turaif	19	19.6	0.6
Arar	21.8	22.7	0.9
Guriat	19.6	19.8	0.2
Al-Jouf	21.9	22.7	0.8
Rafha	23.2	24.2	1
Qaisumah	25.1	26.2	1.1
Tabuk	21.9	22.3	0.4
Hail	22.2	23.5	1.3
Wejh	24.9	25.6	0.7
Gassim	24.8	25.9	1.1
Dhahran	26.1	27.4	1.3
Al-Ahsa	27.1	27.9	0.8
Madinah	28.2	29.3	1.1
Riyadh	26.3	27.8	1.5
Yanbu	27.4	28.6	1.2
Jeddah	28.1	28.7	0.6
Makkah	30.7	31.5	0.8
Taif	22.9	23.5	0.6
Al-Baha	22.7	23.3	0.6
Wadi Aldawasser	28.4	28.4	0
Bisha	25.8	26.3	0.5
Abha	18.5	18.9	0.4
Khamis Mushait	19.2	20	0.8
Najran	25.3	25.6	0.3
Sharorah	28.6	29	0.4
Gizan	30.2	30.2	0

Table 6.4 26 Years Average and 1999 Monthly Average & Anomalies for Qaysoumah

Month	26 yr aver.	1992 aver.	Anomalies
1	12.6	8.8	-3.8
2	14.8	11.8	-3
3	18.9	15.7	-3.2
4	24.7	22.9	-1.8
5	30.5	29.3	-1.2
6	33.6	33.2	-0.4
7	34.8	33.7	-1.1
8	34.7	34.2	-0.5
9	32	31.5	-0.5
10	26.6	25.1	-1.5
11	19.4	18.4	-1
12	14.4	12.6	-1.8

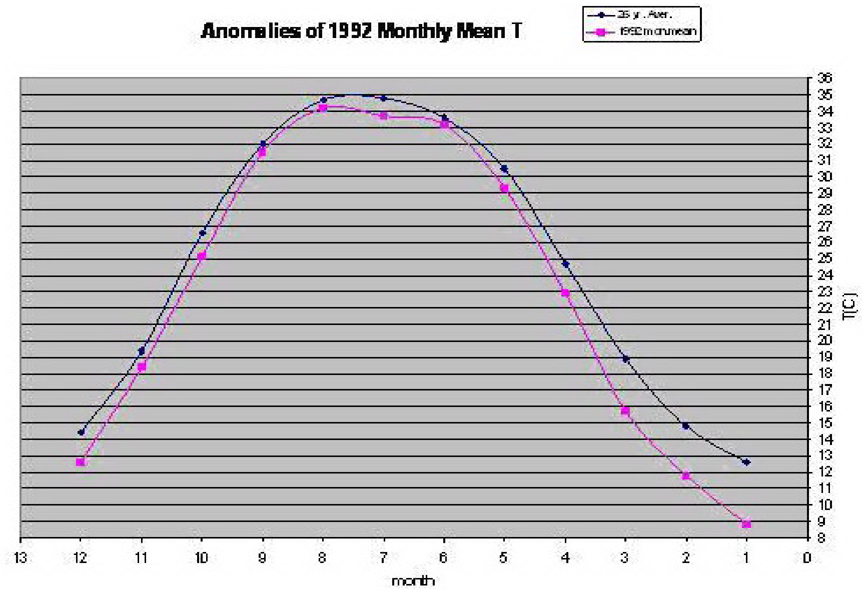


Figure 6.6 Anomalies of 1999 Monthly Mean Temperature for 26 Years and Year 1999

6.2.1.2 Detecting Changes in Temperature and Rainfall during 2004-2008 Period:

In order to verify the consistency of the previously observed temperature and precipitation trends over the baseline period (1978-2003), the time series for all the stations were reconstructed to include the last five years (2004-2008). Example of this extension is shown in Figure 6.7 for Yanbu (temperature) and in Figure 6.8 for Abha (precipitation). Simple statistics were conducted to examine and compare any significant changes in these trends. Table 6.5 exhibits the overall results of this analysis from which the following may be concluded:

- Temperature tendency remained positive over 1978–2008 period for all stations. However, considering the partial changes over the last five years, the visually detected trend varied with six stations showing positive trend, ten stations negative trend and another ten stations steady trend.
- Analysis of rainfall tendency over 1978-2008 period showed an increase in number of station having negative trend for 1978-2003 period (increased from total of 9 to 13 stations). However, considering the partial changes over the last five years 2004-2008), the visually detected trend varied with six stations having positive trend, thirteen stations negative trend and seven stations showing steady trend.

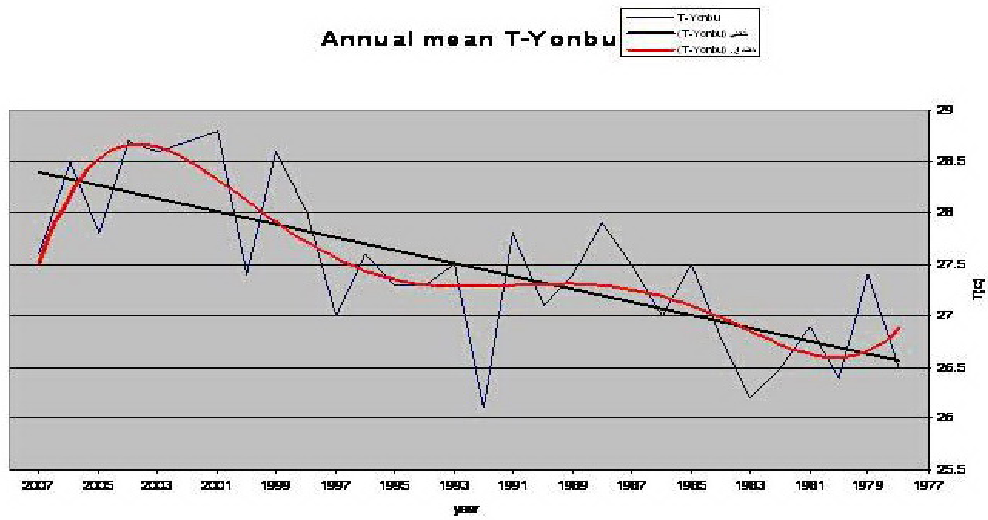


Figure 6.7 Annual Mean Temperature at Yanbu

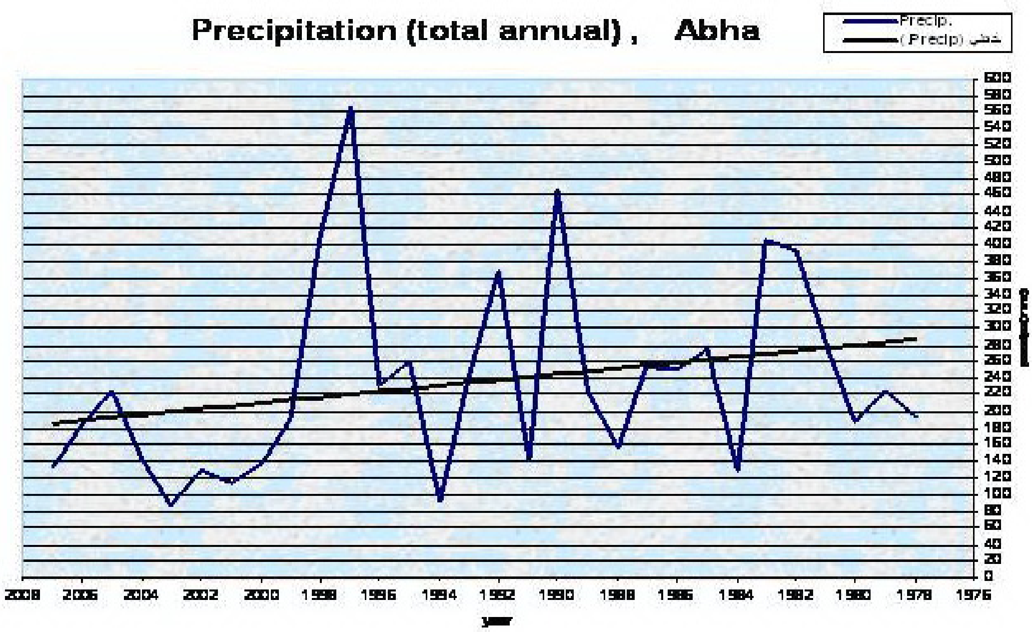


Figure 6.8 Total Annual Mean Precipitation at Abha

Table 6.5 Overall Results of Analysis

Station	T1	T2	T4	R1	R2	R4
Turaif	+	+	-	-	-	=
Arar	+	+	+	-	-	+
Guriat	+	+	-	-	-	-
Al-Jouf	+	+	+	+	+	-
Rafha	+	+	+	+	-	-
Qaisumah	+	+	=	-	-	+
Tabuk	+	+	=	-	-	+
Hail	+	+	=	-	-	-
Wejh	+	+	-	+	+	=
Gassim	+	+	=	+	-	-
Dhahran	+	+	+	+	+	-
Al-Ahsa	+	+	+	+	+	+
Madinah	+	+	-	+	-	-
Riyadh	+	+	=	+	+	=
Yanbu	+	+	-	+	+	+
Jeddah	+	+	=	+	+	-
Makkah	+	+	-	+	+	=
Taif	+	+	-	+	+	-
Al-Baha	+	+	-	+	-	=
Wadi Aldawasser	+	+	-	-	+	+
Bisha	+	+	=	-	-	=
Abha	+	+	=	-	-	=
Khamis Mushait	+	+	-	+	-	-
Najran	+	+	+	+	+	-
Sharorah	+	+	=	+	+	-
Gizan	+	+	=	+	+	-

R1 T1:78- 03 increase+

R2 T2:78- 07 decrease-

R4 T4:03- 07 steady=

6.2.1.3 Temperature Range as Indicator of Continentality:

Continentality is a factor making desertification more likely in certain areas. Desertification is formally defined as "land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors including climatic variations and human activities" (UNCED 1992). Desertification is a term that has long been associated with dry-lands, which cover 40% of the land surface of the globe including Saudi Arabia.

Desertification has become increasingly apparent in the dry sub humid regions of the world. Saudi Arabia is particularly vulnerable to desertification as about 76% of its area is non-arable lands which include 38% of the area as deserts.

Continentality is an important factor in some climate-related practices. e.g. the degree of continentality must be stressed when evaluating the response of the tree line to past, present and future climatic change.

The degree of continentality is a function of the range of minimum and maximum temperatures. The difference in the monthly mean minimum temperature of the coolest month and the monthly mean maximum temperature of the warmest months of the year is used here as an indicator of continentality. This difference is calculated for each station and each year over the period 1978 to 2007. Figure 6.9 shows a plot of a time series of these values for Gassim meteorological station.

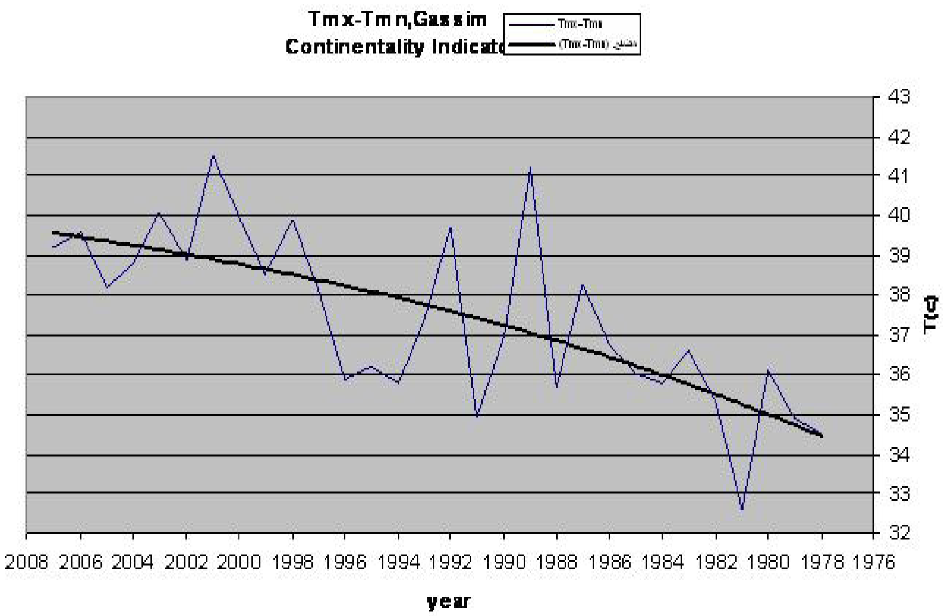


Figure 6.9 Plot of the Time Series of Temperature and Continentality for Gassim (1978 – 2007)

In order to construct a spatial distribution chart of the continentality for Saudi Arabia, the average values of this indicator were calculated for all stations over 1978-2007 period. A plot of the resulted values is shown in Figure 6.10 from which it may be concluded that an area of high continentality is extending from the northeast of the Kingdom to the central and eastern provinces and down to the empty quarter (highest in Rafha 39.8ºC). Gradual decrease of continentality towards the west is apparent all over the Kingdom, forming a low continentality zone extending along the whole western coasts (lowest in Jazan 17.3ºC).

The trend of continentality has also been estimated for all stations using a step-wise method. Results are plotted to produce a spatial distribution chart of the trend (Figure 6.11). Areas that experienced a substantial increase in continentality over the study period were found to be the north-eastern, north-central and northern sections of the red sea coast around Yanbu. Southern parts of the Red Sea coast and Asir mountains showed decreasing trends of continentality. The empty quarter and the north-western provinces showed no appreciable change of continentality over that period of time.

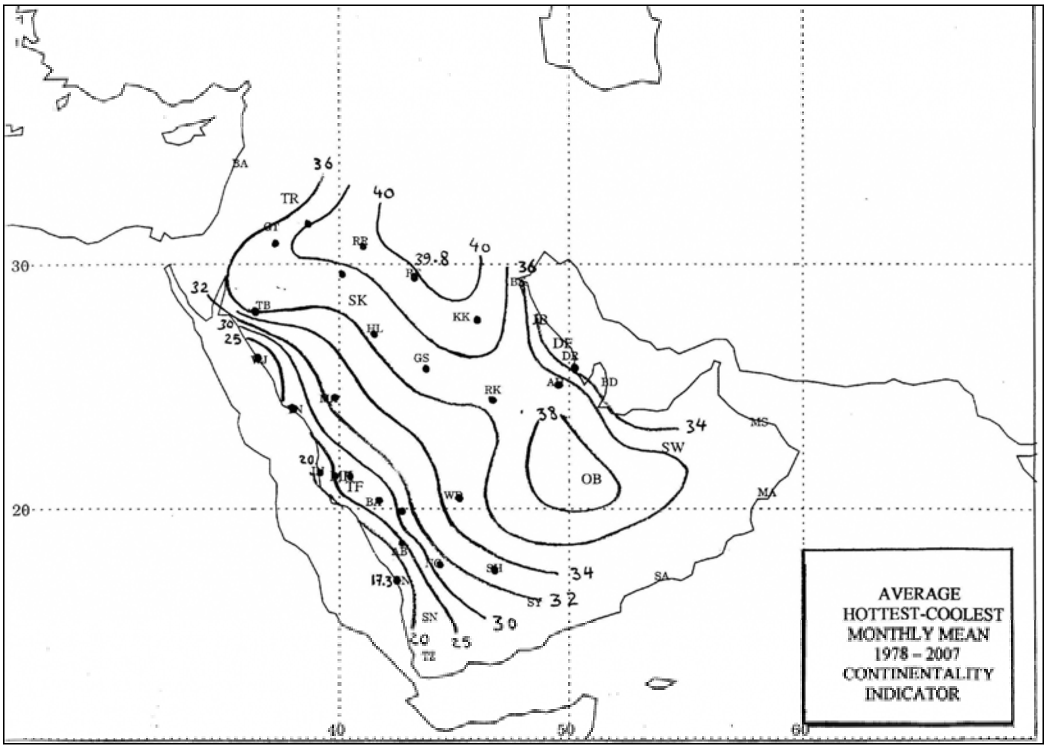


Figure 6.10 Average Warmest and Coolest Monthly Mean (1978-2007)

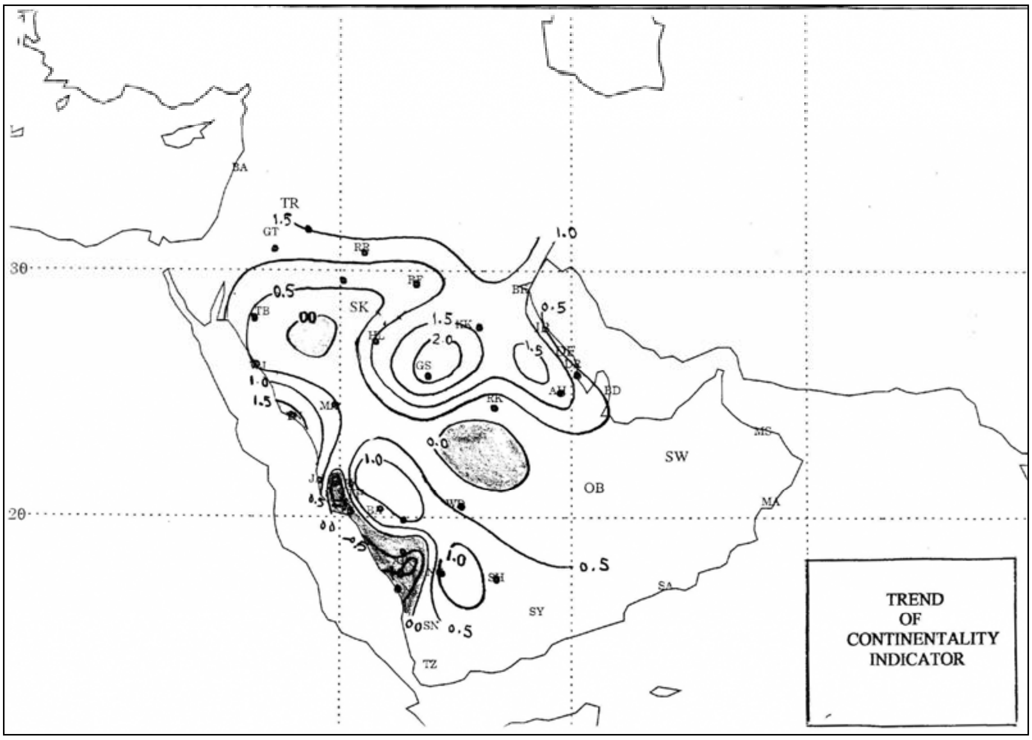


Figure 6.11 Trend of Continentality Indicator (1978-2007)

6.2.2 Elaboration on the Future climate change scenarios:

6.2.2.1 Climate Change Scenarios in FNC:

Climate change scenarios for Saudi Arabia for “FNC”, were developed using a software called “MAGICC/SCENGEN” and an extensive database of Atmosphere/Ocean General Circulation Models (AOGCM) data. Two emission scenarios were selected: P50 (the median of SRES scenarios) to be the “Reference” scenario and WRE350 (a SRES scenario having a CO_2 concentration which stabilizes at

350 ppm in the year 2150) to be the “Policy” scenario. Outputs were produced as seasonal and annual mean temperature in degree celcius and precipitation (%) changes in the year 2041 i.e. 50 years from the central year of the adopted baseline period.

The output comes out as an array (Latitude-Longitude) of 5x5 degree grid for the whole globe. For the purpose of comparison and subsequent analysis, nine grid cells that cover the Kingdom territory were identified (Figure 6.12).

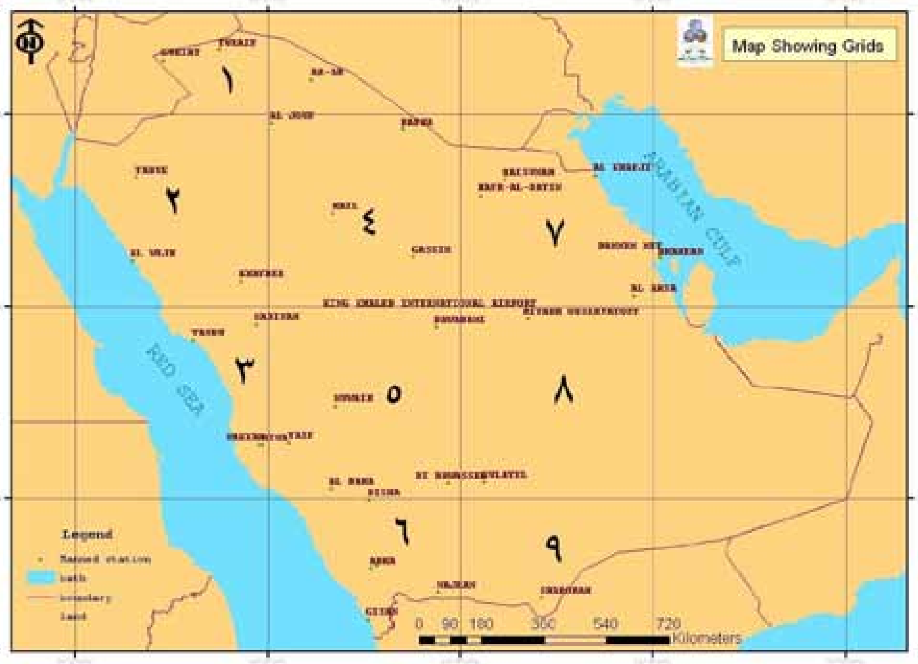


Figure 6.12 Grid Cells Covering Saudi Arabia

Three GCM models were found to simulate closely the climatic trend characteristics of Saudi Arabia. Results obtained from running the combination of these three models are shown in Table 6.6 for each of the nine grid cells presented in seasonal and annual change pattern.

Table 6.6 Changes in Seasonal and Annual Mean Temperature (0C) and Precipitation (%) from CCSR96, IAP_97 and MRI_96

Zone		1		2		3		4		5		6		7		8		9		Mean	
		30 - 35 N		25 - 30 N		20 – 25 N		25 - 30 N		20 – 25 N		15 – 20 N		25 – 30 N		20 – 25 N		15 – 20 N			
		35 - 40 E		35 - 40 E		35 – 40 E		40 - 45 E		40 – 45 E		40 – 45 E		45 – 50 E		45 – 50 E		45– 50 E			
Emissions Scenario		T	P	T	P	T	P	T	P	T	P	T	P	T	P	T	P	T	P	T	P
Winter	Policy	1.5	-18.3	1.6	36.1	1.5	32.6	1.7	11.9	1.6	48.9	1.4	48.3	1.7	16.4	1.6	57.0	1.4	39.1	1.56	30.22
	Reference	1.8	-22.0	1.9	37.1	1.8	36.5	2.0	13.1	2.0	53.3	1.8	54.6	2.0	17.2	2.0	62.2	1.7	42.5	1.89	32.72
Spring	Policy	1.4	-14.0	1.1	5.9	1.1	-1.0	1.2	-8.1	1.2	-6.7	1.2	0.9	1.3	-12.7	1.3	-10.2	1.3	-5.8	1.23	-5.74
	Reference	1.7	-18.0	1.5	1.3	1.4	-6.7	1.6	-11.8	1.6	-12.9	1.6	-1.1	1.8	-16.1	1.7	-15.1	1.8	-8.0	1.63	-9.82
Summer	Policy	2.2	14.4	2.0	65.8	1.2	116.9	1.8	60.5	0.9	130.7	0.2	57.1	1.7	54.9	0.8	109.1	0.2	61.5	1.22	74.54
	Reference	2.7	24.6	2.5	81.2	1.7	132.1	2.3	72.3	1.3	149.4	0.4	66.7	2.1	68.7	1.1	129.1	0.4	73.9	1.61	88.67
Autumn	Policy	1.9	-2.8	2.1	14.6	1.7	10.5	2.1	5.2	1.5	23.0	0.7	22.9	2.1	8.6	1.4	44.1	0.8	29.7	1.59	17.31
	Reference	2.3	-1.3	2.5	19.1	2.1	10.6	2.6	5.6	1.9	24.1	1.1	24.2	2.5	6.8	1.8	45.2	1.1	31.5	1.99	18.42
Annual	Policy	1.7	-13.9	1.7	12.6	1.4	24.5	1.7	4.2	1.3	34.4	0.9	25.9	1.7	1.4	1.3	34.4	0.9	27.4	1.40	16.77
	Reference	2.1	-16.4	2.1	13.0	1.7	26.1	2.1	4.4	1.7	38.5	1.2	29.2	2.1	1.2	1.7	39.1	1.3	31.7	1.78	18.53
Policy (WRE 350) Global-mean dt:0.81 (°C) **Referance** (P 50%) Global-mean dt:1.1(°C) **Year** : 2041																					

Remarkable climate change features were derived from these results as follows:

- The average warming in the Kingdom for the year 2041 is higher than the global average for both the reference and the policy scenarios.
- The highest warming (2.2-2.7ºC) occurred during summer in the northwestern region (cells 1 and 2), while the lowest (0.2-0.4ºC) occurred in summer in southern and southwestern regions (cells 6 and 9).
- The highest increase in precipitation occurred in summer in all regions. Obviously, this is trivial for areas having no summer rain, like those within the grid cells 1, 2,3,4,7 and 8. However, in southern and southwestern regions (cells 5, 6 and 9), where precipitation regime is characterized by two peaks (one in summer and another in spring), such increase has an important synoptic implication, particularly when compared to the spring change.

6.2.2.2 Future Climate Change Scenarios in SNC:

- **Downscaling:**

For many climate change V&A studies, scenarios of climate change derived directly from GCM output are of insufficient spatial resolution. For example, the representation of topography and land surface characteristics in any GCMs are much simplified in comparison with reality which results in the loss of some of the regional climate characteristics having important impacts on the socio-economic condition of the local community. One of particular importance to the Kingdom of Saudi Arabia is the lack of true representation of the Asir Mountains in the previously used GCMs in preparing the climate change scenarios within the FNC and the inherent indiscrimination between seas, shore stripe, mountain ridge and desert land within the same grid square.

A number of methodologies have been developed for deriving more detailed regional and site scenarios of climate change for impacts studies. These are generally based on GCM output and have been designed to meet the demands required by the impacts research community. These "downscaling" techniques are summarized below in Figure 6.13

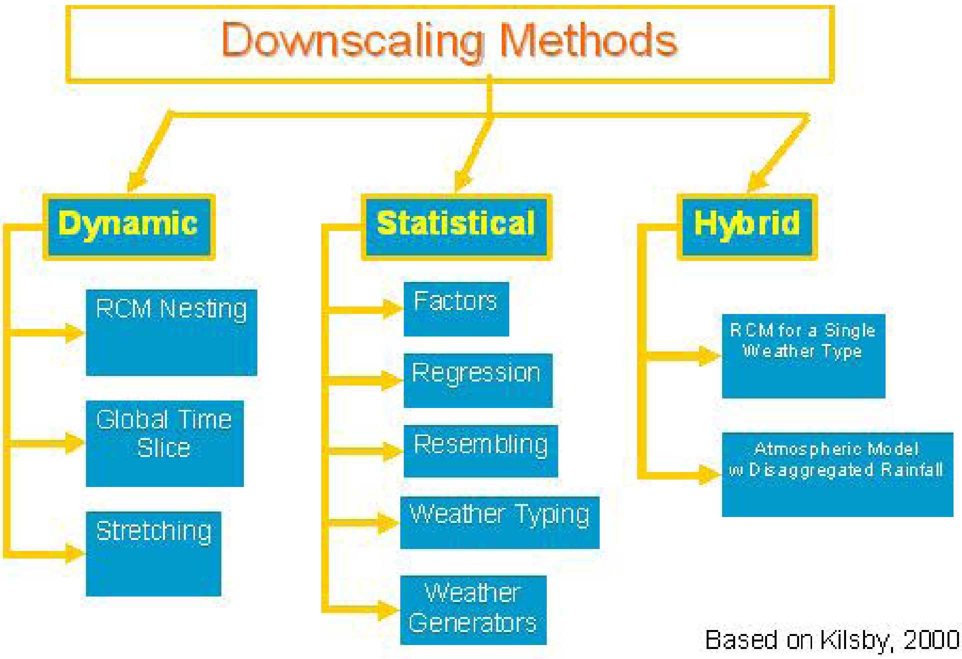


Figure 6.13 Downscaling Techniques

From these many "downscaling" techniques the "dynamic approach" is selected i.e. the application of Regional Climate Model (RCM) rather than (GCM) to obtain high resolution information of climate fields.

Regional climate models (RCMs) are similar to global climate models having higher resolution and therefore contain a better representation of the underlying topography within the model domain, as well as, depending on the model resolution, may also be able to resolve some of the sub-scale atmospheric processes which are parameterized in a global climate model.

The general approach is to 'nest' an RCM within the 'driving' global climate model so that the high resolution model simulates the climate features and physical processes in much greater detail for a limited area of the globe, whilst drawing information about initial conditions, time-dependent lateral meteorological conditions and surface boundary conditions from the GCM. High frequency i.e. 6 hourly, time-dependent GCM fields are required to provide the boundary conditions for the RCM.

PRECIS (Providing Regional Climates for Impact Studies) of Hadley centre has been used as an appropriate RCM for this purpose. This model is an atmospheric and land surface model of limited area and high resolution which is locatable over any part of the globe. Dynamical flow, the atmospheric sulphur cycle, clouds and precipitation, radiative processes, the land surface and the deep soil are all described. Boundary conditions are required at the limits of the model's domain to provide the meteorological forcing for the RCM. Boundary data used in the runs were obtained from:

- ECMWF ERA-40 reanalysis experiment (1957-2001).
- A three-member ensemble of SRES A2 scenario experiment (2070-2100).
- A three-member ensemble of control experiment (1960-1990).
- ECHAM5 data (1990-2090). ECHAM5 is a GCM model developed at the Max Planck Institute of Meteorology.

• **Emission Scenarios:**

The IPCC has developed a Special Report on Emission Scenarios (SRES). These scenarios were developed to estimate how different development paths could affect emissions of greenhouse gases over the 21st century. The four primary storylines in this report are:

A1 – Economic growth and liberal globalization
A2 – Economic growth with greater regional focus
B1 – Environmentally sensitive with strong global relationships
B2 – Environmentally sensitive with highly regional focus.

These are shown schematically in Figure 6.14

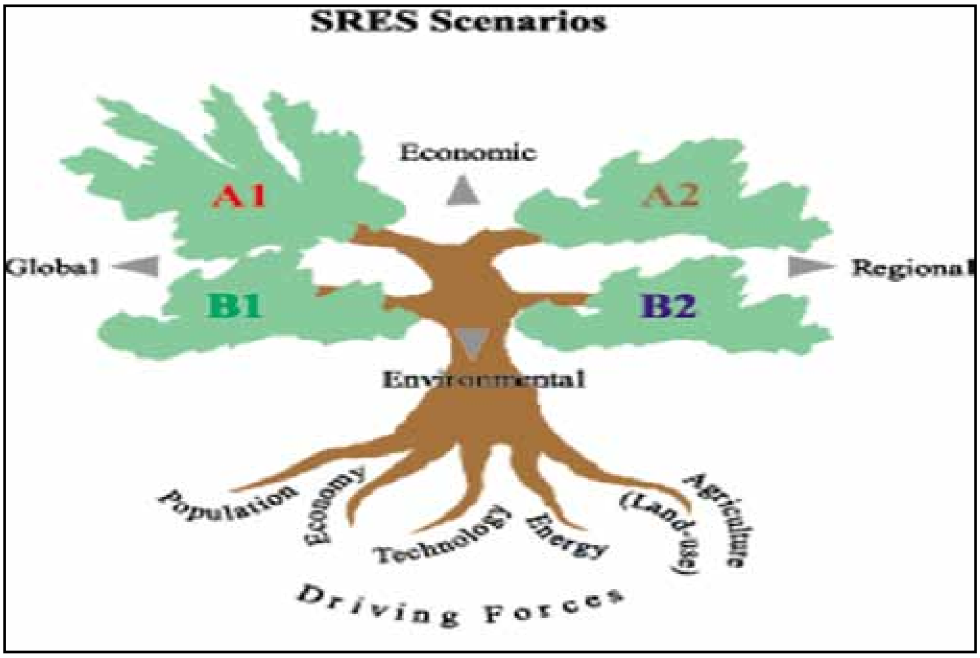


Figure 6.14 Schematic Diagram of SRES Scenarios

In the present work the A2 storyline is adopted. This scenario describes a world with regional economic growth characterized by high population growth, medium GDP growth, high energy use, medium-to-high changes in land use, low resource availability of conventional and unconventional oil and gas, and slow technological advancement. This scenario assumes a very heterogeneous world that focuses on self-reliance and the preservation of local identities, and assumes that per capita economic growth and technological change are more fragmented and slower than in other scenarios. It is planned to conduct further runs of the model using other scenarios in future.

- **Results of PRECIS Regional Model**

Four runs of PRECIS model were conducted as follow:

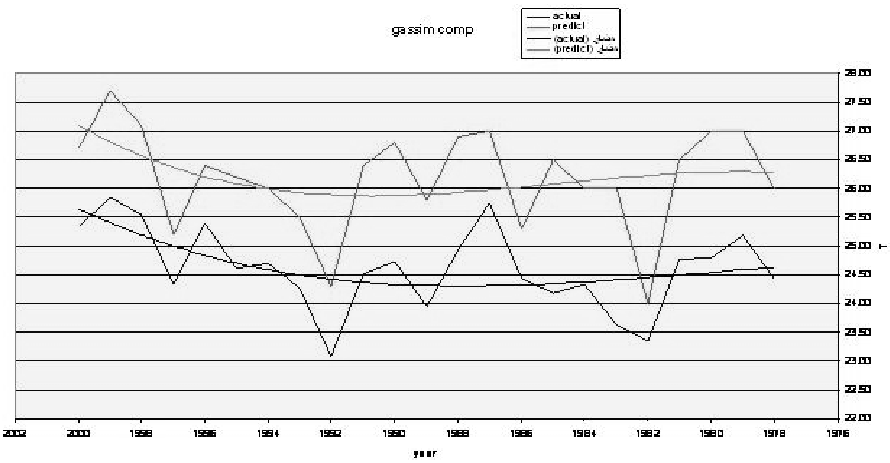
- **Run for the period 1972 – 2001**

Using ECMWF – ERA-40 data, this run has been carried out specifically for comparison with FNC baseline analysis. Current Climate, being the most certain element to deal with, is used to verify the results of the model PRECIS. Hence, experiments were conducted to primarily assess the capability of the model in predicting extreme climatic events, the overall time series behavior and trend over selected locations of the Kingdom.

In comparing the results of the first run (1972-2001) with the actual climate data of some selected stations in the Kingdom for the same period (Table 6.7), some encouraging features were observed as shown in Figures 6.15 – 6.20.

48.4	1985	1	1	0	0	3236	8192	9999	pmeak	-	273.1
47.4	1986	1	1	0	0	3236	8192	9999	pmeak	-	273.1
49.3	1987	1	1	0	0	3236	8192	9999	pmeak	-	273.1
48.6	1988	1	1	0	0	3236	8192	9999	pmeak	-	273.1
48.7	1989	1	1	0	0	3236	8192	9999	pmeak	-	273.1
48.7	1990	1	1	0	0	3236	8192	9999	pmeak	-	273.1
46.9	1991	1	1	0	0	3236	8192	9999	pmeak	-	273.1
45.9	1992	1	1	0	0	3236	8192	9999	pmeak	-	273.1
47.0	1993	1	1	0	0	3236	8192	9999	pmeak	-	273.1
47.9	1994	1	1	0	0	3236	8192	9999	pmeak	-	273.1
48.5	1995	1	1	0	0	3236	8192	9999	pmeak	-	273.1
48.3	1996	1	1	0	0	3236	8192	9999	pmeak	-	273.1
48.9	1997	1	1	0	0	3236	8192	9999	pmeak	-	273.1
48.6	1998	1	1	0	0	3236	8192	9999	pmeak	-	273.1
49.4	1999	1	1	0	0	3236	8192	9999	pmeak	-	273.1
49.5	2000	1	1	0	0	3236	8192	9999	pmeak	-	273.1
48.7	2001	1	1	0	0	3236	8192	9999	pmeak	-	273.1

Table 6.7 Sample of Output Tables for Gassim Tmax



Data file : /home/precis/archive/pmeak/03236.max/ppdata.data
Runids : pmeak
End Time : 2001/ 1/ 1 0:00:00z

Figure 6.15 Comparison of the Actual and Predicted Annual Mean Temperature for Gassim

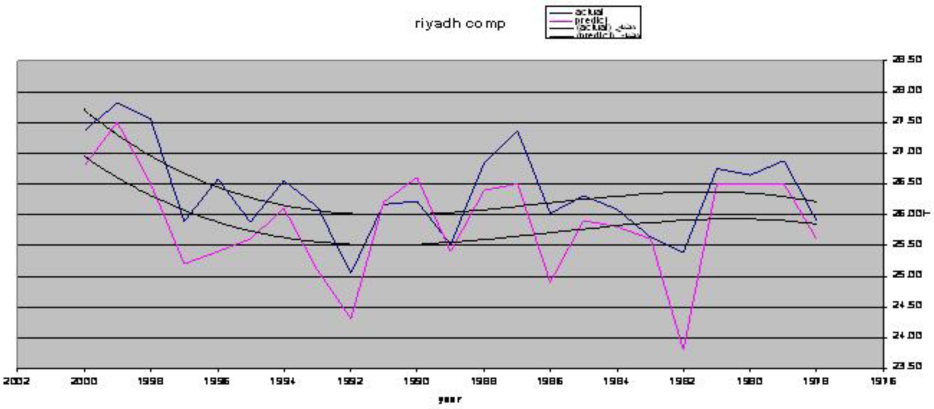


Figure 6.16 Comparison of the Actual and Predicted Annual Mean Temperature for Riyadh

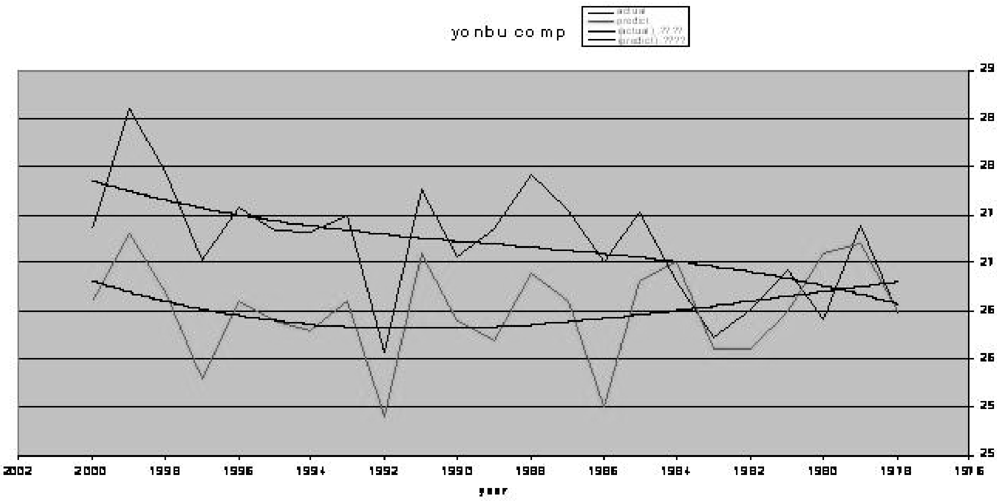


Figure 6.17 Comparison of the Actual and Predicted Annual Mean Temperature for Yanbu

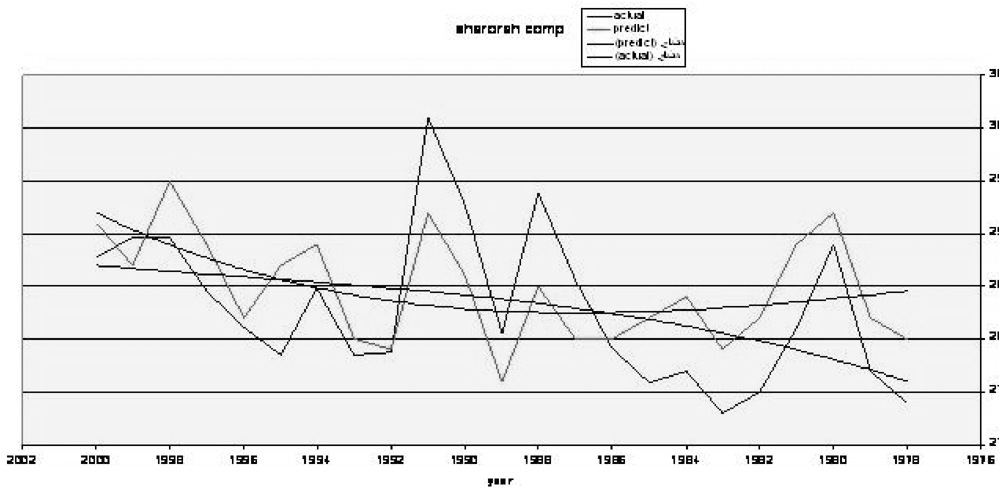


Figure 6.18 Comparison of the Actual and Predicted Annual Mean Temperature for Sharourah

As can be seen from the Figures, PRECIS has simulated well the broad features of the actual regional climate and was able to capture the observed extreme events as recorded in the climate record over the recent past, e.g. the generally cold year of 1992 and the warm year of 1999. The time variation patterns for the actual and the predicted data were reasonably identical. However, some differences in their values were found which were not systematic. The predicted values exceeded the actual values in some stations but were lower in others. They converge with time in some stations and diverge in other. Hence, the model can be used with some confidence to produce the main characteristics and trends of the future climate.

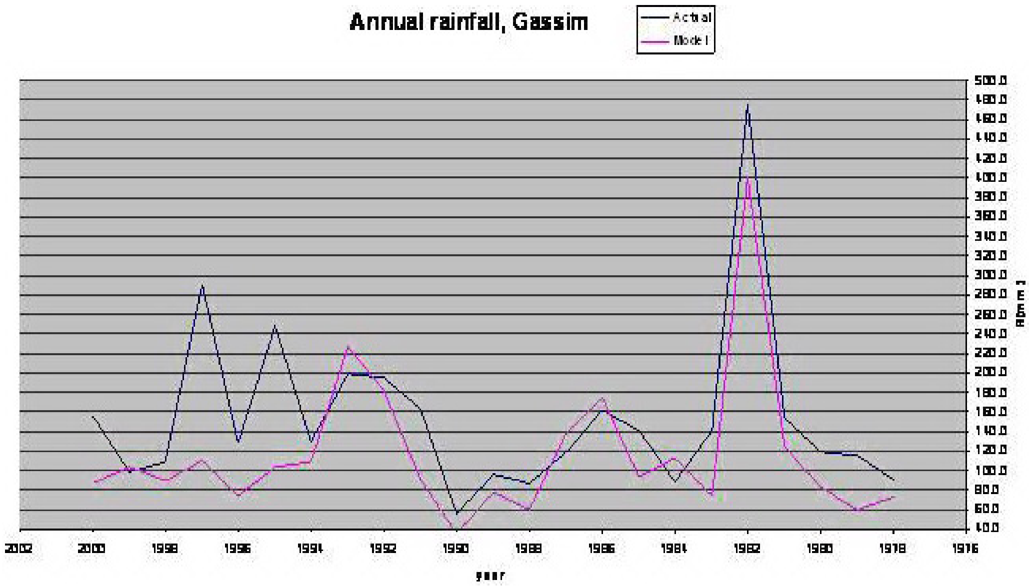


Figure 6.19 Comparison of the Actual and Predicted Annual Rainfall for Gassim

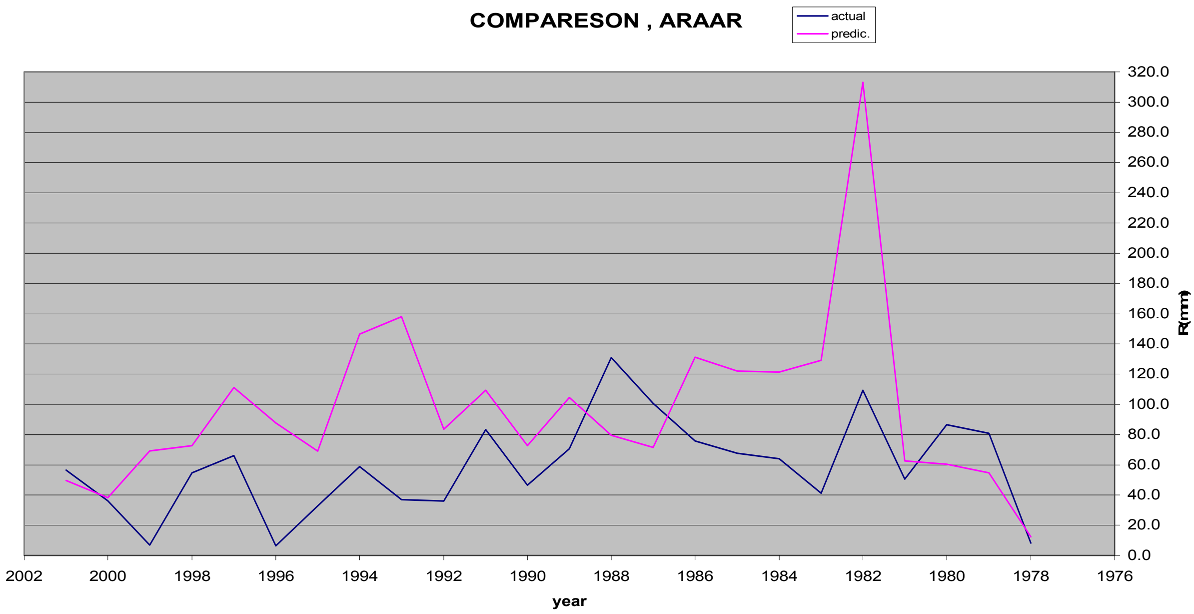


Figure 6.20 Comparison of the Actual and Predicted Annual Rainfall for Arar

The differences found in the magnitude between the predicted and the actual annual mean temperatures may be attributed to one or more of the uncertainties generally inherent in the methodology of producing climate change predictions for impact studies. The main sources of these uncertainties are identified as: uncertainty in future GHG emissions; uncertainty in their future concentrations; science uncertainty (boundary condition and model parameterization); uncertainty in natural climate variability (including the solar activities) and uncertainty in regionalization techniques and locality.

The future emission scenario A2 used here seems to be the most probable source of uncertainty that causing such differences. The straight forward action to address this possibility is to run the climate model for a range of the IPCC SRES emission scenarios (with special consideration to the results and trend analysis of the latest GHG inventory of the Kingdom) and to adopt the one which leads to the closest results to the actual observed climate data over the selected period and locations.

Finally, the spatial distributions of both the annual mean temperature and annual total precipitation from the 1972-2001 run were produced (Figures 6.21 and 6.22) and compared with the actual data analysis as given in the Kingdom's FNC baseline period. In general, there were good resemblance between the actual climatological data analysis and those predicted by the model. Temperature patterns show low temperature at the northwestern area with gradual increase southeastward to the empty quarter (where highest temperatures were recorded), with exception of the southwest mountainous regions where the temperatures were the lowest in the Kingdom. As for precipitation, the predicted pattern turned out to be more complicated due to the fine mesh of the model (50 km). However, the overall features e.g. the low precipitation rate in the northwestern region and the empty quarter and the high rates over the southwestern and central regions were preserved.

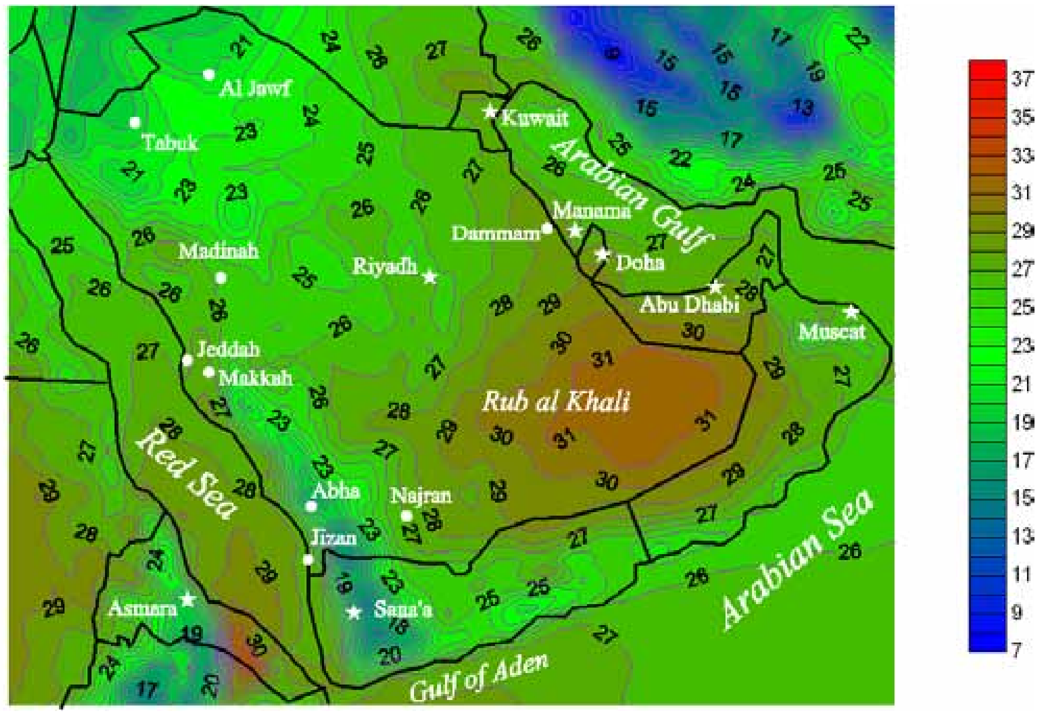


Figure 6.21 Annual Mean Temperature from the 1972-2001 run

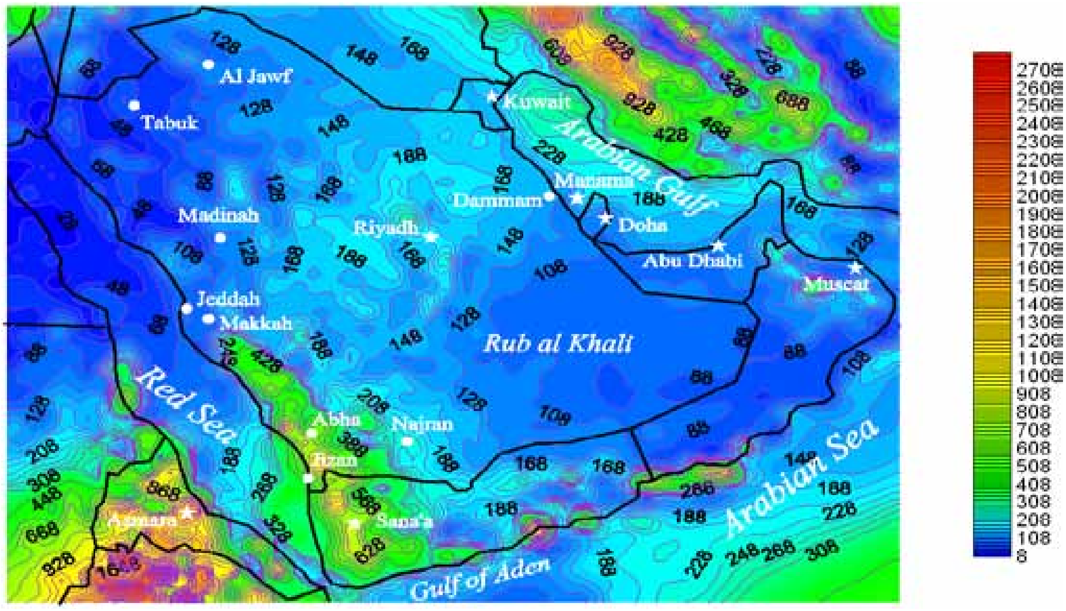


Figure 6.22 Annual Total Precipitation from the 1972-2001 run

- **Run for the period 2070 – 2100**

This run has been carried out using Hadley Centre data, to predict the changes of the 30 years averaged climatic variables for the period 2070-2100, to analyze the seasonally and annually averaged results and to compare these results with the corresponding values of 1972-2001 period.

- ***Temperature:***

The temperature trend over various parts of the Kingdom came out as positive (i.e. an increase in temperature with time) during the 2070-2100 period. Figure 6.23 exhibits a sample of the time series of temperature for Gassim station. The predicted trend, using the step wise method with two 15 years sub-periods, is about 0.8ºC, which is higher than the corresponding value of 0.5ºC predicted for the baseline period of FNC.

The spatial distribution pattern of the annual average temperature over the 2070- 2100 period (Figure 6.24) remains, in general, almost the same as that for the 1972- 2001 period. Both showing lower values over the northwest and the southwestern mountain range and higher values over the eastern province and the empty quarter. However, an appreciable increase in temperature with a varying degree occurs all over the country (Figure 6.25) which depict the spatial distribution of the annual average temperature changes after one hundred years from the baseline period. Further information can be obtained from the seasonal average chart of Figures 6.26, 6.27, 6.28 & 6.29 for winter, spring, summer and fall respectively.

Figure 6.23 2070-2100 Time Series of Mean Annual Temperature for Gassim

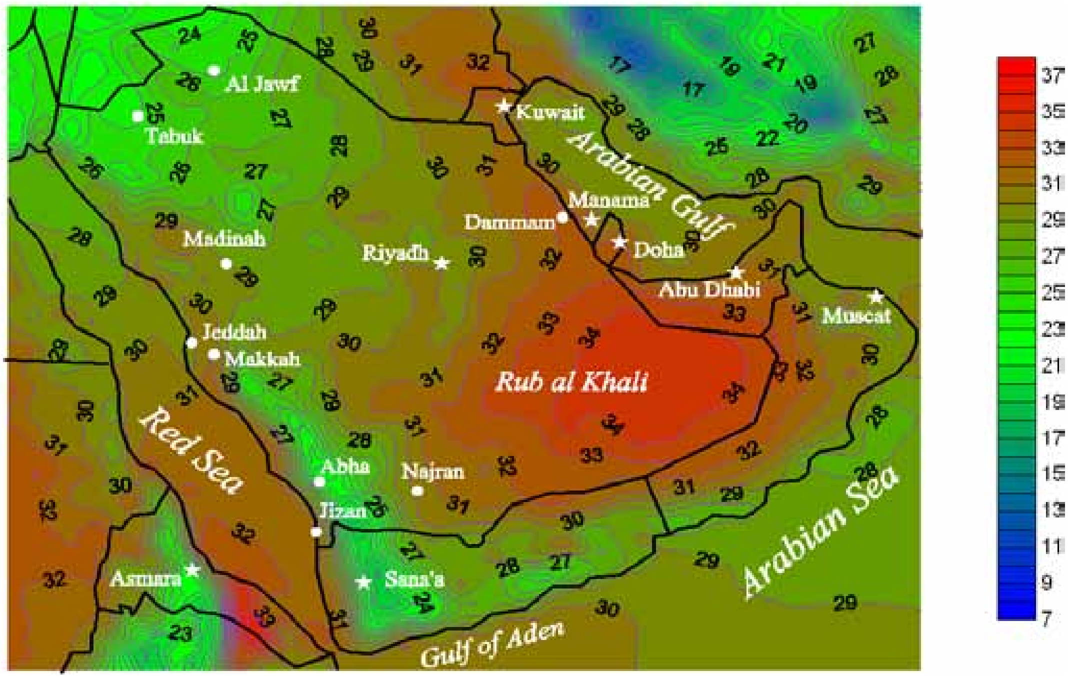


Figure 6.24 Annual Mean Temperature

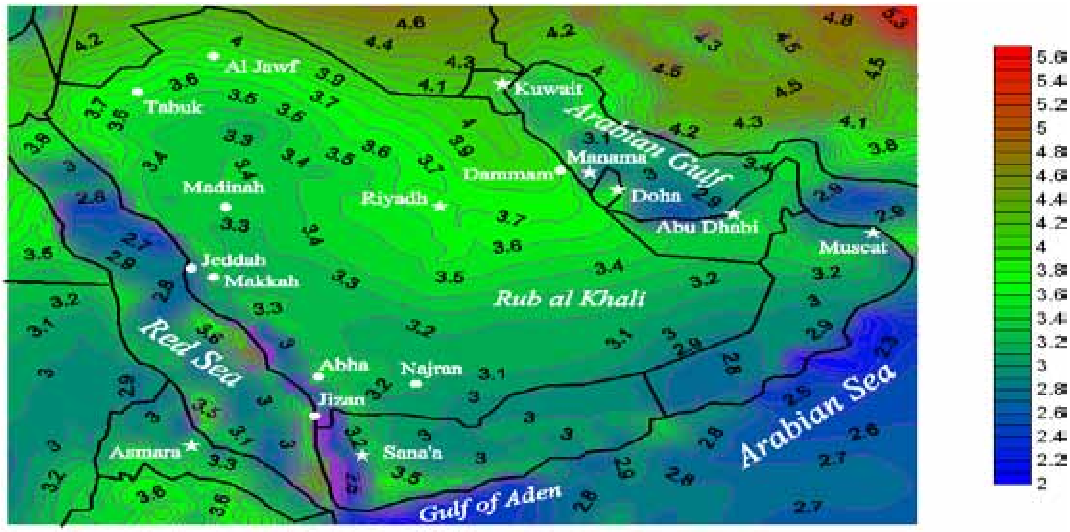


Figure 6.25 Annual Mean Temperature Differences.

The highest increase in temperature will occur over the northern, eastern and central provinces, while the southern, Asir mountains and the western coastal regions will have the lowest increase. Table 6.8 shows the magnitude of the temperature changes for some selected stations representing various regions as follows:

- Arar and Tabuk for the north,
- Gassim and Riyadh for the central,
- Dhahran for the eastern coast,
- Jeddah for the western coast,
- Khamis Mushait for Asir and
- Sharourah for the south.

City	Lon.	Lat.	Mean Temp		Diff.
			Past	Future	
Arar	41.13	30.9	21.6	25.6	4
Tabuk	36.6	28.37	21.1	24.7	3.6
Gassim	43.77	26.3	26.1	29.6	3.5
Riyadh	46.73	24.72	25.9	29.7	3.8
Jeddah	39.2	21.72	26.7	29.5	2.8
Dhahran	50.17	26.27	28.1	31.8	3.7
Khamis	42.8	18.3	19.7	23	3.3
Sharourah	47.1	17.47	28.3	31.4	3.1

Table 6.8 Magnitude of the Mean Annual Temperature Changes for Some Selected Stations

It is important to note that improvements were made by using the regional model PRECIS instead of the GCMs models used in the FNC report. For example, examination of the result in the grid square number (6), which includes Najran, Khamis Mushait and Jazan, showed that when GCMs were applied, the increase in annual mean temperature was uniform (1.2ºC) with no discrimination between sea surface, shore stripe, mountain ridges and desert lands constituting 500x500 km grid square number 6. On the other hand, the introduced regional model, with its high resolution of 50x50 km (Figure 6.26), has been able to differentiate between various types of terrains and hence, predicting different values for different terrains accordingly. The predicted values of the annual mean temperature increase were: 3.1, 3.3, and 2.8ºC for Najran, Khamis Mushait and Jazan respectively.

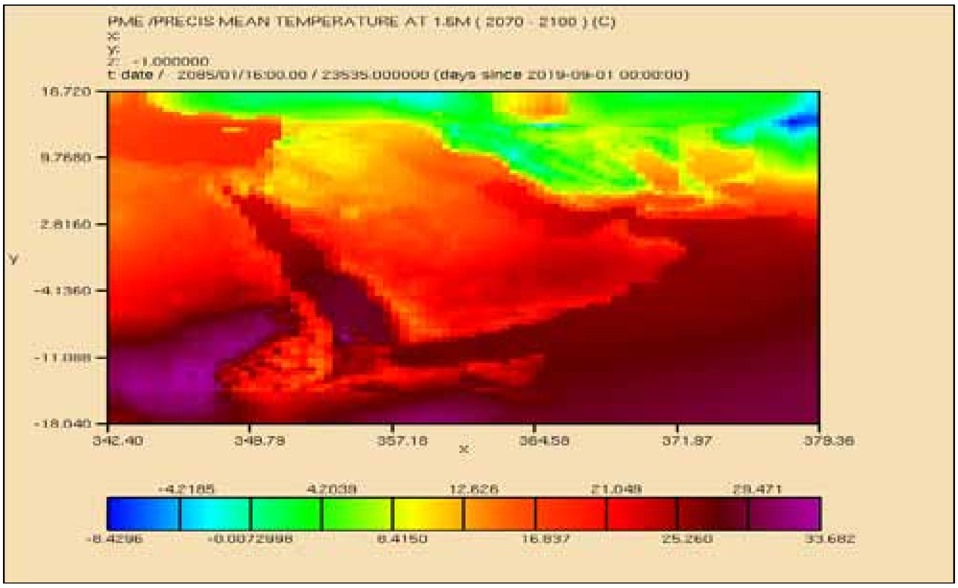


Figure 6.26 Average Winter (D, J, F) Temperature

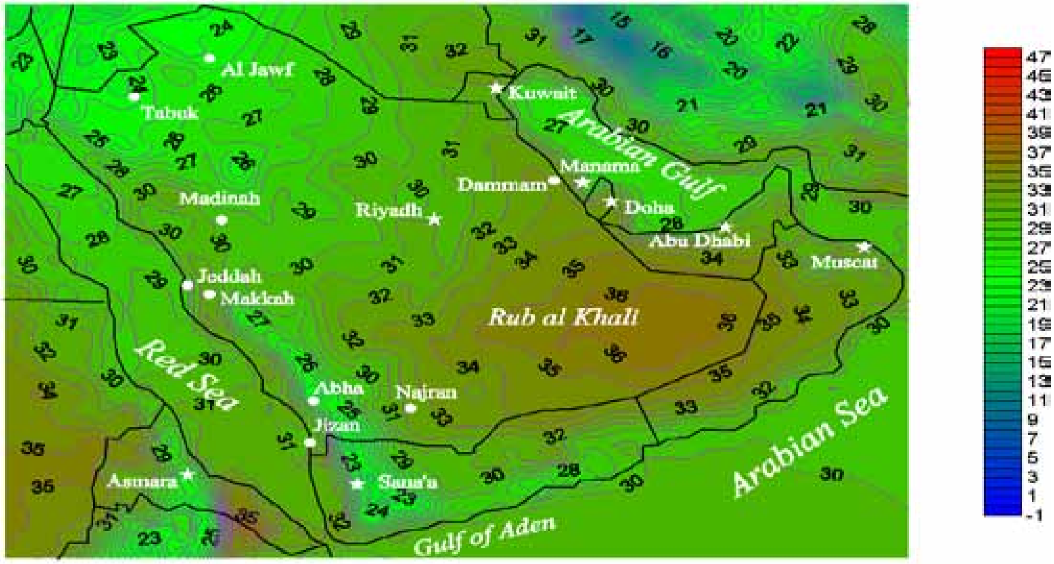


Figure 6.27 Average Spring (M, A, M) Temperature

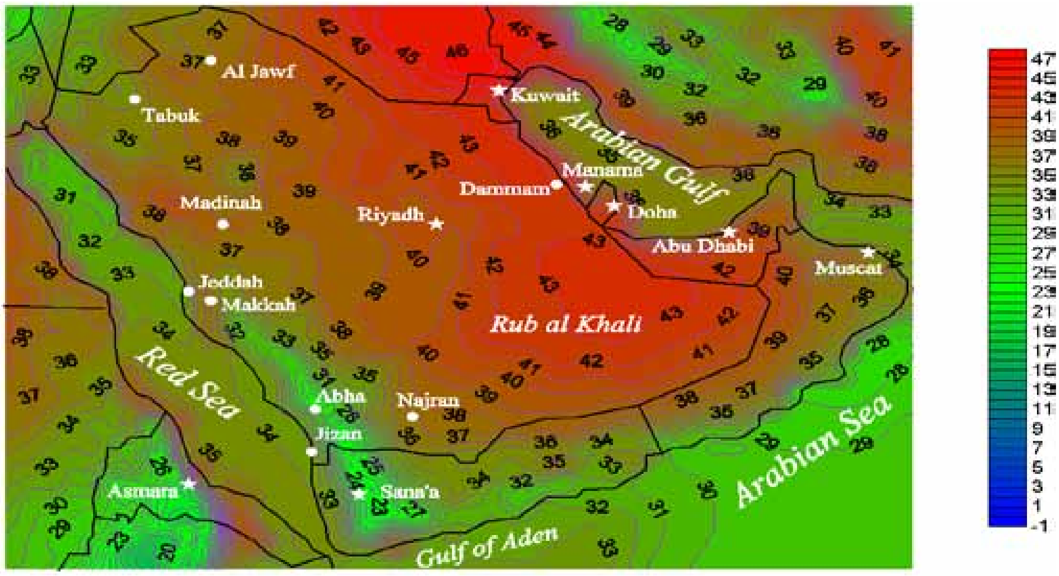


Figure 6.28 Average Summer (J, J, A) Temperature

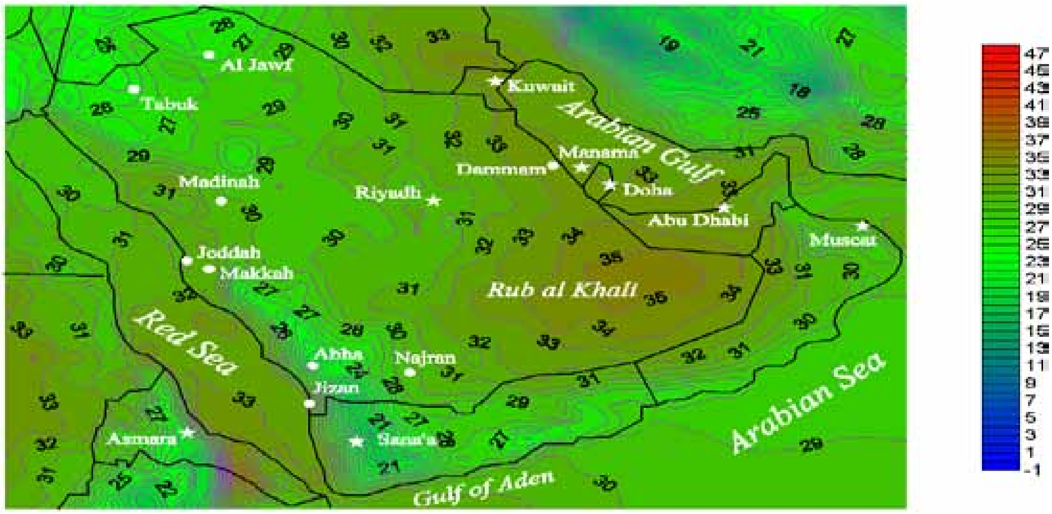


Figure 6.29 Average Fall (S, O, N) Temperature

Similar procedure was also applied to the annual average extreme temperature with the results as tabulated in Table 6.9 for the selected representative stations.

Table 6.9 Values of Mean Maximum Temperature Changes for some Selected Stations

City	Lon.	Lat.	Past	Future	diff.
Arar	41.13	30.9	38.9	44.7	**5.8**
Tabuk	36.6	28.37	36	40.2	**4.2**
Gassim	43.77	26.3	40.2	44.8	**4.6**
Riyadh	46.73	24.72	39	43.1	**4.1**
Jeddah	39.2	21.72	38.8	41.7	**2.9**
Dhahran	50.17	26.27	40.3	44.6	**4.3**
Khamis	42.8	18.3	27.1	32.5	**5.4**
Sharourah	47.1	17.47	36.9	42.1	**5.1**

The spatial distribution pattern of the annual mean extreme temperature over 2070-2100 period (Figure 6.30) shows a general and appreciable increase in temperature (ranging between 2.9 and 5.9ºC) occurring all over the country with a varying degree, as can be seen from Figure 6.31 which depicts the spatial distribution of the annual mean extreme temperature changes after one hundred years from the baseline period.

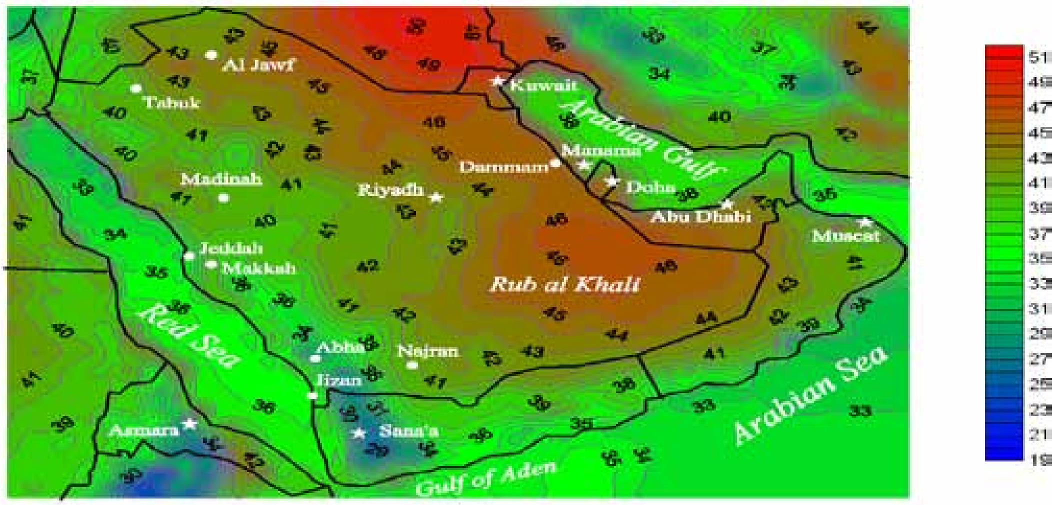


Figure 6.30 Annual Mean Extreme Temperature

Lower values of this increase have been recorded over the northwest region between Madinah and Tabuk and along the northern half of the Red Sea coast, including Jeddah. The higher values are noticeable far to the north of the country and over the eastern slopes of Asir Mountain with further extension to the east (to Sharourah).

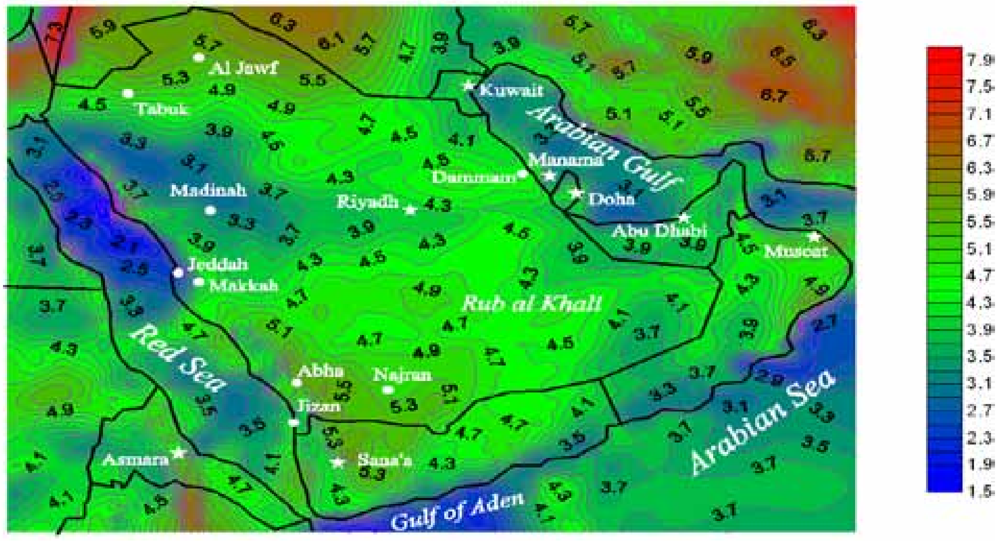


Figure 6.31 Annual Mean Extreme Temperature Difference

- **Precipitation:**

The spatial distribution pattern of the mean annual total precipitation over the 2070-2100 period (Figure 6.32) differs in general, from that for the 1972-2001 period, especially over the northeastern and central regions where lower values prevailed. However, no change in the pattern has been recorded over the northwest province and the empty quarter (low values) and over the southwestern mountain range (high values). As can be seen from Figure 6.33, which depict the spatial distribution of the mean annual total precipitation changes after one hundred years from the baseline period, three quarter of the country (mainly central, northern and eastern regions) will suffer from excessive dryness. The increase in rainfall will be limited only to the southern (Sharourah), the southwestern (Jazan) territories and to Asir mountains (Abha). It is worthwhile in this context to compare the above findings with trends of the total annual rainfall distributions of the baseline period (1978-2003) and the change occurred in the total annual rainfall after 50 years as obtained in the FNC. Figures 6.34 a, b show a clear gradual expansion of the rain reduction areas toward the south. This reflects the continuous mode of this change leading eventually to the 2070-2100 distribution.

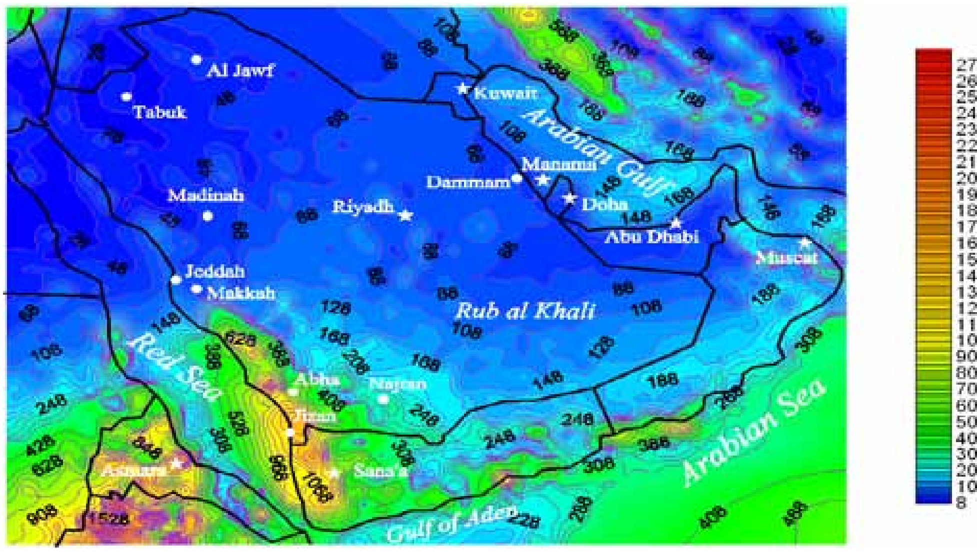


Figure 6.32 Annual Precipitations

Examination of the spatial distribution patterns of the seasonally averaged precipitation reveals (as shown in Figure 6.35 for winter, Figure 6.36 for spring, Figure 6.38 for summer and Figure 6.39 for fall) that the summer rainfall will be the highest among other seasons over the southern, the southwestern territories and Asir mountains, where current precipitation regime is characterized by two peaks (one in summer and another stronger in spring). This finding has an important synoptic implication, particularly when compared to the spring value, as precipitation there is strongly correlated with the average location and the north - south movement of the "Inter Tropical Conversion Zone" (ITCZ) over those regions. Winter precipitation however, will remain the lowest as compared to other seasons.

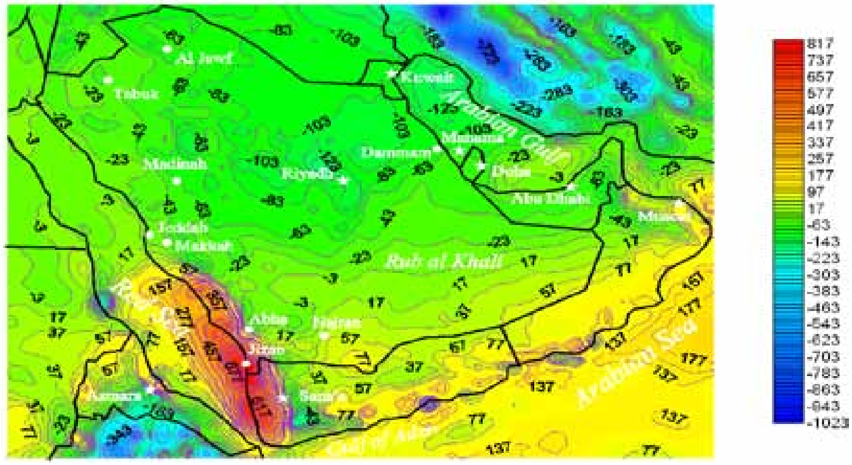


Figure 6.33 Mean Annual Total Precipitation Difference

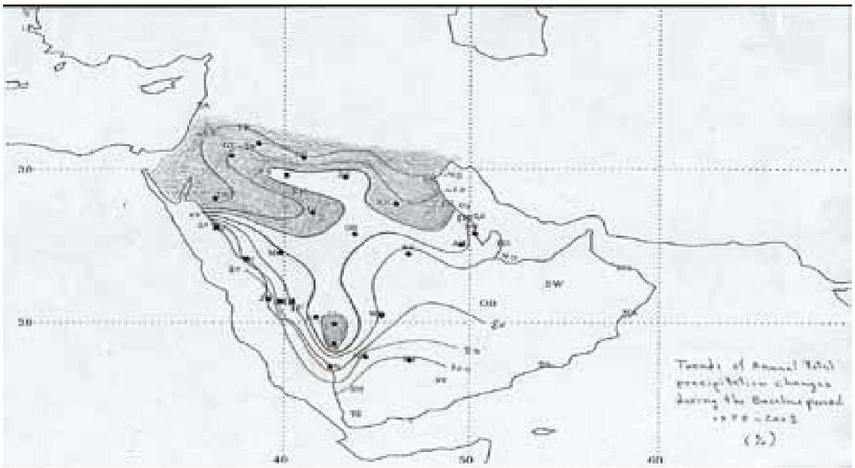


Figure 6.34a Average Annual Total Precipitation Changes for 1991

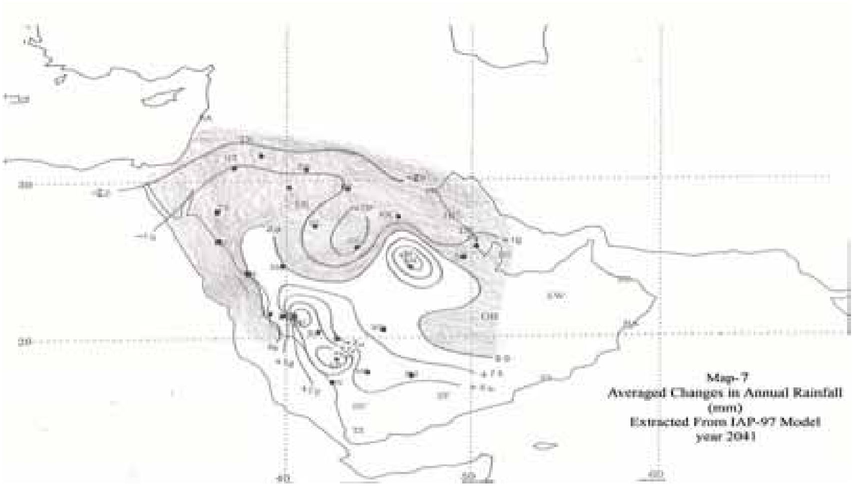


Figure 6.34b Average Annual Total Precipitation changes after 50 years from the Baseline Period (for 2041)

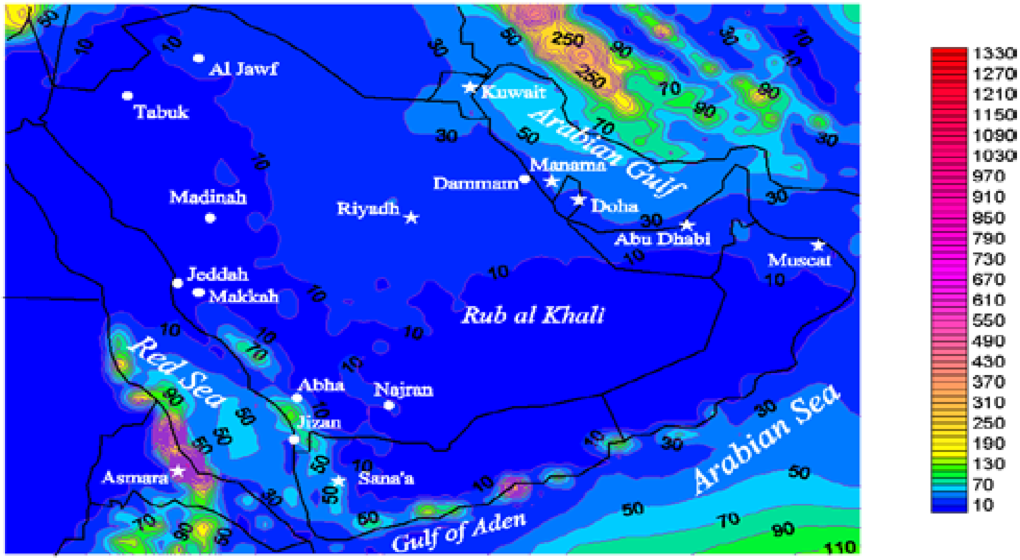


Figure 6.35 Winter Precipitation.

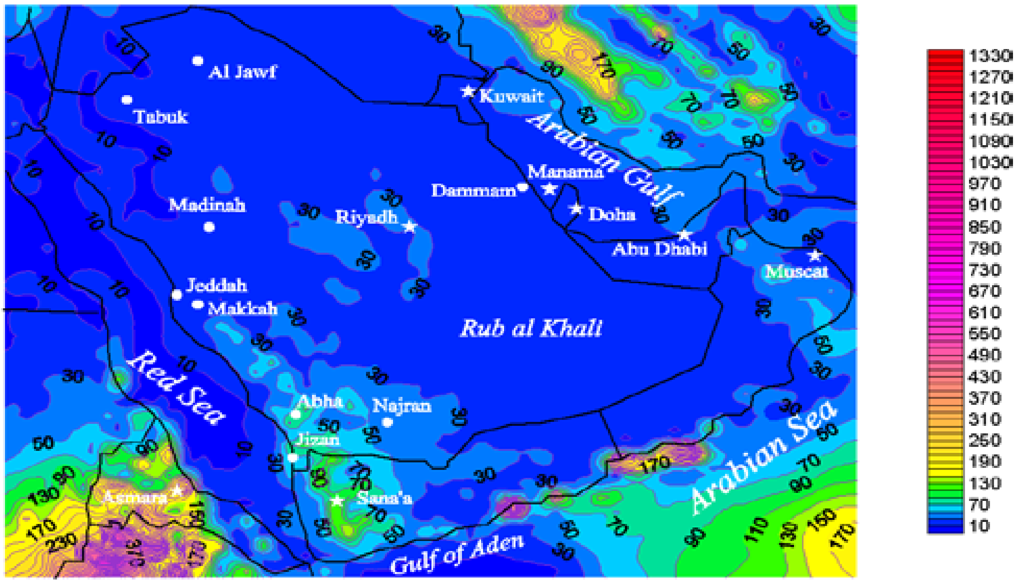


Figure 6.36 Spring Precipitation.

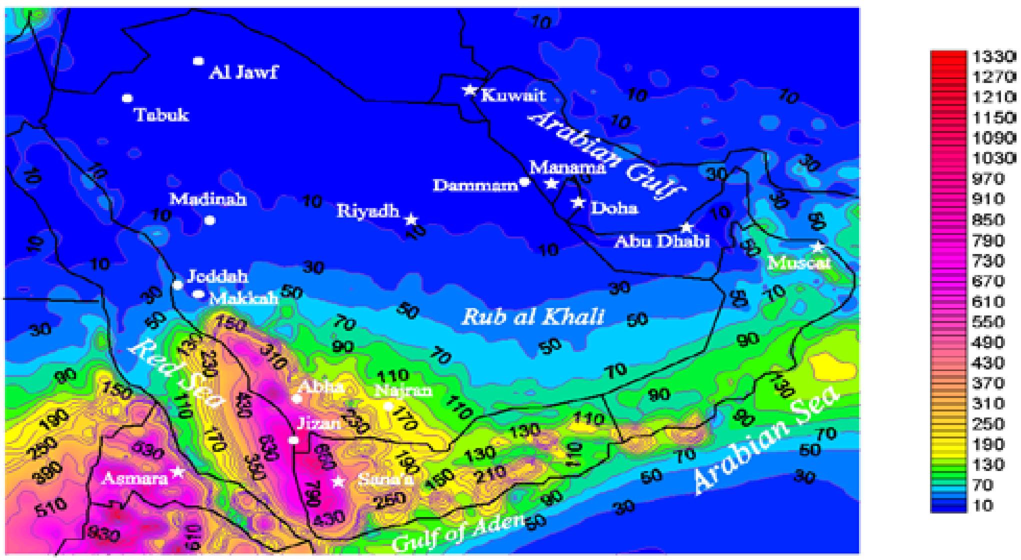


Figure 6.37 Summer Precipitation

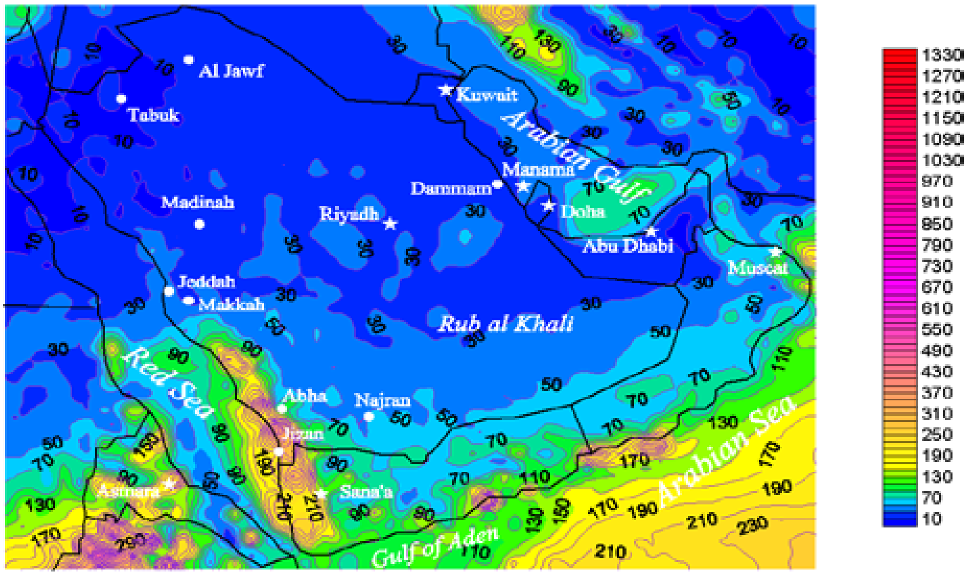


Figure 6.38 Fall Precipitation

- ***Humidity:***

The spatial distribution chart (Figure 6.39) shows higher mean annual RH values along the coasts with a very rapid decrease (strong gradient) towards the interior parts of the country, reaching as low values as 23% over a large area extending from Madinah eastward to Riyadh and southward to cover the empty quarter. Apart from the coastal zones, high values will also be found over Asir Mountains.

Figure 6.40 shows the spatial distribution of the mean annual RH changes over the period 2070–2100 from that of the baseline period. The figure reveals that there will be a general decrease in RH all over the country with maximum value of -9.5% in the northeastern districts and minimum value of -2.5% in the southeastern part of the empty quarter. This is an important finding as in a dry country like Saudi Arabia, where vegetation depends vitally on the atmospheric humidity for their survival, any appreciable change in this parameter will have considerable impact on the already fragile ecosystem.

Figures 6.41, 6.42, 6.43 & 6.44 show persistent strong gradient of RH iso-lines across the coasts in all seasons. The averaged winter RH will continue to be generally the highest among all seasons with a lowest value of 32% over the empty quarter and the northwestern region. This is in contrast to the summer distribution having as low RH value as 10% over the northern region.

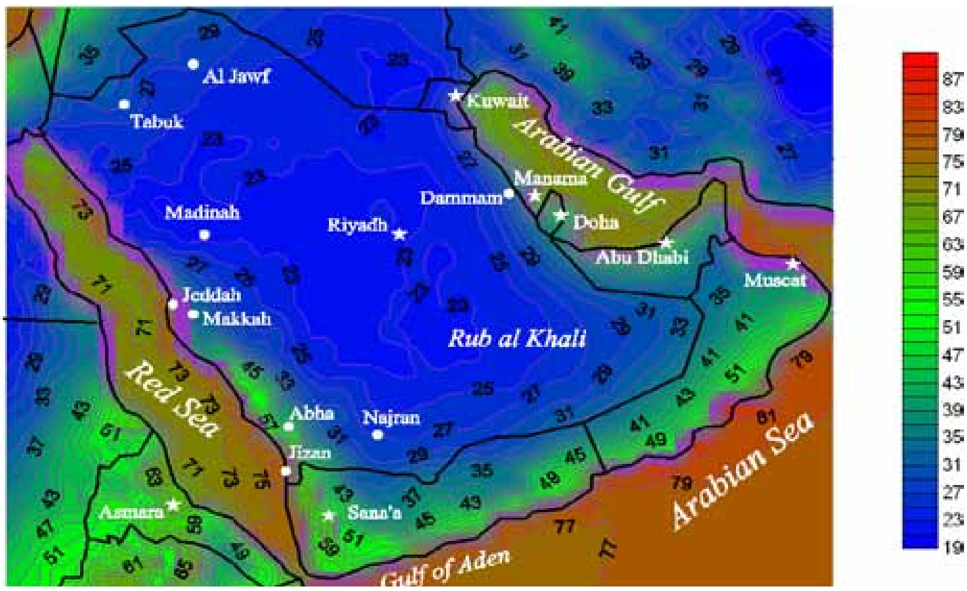


Figure 6.39 Annual Mean RHs

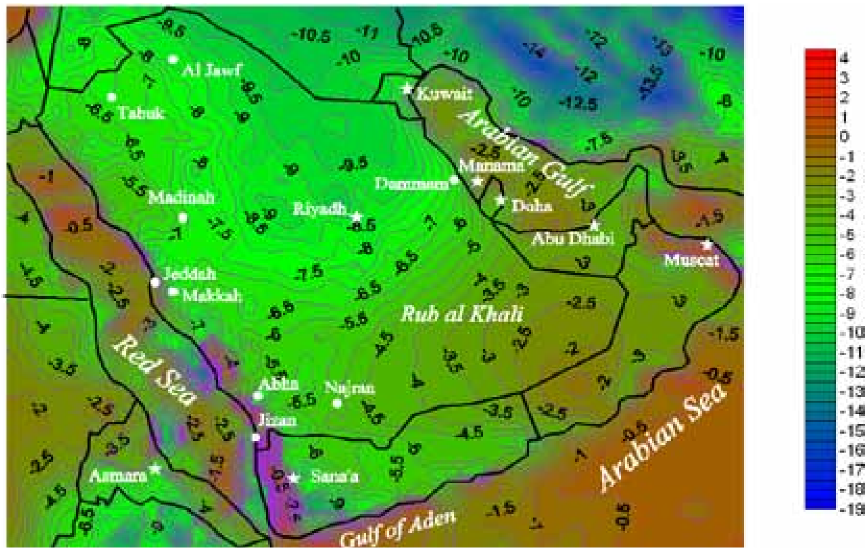


Figure 6.40 Annual Mean RH Differences

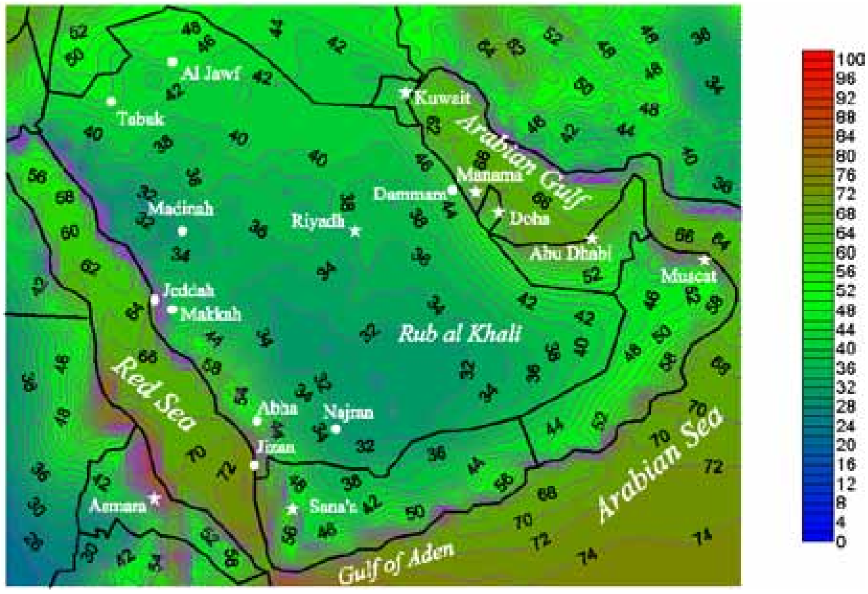


Figure 6.41 Winter RHs

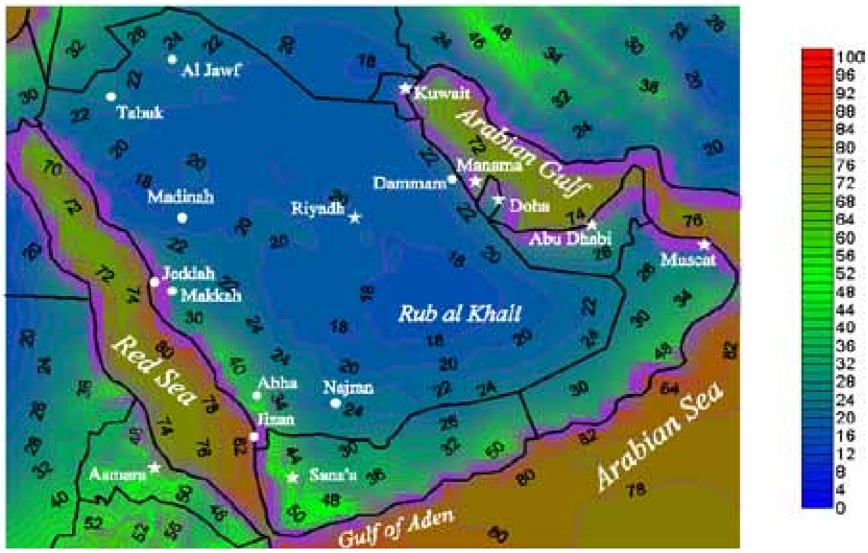


Figure 6.42 Spring RHs

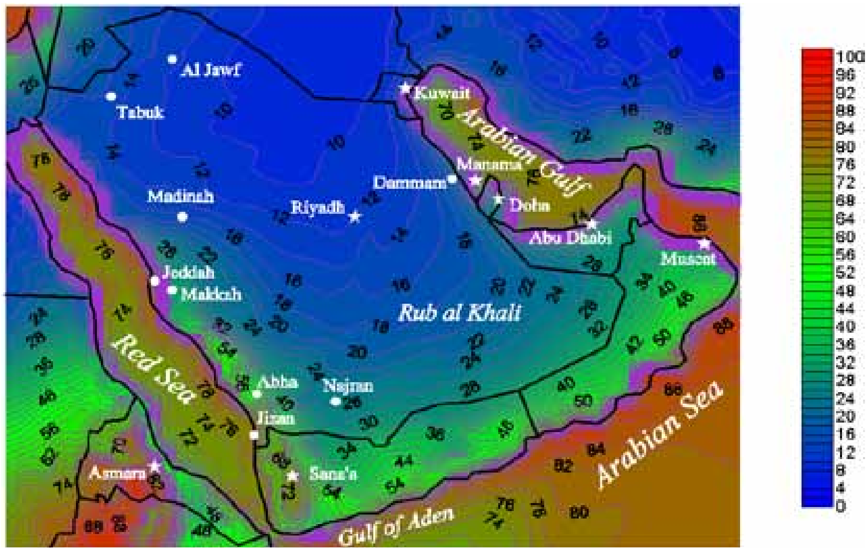


Figure 6.43 Summer RHs

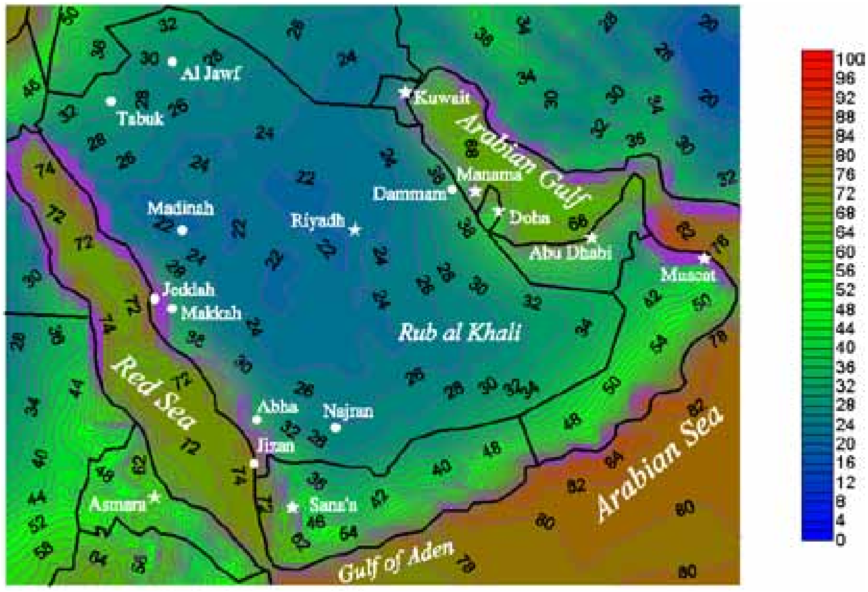


Figure 6.44 Fall RHs

- **Run for the period 1960 – 1990:**

Using Hadley Centre data, this run has been carried out to verify the Hadley Center GCM model performance only and hence, its products need not be presented in this report.

- **Run for the period 2000 – 2070:**

ECHAM5 data, the boundary data in this experiment, were used in order to produce the expected climate change for the period 2001-2070. These data were provided by Hadley Centre at a late stage of SNC project. However, the team was able to run PRECIS for the period 1990-2036 before the model stopped working unexpectedly. Moreover, upon checking the product of this run against the actual data of some selected locations, serious and considerable differences were found both in values and trends of the climate parameters. Figures 6.45 a, b, c & d show the time series of the mean annual temperature for the same four stations used in the analysis of the 1970-2000 run products. No resemblances in the year-to-year variations between the two products were found during the overlapping period of 1991-2000. Furthermore, the numerical values of the mean annual temperature, as tabulated in tables 6.10 a, b, c & d show unacceptable differences from both the actual baseline data and the 1970-2000 run products.

Hadley Centre announced (PRECIS newsletter, July 2010 issue) that a problem was encountered in certain boundary data sent out of the center since last autumn. In a recent communication about this issue, the Hadley center confirmed the flaws in ECHAM5 boundary data and promised to send new driving data in near future which will enable the team to rerun the model for the period 2000-2070.

The analyzed products of new run will be submitted as a supplement to this report.

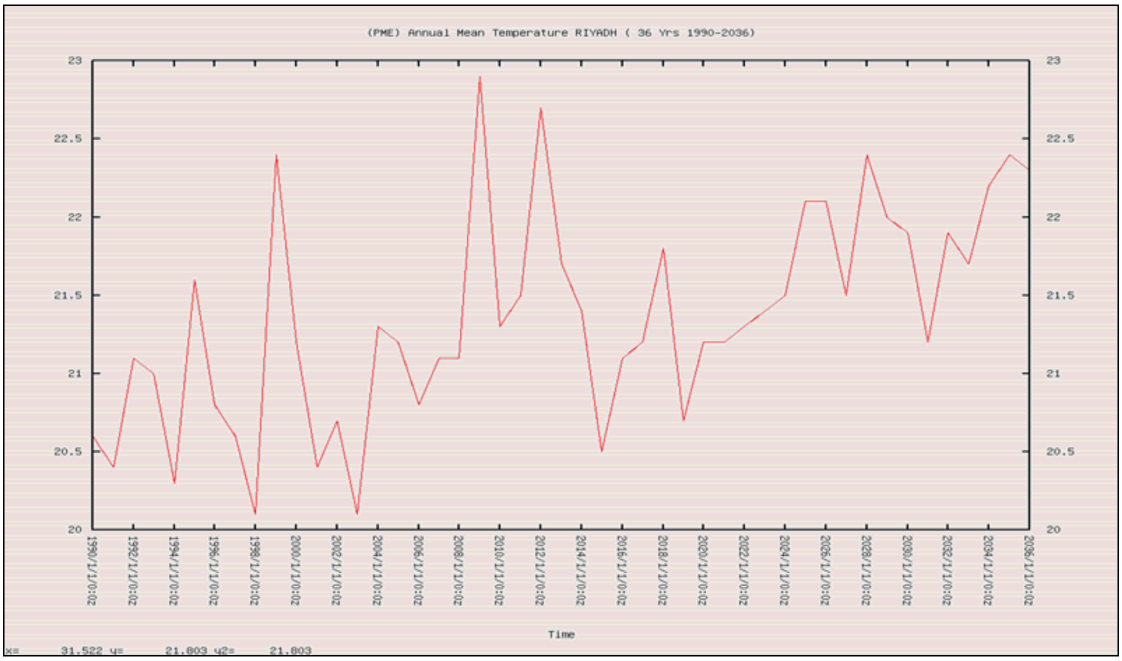


Figure 6.45a Time Series of Mean Annual Temperature at Riyadh

Table 6.10a Numerical values of the Mean Annual Temperature at Riyadh

Year	Actual	Run-1	Run-4
1990	26.22	26.6	20.6
1991	26.17	26.2	20.4
1992	25.04	24.3	21.1
1993	26.13	25.1	21.0
1994	26.55	26.1	20.3
1995	25.88	25.6	21.6
1996	26.58	25.4	20.8
1997	25.89	25.2	20.6
1998	27.55	26.5	20.1
1999	27.81	27.5	22.4
2000	27.37	26.8	21.2
2001	27.57		20.4
2002	27.28		20.7
2003	27.53		20.1
2004	27.00		21.3
2005	27.00		21.2
2006	27.00		20.8
2007	27.30		21.1

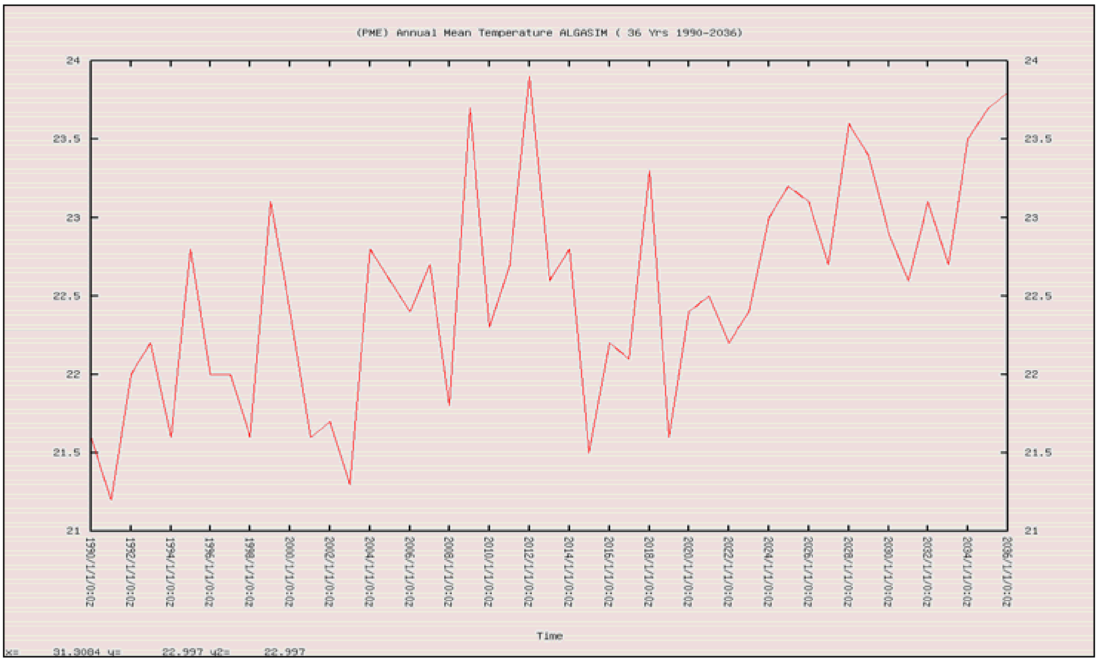


Figure 6.45b Time Series of Mean Annual Temperature at Gassim

Table 6.10b Numerical Values of the Mean Annual Temperature at Gassim

Year	Actual	Run-1	Run-4
1990	24.73	26.8	21.6
1991	24.52	26.4	21.2
1992	23.08	24.3	22
1993	24.26	25.5	22.2
1994	24.7	26	21.6
1995	24.61	26.2	22.8
1996	25.41	26.4	22
1997	24.33	25.2	22
1998	25.56	27.1	21.6
1999	25.86	27.7	23.1
2000	25.34	26.7	22.5
2001	25.71		21.6
2002	25.65		21.7
2003	25.93		21.3
2004	25.5		22.8
2005	25.4		22.6
2006	25.6		22.4
2007	25.8		22.7

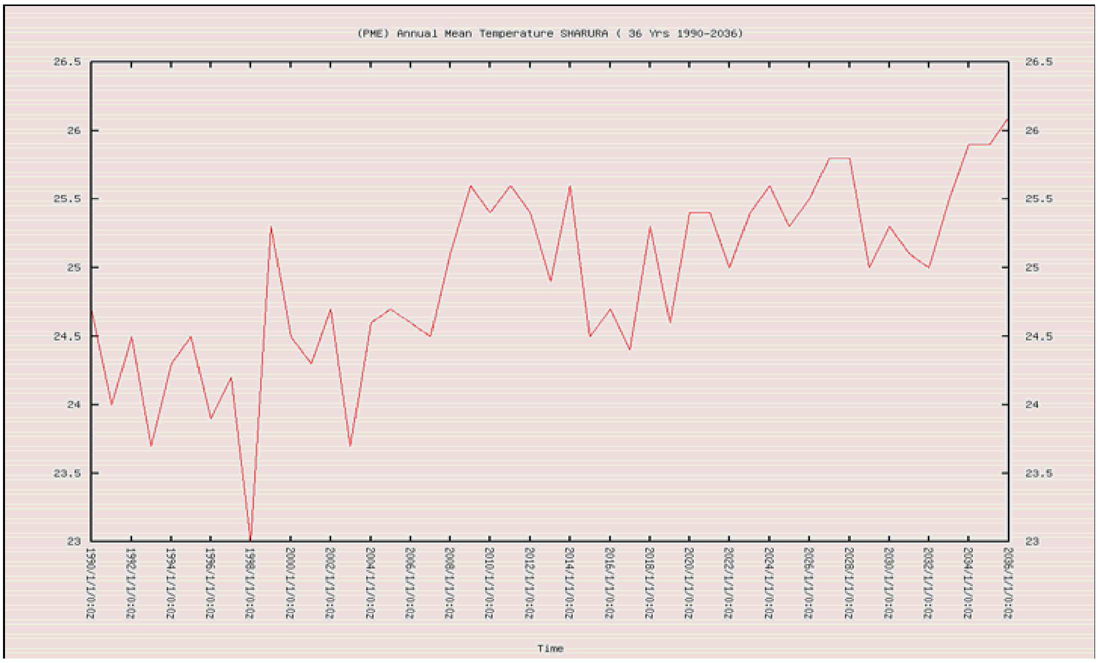


Figure 6.45c Time Series of Mean Annual Temperature at Sharourah

Table 6.10c Numerical Values of the Mean Annual Temperature at Sharourah

Year	Actual	Run-1	Run-4
1990	29.27	28.6	24.7
1991	30.10	29.2	24.0
1992	27.88	27.9	24.5
1993	27.85	28.0	23.7
1994	28.48	28.9	24.3
1995	27.85	28.7	24.5
1996	28.11	28.2	23.9
1997	28.46	28.9	24.2
1998	28.97	29.5	23.0
1999	28.97	28.7	25.3
2000	28.78	29.1	24.5
2001	28.73		24.3
2002	28.72		24.7
2003	28.72		23.7
2004	28.20		24.6
2005	28.20		24.7
2006	28.80		24.6

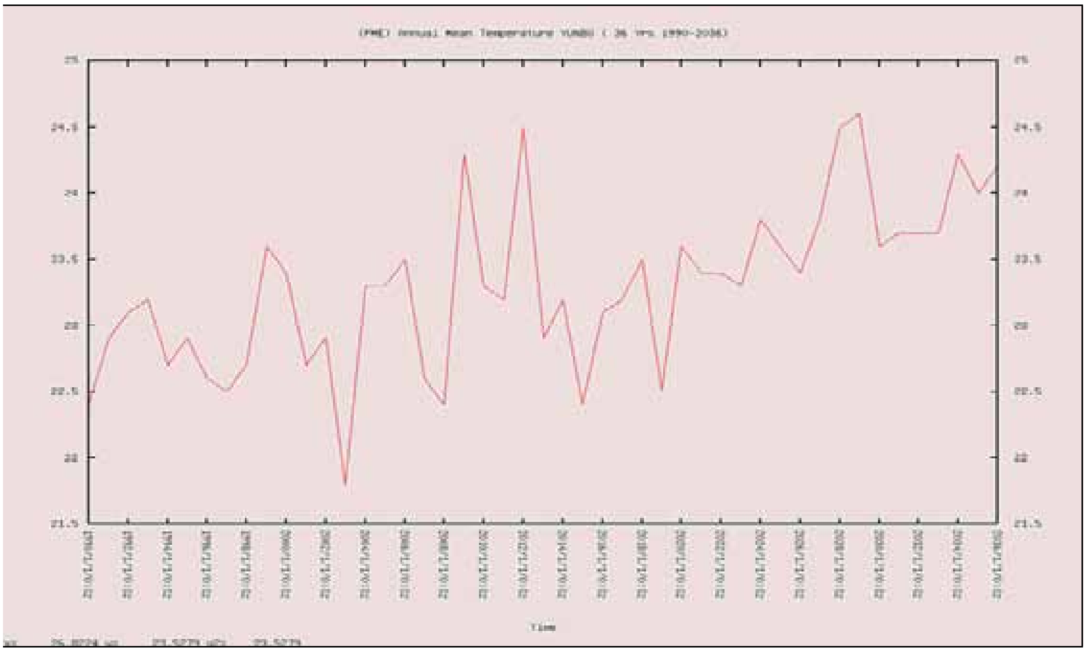
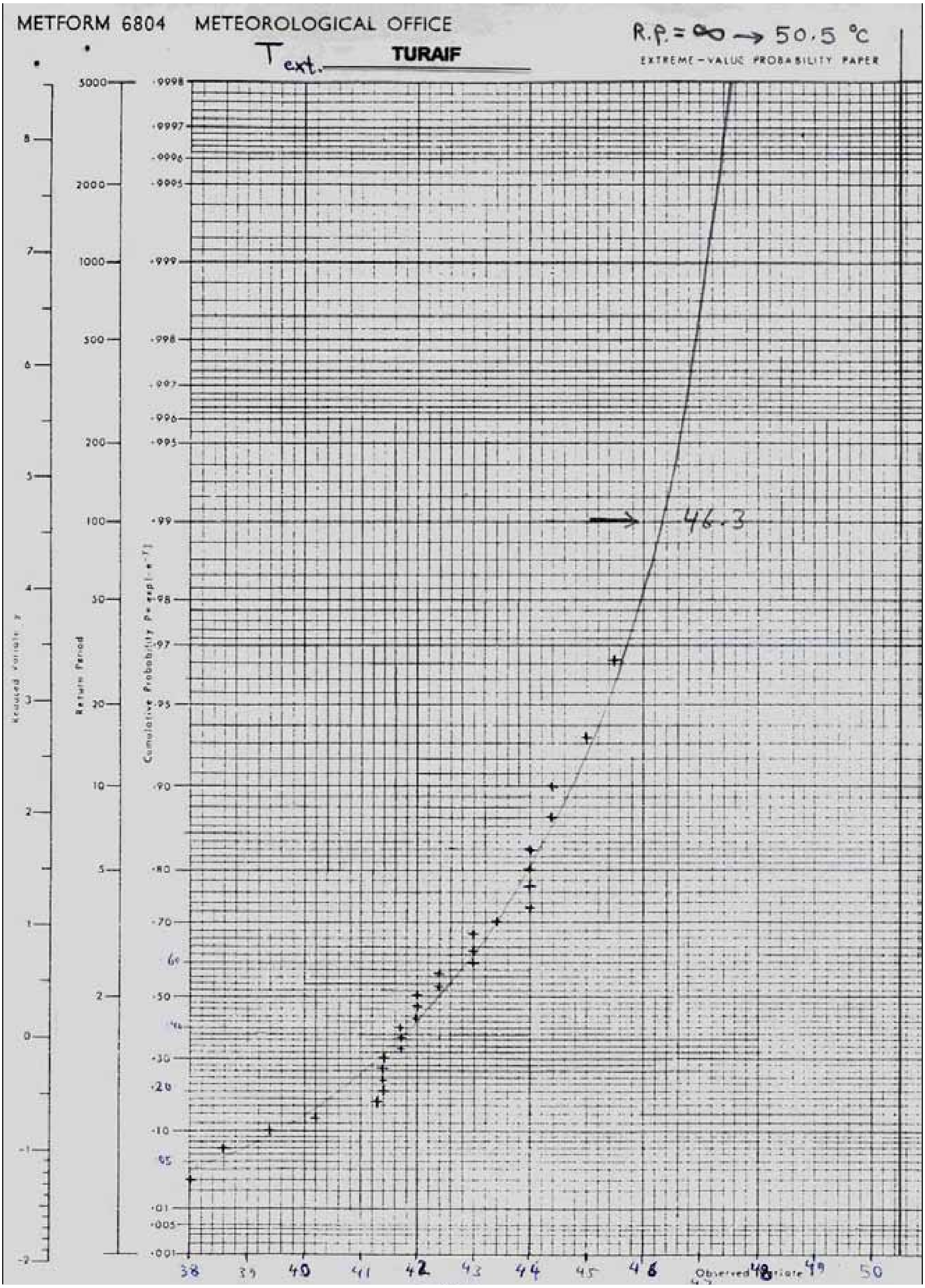


Figure 6.45dTime Series of Mean Annual Temperature at Yanbu

Table 6.10d Numerical values of the Mean Annual Temperature at Yanbu

Year	Actual	Run-1	Run-4
1990	27.07	26.4	22.4
1991	27.78	27.1	22.9
1992	26.08	25.4	23.1
1993	27.49	26.6	23.2
1994	27.32	26.3	22.7
1995	27.33	26.4	22.9
1996	27.58	26.6	22.6
1997	27.03	25.8	22.5
1998	27.96	26.7	22.7
1999	28.61	27.3	23.6
2000	27.35	26.6	23.4
2001	28.83		22.7
2002	28.73		22.9
2003	28.62		21.8
2004	28.7		23.3
2005	27.8		23.3
2006	28.5		23.5
2007	27.6		22.6

Figure 6.46 Yearly Absolute Maximum Temperatures for Turaif



6.2.2.3 Application of Statistic of Extremes Theory:

The aim of this section is to explore the probable upper limits of some variables for selected return periods.

The theory of extreme values distribution has been successfully used in climatology and hydrology. This approach is applied here to estimate the extreme temperature value that will not be exceeded over some pre-specified RETURN PERIOD (An extreme value "x" with return period "Tx" has a probability "P_x =1/Tx" of being exceeded in any one year).

A double exponential distribution of the extreme values is used in this study to obtain values of the absolute maximum temperature "x" for extended return period (100 years). The practical procedure may be carried out either numerically or graphically. The graphical method is adopted here.
In this method a special probability paper (as shown below) is used.
If a series of N annual maxima are arranged in ascending order (x_1, x_2 …,x_m,….x_n), then each value x_m has a plotting position corresponds to its probability. This paper was designed in accordance with a suggestion by Weibull (WMO 1982) for the plotting position in the form:

$$p_{xm} = m/ N+1$$

Smooth x, y curve can be drawn and then extrapolated beyond the series period to obtain the required x value.

Only 26 out of the 31 surface observing stations of the Saudi network are used in the present analysis. These are having record length in access of 25 years. The recorded yearly absolute maximum temperature for these stations was retrieved from PME database centre (SIDC). These data were subjected to a thorough scrutiny to ensure their quality, continuity and homogeneity.

Example of the results is given in Figure 6.46 for station "Turaif". Results estimated for all stations are listed in Table 6.11, from which a spatial distribution chart for the upper limits of the absolute maximum temperature is constructed for 100 years return period i.e. the year 2078. (Figure 6.47)

As can be seen from Figure 6.47, the resulted distribution turned out, surprisingly, to be a very well organized pattern having the lowest values (less than 0.4ºC) over the central, mid-west and Asir regions and the higher values (more than 0.8ºC) stretching over the eastern coasts, southern and northwestern parts of the country with a maximum probable increase of 1.3ºC in Guriat. It should be mentioned here that the resulted substantial increase in the extreme temperature over the northwestern zone of the country is in full agreement with, and is an extension of, the predicted excessive warming over the Mediterranean basin as resulted from many climate prediction models (Figure 6.25). It may be noted that the magnitude of the estimated values of statistical approach is much less than those predicted by models. This is due to the fact that models have included some GHG emission scenario in their calculation while the statistical method used actual data and hence represent the "business-as-usual" scenario.

Table 6.11 Recorded and Predicted Temperature for 100 Years Return Period for all Stations

100 Years Return Period	N = 29 Years		
Station	**Record**	**Predicted**	**Increase**
Turaif	45.5	46.3	0.8
Arar	48.2	48.6	0.4
Guriat	47.7	49.0	1.3
Al-Jouf	46.7	47.2	0.5
Rafha	49.4	49.8	0.4
Qaisumah	51.0	51.6	0.6
Tabuk	46.4	47.3	1.0
Hail	44.5	44.7	0.2
Wejh	47.5	48.4	0.9
Gassim	49.0	49.3	0.3
Dhahran	51.0	51.9	0.9
Al-Ahsa	50.8	51.5	0.7
Madinah	49.0	49.3	0.3
Riyadh	48.1	48.4	0.3
Yanbu	49.5	50.0	0.5
Jeddah	49.0	49.6	0.6
Makkah	49.6	50.1	0.5
Taif	40.2	40.5	0.3
Al-Baha	39.6	40.0	0.4
Wadi Aldawasser	48.0	48.4	0.4
Bisha	43.8	44.2	0.4
Abha	34.1	34.2	0.1
Khamis Mushait	35.6	35.8	0.2
Najran	44.2	45.2	1.0
Sharourah	46.7	47.6	0.9
Jazan	46.3	47.5	1.2

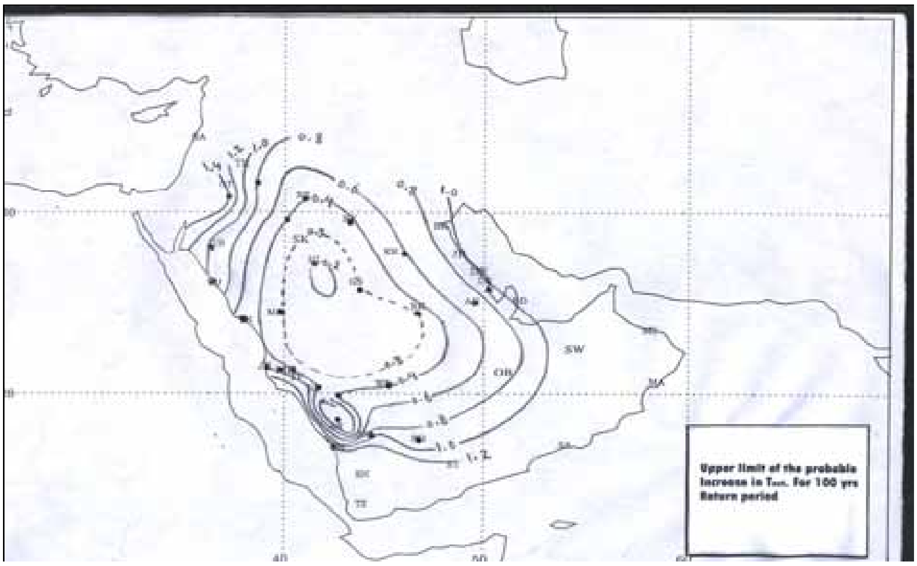


Figure 6.47 Spatial Distribution Chart for the Probable Increase of the Absolute Maximum Temperature for 100 Years Return Period.

6.3 References:

UNCED 1992, The Official Report of the Summit Conference, Rio De Janerio (Expanded Definition of Desertification).

WMO 1983, Guide to Climatological Practices, WMO No. 100.

SECTION - 7

Vulnerability, Impact Assessment and Adaptation of Saudi Arabian Coastal Zone to Sea Level Rise

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7.1 Introduction:

7.1.1 Background:

The First National Communication Report was submitted to the United Nations Framework Convention on Climate Change in November 2005. The report highlighted the main elements of addressing vulnerability, impact assessment and adaptation to the Sea-Level Rise (SLR) on the Red Sea and the Arabian Gulf. Three Intergovernmental Panel on Climate Change (IPCC) sea-level rise prediction scenarios (low, medium, and high) were employed for modeling coastal erosion in Saudi Arabia for the First National Report. The low scenario predicted about 401 hectares of the Arabian Gulf could be subjected to coastal erosion by 2100, the medium scenario predicted about 984 hectares, and the high scenario predicted about 1,726 hectares, respectively. Along the Red sea, the low scenario predicted about 1,087 hectares could be subjected to erosion by 2100 hectares, the medium scenario predicted about 2,663 hectares, and the high scenario predicted about 4,674 hectares, respectively. Based on these scenarios, potential socio-economic activities along the coastal zone were identified. The bio-geophysical impacts were identified as saltwater intrusion, coral reef bleaching, and coastal inundation and erosion.

This report is building on the First National Assessment and going further into identifying actual historical impacts using remote sensing images on coastal ecosystems between the year 1990 and 2000.

7.1.2 Study Objectives:

In addition to fulfillment of the Kingdom's commitments to the UNFCCC, the objectives of this report are summarized as to:

- build on the first national assessment report;
- focus on identifying the impacts on different ecosystems;
- address options for adaptation purposes to these impacts; and
- assist current policy measures used to mitigate future impacts

These objectives were applied to all coastal zones along the Red Sea and the Arabian Gulf.

7.1.3 Location and Topography:

Saudi Arabia's Red Sea coast on the west stretches for 1760 kilometers and its Arabian Gulf coast covers 650 kilometers, including 35 sq. km of mangroves and 1480 sq. km of coral reefs. The country has an arid climate with an average annual rainfall of 100 mm. Almost two thirds of the country is arid and most of the remainder is sand desert.

Located between Africa and mainland Asia (Figure 7.1) with long frontiers on the Red Sea and the Arabian Gulf and with the Suez Canal near to its north-west border, the Kingdom lies in a strategically important position. Structurally, the whole of Arabia is a vast platform of ancient rocks, once continuous with north-East Africa. In relatively recent geological time a series of great fissures opened as the result of which a large trough, or rift valley, was formed and later occupied by the sea, to produce the Red Sea and the Gulf of Aden. The Arabian platform is tilted, with its highest part in the extreme west, along the Red Sea, sloping gradually down from the west to the east. The Red Sea coast, where the upward tilt is greatest, is often bold and mountainous, with peaks of 3,000 meters.Along the Red Sea coast, there is a narrow coastal strip (Tihama) which broadens out in the Jeddah area and provides access through the highlands to the interior. On the Eastern side of the Kingdom, the Arabian Gulf coast is flat and low-lying. The shallow seas in this region deposited layers of younger sedimentary rock, allowing the creation of the vast oil reserves for which the area is famous. The coast is fringed with extensive coral reefs which make it difficult to approach the shore in many places.

Saudi Arabia consists of a variety of habitats such as sandy and rocky deserts, mountains, valleys ('wadis'), meadows ('raudhas') salt-pans ('sabkhas'), lava-areas ('harrats'), etc. It includes most types of terrain which can be generally divided into two distinct groups of rocks; the Arabian shield and the Arabian Platform. The Arabian shield is formed of igneous and metamorphic rocks of Precambrian age, that have been uplifted on the entire western sides and the Arabian Platform, situated in the Central and Eastern parts of the Kingdom, is composed of unaltered, younger sedimentary rocks. The latter group of rocks consists of escarpments, ridges, buttes, rocky and sandy deserts etc.

Figure 7.1 Kingdom of Saudi Arabia Map

7.1.4 Coastal Cities and Towns:

Along the Red Sea, there are fifteen coastal cities and towns distributed in five provinces. These coastal cities have a total length of about 210 kilometers and area of 645 square kilometers (Table 7.1). Moving from North to South, Yanbu, Jeddah and Jazan cities have denser population with variety of socio-economic activities including commercial, agricultural, recreational and industrial.

Province	City	Coastal Length km	Coastal Areas sq.km	Socio-economic Activities
Tabuk	Haql	5.8	6.15	Fishing
	Duba	8.1	4.75	Fishing – Seaport
	AlWajh	9	8.7	Fishing
	Ummlujj	7.5	5	Fishing
Al Madinah	Yanbu	30	107	Industrial - Fishing – Industrial and commercial seaports
Makkah	Rabigh	13.45	22.2	Industrial – Fishing – Industrial seaport
	Thuwal	3.5	3.5	Fishing – Educational
	Dahban	5	3	Fishing – Recreational
	Jeddah	95	450	Commercial – Industrial – Commercial and Industrial seaports
	Al Laith	1.5	2.4	Fishing
	Alqunfudah	12.4	7	Fishing
	Al Birk	1.8	1.5	Fishing
Jazan	AL Qahmah	5	5	Agriculture – Fishing
	Jazan	10	18	Agriculture – Fishing – Commercial and Industrial seaports
	Al Luhayyah	2	0.8	Fishing
Total		**210.05**	**645**	

Table 7.1 Red Sea Coastal Cities and Towns

As for the Arabian Gulf, there are 10 coastal cities and towns having a total coastal length of about 122 Km and 468 Square Km area (Table 7.2). Among these, Khafji, Jubail, Ras Tanura, Dammam and Al Khobar have denser population and considered as the industrial and agricultural nerve of the Saudi economy. Most of the Saudi Arabian oil and gas resources are located along the Arabian Gulf. In addition, the largest desalination plant that supplies fresh water to the Eastern and Central Provinces comes from the Arabian Gulf.

Table 7.2 Arabian Gulf Coastal Cities and Towns

City /Town	Coastal Length km	Coastal Areas sq. km	Socio-economic Activities
Khafji	11	22.8	Industrial – Industrial seaport
Safaniya	5.5	3.1	Industrial
Tanajeb	2	1.45	Industrial
Manifa	2.3	1.15	Industrial
Jubail	28.7	118	Industrial – Industrial seaport
Ras Tanura	17.4	23.8	Industrial – Industrial seaport
Qatef	6.4	12.7	Agriculture – Fishing – Industrial
Sihat	19.3	53.5	Agriculture – Fishing
Dammam	20	142	Commercial – Industrial – Commercial seaport – Recreational
Al Khobar	10	90	Commercial – Industrial – Recreational
Total	**122.6**	**468.5**	

7.2 Impact Assessment:

7.2.1 Coastal Characteristics:

Saudi Arabia is an arid desert where water, agricultural, and recreational resources are limited. This and other socio-economic factors have caused more than 50% of the Saudi Arabian population to move to coastal cities and towns. In addition, many of the oil and gas sectors, which are the main economic nerve of the country, are located within 50 Km of the coastline.

Sea-level Rise (SLR) may pose a significant impact on the Saudi Arabian coasts, particularly those having low-lying gradients with important socio-economic activities including industrial, agricultural and recreational. It is speculated that the impact of SLR in the Eastern Province would be higher than other provinces along the Red Sea due to its geomorphologic nature, where low lying coastal plains dominate most of the coastal zone. Furthermore, important infrastructures such as roads, residential areas, industrial complexes, desalination plants, and seaports were constructed close to the Arabian Gulf coastline. It is important to note that sea-level changes are induced by natural factors such as changing ocean basin volume and depth as the earth's plates separate and collide with each other, as well as by anthropogenic global warming causing deglaciation. (Gornitz, (2007); Nicholls and Klein (2005); IPCC (2007)).

7.2.2 Methodology:

With the absence of high resolution digital elevation maps together with identifying the location of existing structures from coastlines, it would be difficult to predict the extent of the impact of a sea level rise on ecological resources and socio-economic activities. In addition, there are many uncertainties concerning future development plans of coastal areas. Provision of collecting such information requires significant financial and technical resources that are currently unavailable.

An alternative methodology to assess the impact of the sea level rise on the Arabian Gulf and Red Sea coastal zone was employed in this study. This methodology relies on the comparison of Landover information between the period of 1990 and 2000. This Landcover/Geocover information was used as indicators to any coastal changes, which could take place as a result of sea-level rise or other coastal developments such as backfilling and reclamation. The Landcover/Geocover information considered in this study includes changes (loss or gain) of wetlands; mangrove communities; shrubs; erosion and inundation; and man-made structures. An image processing technique was employed to quantify the area of each land cover based on its distinctive classification color. Table 7.3 describes the characteristics of each Landover.

Table 7.3 Landcover/Geocover Classification

	Class Title	Definition
3	Shrub/Scrub	Woody vegetation less than 3 meters (10 ft) in height
4	Grassland (>10% ground cover)	Grass and herbaceous areas. Category may include herbaceous wetlands if images are collected during dry season or periods of drought.
6	Man Made-Other, Urban/Built Up	Cities, towns, wide roads, airports, other developed areas. Areas of non-urban cover within the urban fringe are only separated from the urban category if they exceed 25 ha (500 x 500 m if square or 307 pixels) in size and 2 pixels (58 meters) in width.
7	Agriculture, General	All non-rice agricultural fields, both with crop or fallow; highly managed pastures and hay lands (but not grasslands commonly referenced as "rangeland"); complex mosaics of natural vegetation and cropland. Some orchards and tree plantations, such as palm or date plantations, may be included in this category.
9	Wetland, Permanent/Herbaceous	Emergent herbaceous wetlands, as well as other irregularly inundated areas that may not be vegetated, including: mud flats, saltpans, and playas. Vegetated herbaceous wetlands may be referenced as "marsh".
10	Wetland, Mangrove	Regularly inundated coastal areas that are covered by mangrove species. Areas of burn scar within a mangrove wetland are included in this category.
11	Water	All type of water bodies, including rivers, lakes, reservoirs, ponds, bays, and estuaries.

The Red Sea was divided into 29 equal grids, covering about 1,160 kilometer and the Arabia Gulf to 12 grids, covering about 480 kilometer, each grid consist of 40 Km length by 70 Km width, making an area of 2,800 square kilometer. Quantitative landcover information of the year1990 was compared with 2000; any loss or gain was recorded and attributed to sea-level rise and man-made coastal development. Appendix 1 presents all Landover images for both 1990 and 2000 periods.

As an example, Figure 7.2 demonstrates the costal change that occurred in Dammam and Al Khobar cities during the period 1990 and 2000. The figure reveals that in 2000 many wetlands were developed inlands as shown in areas 1, 2, 3 &4. This concludes that there has been a rise in water table in this area, which could be attributed to sea-level rise. The figure also demonstrates the expansion of residential, commercial and industrial activities that occurred during the same period (area 5, 6, &7). Such expansion would prevent any costal retreat and therefore result to negative impact on coastal ecosystems and socio-economic activities along the coastal zone.

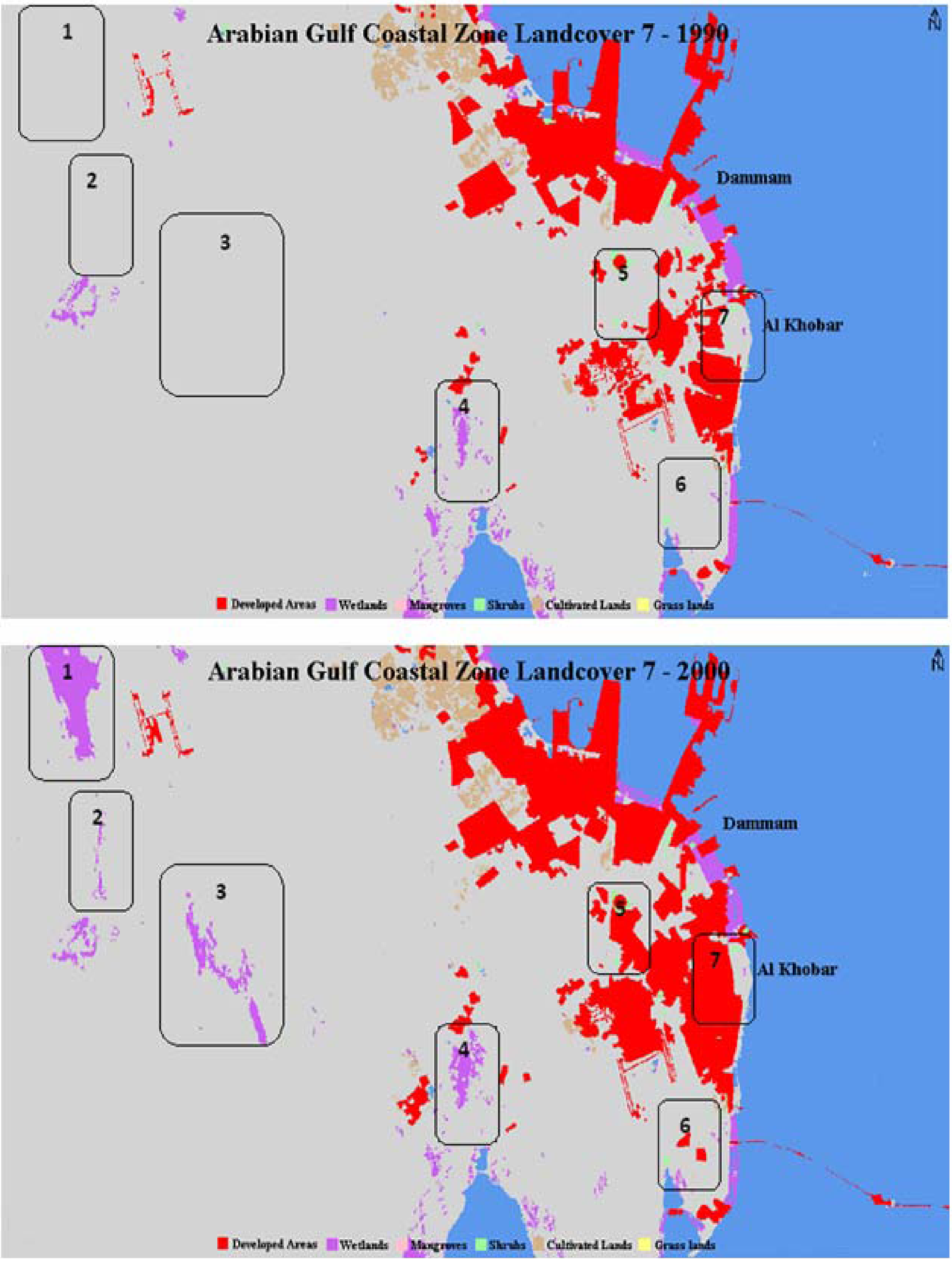

Figure 7.2 Al Khobar and Dammam City Landcover Analysis

7.2.3 Biogeophysical Impact:

As described in the First National Communication Report submitted to the UNFCC, the accelerated sea-level rise would have a biogeophysical and Socio-economic impact on the Saudi Arabian coasts. The biogiophysical impacts are summarized as: impact on wetlands, impact on shrubs, impact on coral reefs and impact on mangroves. As for the socio-economic impact, it would be through inundation and erosion of existing structures such as roads, buildings and coastal frontage.

As described in the above methodology, 29 grids of the coastal area of the Red Sea and 12 grids of the

Arabian Gulf were analyzed with regard to their landcover. Any change that has occurred between the year 1990 and 2000 was attributed to possible sea level rise. This chapter summarizes the outcome of this assessment.

7.2.3.1 Impact on Wetlands [1]:

Analysis of wetlands classified images (Table 7.4) revealed that between the year 1990 and 2000 Arabian Gulf and Red Sea wetland area has increased about 311.91 square kilometers. The table shows that in Tabuk, Makkah and Jazan Provinces there has been a loss of wetlands while in Madinah and Eastern Provinces there has been a again in wetlands. The loss of wetland along the Red Sea is attributed to both coastal developments, where many wetlands were backfilled and the geomorphology of the coastal zone, where the coastal gradient of the Red Sea coast is higher than that of the Arabian Gulf coast. Though a lot of developments have taken place in the Eastern Province, the total area of wetlands has increased by 35.47 percent between the year1990 and 2000. Such gain is attributed to the low lying nature of the coastal zone, where many wetlands or salt marshes were developed inlands in low lying areas. If such increase of wetlands will take place in the next decades, many properties will be subjected to inundation and salt water corrosion. This problem already exists in the Eastern Province where salt marshes are being observed in many low lying areas. It is therefore concluded from this observation that the socio-economic impact of sea-level rise due to inundation of coastal structures will be higher along the Arabian Gulf coast than the Red Sea coast. All underground structures such as underground tunnels, water and sewage systems will be subjected to coastal inundation and erosion. However, it must be noted that this conclusion did not factor the extensive backfilling of wetlands in both the Arabian Gulf and Red Sea that has occurred during this period.

Table 7.4 Wetlands Land Cover Analysis

Province	Area 1990 Km^2	Area 2000 Km^2	Area Gained (+) Area Lost (-) Km^2	Percentile
Tabuk Province	97.48	74.40	-23.08	-23.68
Madinah Province	20.76	33.09	12.33	59.39
Makkah Province	166.14	133.49	-32.65	-19.65
Jazan Province	64.96	28.13	-36.83	-56.70
Eastern Province	1,105.53	1,497.67	392.14	35.47
Total	**1,454.87**	**1,766.78**	**311.91**	**21.44**

IPCC suggested that by 2080, sea level rise could convert as much as 33% of the world wetlands to open water. Coastal wetlands, such as salt marshes and mangroves are vulnerable to sea level rise because they develop within few feet of sea level (IPCC, 2007). As sea level rises, the outer boundaries of the wetlands will be eroded and inundated. New wetlands will be formed inland. However, the area of wetlands lost or inundated is much larger than the area developed. As mentioned earlier, most of the Saudi Arabian coasts have smooth gradients. Any rise in sea level would cause inundation of large wetlands and development of new wetlands inland. As mentioned earlier, this phenomenon was observed in the Eastern Province where coastal plains dominate most of the Arabian Gulf coastal zone.

[1] A wetland or a salt marsh is a type of land that is a transitional intertidal between land and salty or brackish water (e.g.: sloughs, bays, estuaries). It is dominated by halophytic (salt tolerant) herbaceous plants. Historically, salt marshes have sometimes been treated as "wastelands", along with other wetlands. They were developed on area of low ground that is subject to daily flooding of salt water. It is covered with a thick mat of grasses and other plants like sedges and rushes. Salt marshes are among the most productive ecosystems on earth. For instance, live Cordgrass is not only used as a source of food, but the dead plants are also a source of nourishment for bottom-dwelling scavengers such as worms, fishes, shrimps, marsh snails, and crabs. Insects are also abundant in the salt marsh. Most of these insects consume living plants, and are preyed upon by the birds and fish that inhabit the salt marsh. Fishes, crabs and shrimps live in salt marshes where stems, leaves, and roots provide food and shelter from predators. The abundance of food and protection given by marsh plants allows the young of salt marsh inhabitants to survive to adulthood.

Salt marshes are the most abundant type of ecosystem along the Red Sea and Arabian Gulf coasts. They usually grow on tidal mudflats in bays and other sheltered locations, where wave and current energy is low. Therefore, the sediments mainly consist of fine grained particles and a significant content of organic matter due to the high productivity of mudflats. All plants growing on salt marsh shores are supposed to be very salt tolerant, as they have to withstand the seawater. Most of the dominant species along the Saudi Coasts are halophytes such as Halocnemum strobiliaceum or Arthrocnemum macrostachyum. Additionally some flowering herbs and grasses are common in these areas.

7.2.3.2 Impact on Shrubs:

A comparative analysis of remote sensing images on coastal shrubs between the year 1990 and 2000 has revealed to a loss of 34 square kilometers in all provinces Kingdom-wide (Table 7.5). These losses are attributed to coastal development and possible sea-level rise. If no mitigation measures are implemented more losses in vegetation cover will continue causing more coastal erosion and losses of coastal habitats.

Table 7.5 Shrubs Land Cover Analysis

Province	Area 1990 Km^2	Area 2000 Km^2	Area Gained (+) Area Lost (-) Km^2	Percentile
Tabuk Province	74.40	70.04	-4.36	-5.86
Madinah Province	8.86	7.09	-1.77	-19.98
Makkah Province	428.69	422.51	-6.18	-1.44
Jazan Province	1,103.49	1,084.52	-18.97	-1.72
Eastern Province	63.13	59.76	-3.37	-5.33
Total	**1,678.57**	**1,643.92**	**-34.65**	**-2.06**

Sea level rise will significantly impact tidal marsh vegetation, because marsh vegetation is strongly affected by the frequency and duration of tidal inundation. The distributional limits of intertidal plant species are controlled at lower elevations by their sensitivity to physiological stress caused by flooding and at higher elevations by competition with other plant species. As sea level rises, physiological stress will increase for intertidal vegetation (plants will drown) and the lower distributional limit of each species will rise in tandem with sea level. This will also strongly affect tidal marsh geomorphology as vegetation stabilizes tidal channel banks.

7.2.3.3 Impact on Mangroves:

Remote sensing images have detected presence of Mangrove communities in Makkah and Jazan provinces. No mangrove communities were detected along the Arabian Gulf coast due to the fact that most of the mangrove heights are less than 3 meters, which is not detectable through remote sensing technique. Table 7.6 revealed that between 1990 and 2000, about 8.46 percent of the mangrove communities were lost in Makkah Province, whereas during the same period about 2 percent were lost in Jazan Province. Such loss of Mangroves is attributed to sea-level rise and coastal development. If mangroves continue to decline in coastal zone areas in the next decades, coastal erosion will increase causing damages to various coastal properties and ecological resources.

Table 7.6 Mangroves Landcover Analysis

Province	Area 1990 Km^2	Area 2000 Km^2	Area Gained (+) Area Lost (-) Km^2	Percentile
Makkah Province	12.05	11.03	-1.02	-8.46
Jazan Province	11.37	11.14	-0.23	-2.02
Total	**23.43**	**22.17**	**-1.26**	**-5.38**

Mangroves[2] play an important role to stabilize beaches and prevent coastal erosion. Different mangrove communities react differently to adapt to any changing environment. For example, Avicinnia marina tolerate high salt concentrations (>30%). Nevertheless, these species are vulnerable to sea-level rise. A small change in mean sea-level would result in a considerable change in the duration of immersion of mangroves at any point in the littoral zone, causing plant mortality.

Both the Arabian Gulf and Red Sea are rich in Mangroves that play an important role in protection of coastal areas and are home for many marine species. Mangrove forests are found in the form of fragmented stands in many tidal areas on the Red Sea and the Arabian Gulf coasts, south of latitude 26° North. They consist mainly of Avicenia marina trees. On the coast of the Red Sea, Avicenia marina is accompanied by a few examples of Rhizophora mucronata, while on the Saudi Arabian Gulf Rhizophora mucronata is very rare. They grow mostly at the end of the fresh water streams where the silt and organic matter are carried over by the water runoff from the valleys to the shore of the Red Sea. The majority of the mangrove forests are found on the Eastern coast of the Red sea between Jazan in the south and Dibain in the north. Mangrove forests are distributed in several areas along the Red Sea. In Al Darb area, at Al Raqabah, Avicennia marina trees form a large ecosystem. Mangrove also occur at Al Qahmah and at Wadi Dhahaban, showing different ranges of height in the different sites. The tallest mangrove trees (6 m height) are located in Al Qahmah. Avicennia marina is also overspread in Rabigh and Jazan areas and in Farasan Island, where Rhizophora mucronata is also present (FAO). The estimated area of mangroves on the Red Sea shore is about 200-6,000 ha, less than that on the Arabian Gulf.

Mangrove ecosystems are limited along Arabian Gulf and they are confined to the Dammam area (Tarut Bay), with well developed communities consisting of Avicennia marina, and in Gurmah Island. Two mangrove planting sites were established in 1981 in Al Khafji both planted with Avicennia marina. Some smaller plots of Rhizophora stylosa, R. mangle, Lumnitzera racemosa and Bruguiera gymnorrhiza were also laid out. In the Arabian Gulf, mangrove ecosystems have been principally affected by the large oil spill from the 1991 Gulf War.

Figure 7.3 Mangrove Communities in Jazan Province

Avicennia Marina are widely distributed in Jazan coastal area, Figure 7.3 demonstrates the distribution of mangrove communities. Any sea level rise would have a significant impact on these communities.

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[2]Mangrove is an ecological term referring to a taxonomically diverse assemblage of trees and shrubs that form the dominant plant communities in tidal, saline wetland along coastal zones. They are a great source of timber, thatch, poles, and their bark is used for tanning materials. Some species have food and medical value. The development of composition of mangrove communities depend largely on soil type, salinity, temperature, and frequency of inundation, accretion of silt, tidal and wave energy. Intertidal, sheltered, low-energy muddy sediments are the most suitable habits for mangroves and, under optimal conditions, forests up to 45 m in height can develop in some coastal areas.

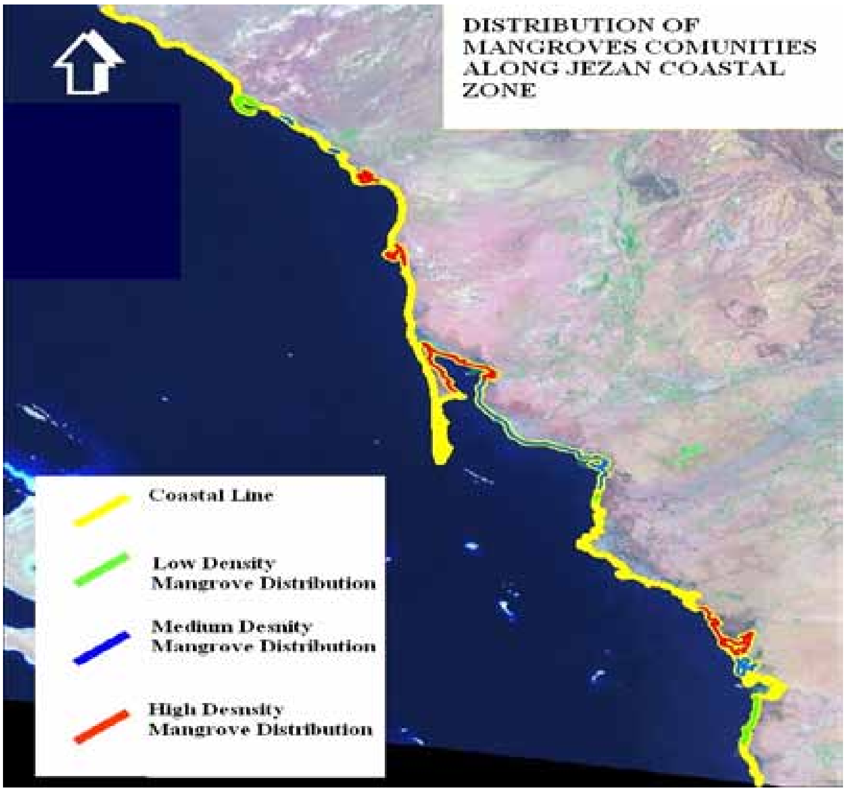

Figure 7.4 Distribution of Mangroves in Jazan Province

7.2.3.4 Impact on Agriculture:

Remote sensing images demonstrate that there has been a gain of agricultural land in all provinces situated along the Arabian Gulf and Red Sea coastal zones of about 5.27 percent between the year 1990 and 2000 (table 7.7). This gain is attributed to population expansion and more demand for local agricultural products. The table demonstrates that Jazan province has the highest cultivated lands in the Kingdom (610.10 square kilometer) and next to it is the Eastern Province, mainly in Sehat and Qateef area (130.96 square kilometer). Analysis of these images shows that the agricultural activities were not impacted by sea-level rise during this decade.

Table 7.7 Coastal Agriculture Landcover

Province	Area 1990 Km^2	Area 2000 Km^2	Area Gained (+) Area Lost (-) Km^2	Percentile
Tabuk Province	1.54	1.82	0.28	18.18
Makkah Province	81.99	113.26	31.27	38.14
Jazan Province	607.53	610.10	2.57	0.42
Eastern Province	122.21	130.96	8.75	7.16
Total	**813.27**	**856.14**	**42.87**	**5.27**

7.2.3.5 Inundation and Erosion Impact:

Analysis of remote sensing images has revealed that between the year1990 and 2000 about 0.65 percent of the Saudi coasts were inundated by sea water (Table 7.8). The table presents that in Tabuk, Madinah and Makkah provinces there has been a loss of water bodies (mainly sea), and whereas in the Eastern and Jazan provinces there has been a gain of water body. Such gain is attributed to possible sea level rise and the smooth coastal gradient in these provinces.

Table 7.8 Analysis of Inundated and Eroded Coastal Lands

Province	Area 1990 Km^2	Area 2000 Km^2	Area Gained (+) Area Lost (-) Km^2	Percentile
Tabuk Province	12,898.02	12,882.02	-16	-0.12
Madinah Province	3,646.88	3,628.17	-18.71	-0.51
Makkah Province	16,440.23	16,438.57	-1.66	-0.01
Jazan Province	6,486.22	6,867.57	381.35	5.88
Eastern Province	14,519.02	14,526.49	7.47	0.05
Total	**53,990.37**	**54,342.82**	**352.45**	**0.65**

Coastal erosion[3] and inundation is expected to be directly impacted from sea-level rise. Coastal slope is the primary factor controlling the magnitude and range of sea level rise impact over time for many coastal areas. Majority of coastal areas in Saudi Arabia, particularly in the Eastern province are flat (0 – 3%). Those flat coastlines are expected to be highly impacted by SLR and gradual by inundated over time.

As a result of sea level rise, low gradient areas will be saturated with seawater. There are two types of inundation that will be impacted by sea level rise: Permanent inundation and episodic inundation. The effect that permanent inundation will have on areas is dependent on the local gradient. Areas that have low gradients at a coast are beach ridges, plains, deltas, mudflats, estuaries, lagoons, and bays. Episodic inundation is a result of storm surges. As sea level rises, episodic inundation will be more frequent for these low-lying areas. A 50-cm rise in sea level will inundate 8,500 to 19,000 sq. km of dry land (IPCC, 1998).

All Coasts will be exposed to increasing risks, including erosion, over coming decades due to climate change and sea level rise (IPCC,2007: Findings of Working Group II). Most of the Saudi Arabian coasts are plain and flat; few centimeters increase of sea level rise would cause significant erosion. Existing structures (e.g. roads, buildings, industrial facilities, sea ports, and recreational facilities) would have significant impact by such rise.

7.2.3.6 Impact on Groundwater:

Coastal groundwater table is associated with sea-level rise. As a result of sea-level rise, fresh groundwater and surface water could be displaced by saline water, which could have a significant adverse impact on water supply and agriculture. Also over abstraction of groundwater can also contribute to saltwater intrusion, where displaced groundwater is recharged by seawater. With growing population in coastal regions, saltwater intrusion is expected to occur more widely, and may enhance the rate of saltwater infiltration. The inland distance that a water table will be affected by sea-level rise depends on a range of factors including elevation and subsurface permeability. In some locations, rising water table can occur as far as tens of kilometers inland. Such rise would have an impact on foundation, drainage systems and underground infrastructures. About 60 percent of the water resources of Saudi Arabia are extracted from groundwater. Salt water intrusion will certainly have negative impact on Saudi economy and may require seeking other alternative resources.

[3]Erosion occurs when wind, and water take away sediments of land. Sediments are made of rocks, dirt, and earth. Erosion by wind action occurs mostly on beaches and deserts having less vegetation or plants. Wave erosion occurring along beaches and coasts is caused by the impact of breaking waves on the land. Both wind and water actions have important parts in this process and constantly change the boundary between land and water. Coastal erosion takes land away forever from one area to deposit it someplace else. The beach is constantly pounded by waves which eventually break fragments of ground and rock into sand.

7.2.3.7 Impact on Coral Reefs:

Coral reefs are the most spectacular and divers marine ecosystems of the planet. They have a crucial role in shaping the ecosystem which dominated tropical ocean over the past 200 million years. Reduction of coral reefs would have negative consequences on the marine ecosystem. They represent crucial source of income and resources through their role in tourism, fishing, coastal protection, and building materials.

Sea temperatures in many tropical regions have increased by almost 1ºC over the past 100 years and are currently increasing at a rate of 1 to 2ºC. Coral bleaching occurs when the thermal tolerance of corals and their photosynthetic symbionts (zooxanthellae) is exceeded. Mass coral bleaching has occurred in association with episodes of elevated temperature over the past 20 years and involve the loss of the zooxanthellae following chronic photoinhibition (Ove Hoegh-Guldberg). The Red Sea's reefs epitomize diversity; they are home to more than 200 soft and hard corals. In fact, it has the highest diversity of coral reefs than any other section of the Indian Ocean. These reefs act as the primary source of food and shelter for fish and invertebrates. They have a significant impact on the environment by also protecting the shoreline from erosion.

It is generally accepted that the 1998 sea-surface temperature (SST) anomaly and bleaching event caused widespread perturbations in Indo-Pacific coral systems, and it is considered by many to have been the most important bleaching event documented so far (National Coral Reef Institute, Oceanographic Center, Nova Southeastern University, USA, 2001). This event had affected both the Red Sea and the Arabian Gulf coral reefs. According to the status of the coral reefs of the world report published in 2004, this event has caused death to about 65% of the Arabian Gulf reefs and 4% of the Red Sea reefs. Clive Wilkinson of the Global Coral Reefs Monitoring Network has noted that extensive bleaching was seen in the Gulf in 1996; and now there has been extensive bleaching over the entire Arabian Gulf and part of the Arabian Sea in 1998. The Red Sea also experience warm temperature, but bleaching is an infrequent and some localized bleaching was seen over several months of mid-1998. Most of the Arabian Gulf and Red Sea reefs populations are in shallow waters. The highest coral cover of 3 sites surveyed in Saudi Arabia was on Wejh bank in the north, with an average of 40% cover at 5m. In Jeddah in the center, there was 20% average cover at 5m and 28% cover in the reefs of Farasan Island in the south (Hassan et al., 2002). Any increase in temperature due to climate change would have a devastating impact on those reefs causing bleaching and death of reefs in Red Sea and Arabian Gulf. In a pioneering use of computed tomography (CT) scans, scientists at Woods Hole Oceanographic Institute (WHOI) have discovered that carbon dioxide (CO_2)-induced global warming is in the process of killing off a major coral species in the Red Sea. As summer sea surface temperatures have remained about 1.5 ºC above ambient over the last 10 years, growth of the coral, *Diploastrea heliopora*, has been declined by 30% and "could cease growing altogether by 2070" or sooner.

7.3 Adaptation of the Impacts:

Based upon the topography, financial resources and site specifics, the following mitigation measures are proposed for sustainable coastal defense strategies to combat the impacts identified in the last section for both the Arabian Gulf and the Red Sea: spatial planning, sand nourishment, dune management, salt marsh management, sea grass beds and sea dikes. The investigations were based upon two geomorphological scenarios: below breakpoint and above breakpoint. Below breakpoint, the Saudi Arabian coasts will be able to maintain its present appearance (despite moderate sea-level variability) by sediment redistribution. Above breakpoint, the Saudi Arabia Coasts will not be able to balance sea-level variability and the tidal basins will start to drown, i.e. evolve in the direction of coastal lagoons (a shallow water area, separated from the open sea by barriers).

7.3.1 Spatial Planning:

Concerning spatial planning, the establishment of coastal regional plans that include establishment of buffer zones and coastal flood hazard zones is recommended as a promising non-technical Best Environmental Practice (BEP) measure. In the buffer zones, space can be reserved and used as costal defense line. In the flood hazard zones, restrictions and/or regulations for spatial utilization aim to reduce the consequences of storm surges. In the coastal spatial plans, the significance of climate change and its consequences, increased sea level rise and changed storminess, should be duly considered. The determination of buffer zones and flood hazard zones in coastal spatial plans becomes specifically significant above the breakpoint. In this case, traditional techniques might become less feasible to maintain present safety standards.

7.3.2 Sand Nourishment:

Sand nourishment is seen as BEP measure that successfully counteracts coastal erosion. Further, it helps to stabilize the dunes (constituting a natural dune-foot protection and as a sand source) and their functionality as flood defenses. Concerns exist with respect to interferences with nature that result from extraction and deposition of the sand. Hence, the measure should be applied in a way that minimizes the effects on the environment. Compared to other techniques (groynes, revetments) to stabilize sandy coastlines, sand nourishment is, in general, to be preferred. In the long-term and, especially above the breakpoint, nourishment of sand on strategic locations in the Arabian Gulf and Red Sea may help to balance the sand deficit that results from sea level variability.

7.3.3 Dune Management:

Dune management comprises of a number of measures (dune restoration, dune relocation, natural dune dynamics and over-wash) that ensure the functionality of dunes as flood defenses. Allowing natural dynamics and over-wash have clear ecological benefits as they add to the naturalness of the environment. Dune restoration and relocation, e.g., by building sand fences or planting marram grass, do interfere with nature. However, from an ecological point of view, these techniques are to be preferred above hard constructions like dikes that would otherwise become necessary. Especially above breakpoint, dune relocation in combination with sand nourishment might be a BEP measure to maintain defense standards. Even though, there might be a point where the techniques described above do not suffice and, with present safety standards, hard techniques may become necessary to protect inhabited lowlands.

7.3.4 Salt Marsh Management:

Salt marsh management techniques (i.e. groynes, drainage furrows and grazing) aim at maintaining the flood defense functions of the marshes. At the same time, salt marshes have an outstanding ecological value and should be preferred as dike foot protection compared to hard constructions. Groynes function in that they reduce wave energy and currents, thereby creating an environment where sedimentation prevails and erosion is lessened. Hence, they interfere with natural dynamics. Without groynes, widespread erosion of salt marshes would occur. Natural material (wood) should be applied if feasible. Artificial drainage furrows constitute an interference with natural dynamics as well. They should only be applied to secure dike-foot dewatering (avoiding otherwise necessary hard constructions) and, if necessary, to secure dewatering on grazed salt marshes. Natural structures should be used wherever possible as part of the drainage system. Livestock grazing on salt marshes is controversial and still subject of discussion. It is considered to be a BEP measure where, after storm surges, high amounts of flotsam would, otherwise, have to be removed from the outer dike slopes. At present, salt marsh management differs from country to country and is also dependent on the regional and local boundary conditions.

7.3.5 Promoting Mussel and Sea Grass Beds:

Promoting mussel and sea grass beds aims at stimulating accumulation and stabilization of intertidal flats. As it is capable of enhancing biodiversity, it has ecological benefits. From a coastal defense point of view, the measure could only perform a very local and limited effect that it may reduce wave energy. During storm surges, the large water depths reduce the wave damping effect to zero.

7.3.6 Sea Dikes:

Under sea dikes subject, a number of measures (dike strengthening, dike relocation and second dike line) were investigated that ensure the functionality of dikes as flood defenses. Measures that maintain the functionality of the sea dike system are indispensable to secure present safety standards. Sea dikes, on the other hand, strongly interfere with nature. Hence, necessary dike-strengthening measures should be carried out in a way that minimizes the adverse effects on nature; for example by using material from the old dike and by strengthening on the landward side (if possible).

7.4 Policies and Measures :

The Saudi Arabian Coastal Zone Management Plan (CZMP) has identified the coastal problems facing the Reds Sea and Arabian Gulf as coastal construction (including dredging & reclamation); industrial pollution; cooling water discharge; solid waste and litter; oil spills and discharges; physical damage to coral reef; sewage discharges; population pressures; desalination plant discharges; over-fishing & other fishing impacts; agriculture; coastal mining and quarrying and sediment. These problems/threats can be seen as comprising two main groupings, namely - physical alteration of the coastline, and pollution from land-based sources. These threats have impacts on ecosystems affecting coastal fisheries (both subsistence and commercial), special habitats (mangroves, seagrass meadows, coral reefs) and threatened species such as the dugong. They also have impacts on people by affecting environmental quality, employment and income, and sometimes their health.

In recognition of the value of its coastal areas and resources, and the threats posed by existing and potential problems, Saudi Arabia has put in place a number of legislations and adaptation measures which will manage the process of coastal development to ensure that its benefits are sustainable. The following Measures were proposed, adopted and implemented to conserve and protect coastal zone and marine environment:

7.4.1 Institutional Framework:

The Government of Saudi Arabia has taken several steps and decisions to control and protect the coastal zone and marine environment. Since the coastal zone management is a participatory process and participation by various government sectors, the private sector, NGOs, and the general public is an essential element, attempts have been made by Saudi Arabian government to involve, beside PME, coastal stakeholders, even if only at the official and administrative levels. Currently the Kingdom has three directives that regulate and implement the coastal zone management plan, which are:

- Decision of Council of Ministers number 14 (dated 21/1/1408 H) on fishing, utilization and protection of living marine resources of KSA territorial water;
- Royal Decree number 1982 (dated 15/9/1419 H) regarding reclamation and backfilling of coastal zone areas;
- Royal Decree number M/34 (dated 28/7/1422 H) regarding the general environmental regulations.

7.4.1.1 Quadripartite Committee:

A Coastal Committee has been established with representatives of the relevant ministries and other bodies to receive and process applications for coastal development. The committee has an equal representative power and its participants are: Municipality and Rural affairs; Ministry of Agriculture; Coast Guard and PME. The Committee advises PME and/or any other agency with the power to grant or withhold approvals for coastal development. A developer from either public or the private sector, can submit a development application for any of the following activities:

- Land reclamation of the owned area along the shoreline
- Land reclamation or dredging within the coastal area
- Utilization or land acquisition of reclaimed area

- Development projects on owned coastal areas especially along the waterfront
- Developmental projects or rehabilitation of sites that previously had been reclaimed or dredged incompletely or without complying fully with the requirements of the Coastal Committee.

7.4.1.2 Process of Coastal Land Reclamation and Dredging:

Any projects which will alter the coast or have a negative effect on land or in the water are prohibited by law in principle. For example, the owners of water frontages are not allowed to dredge or reclaim whether for tourist or residential developments either public or private. However, such actions may be permitted for proposals which are considered to be in the national interest, or security or of significant economic interest, e.g. projects related to widening or deepening of navigational channels and their maintenance. These projects are normally initiated or coordinated by one of the following government agencies: the Ministry of Defense and Aviation, Ministry of Interior, Ministry of Petroleum and Minerals, Port Authorities, the Royal Commission of Jubail and Yanbu, Ministry of Agriculture, the power plants, desalination plants, and other agencies related to scientific research or environmental monitoring. The agency concerned or its representative will apply to the municipality of the locality, using the prescribed application forms which include the environmental impact study. The application must also address the implementation methods and the disposal plans for the dredging spoils, as well as the duration of the project activities.

The National Coastal Committee will assess the viability and the justification of the proposal to reclaim and dredge within the coastal area, assuring itself that the proposed work is required either for security or rehabilitation or general interests or reshaping of the coastline. After agreeing to the proposal, the Committee will prescribe specific conditions it feels are necessary to minimize impacts and, in particular, to protect the coral reefs

7.4.1.3 Harbors and Bridges:

The establishment of new private harbors is discouraged. To the extent possible, the design of harbors and bridges should employ floating construction so as to avoid the creation of physical barriers which alter water circulation or impede its movement.

7.4.1.4 Development of Private Water Frontage Areas:

As noted above, the development of coastal areas particularly along the shoreline is not allowed except in the case of national interest, security, economy and public utilities undertaken by designated governmental organizations. If a developer still wishes to apply for a permit, an application must be submitted to the municipality. The application must clearly describe the development activities and the coastal land involved, as well as provide an EIA study indicating the effect of the development on the surrounding environment including consideration of alternatives and/or remediation of any impact. Upon the approval of the study by PME, the formal designation of coastline boundaries must determine the built-up areas together with areas that are to remain free of development and serve as green areas for recreation.

7.4.1.5 Project Monitoring by the Relevant Agencies:

Various agencies (mainly those with membership of the National Coastal Committee) must fulfill their environmental protection mandates, together with their goals and objectives of monitoring coastal developments and ensuring environmental safety and security as well as human health and safety and the protection of the Kingdom's natural resources on a sustainable basis.

7.4.2 Legislative Measures:

The Red Sea and Arabian Gulf are centers of diversity for corals, marine invertebrate and vertebrates, turtles and birds. The fishing industry is important for both local and the national economies. Accordingly, conservation of biodiversity and sustainable use of these resources are essential. In Saudi Arabia, a number of sets of environmental regulation, standards and guidelines were sanctioned, the most salient of these legislative measures is the National Integrated Coastal Zone Management.

7.4.2.1 National Integrated Coastal Zone Management (ICZM):

A draft of ICZM is at the final stage of approval. Implementation of ICZM calls for close co-ordination among operational agencies of ICZM in order to ensure that each management program is consistent with the Kingdom's national environmental policy as outlined in the development plans. The draft ICZM consists of and addresses the following issues:

1. Development of appropriate institutional arrangements to promote the wise and sustainable use of the nation's coastal land and water resources, including resolution of current conflicts among competing use needs and/or responsibility for coastal areas and resources;
2. Improving the information on coastal environments (habitats/ecosystems) that produce important socio-economic and environmental resources at the local, national and international levels;
3. Planning and management guidelines that will help establish wise and sustainable use of coastal ecosystems;
4. Planning and management guidelines for the site, design and management of activities that require access to coastal land and water resources;
5. Formulation of a basic Coastal Zone Management Plan by PME and operational local area coastal zone management plans by sectoral agencies with responsibilities for the planning and management of development and conservation activities; and
6. Increased public awareness of the importance of coastal land and water resources for their economic and social welfare;

- ***Local Area Coastal Zone Management Plans:***

Because of the delay in the review and approval process of the National ICZM plan, Local Area Coastal Zone Management plans were prepared with the following goals:

(i) Resources of the coastal zone should be preserved, protected and developed in a manner that provides the maximum benefit for current and all succeeding generations;

(ii) The development and implementation of management plans should achieve wise use of land and water resources of the coastal zone, giving full consideration to ecological, historic, esthetic and spiritual values as well as to the needs of economic development. These plans should at least provide for:

- Protection of natural resources, including sharms, coral reefs, beaches, dunes, islands, fish and wildlife and their habitat, within the coastal zone;
- Management to minimize loss of life and property caused by improper development in flood-prone, storm surge, geological hazard, and erosion-prone areas and in areas of subsidence or which will become inundated through sea-level rise and salt water intrusion, and destruction of natural protective features such as beaches, dunes, wetlands, coral reefs and islands;
- Protection of groundwater resources from pollution and saline intrusion resulting from poorly planned and managed coastal development;
- Priority consideration being given to coastal-dependent uses and orderly processes for siting major facilities related to national defense, energy, fisheries development, recreation, ports and transportation, and to new commercial and industrial development in or adjacent to existing development;
- Public access to the coasts for recreational purposes;
- Assistance in the redevelopment of deteriorating urban waterfronts and ports, and preservation and restoration of sensitive historic, cultural and esthetic coastal features and sites;
- The coordination and simplification of procedures in order to provide for expedited government decision-making for the management of coastal resources;
- Coordination with national agencies which are affected by decisions; and

- Assistance to support comprehensive planning for conservation, and management of living marine resources, including planning for the siting of pollution control and aquaculture facilities within the coastal zone.

(iii) In areas where conflicts between multiple uses endanger economic efficiency and/or natural resources, the preparation of special area management plans is encouraged. Special Area Management Plans provide for increased specificity in protecting significant natural resources, environmentally sensitive areas, areas of special potential for coastally-dependent economic growth, areas with significant natural resources, and areas in which development may be hazardous for property or life, and improved predictability in governmental decision making

(iv) All levels of the Kingdom's Coastal Zone Management Plans should implement actions and policies established in regional and international agreements to which the Kingdom of Saudi Arabia is signatory.

7.4.2.2 International Obligations:

The Kingdom participates in the activities of several international environmental organizations such as:

- (UNEP) United Nations Environmental Program
- (IUCN) International Union for the Conservation of Nature and Natural Resources
- (WMO) The World Meteorological Organization

7.4.3 Coastal and Marine Data and Information:

The Faculty of Marine Science of King Abdul Aziz University on the western coast has conducted an oceanographic survey of the marine communities and properties of the coastal waters between Yanbu and Jeddah, as well as other research programs which involve chemical, biological and geological aspects of the Saudi Arabian Red Sea coast. Similarly, King Fahd University of Petroleum and Minerals (KFUPM) Research Institute (RI) undertakes a number of research projects on the Arabian Gulf marine ecosystem. In addition, Royal Commission for Jubail and Yanbu (RCJY), Jubail and Yanbu projects and Saudi Aramco conduct a number of marine ecosystem monitoring programs in areas of their jurisdiction aimed at protecting marine ecosystem from pollution.

7.4.4 Other Measures:

Since 1985 it has been a requirement under Saudi Arabian law that any new industrial or commercial project, either public or private, must undertake an environmental impact assessment (EIA) before obtaining other approvals or permits. The EIA study must be based on the current PME regulations and standards with the objective of minimizing impacts on the environment. This requirement also satisfies obligations taken up under agreements with the Gulf Cooperation Council (GCC) and the Arab Environment Council.

7.5 Areas of Improvements for Future Assessments:

This section is addressing recommendations, future assessment and suggested area of focus on key aspects to be considered in succeeding studies. These recommendations are:

- Future studies should compile and review SLR studies conducted in different regions of the KSA and analyze similarities/differences with global SLR.
- Future studies should compare the impacts identified for the KSA with other regions in an expanded treatment of the impacts of SLR on coastal systems and resources.
- Future studies should address the issue of uncertainty in SLR. The 20th century global sea level, according to tide gauge data, has been increasing by about 1.7-1.8 mm/yr.
- Future studies should address the importance of local data resources, both marine and land-based to effectively evaluate and quantify SLR impacts on coastal systems in the KSA.
- Future studies should validate the concerns in the KSA regarding accelerated SLR (ASLR).
- Future studies should add scenario analysis in the next national communication report. In plan-

ning for adaptation, scenarios are typically downscaled from general circulation models (GCMs) to the national and sub-national scale, aiming to determine the likely impacts of climate change under alternative future scenarios.

- Future studies should review and provide quantitative relationships between climate change and impacts of systems that are valuable to the KSA.
- Future studies should fully address adaptation to climate change and what that means for the KSA.

7.6 References:

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Nicholls, R.J. and R.J.T. Klein (2005): Climate change and coastal management on Europe's coast. In: Vermaat, J.E., L. Ledoux, K. Turner and W. Salomons (eds): Managing European coasts: past, present and future. Berlin: Springer (Environmental Science Monograph Series), pp. 199-225.

Neal E. Cantin, Anne L. Cohen, Kristopher B. Karnauskas, Ann M. Tarrant, and Daniel C. McCorkle. Ocean Warming Slows Coral Growth in the Central Red Sea. Science, 16 July 2010: Vol. 329. no. 5989, pp. 322 - 325 DOI:10.1126/science.1190182.

SECTION - 8

Vulnerability, Assessment and Adaptation of Water Resources to the Impacts of Climate Change in the Kingdom of Saudi Arabia

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8.1 Climate Change in Saudi Arabia:

8.1.1 Prediction Model:

PRECIS (Providing Regional Climates for Impact Studies) of Hadley centre has been taken as an appropriate RCM for developing climate change scenarios. This model is an atmospheric and land surface model of limited area and high resolution which is locatable over any part of the globe. All parameters such as dynamical flow, atmospheric sulphur cycle, clouds and precipitation, radiative processes, land surface and the deep soil are described in this model. Boundary conditions are required at the limits of the model's domain to provide the meteorological forcing for the RCM. Boundary data used in runs were obtained from:

- A three-member ensemble of control experiment(1960-1990)
- A three-member ensemble of SRES A2 scenario experiment (2070-2100)
- ECMWF ERA-40 reanalysis experiment (1957-2001)

This study, which uses PRECIS model predictions, investigates the possible effects of global warming on water resources by the end of this century (2100). Changes in precipitation, temperature, wind speed, and relative humidity across Saudi Arabia were determined for past (1960-1990) and future (2070-2100) phases. Changes in evapo-transpiration for each of the 2542 grids were estimated using the FAO-approved Penman-Monteith approach. Differences in water levels were estimated for these grids. The possible effects of climatic change on water availability, water quality, communicable diseases, agricultural products, and ecology in Saudi Arabia were investigated, and the implications of this change on future water resource management outlined.

8.1.2 Future Climate Change Scenarios by PRECIS:

Changes in wind speed, temperature, relative humidity, precipitation, Evapo-transpiration and water levels from past (1960-1990) and future (2070-2100) phases at each of the 2542 grids are summarized in the following sections. The soil moisture data from the IPCC Data Distribution Centre show that there will be no soil moisture in any of the grids across the Kingdom in 2100; the soil surface will be perfectly dry and/or sandy/rocky in each grid. The possible effects of climatic change on human health, the ecology, communicable diseases, agriculture, the water supply, and water quality degradation are also discussed in this section.

8.1.2.1 Wind speed:

The monthly average changes in the absolute value for wind speed from 2070 to 2100 based on PRECIS model predictions are in the range of -0.6 m/sec (July and August) to 1.4 m/sec (July). Changes in the annual average wind speed are shown in Figure 8.1. In January, the wind speed will decrease in the Turaif, Al-Jouf, Tabuk, and Rub Al Khali regions by 0.1 m/s to 0.3 m/s, and increase in the Makkah and Asir regions by 0.1 m/s to 0.8 m/s. In February, the wind speed will increase throughout the southwestern parts of the Kingdom by 0.1 m/s to 0.3 m/s. In the northeast, the wind speed will decrease from 0.1 m/s to 0.3 m/s. A significant increase in wind speed will be observed for the southwestern region in June and for the southwest and north regions in July (1-1.3 m/s). A considerable decrease in wind speed will be observed for the northeastern region during July and August (0.6-0.8 m/s); it increases in the entire Kingdom during April, May, and June, and decreases in most regions in October. The simulation results reasonably indicated that wind speed and direction will vary spatially and temporally throughout the Kingdom.

The southwest part of the Kingdom has a significant increase in wind speed throughout the year, while in the southeastern part, wind speed decreases from January to March, and an increase is estimated for April to December. The most significant increases, from 20% to 28%, appear in the central to southwest parts of the Kingdom in June and the southwest and north in July. The most significant decreases, from -8% to -10%, appear in the north in January, in the northeast in July and August, and the southwest in September.

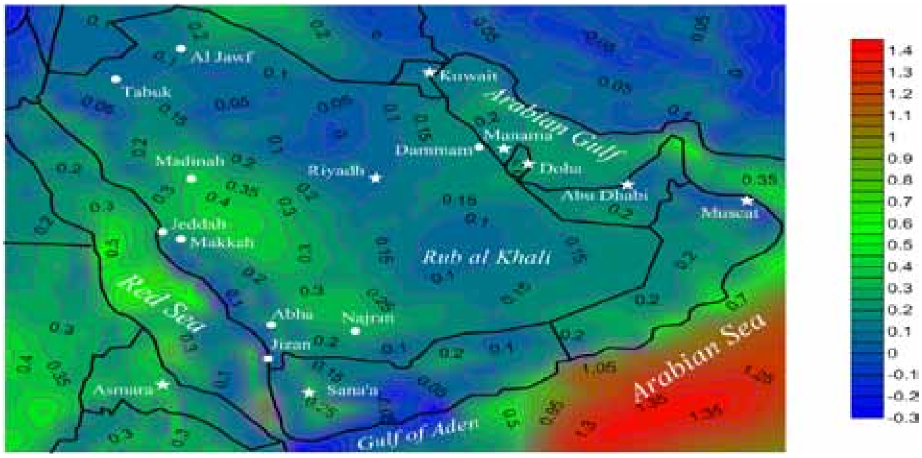

Figure 8.1 Annual Average Wind Speed Change from 2070 to 2100 (m/sec)

8.1.2.2 Temperature:

This study finds an increase in temperature from 2070 to 2100 throughout the Kingdom of Saudi Arabia. The northern parts (Jordan and Iraq sides) of the Kingdom will experience more increases of temperature than those of the southern sides (i.e., near the Yemen and Oman borders). The maximum increase in temperature, from 5°C to 6°C, will be observed in the central part in April and in the northwest and central parts in May. It appears that the most significant increase will be throughout the Kingdom during April to June. The minimum monthly temperature increase is expected to be 0.8°C in January, while a maximum increase of 6°C is expected in April. In January, the temperature changes slightly from 0.8° to 1.2°C in most parts of the Kingdom, and a little higher on the west coast (1.2°-2.6°C). In February and March, an increasing trend will be observed from the southeast (2.8° and 3.4°C) to northwest near Tabuk (3.2°C and 4°C). Between April and May, the central region near Riyadh has the highest temperature increase. Between June and July the region between Madinah and Makkah will experience a relatively low increase in temperature, while the northeast will have a relatively high increase. From August to November, the change of temperature increases from the south to the north. In the north, an increase of up to 5.8°C is expected during the summer months. A relatively low temperature increase is expected in January and December. Details of the annual average changes in temperature across the Kingdom are shown in Figure 8.2.

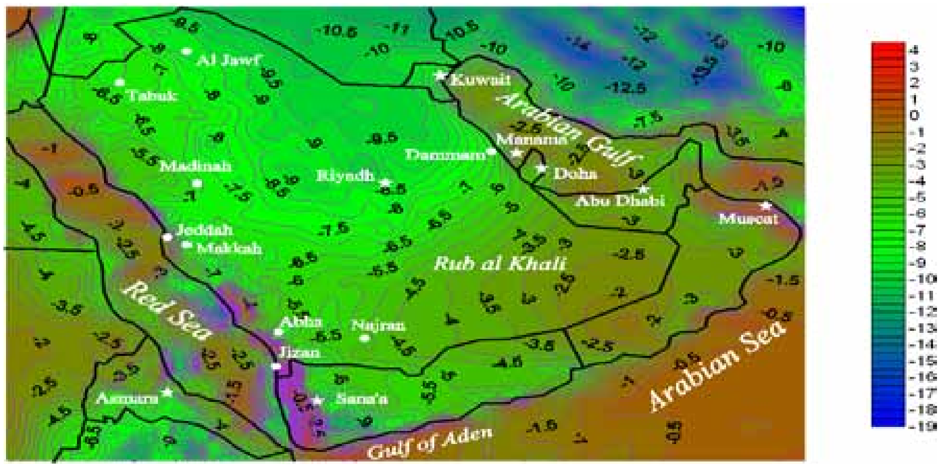

Figure 8.2 Annual Average Temperature Change from 2070 to 2100 (°C)

8.1.2.3 Relative Humidity:

The changes of relative humidity on an average basis are shown in Figure 8.3. An overall decrease in relative humidity is expected in the entire Kingdom throughout the year except the period from July to October. In this period, a slight increase appears in the southeast and decreases from the southeast to the northwest. The highest decrease in relative humidity, from 20% to 26%, is expected in the northeast in January. The highest increase, from 8% to 10%, is expected in the southeast in August. In January and February, a relatively low decrease of relative humidity appears in the coastal zone and in the southeast, and decreases to the northeast; the highest decrease, from 18% to 20%, occurs on the northeast boundary of the Kingdom in these two months. From March to May, the highest decrease in relative humidity shifts from the northeast to the central part and increases from the northwest to the southeast. Between July and October, a slight increase in relative humidity will occur in the southeast, the highest increase from 5% to 10%, appears during August and September. A slight decrease, from 0% to 10%, occurs in the north. In November the relative humidity decreases from 1% in the southeast to 10% in the northwest. In December, a high decrease of relative humidity from 7% to 10% appears in the central part of the Kingdom and in the other parts from 4% to 6%.

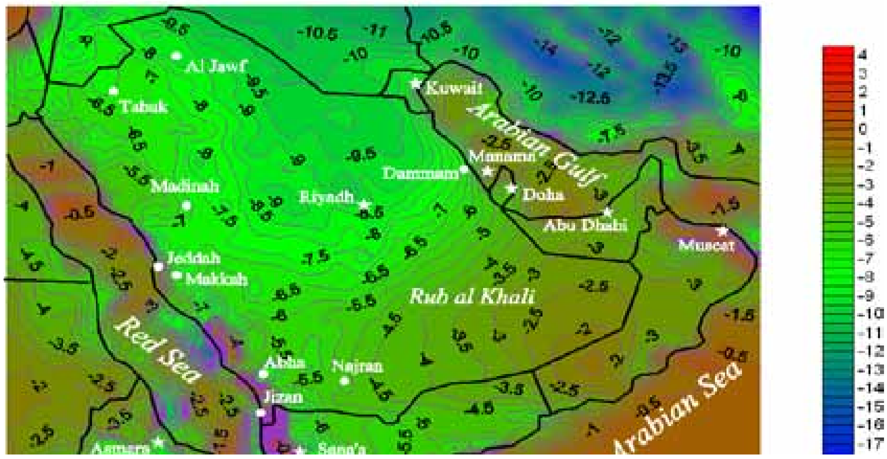

Figure 8.3 Annual Average Relative Humidity change from 2070 to 2100 (%)

8.1.2.4 Precipitation:

The changes of relative humidity on annual basis are shown in figure 8.4. Changes in precipitation show regional and temporal variations across the Kingdom for 2100. The precipitation will decrease in the entire Kingdom from December to June. However, between July and November, an increase in precipitation in the southern part of the Kingdom and a decrease in the northern part is predicted. From December to February, the central region close to the Arabian Gulf has the highest decrease in precipitation,

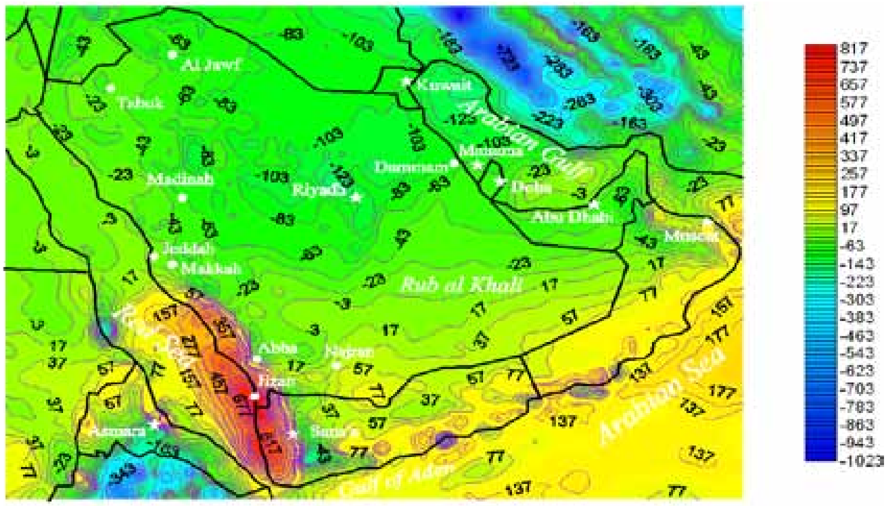

Figure 8.4 Annual Total Precipitation Change from 2070 to 2100 (mm/year)

from 12 mm to 30 mm (total), and in other parts of the Kingdom, the decrease remains between 3 mm and 10 mm. The region of highest decrease moves from the coastal zone in the northeast to that in the southwest. From March to May, the highest decrease is in the central part of the Kingdom ranging from 20 mm to 30 mm and elsewhere, the decrease will be in the range of 3 mm to 12 mm. In June, almost no change of precipitation will occur from past to future phases in the entire Kingdom. From July to October, an increase of 3 mm to 100 mm occurs in the south; the highest increase is in the southwest coastal zone near Abha and Jazan in July and August. In November, it increases around 3 mm in the south, and decreases around 3 mm in the north. Regions with high elevations have a relatively high decrease of precipitation in winter seasons, but a high increase in summer. The annual total precipitation decreases in most parts of the Kingdom and only increases in the south. The highest increase, from 400 mm to 600 mm, appears in the southwest coastal zone near Abha and Jazan, while the highest decrease, from 100 mm to 120 mm, appears in the region around Riyadh. These numbers seem to be unrealistic considering low precipitation in the entire Kingdom.

8.1.2.5 Evapo-transpiration:

The changes in Evapo-transpiration (ET) across Saudi Arabia from 2070 to 2100 were estimated using the grid-wise climatic data of IPCC's Hadley model in equations 1 to 8 as discussed in section 6. This study predicts an overall increase of Evapo-transpiration throughout the Kingdom in both past (1960-1990) and future (2070-2100) phases. The highest increase of ET is predicted as 3.5 mm/day (average) in July in the northernmost part of the Kingdom, and the highest decrease (-1.2 mm/day average), in August in the southeastern most part.

From January to May, a relatively high increase of ET appears in the central part of the Kingdom, but tends to decrease in the northwest and southeast. The overall ET increases from January to April, then decreases slightly in May. In May, the highest ET occurs in the central to northeast and southwest parts of the Kingdom, and decreases to the southeast and northwest. In June, a relatively high ET, from 2.5 mm/day to 2.8 mm/day, occurs on the northeast and southeast boundaries of the Kingdom as well as in the southwest region near Najran. In July, the highest ET is in the northeast near Al Jouf and ranges from 3.0 mm/day to 3.5 mm/day, and is relatively high in the area near Najran, from 2.5 mm/day to 2.7 mm/day; the rest of the Kingdom remains at 0.5 mm/day to 1.5 mm/day.

A decrease of ET occurs in the southwest in August and September from -0.1 mm/day to -0.8 mm/day, and tends to increase in the northwest in August from 2.1 mm/day to 2.8 mm/day and in the northeast in September from 1.9 mm/day to 2.2 mm/day. In October and November, the ET increases by 0.5 mm/day to 1.5 mm/day from the southeast to the northwest. ET has a uniform distribution in December, from 0.5 mm/day to 1.0 mm/day. The detailed changes in ET across the Kingdom are shown in Figure 8.5.

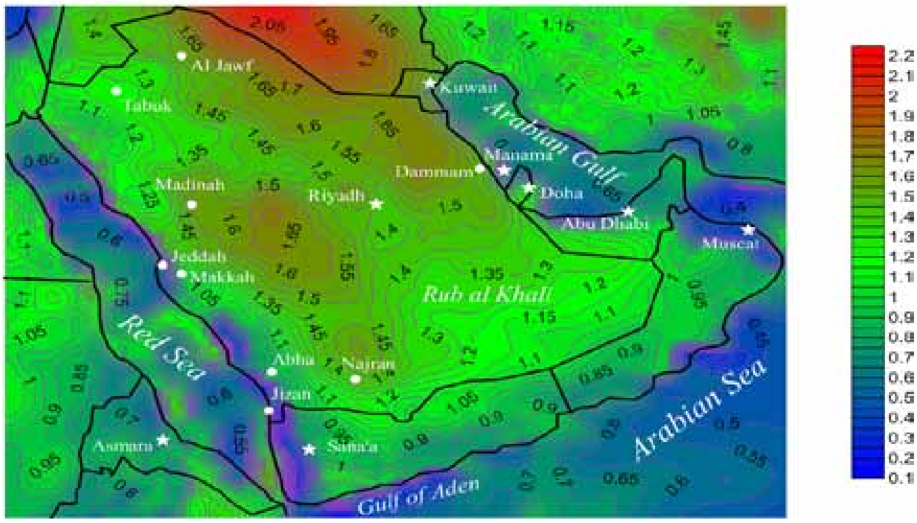

Figure 8.5 Annual Average Evapo-transpiration Change from 2070 to 2100 (mm/day)

8.2 Impact of Climate Change on Water Resources:

8.2.1 Water Resources in Saudi Arabia:

With no perennial rivers, Saudi Arabia is one of the driest regions in the world. In the Kingdom of Saudi Arabia, renewable and non-renewable groundwater, desalinated seawater and limited surface water must meet the Kingdom's water needs. Eastern Arabia and the Jabal Tuwayq area have artesian wells and springs. In Al Ahsa, a number of large, deep pools are constantly replenished by artesian springs as a result of underground water from the eastern watershed of the Jabal Tuwayq. Such springs and wells permit extensive irrigation in local oases. In Hijaz and Asir, wells are abundant, and springs are common in mountainous areas. In Najd and the large deserts, there are very few places with water availability. Water must be pumped to the surface, and even where water is available, its quality is very poor.

8.2.2 Policies:

There is general agreement within countries about the need for enhanced regional and local climate change scenarios. The greatest demand is for climate information for the next 20–50 years. Uncertainties need to be reduced and more reliable information is needed to distinguish between the consequences of climate change and natural climate variability through more research on the use of regional models, and in the improvements in the accuracy of hydrological and hydraulic models, including groundwater. There is also a need to improve the coupling of climate and hydrological models.

There is also a need to maintain observation networks to identify climate change trends and introduce remote-sensing techniques in hydrological monitoring and local data to be merged with hydrological data.

The United Nations Framework Convention on Climate Change (UNFCCC), adopted in 1992, includes the issue of adaptation in various articles. For example, it places obligations on member states to develop programmes to facilitate adaptation and to cooperate in preparing for adaptation, and called upon developed parties to provide financial assistance to enable the adaptation by developing countries. Within the UNFCCC process, increasing attention is given to actions regarding climate change adaptation in developing countries, with new funding mechanisms in place.

Stern Review (2006) examined adaptation in the developed countries by reducing the costs and disruption caused by climate change, particularly from extreme weather events like storms, floods and heat waves. Adaptation in developed countries is still at an early stage even though market structures are well-developed and the capacity to adapt is relatively high, and suggested that governments will have a role in providing a clear policy framework to guide effective adaptation by individuals and firms in the medium and longer term. Four key areas were identified for action:

(i) High quality climate information will help in driving efficient markets and improved regional predictions, particularly for rainfall and storm patterns;
(ii) Land-use planning and performance standards will encourage investment in buildings, and long-lived infrastructure to take account for climate change;
(iii) Long-term policies for climate-sensitive public goods will protect natural resources, coastal protection and emergency preparedness;
(iv) A financial safety net will help the poorest in society.

Adaptation to climate change in the water sector needs to be incorporated into overall policy frameworks. A recent analysis of policy frameworks for water has shown what has to be done, when and by whom and it depends not only on the rate of climate change, but also on the existing policy frameworks in each country. These policy frameworks generally contain the following elements:

- a system of legal frameworks that stipulate rights and responsibilities (e.g. water rights and abstraction permits);
- institutions: national, regional, and local;
- policies that guide national, regional/state, local laws which clearly defines the role of players

(governments, ministries, departments, regulators and other authorities);
- physical water infrastructure: dams, levees reservoirs and sewerage systems;
- a set of water management plans with the flexibility to anticipate and respond to climate change;
- a system for sharing current and projected climate information.

Three priorities can be set in relation to adaptation in the water sector in order to reduce vulnerability and demand.

(i) Reduction in Uncertainties in Hydro-Meteorological Trend Predictions:

An increase in the occurrence of floods, droughts and other extreme weather events due to climate change poses a considerable threat to national economies and sustainable development. Current and future risks and uncertainties associated with such climate-related problems need to be addressed to safeguard people and societies from increased loss of life, property and assets.

(ii) Protection and Restoration of Ecosystems:

Degradation of water and land resources threatens the production of goods and services from river-basin ecosystems. Protection and restoration of such ecosystems is urgently needed to maintain and restore natural capacities that help to protect people and assets from the impacts of increased climate variability and extreme events.

(iii) Close Gap between Water Supply and Demand:

In many regions, water demand now exceeds or threatens to outstrip sustainable levels of supply. Conventional strategies to increase water supply can no longer meet growing needs, and are unable to cope with the uncertainty arising from increased climate variability and climate change. Sustained efforts are therefore needed to reduce water demand. This could have ancillary benefits of reduced energy consumption for water treatment and distribution.

The main objectives of the water sector will be realized through adaptation of the following policies:

- To review the existing policies of the agriculture and water sectors and to regulate water consumption priorities.
- To reconsider the administrative organization of the water sector and consolidate all agencies responsible for management of this sector into a single autonomous agency.
- To support a computerized central database covering all aspects of water uses.
- To expand and upgrade the hydrological and hydro-geological monitoring network.
- To expand application of advanced methods and technologies for conservation of water and improvement of utilization efficiency, in cooperation with the Saudi research centers.
- To develop and support renewable surface and ground water resources more efficiently and supporting the dams construction program.
- To update the detailed hydro-geological studies and to issue the national water plan in cooperation with universities, KACST and related government agencies.
- To improve the system of collecting water fees.
- To enhance the role of the private sector in the field of water services.
- To develop non-conventional water resources, including construction of desalination plants and appropriate facilities in order to support other sources of water, as well as implementation of projects for re-use of reclaimed waste water and agricultural drainage water.
- To train Saudi manpower in the water sector.

8.2.3 Assessment of Climate Change Impacts on Water Resources:

In the ecosystems of arid regions such as Saudi Arabia, limited water resources (groundwater and surface water) and a sensitive desert environment are major features. Any increase in air temperature and other meteorological parameters affects the reference crop evapo-transpiration, crop water requirements and water recharge to aquifers. Groundwater resources are the major water supply source for the Kingdom. More than 90% of the national water use is met through groundwater, which is pumped from local aquifers. Surface water is very limited because of the low annual precipitation. The annual recharge to aquifers from the low average rainfall has been significant for partially compensating for the water withdrawal from the aquifers. Furthermore, irrigation requirements are more than 90% of the total water demands. These demands are met mainly from groundwater resources. Any increase in the air temperature and other meteorological parameters will affect the availability of groundwater and surface water conditions due to an increase in the evaporation rates from open water bodies, soil, and plants and by the reduction in water recharge in aquifers. Such recharge reduction will result in a deterioration of the water quality and the production of aquifer systems in the Kingdom and will result in water shortage. Consequently, urban, industrial, and agricultural water supplies from groundwater will be affected; this in turn will affect the survival of plants and vegetation and hence increase desertification, with serious socio-economic impacts. Thus, any increase in ET will result in an increase in the rate of evaporation and a decrease in the available water supplies, thus lowering the aquifer recharge. Similarly, an increase in ETo will result in increased water demands for urban, industrial, and agricultural uses. Normally, an increase of about 20-30% from winter to summer will occur in the domestic and industrial sectors; however, this increase is expected to be aggravated by a temperature rise, especially in the summer months. Irrigation water demands will also be alleviated by increased ETo, and crop water requirements in the Kingdom's various agricultural regions will also increase. Consequently, the available water resources able to meet increasing demands will be further stressed due to a decrease in water recharge and surface runoff and also due to an increase in the domestic, industrial, and agricultural demands in the Kingdom.

8.2.3.1 Impacts of Climate Change on Groundwater Recharge and Surface Water:

Necessary geological, hydrological and hydro-geological data and information, including maps for the Kingdom's main aquifers, have been reviewed. New geological maps, developed for these aquifers, show their outcrop extent. Data on hydro-geological features of the aquifers were also reviewed, including recharge studies and assessments on various aquifer systems. The values of recharge on the outcrops of different aquifers have been defined. The recharge values for different aquifers are given in Table 8.1.

Aquifer	Region	Annual Recharge MCM/year
Saq	North Western Region	290
Tawil	Northern Region	52
Neogene	Eastern Region	391

Table 8.1 Estimated Annual Recharge in Some Aquifers

Based on several hydro-geological studies, the calculated total annual recharge to all aquifers in the Arabian Shelf is about 2,762 MCM (KFUPM/RI, 1988; Al Alawi and Abdulrazzak, 1993). The annual recharge to shallow aquifers in the Arabian Shield is 1,196 MCM (BAAC, 1980). Thus, the total annual recharge to all aquifers in the Kingdom is about 3,958 MCM. The average increase in ETo, as calculated and explained in Section 3.4, which reduces the recharge to all aquifers, has been defined as 2.3% and 12% of the total annual recharge at 1ºC and 5ºC increase in temperature, respectively. The calculated reduction in the values of the total annual recharge is about 91.4 MCM and 475 MCM at 1ºC and 5ºC increases in temperature, respectively.

The reduction in annual surface runoff of 5,000-8,000 MCM at an ETo increase of about 2.3% and 12% and a 1ºC and 5ºC increase in temperature, respectively, were calculated. At a 1ºC increase in temperature, a 2.3% increase in ETo will decrease the annual surface runoff by about 115-184 MCM (average of 150 MCM). At a 5ºC increase, a 12% increase in ETo decreases the annual surface runoff by about 600-960 MCM (average of 780 MCM).

The total annual reduction in water resources equals the reduction in recharge and surface runoff. Thus, the total water resource reduction will be about 241 MCM and 1,435 MCM at a 1ºC and 5ºC increase in temperature, respectively.

The reduction in water recharge to aquifers and surface water runoff will result in the deterioration of the water quality and the production of aquifer systems in the Kingdom, and these aquifers will not be able to satisfy the growing demands for water. Consequently, the urban, industrial, and agricultural water supplies from groundwater and the limited surface water will be affected, and serious socio-economic impacts will result.

8.2.3.2 Impacts of Climate Change on Irrigation Water Demands:

The calculated increase in ETo and irrigation requirements (IR) is used to calculate the increase in IR of various crop types in different regions of the Kingdom at 1ºC and 5ºC increases in temperature.

8.2.3.3 Impacts of Climate Change on Domestic and Industrial Water Demands:

The domestic and industrial water use increase at 1º to 5ºC is assumed to be about 5% and 25%, respectively. Thus, the expected rise in domestic and industrial demands will range between 75 and 390 MCM at 1ºC and 5ºC increases in temperature, respectively.

8.2.3.4 Expected Total Water Stress from Expected Climate Change in Saudi Arabia:

The calculated total water stress ranges between 1,520 and 4,947 MCM at 1ºC and 5ºC increases in temperature, respectively (Figure 8.6). This represents a serious challenge to domestic, industrial, agricultural, and natural vegetation in the Kingdom's various land forms. Early monitoring and warning systems and appropriate contingency plans should be developed in advance for the protection of national interests and to minimize desertification-induced processes in the Kingdom.

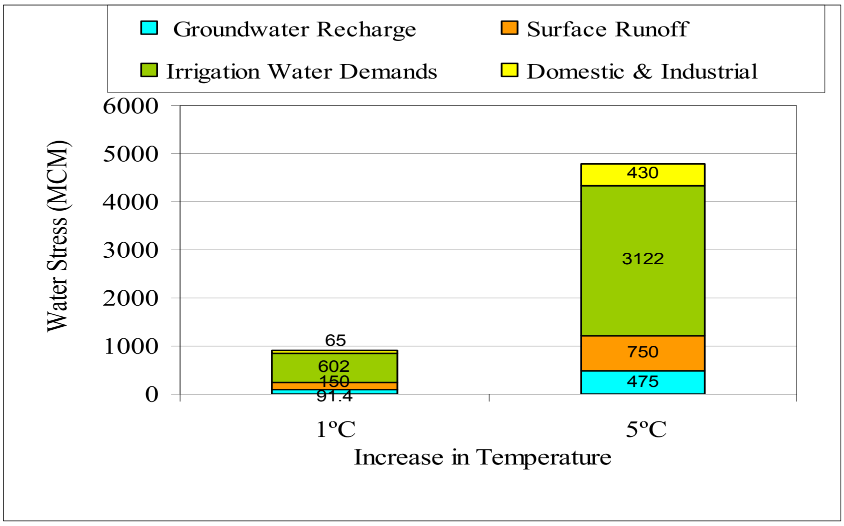

Figure 8.6 Stress on Water Resources as a Result of Climatic Change (MCM)

8.3 Conclusions and Recommendations:

8.3.1 Conclusions:

The possible effects of climatic changes on water resources, water quality, water supply, agriculture, human health and ecological systems in Saudi Arabia in 2100 have been investigated in this study. The changes in wind speed, precipitation, temperature and relative humidity from 2070 to 2100 were estimated from PRECIS model predictions. Using these data, changes in Evapo-transpiration values and water levels for the 2542 grids (grid spacing: 0.26° Latitude by 0.26° Longitude) covering Saudi Arabia (Latitude: 16.5°N–32.5°N; Longitude: 33.75°E–56.25°E) were estimated. The wind speed and direction will vary from 2070 to 2100 spatially and temporally throughout the Kingdom. Changes in wind speed will be significant in many areas. The temperature will increase by 0.8°C to 6.0°C; as indicated in this paper, a 1°C increase in temperature can affect human health, ecosystems, and agricultural production. The overall amount of precipitation will decrease in 2100. Relative humidity will have variable effects, depending on the region; however, an overall decrease in relative humidity will be observed. Estimates of climatic parameters show that in the future Saudi Arabia may suffer from increased drought, more communicable diseases, less production of agricultural food, and insufficient water.

Because of aridity and the low reserves of water in underground aquifers, Saudi water resources are already under stress. Climate change may add further stress. This study estimated monthly average Evapo-transpiration in the range of -1.2 to 3.5 mm/day for 2100, which increases during the year. The increase of Evapo-transpiration will cause a decrease in water levels. It is likely that water level decrease will affect hydrologic cycles, flow directions, and salinity conditions, which subsequently affect the amount and quality of water stored in shallow and deep underground aquifers. Thus, water supplies in the future may face a serious challenge.

It has been documented that climatic changes may affect the spread of communicable diseases including diarrhea, cholera, malaria, and dengue in the deserts, including those of Saudi Arabia. These diseases have the potential to reduce human workability which may possibly result in an increase of medical expenses throughout the Kingdom. This study predicted average yearly temperature increases of 0.8°C to 6.0°C in 2100. This increase may result in a 7.5% to 10% increase in mortality for Saudi Arabia in 2100. In addition, an increase in temperature and its variability will increase uncertainty in future food production.

Saudi Arabia has a sensitive ecosystem for any level of climate change and most regions are highly vulnerable to such changes, especially to desertification processes and water resources. In most regions, climate change, as represented by a temperature increase, would elevate the levels of reference Evapo-transpiration by about 1-4.5% at a 1ºC increase, and by about 6-19.5% at a 5ºC increase. Crop irrigation water demands would rise by about 602 and 3,122 MCM at 1ºC and 5ºC increases, respectively. The expected yield losses of different types of field crops (including cereals, vegetables, and forage crops) and fruit trees (including date palms) will range from 5% to more than 25%.

8.3.2 Recommendations:

The above findings on the impact of climate change on water resources are based on simplified assumptions in the prediction of various climatic parameters in the Hadley model and limited input data resources within the Kingdom of Saudi Arabia. This study has limitations in terms of application, most of which can be attributed to the simplification of various natural systems in the prediction of climatic parameters by the PRECIS model and simplification of the Evapo-transpiration determination approach in predicting water level changes across the Kingdom. Further investigations are, therefore, needed to improve the prediction and should include:

- The impact of climate change on possible increases in reference Evapo-transpiration using data from all meteorological stations throughout the Kingdom.
- The impact of climate change on possible decreases in surface rainfall runoff in the Kingdom using more detailed data and local hydrological information from its different regions.
- The impact of climate change on possible decreases in aquifer recharge using more detailed hydro-geological data about local aquifers in various regions.
- A detailed assessment of water use stress on natural vegetation.
- The possible impact of micro-climate changes in all regions.
- An impact study of a possible rise in seawater levels on ecosystems and desertification hazards in coastal belts.
- Identification of the measures to combat the impact of climate change on water and desertification in the Kingdom.

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Section 9

Vulnerability, Assessment and Adaptation of Desert Ecosystem to the Impacts of Climate Change in the Kingdom of Saudi Arabia

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9.1 Introduction:

The Kingdom of Saudi Arabia is a land mass of approximately two million square kilometers which consists of five distinct types of landforms namely: mountains, plateau, desert, coastal plains, and lava flows (Harrat). The desert area of the Kingdom mainly consists of the Rub Al Khali (including the Al-Jafurah in the south, Great Nafud in the north and Ad-Dahna desert connecting the two bodies of sand). About 30% of the Arabian Peninsula is covered with sand in the form of sand-seas. Several bodies of sand are also prominent along the side of the Tuwayq escarpment. The Great Nafud is a very large depression filled up with masses of sand and covers an area of almost 60,000 sq. kilometers. One striking aspects of this body of sand is lack of oases and river-system. A narrow, triangular strip of sand extending northwards from the empty quarter to east of Hofuf and then following the coastal plain is called Al-Jafurah. In contrast with the reddish hues of sands in the Nafud, the Dahna and rest of the empty quarter, the sands of Al-Jafurah are buff to tan in colour. Coastal form covers the costal area of Saudi Arabia while the Plateau covers the middle part of Saudi Arabia. The mountains are located in the Southwestern part of Saudi Arabia. Lava flow (Harrat) covers the West and Northwestern parts of Saudi Arabia.

Figure 9.1 Vegetation Cover of Annual and Perennial Herbs in the Great Nafud desert

Figure 9.2 Calligonum Artemisia Monosperma in Ad-Dahna Desert

This section describes the status of desertification in the Kingdom of Saudi Arabia, efforts made at national level to combat desertification, rehabilitation of deteriorated resources and formulation of National Strategy and National Action Program (NAP) for combating desertification.

The Ministry of Agriculture was appointed as the coordinating body for implementation of NAP both at the National and International levels. National committee for the formulation of the National Action Program (NAP) and Strategy for combating desertification completed its task with a technical help from the United Nations Environment Program for West Asia (ROWA-UNEP). The report includes a review of related plans and strategies and a number of measures adopted concerning the conservation of natural resources. A committee has also been formed to propose an effective mechanism to face the natural disasters such as drought and to add the early warning system to the proposed activities and programs for the evaluation and monitoring of desertification. This report also focuses on the monitoring of the implementation of the United Nations Convention on Combating Desertification.

9.2 Activities implemented for Combating Desertification in the Kingdom:

9.2.1 Capacity Building:

The Kingdom of Saudi Arabia is fostering and implementing a number of activities related to artisans and the cultural inheritance of local communities in order to support and implement the convention at the national level. A fund for human resources development is secured. A number of staff concerned with desertification control were trained as well as a number of research works have been carried out about sand dune fixation and planting of trees with low water requirements as well as treated wastewater reuse in sand dunes fixation.

9.2.1.1 Monitoring and Control Urban Expansion:

The government has taken steps to develop rural areas so that migration to the cities is minimized and stopped to minimize the burden on the ever strained resources of the cities. In addition, city limits have been defined not to allow cities to encroach into the rural agriculture and range lands.

9.2.1.2 Sustainable Agriculture Development:

Ministry of Agriculture is conducting detailed studies in agriculture areas (i) to determine the negative factors affecting the production of crops (ii) to determine the environmental risks and (iii) to monitor land degradation in order to develop strategies, standards, guidelines and adequate methodologies to utilize the best and sustained use of water and soil to guarantee the sustainable agriculture activities. This has been done with the involvement of stakeholders including relevant ministries, agencies and private sector entities. There is involvement of highest policy makers to study and implement policies to reduce the use of pesticides and to use fertilizers in a right way especially those containing nitrogen. In December 2006, Council of Ministers approved the new pesticide law regulating use of pesticides for agriculture based on the research and right usage of pesticide without over-usage.

In addition, the Kingdom discouraged those crops growing which require excessive water use such as wheat. In 1995, stopped export of wheat, reduce wheat agriculture area and stopped paying subsidies on wheat. The abandonment of 4,000 new projects for animal feed and change it to agriculture crops was part of government policy to conserve water. Since 2000, a significant reduction of area for animal feed and water consumption rate has been noted. Ministry of Agriculture studied the current status of desertification in the Kingdom and published natural resources atlas with digital maps of the Kingdom.

9.2.2 Conservation of Renewable Natural Resources (Soils, Water, Vegetation Cover, Domestic, Commercial and Wild Animal Resources):

A number of forest sites, rangelands and some other vulnerable ecosystems have been protected through conservation efforts. Regular maintenance including pest control was carried out for forest sites, alien plants in forest and range areas. A number of nurseries for the production of local plants and production and storage of local range plants were established. A vegetation map was produced, four new National

Parks were established and forest and range inventory was carried out using remote sensing techniques and field measurements.

Government departments encouraged multiple use of water. A special project was carried out for the qualitative and quantitative evaluation of ground water resources in some valleys of the Kingdom. Currently, a plan is prepared to manage water resources. Twenty seven (27) new dams are under construction with a total capacity of about 1,690 million cubic meters. Special measures have been taken for the sustainable use of lands in the areas of mining in order to decrease dispersing of dust and to rehabilitate these mining sites.

9.2.3 Rehabilitation of Ecosystems and Deteriorated Habitats:

A number of deteriorated forest and range sites have been rehabilitated through protection, seed diffusion and distribution and by stepping up of the capabilities of seed production centers distributing seeds and seedlings to the farmers. Rehabilitation has also been undertaken to the windbreaks of the sand dune fixation project in Al Ahsa and fixation of sand creeping in a number of different sites. A study was carried out about the effects of urban expansion towards the forests in Asir and Najran areas. More than 37 sites in the protected areas in the Kingdom help in to reduce the rate of desertification compared to open grazed areas.

9.2.3.1 Stabilization of Sand Movement:

Movement of sand makes serious risk and threaten roads and other surrounding constructions and is considered one of the most important effect of desertification in the Kingdom. Since early sixties, the Kingdom gave it a priority to solve this issue and established green belts and barriers around the cities and on the sides of roads. Sand movement has been stopped on the sideways of all major roads, cities and constructions. Tree plantations proved to be most effective and suitable economical and environmentally safe method for controlling sand movement.

9.2.4 Evaluation, Revision, Upgrade and Updating of Regulations and Policies Concerning Renewable Natural Resources:

The updated Legislation for Forest and Range management, National Forest and Range Strategy and National Forest Program have been approved. Land use and main road network demarcations have been taken into consideration which will lead to protection of forest, range and other important ecosystems. Measures were undertaken for ecological assessments in ecotourism development sites. The Council of Ministers has approved necessary regulations for the reuse of treated wastewater in addition to the regulations for wastes and the municipal dumping sites. Marble miners have been obliged to submit environmental impact assessment for their projects.

9.2.5 Monitoring and Evaluation of Drought and Desertification:

The Ministry of Agriculture has monitored the deteriorated rangeland sites in the northern region of Saudi Arabia and causes of their deterioration. Soil maps showing the deteriorated sites have been produced while manual detailing evaluation process of deteriorated areas at national level is under preparation. In addition, a project is underway to monitor the amount of soil lost by wind erosion in Riyadh area and its characteristics. Another project is implemented to monitor the degree of desertification and its causes in the southwest region of the Kingdom. 300 monitoring wells have been constructed all over the Kingdom for the monitoring ground water.

9.2.6 International and Regional Cooperation, Conventions and Treaties for Evaluation and Control of Desertification:

A forestry outlook has been prepared and published by Ministry of Agriculture. Currently, a project has been initiated for monitoring and rehabilitation of Juniper forests in southwest of Saudi Arabia in cooperation with United Nations Food and Agricultural Organization (FAO). First National Communication of the Kingdom having a chapter on desertification was submitted to UNFCCC. Strategy for combating desertification in cooperation with UNEP and strategy for sustaining biological diversity, forage strategy, a draft for agricultural strategy, and the National plan for water were formulated in cooperation with the World Bank.

9.2.7 Environmental Education and Awareness for Combating and Control of Desertification:

A number of relevant research articles have been published in the agricultural, environment and development magazines by researchers and academies. Brochures and pamphlets have been printed and distributed by the Ministry of Agriculture on subjects like combating desertification, sand dunes fixation, the international day for combating desertification, deteriorating rangelands in the north, forestry encouraging tourism, land deterioration, tree planting weeks, afforestation of dry lands, roadside tree planting, raising some of the important plants in Al Gassim region, looking after trees etc.

Television and radio broadcasting programs have been carried out concerning desertification control and environmental conservation. Annual tree planting week, and international program called 'Do not leave a footprint' which aimed to make awareness among tourists in the natural sites. A number of directional signs erected in the forest and range areas to guide the tourists. The Kingdom has prepared and implemented a unified program to celebrate the international year for deserts and combating desertification in 2006. Seminars and workshops were hosted and stickers and postal stamp for this occasion were issued.

9.3 Socio-Economic Impacts:

In the process of desertification, biologically and economically productive land becomes less productive and less able to support the communities that depend on it. More serious impacts are expected in the rangelands which provide natural grazing for animals of rural communities especially the nomads such as sheep and camels in all regions of the Kingdom. These negative impacts include degradation of soil organic and nutrients contents, deterioration of soil structure and salinity built up. They become more dry and susceptible to wind erosion, especially with lower vegetation cover. This could ultimately generate "dust bowl" conditions in some areas. The hazard of water erosion would also be made worse by any accompanying increase in runoff intensity. The expected decrease in precipitation or increase in evaporation will cause increased saline conditions. The reduction in surface moisture or vegetative cover would increase temperatures and reduce rainfall as less energy is used in evapo-transpiration and less water is recycled.

Desertification is likely to become irreversible if the environment becomes drier and the soil becomes further degraded through erosion and compaction. Lower precipitation combined with increased evaporation would directly reduce runoff and ground water levels. Poorer infiltration due to soil degradation would reduce aquifer recharge, while reservoirs could be seriously affected by an increase in sedimentation due to erosion. Many valuable ecosystems could be lost as species fail to survive with the shift in climate boundaries.

The possible climate change is likely to both reduce the productivity of rangelands and change the areas amenable to livestock production. Rangelands sustain a large number of people in the Kingdom through their support for livestock and forage crops. The most serious impacts on livestock production would be in the northern, southern and central parts of Saudi Arabia, where the rangelands are already under pressure from land use changes and population growth. The livestock production would suffer due to deterioration in the quality of rangeland associated with deterioration of natural plants and soil conditions in high vulnerable areas for desertification. Substitution of the natural grazing lands for supporting the cattle in different regions of the Kingdom by cropped forage will be difficult due to the expected reduction in water supply sources. Import and supply of forage crops to nomads and rural communities will not be viable economically.

The above impacts with the expected deterioration of soil and water conditions, wild plants, grazing lands, crop yield, water supplies, rainfall, surface runoff and aquifer recharge will be having serious impacts on the social and structure and economic survival in rural areas. The welfare of these communities will be seriously threatened. Consequently the sustainability of economic development and the social structure in rural areas will be under serious challenges. Serious social impacts could occur as millions will be forced out from their homelands as a result of desertification, poor harvests and water supply stresses. National economy would be adversely affected not only by the direct impacts of climate change, but also through the cost of adaptive measures and the knock-on implications of changes elsewhere.

9.4 Conclusions and Recommendations:

Most of Saudi Arabia has sensitive ecosystem for any level of climate change impacts especially on surface and groundwater resources and desertification processes. Assessment of these impacts indicated clearly that most regions have high vulnerability levels for climate change impacts on desertification processes and water resources. The climate change impacts as represented by temperature increase would elevate the levels of reference evapo-transpiration by about 1-4.5% at 1ºC increase, and by about 6-19.5% at 5ºC increase in most regions. The agriculture water demand would rise by about 602 and 3,122 MCM at 1ºC and 5ºC increases in temperature respectively. The resulting expected yield losses of different types of field crops (including cereals, vegetables and forage crops) and fruit trees (including date palms) will range between 5% - > 25%.

The value of these losses represent more than the actual profit for farmers from agricultural activities in different regions of the Kingdom. This represents a serious challenge to survival of the agriculture sector as a major economic sector in the national economy. Compensation of the crop losses through import from foreign countries represent additional burden on the economy. Furthermore, the agricultural activities support about 25% of the national population who still live in rural areas. The deterioration of agriculture sector represents a threat to the social structure and welfare of rural communities. The natural plants in range lands and the cultivated crops will suffer from water shortages as low annual rainfall in the majority of the regions can not compensate for the elevated plant water requirements.

Additionally, the top soil in range lands and in irrigated areas will suffer from salinization increasing salinity levels by approximately 2.8 times the original salinity levels. Hence, the flora in all regions will be under increasing vulnerability for disease out breaks, retarded growth and collapse. Vegetation cover will be reduced and lands will be more exposed for erosion and desertification. These problems are expected to aggravate due to expected reduction in water supplies from local aquifers because of reduced aquifer recharge and surface runoff. The total annual reduction in recharge and surface runoff will be about 241 MCM and 1,435 MCM at 1ºC and 5ºC increases in temperature respectively.

The above findings of the climate change impacts on desertification and water resources have been carried out within the limited time, financial and data resources. Further investigations are required to assess these impacts to confirm the present findings, to cover the missing parts and to relate the assessment of the Kingdom with regional and international conclusions and predictions. This will help in developing better and more effective plans to combat climate change impacts and to protect the Kingdom from desertification and to achieve sustainability of water resources and socio-economic developments. These future investigations are summarized below:

- The impacts of climate change on possible increase in reference evapo-transpiration using data from all meteorological stations in different parts of the Kingdom.
- The impacts of climate change on possible decrease in surface runoff in different parts of the Kingdom using more detailed data and local hydrological information in different regions of the Kingdom.
- The impacts of climate change on possible decrease in aquifer recharge using more detailed

hydro-geological data about the local aquifers in different regions of the Kingdom.

- The impacts of salinity increase in the top soils in different regions of the Kingdom using more detailed and measured data about the salinity levels of soils on the soil productivity.
- The impacts of increase in salinity level on the yield of cropped areas using more detailed information about the soils, cultivated crop types and areas and water in different regions.
- The impacts of salinity levels and evapo-transpiration increase on natural vegetation using more data about vegetation in different regions.
- Assessment of irrigation water use and yield losses on socio-economic aspects using more economic data about the value of agricultural crops.
- Assessment of water use stress on natural vegetation in more detailed approach.
- Assessment of socio-economic impacts in different regions using more data about the range lands in different regions.
- Assessment of socio-economic impacts using more detailed data about the values of forage losses in natural rangelands and their replacement by imported forage.
- The socio-economic impacts due to possible collapse of the social fabric and ecosystems in different regions of the Kingdom.
- Assessment of socio-economic impacts of water supplies for domestic and industrial sectors using more detailed information about domestic and industrial water supplies and their related costs in urban and rural areas.
- Assessment of socio-economic impacts using more detailed data about the value of economic developments in rural and urban areas.
- The design of monitoring and early warning systems which should be developed to avoid consequences on recharge, runoff, soils and plants.
- It is also recommended to investigate the possible impacts of micro-climate changes in all regions of the Kingdom and to relate the climate change impacts in the Kingdom with the regional and international impacts.
- The impacts of possible rise in sea water level on the ecosystems and desertification hazards in coastal belts of the Kingdom.
- The required measures to combat the impacts of climate change on the water and desertification in the Kingdom on local and international levels.

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SECTION - 10

Vulnerability, Assessment and Adaptation of Biodiversity to the Impacts of Climate Change in the Kingdom of Saudi Arabia

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10.1 Introduction:

According to the Intergovernmental Panel on Climate Change (IPCC) Working Group I (WGI) Fourth Assessment Report from 1850 to 2005, the average global temperature increased by about 0.76ºC and global mean sea level rose by 12 to 22 cm during the last century. The report also projected a further increase in temperatures of 1.4ºC to 5.8ºC by 2100. Predicted impacts associated with such temperature increase include: a further rise in global mean sea level, changes in precipitation patterns and more people at risk from dangerous "vector-borne diseases" such as malaria.

The global biota has been affected by fluctuating Pleistocene (last 1.8 million years) temperature, precipitation and has coped through evolutionary changes, and the adoption of natural adaptive strategies. Such climate changes, however, occurred over an extended period of time in a landscape that was not as fragmented as it is today and with little or no additional pressures from human activities. Habitat fragmentation has confined many species to relatively small areas within their previous ranges, resulting in reduced genetic variability. Warming beyond the ceiling of temperatures reached during the Pleistocene will stress ecosystems and their biodiversity far beyond the levels imposed by the global climatic change that occurred in the recent evolutionary past.

Human activities have already resulted in the loss of biodiversity and thus may have affected goods and services crucial for human well-being. The rate and magnitude of climate change has and will continue to affect biodiversity either directly or in combination with other drivers of change.

There is ample evidence that climate change affects biodiversity. According to the Millennium Ecosystem Assessment, climate change is likely to become one of the most significant drivers of biodiversity loss by the end of the century. Climate change is already forcing biodiversity to adapt either through shifting habitat, changing life cycles, or the development of new physical traits.

Figure 10.1 Geographical areas of Saudi Arabia

Conserving natural terrestrial, freshwater and marine ecosystems and restoring degraded ecosystems (including their genetic and species diversity) is essential for the overall goals of both the Convention on Biological Diversity and the United Nations Framework Convention on Climate Change because ecosystems play a key role in the global carbon cycle and in adapting to climate change, while also providing a wide range of ecosystem services that are essential for human well-being and the achievement of the Millennium Development Goals. Biodiversity can support efforts to reduce the negative effects of climate change.

The vast landscape of Saudi Arabia is composed of a variety of habitats such as mountains, Valleys (Wadis), sandy and rocky deserts, meadows (Raudhahs), salt pans (Sabkhahs) and lava areas (Harrats), etc. In a broad geographical sense, Saudi Arabia can be divided into two distinct zones; the rain fed highlands of the western and southwestern regions and the vast arid and extra arid lands of the interior with extremely low rainfall. The following map (Figure 10.1) shows geographical areas of Saudi Arabia namely deserts, hills and mountains as well as marine bodies of Red sea and Arabian Gulf on the west and east respectively.

The location of Saudi Arabia is in a climatic transition zone which comes under the influence of both tropical and temperate climates. Rainfall over Saudi Arabia is highly variable in amount and distribution. Throughout the arid parts of the interior, annual precipitation may vary from no rain at all to over 200 mm. However, there is usually some rainfall in the form of sporadic showers during winter. In the southwestern highlands, annual average rainfall is about 250 mm with as much as 1000 mm falling in some years. Winters are cool to warm (2ºC – 20ºC) while summers are very hot with temperature ranging from 35ºC – 50ºC. Humidity is high along the Red Sea and Arabian Gulf coasts but is low in the interior parts (for detailed climatological conditions, refer to chapter 6 of this report).

10.2 Climate Scenarios Analysis for Saudi Arabia:

Chapter 6 entitled Climate Change Scenarios of this report provides detailed analysis of the climate of Saudi Arabia and predicted trends of change in temperature, precipitation and humidity over various regions and grid cells of the Kingdom. These are briefly discussed and presented below. For details, refer to the above mentioned chapter.

- The spatial distribution pattern of the annual mean extreme temperature over the 2070-2100 period (Figure 6.30) shows a general and appreciable increase in temperature (ranging between 2.4 and 5.9ºC) occurring all over the country, but with a varying degree, as can be detected from Figure (6.31) which depict the spatial distribution of the annual mean extreme temperature changes after one hundred years from the baseline period.
- Lower values of this increase are to be noticed over the northwest region between Madinah and Tabuk and along the northern half of the Red sea coasts, including Jeddah. The higher values are noticeable far to the north of the country and over the eastern slopes of Asir mountain with further extension to the east (to Sharourah).
- The spatial distribution pattern of the mean annual total precipitation over the 2070-2100 period (Figure 6.32) differs, in general, from that for the 1972-2001 period, especially over the north-eastern and central regions where lower values prevail. However, no change in the pattern has occurred over the north-west province and the empty quarter (lower values) and over the south-western mountain range (higher values). As can be detected from figure 6.33, which depict the spatial distribution of the mean annual total precipitation changes after one hundred years from the baseline period, three quarter of the country (mainly central, northern and eastern regions) will suffer from excessive dryness. The increase in rainfall will be limited only to the southern (Sharourah), the southwestern territories (Jazan) and Asir mountains (Abha).
- Examination of the spatial distribution patterns of the seasonally averaged precipitation reveals

that the summer rainfall will be highest compared to other seasons over the southern, southwestern territories and Asir mountains, where current precipitation regime is characterized by two peaks (one in summer and the other stronger in spring). This finding has an important synoptic implication, particularly when compared to the spring value, as precipitation there is strongly correlated with the averaged local precipitation and the north - south movement of the "Inter Tropical Conversion Zone" (ITCZ) over those regions. Winter precipitation in these areas will remain the lowest as compared to other seasons.

- As expected and as can be seen from the spatial distribution chart (Figure 6.39), the higher mean annual RH values will be observed along the coasts with a very rapid decrease (strong gradient) towards the interior parts of the country, reaching as low as 23% over a large area extending from Madinah eastward to Riyadh and southward to cover the empty quarter. Apart from the coastal zones, high values will also remain over Asir mountains.
- Examining the spatial distribution of the mean annual RH value changes over the period 2070 – 2100 from that of the baseline period (Figure 6.40) reveals that there will be a general decrease in RH values all over the country with maximum decrease of 9.5% in the northeastern districts and minimum decrease of 2.5% in the southeastern part of the empty quarter. This is a critical finding as in a dry country like Saudi Arabia, where desert shrubs and trees etc., depend vitally on the atmospheric humidity for their survival. any appreciable changes in this parameter will damage the already fragile ecosystem of the communities.
- As for the seasonally averaged RH values, it may be noticed from the spatial distribution charts (Figure 6.41 for winter, Figure 6.42 for spring, Figure 6.43 for summer and Figure 6.44 for fall) the persistent of the strong gradient of RH iso-lines across the coasts in all seasons. Also, the averaged winter RH will continue to be generally the highest among seasons with a lowest value of 32% over the empty quarter and the northwestern region. This is in contrast to the summer distribution having as a low value as low as 10% over the northern region.

In addition, analysis of probable increase of the absolute maximum temperature for 100 years return period i.e. from 1978 to 2078 has turned out to be a very well organized pattern having the lowest values (less than 0.4ºC) over the central, mid-west and Asir regions and the higher values (more than 0.8ºC) stretching over the eastern coasts, southern and northwestern parts of the country with a maximum probable increase of 1.3ºC in Gurayyat.

It should be mentioned here that the resulted substantial increase in the extreme temperature over the northwestern zone of the country is in full agreement with, and is an extension of, the predicted excessive warming over the Mediterranean basin as resulted from many climate prediction models (Section 6). It may be noticed that the magnitude of the estimated values of the statistical approach is much less than those predicted by models. This is due to the fact that models have included some GHG emission scenario in their calculation, while the statistical method here used actual data and hence represent the "business-as- usual" scenario.

These conclusions show that there will be change in temperature, precipitation and relative humidity all over various regions of the Kingdom, all the three factors having potential to impact the biodiversity in the Kingdom.

10.3 Current Status of Biodiversity in Saudi Arabia:

Biodiversity is often described at three basic levels of biological integrations, such as genetic diversity, species diversity and ecological diversity. The natural resources, particularly the wild plants are widely regarded as a vital component of the world's biological diversity and an important resource for the planet.

In Saudi Arabia, biodiversity of the terrestrial, freshwater and marine ecosystems are critical as there is no river ecosystem in the country. Biodiversity is determined by the interaction of many factors that differ spatially and temporally. It is determined for example by: (a) the mean climate and climate variability; (b) the availability of resources and overall productivity of a site; (c) the disturbance regime; (d) the original stock of biodiversity; (e) spatial heterogeneity of habitats; (f) the intensity and interdependency of biotic interactions, such as competition predation, mutualism and symbiosis; (g) the intensity and kind of sexual reproduction.

Terrestrial, marine and freshwater biodiversity in Saudi Arabia is discussed below in details.

10.3.1 Terrestrial Biodiversity:

Saudi Arabia is approximately 1,969,000 square kilometers occupying 2/3 of the Arabian Peninsula and extends from 32 12'N latitude on the Jordanian border in the north to 16 00'N latitude at the Yemeni border in the south. It is bounded by the Red Sea in the west at 32 36'E longitude and the Arabian Gulf in the east at 56 00'E longitude.

Western Saudi Arabia is dominated by a mountain chain running the entire length of the country, known as the scarp of the Hejaz and Asir mountains and overlooks the fertile Tihama coastal plains to its west. It runs parallel to the Red Sea and rises to between 1,300-3,000 m. above sea level. This fertile crest falls towards the east as a desert plateau to the dry interior, or the Najd, containing the great sand deserts of the empty quarter, Nafud and Dahna. The eastern region lies on the Arabian Gulf coast and contains salt flats.

Saudi Arabia enjoys a distinguished bio-geographical location. It includes portions of two out of the eight known global terrestrial realms; namely the Palearctic and the Afrotropical. It is thus an area of great ecological significance. Saudi Arabia divides naturally into seven terrestrial physiographic regions:

1. Tihamah coastal plain along the Red Sea
2. Western Highlands
3. Arabian Hinterland
4. The Cuesta Region (Sedimentary Najd)
5. Aeolian Sands
6. As-Summan and Widyan Plateaus
7. Arabian Gulf Coastal Region

10.3.1.1 Status of Terrestrial Flora:

The diversity of plant life is a vital component of Saudi Arabia's terrestrial ecosystems which plays a key role in maintaining region's environmental balance and stability. It also helps in the protection of watersheds, stabilization of slopes, improvement of soils, moderation of climate and the provision of a habitat for much of Kingdom's wild fauna. Plants also fulfill the basic needs required for man such as food, clothing, fuel, shelter and medicine. Saudi Arabia contains one of the diverse floras of this region. In addition to the endemic plants, the influences of the surrounding floristic regions can be seen in many parts of the plant diversity hotspots.

Saudi Arabia is generally an arid country with a few exceptional sub-humid regions on the southwestern escarpments and is divided into three distinctive geological units: the Saharo-Sindian, Somali-Masur and Afro-Montane. The vegetation of the Saharo-Sindian region is sparse and about 60% of the vegetation, mainly in the low lying areas, is represented by annuals of which population density varies from year to year, depending on the amount of rainfall and the amount of seed deposits from previous years. The western region is rich in vegetation when compared to the central and eastern region. The northwestern mountains are rugged and floristically poorer than the southwestern mountains, with affinities to the Mediterranean and North African floristic regions. However, the entire southwestern region is the richest in terms of species diversity and contains the highest concentration of endemism, despite the fact that these high altitude areas are heavily populated with human settlements dating to ancient times.

The 2250 species of flora in Saudi Arabia belong to 132 families and 837 genera. About 105 species inhabit sand dunes, 90 are halophytes, 75 are trees and 12 are aquatic plants. Out of these species 40 are considered endemic, the influence of the floras of neighboring countries, particularly Yemen and Oman, is high on the flora of Saudi Arabia. About 20% of the flora, that include the rare and endemic species, are present in small populations in their respective niches.

Figure 10.2 Vegetation, Terrace Farming and Developmental Activities in Southwest Highlands of Saudi Arabia

10.3.1.2 Status of Terrestrial Fauna:

Mammals:

A checklist of 98 species of mammals has been recorded from the Arabian peninsula. Of these, 76 species occur in Saudi Arabia. Large mammals usually provide a good indication of the status of the other fauna and indeed the whole ecosystem. If their numbers are satisfactory this is likely to be true for all other vertebrates and invertebrates, and if the large mammals are under stress this is a good indicator that the situation of other plants and animals is not well.

The Arabian oryx, Oryx leucoryx, was plentiful throughout Arabia in the 1800's, but its numbers continued to decrease in the 1900's until it became extinct in the wild in the 1970's. Fortunately, some animals were kept in captivity and the captive-bred populations and a successful reintroduction program helped its return back to the wild. It is doing well in some nature reserves.

The two Gazelles species, the reem and idmi were reported as widespread and common in the 1930's. Heavy gazelle mortality was reported in the Hijaz in the early 1960's. The Nubian ibex survives at low densities in most of its historical range, and the caracal, wolf and hyena persist in low populations. The lion was the first large mammal species known to have become extinct from the Arabian Peninsula in the early 1900's. The cheetah is probably extinct with the last authentic records from the 1950's.

Several wild mammal species pose commensalism problems for residents in the areas which they intrude, among them the red foxes, Vulpes and the sacred baboons.

FIG. 10.3 EPAULE FRUIT BAT

FIG. 10.4 HAMADRYAS BABOON

FIG. 10.5 RUPPEL'S FOX

FIG. 10.6 REEM (SAND) GAZELLE

FIG. 10.7 ARABIAN LEOPARD

FIG. 10.8 ARABIAN ORYX

Birds:

About 444 bird species have been recorded in Saudi Arabia, of which about 185 species are known to breed in the Kingdom. Of the breeding species, 45 are believed to be of Ethiopian origin, 30 of Asiatic origin with the remainder Palearctic. The Kingdom has 10 endemic species of birds.

FIG. 10.9 HOUBARA BUSTARD

IG. 10.10 SHORT-EARED OWL

FIG. 10.11 COMMON QUAIL

FIG. 10.12 LAPPET FACED VULTURE

FIG. 10.13 ARABIAN BUSTARD

FIG. 10.14 ARABIAN MAGPIE

Palearctic - Philby's rock partridge Arabian red-legged partridge South Arabian wheatear Yemen linnet. Of the Indo-Malaysian species, the Arabian woodpecker, and of Afrotropical origin: Yemen thrush, Yemen warbler, Arabian waxbill, Arabian serin and Yemen serin. Although most of the birds of Saudi Arabia have affinities with neighboring countries, it is most likely that at least five species originated in Arabia. These are the Arabian (Blandford's) warbler blanfordi, shining (Abyssinian) sunbird, white-breasted white eye, Ruppell's weaver and golden-winged grosbeak. The bird life of Saudi Arabia has not been fully explored. It is likely that new species will colonize Saudi Arabia from those coming through the strait of Hormuz between Oman and Iran, which is only 60 km wide, with islands reducing the distance by half, and the strait at Bab Al-Mandab between Yemen and Africa which does not exceed 29 km in width. This makes it easy for those species to come across. The Arabian Peninsula is functionally very significant for migrating birds from Asia, Europe and Africa.

The information on the status of the houbara bustard as a resident breeding bird needs more documentation. The Arabian bustard is a rare species in Saudi Arabia. Both bustard species are under serious threat from uncontrolled hunting and habitat loss. There are also a number of species which have been introduced to Saudi Arabia that have established free ranging populations in rural and urban areas such as the ring-necked parakeet and house crow.

Amphibians and Reptiles:

All of Saudi Arabia's 7 native amphibian species are restricted to freshwater seeps and ephemeral pools. They are the Tihamah toad, Dhofar toad, green toad, Arabian toad, Savigny's tree frog, Arabian water frog and Arabian skittering frog.

There are 45 species of terrestrial snakes in Saudi Arabia, of which 23 species are poisonous and 10 species of sea snakes, all of which are poisonous. Because of the desert nature of the country, none of the terrestrial snakes are found in great numbers. Some species may have localized abundance. There are 67 known species of lizards in Saudi Arabia. The small-scaled dhubb is under pressure from hunting for its flesh.

Insects:

There are no complete studies on the insect species of Saudi Arabia. Zoological analysis of Arabian and

Middle Eastern butterflies reveals species with Palearctic, Afrotropical and oriental affinities. Eight (8) endemic species are recorded in the Asir region and 23 sub-species in the Hijaz, Central Arabia, Eastern Arabia and Asir regions.

10.3.2 Marine Biodiversity:

Saudi Arabia has about 1,850 km of coastline along the Red Sea and about 650 km of coastline along the Arabian Gulf. Red Sea is one of the deepest regional seas in the world reaching 2,500 meters in depth with an average of 500 meters. It is about 1,930 km long and relatively narrow averaging about 280 km in width. It is a critical link between the Indian Ocean and the Mediterranean Sea. The entrance of the Red Sea at the Bab Al-Mandab Straits is 29 km wide and opens into the Indian Ocean. The continental shelf, the shallow coastal area is only about 100 meters deep, is narrow in the north and widens considerably in the south where it is over 100 km wide.

The Arabian Gulf is an extremely shallow and almost land-locked sea that is 1,000 km long and 230-250 km wide and is roughly rectangular in shape. The entrance from the Gulf of Oman at the Strait of Hormuz is 60 km wide. The Gulf is shallow with an average depth of 35 meters and a maximum depth of 100 meters on the Iranian side. 18% of the area of the Gulf is less than 5 m deep. There is no continental shelf.

Both the Red Sea and Arabian Gulf play a principal role in the development of Saudi Arabia. This is largely due to their importance in petroleum exploration, production and transport, in addition to the development of an urban, commercial, and industrial base directly and indirectly connected with petroleum production and marketing.

Waters of both seas provide the Kingdom with desalinated fresh water. The fisheries represent another renewable resource of direct economic benefit to national development. The coastal environment is of recreational value. Their water is rich in species of reef forming corals with varying shapes and colours. In addition to colorful and exotically shaped fish such as the butterfly fish, angelfish and parrotfish, that inhabits the seas and reef of Saudi Arabia and is an underwater paradise for the naturalist, divers and photographers.

10.3.2.1 Status of Marine Flora:

Inter-Tidal Habitats:

Salt marshes:

These elements of coastal wetland communities are poorly developed because of the scarcity of fresh water. Despite this scarcity they produced organic matter that is a source of food for many species.

Three principal vegetation types are recognized in these salt marshes:

- Palm groves and fresh water reed swamps
- Halophytic communities associated with periodic inundation by sea water, and
- Salt pans or sabkhas that are widespread and characterized by sparse halophytes and an algal/microbial mat.

Mangroves:

Mangroves are widely scattered along the Red Sea coast. The mangroves are most intensive in the south where they benefit from greater valley (wadi) discharges and a more protected coastline. In the Arabian Gulf, mangroves are less widespread, less developed structurally and are under much greater threat from physical developments.

There are two species of mangroves in Saudi Arabia, Avicennia marina (Shora or Gorm) is the most common and Rhizophora mucronata (Gindel), which is found in only eleven sites on the Red Sea coast.

Broad Inter-Tidal Flats and Sandy/Rocky Beaches:

This third biotope is important for turtle nesting, fishing and recreational activities.

Sub-Tidal Habitats:

Sub-tidal habitats are of importance because they generate much of the energy in the coastal ecosystems from relatively small areas. It includes;

Sand and Mud Flats:

Sand and mud flats are widely distributed, especially in the Gulf covering about 95% of the sub-tidal zone. Algae and invertebrates, account for the greatest biomass in these large areas of relatively low productivity. Shrimp harvests are an important economic activity.

Seagrass Beds:

Seagrass beds look like underwater meadows and are among the most productive of the global ecosystems. Eleven species of all the seven known genera of seagrass occur in the Red Sea. There are three species in the Arabian Gulf.

Sea grasses have a fundamental role in primary production and the maintenance of fisheries. Many important species of fish shelter, feed and breed in the sea grasses. Beds of sea grass are also important for stabilizing the coasts and preventing them from being washed out. They are the natural habitat for the endangered dugong and green turtle.

Algal Flats:

Algal flats are found in shallow waters in large bays along the Arabian Gulf coast and often occur in association with sea grass beds. These habitats are very productive and at the same time most susceptible to oil pollution.

10.3.2.2 Status of Marine Fauna:

Fish:

Over 1280 species of fish have been recorded in the Red Sea and 542 species in the Arabian Gulf. Artisanal fishing is an important socio-economic occupation and 180 species have been recorded in the fish markets of the Red Sea and 110 species in the markets of the Arabian Gulf.

Among the saltwater fish, najil, hamour and roving are of special economic importance and under pressure from overfishing. Sharks in general are threatened by the Asian shark fin market, while the humphead wrasse and bumphead parrotfish are common targets of spear fishing because of their size. The butterfly fishes are vulnerable to over harvesting from the growing trade in ornamental fish.

Molluscs and Crustaceans (other than shrimps):

The Gulf had an important traditional pearl fishing industry that has been in decline since the 1930’s. Small quantities of clam, squid and octopus are caught and sold along the Red Sea coast. Three species of lobster are known from the Red Sea as well as two species of crabs that are sold in small quantities in local markets.

Birds:

The Red Sea and Arabian Gulf coasts and their associated islands are globally important areas for birds whether they are Palearctic migrants, winter residents or resident breeding species. The tidal flats of the Arabian Gulf are considered among the worlds most important over-wintering areas. They are home to 1-2 million waders of 125 species. In addition, the Gulf is an important stop-over for millions of passage migrants of which 113 species have been recorded. The sooty falcon is a breeding summer visitor on marine islands in both the Red Sea and the Gulf.

Marine Turtles:

There are 5 species of marine turtles in Saudi Arabian waters. They are; green turtle (Red Sea/Gulf), hawksbill turtle (Red Sea/Gulf), loggerhead turtle (Red Sea/Gulf), olive ridley turtle (Red Sea), leatherback turtle (Red Sea). Both the green and hawksbill turtle occur naturally in high numbers although they are regarded as endangered internationally. The hawksbill is associated with coral formations whereas the green turtle is associated with sea grass beds.

Marine Mammals:

Dugong Dugong dugon occurs naturally in high numbers in Saudi Arabian waters that are one of the two most important areas in the world for this internationally threatened species.
There are seven Dolphin species in Saudi Arabia. The common species of dolphins are the rough-toothed Dolphin Delphinus steno common Dolphin Delphinus delphis, striped Dolphin, plumbeous Dolphin Sousa chinensis, Risso's Dolphin, spotted Stenella attenuata, and bottlenosed dolphins. In addition, the finless Dolphin porpoise is found in the Gulf.

Ten species of whales are reported to occur in Saudi Arabian waters two of which are Bryde's whale and the humpback whale. Recently, Mink Whale has been reported in the Red Sea.

Coral Reefs:

Coral reefs are the most widespread biotope on the Red Sea coast. Reef development and species diversity peak in the central region where there are over 150 species of corals off Yanbu, compared with 30 in the Gulf of Aqaba and less than 10 in the southern most reefs. In the Red Sea, 450 species of fish are commonly associated with coral reefs. The corals are famous for their beauty and 250 species of Red Sea corals have been recorded. Coral reefs are less extensive in the Arabian Gulf where they occur around the six offshore islands and in numerous patches between As-Saffaniyah and Ras Tannourah. Coral reefs provide shelter and food for marine life, particularly economically important fish such as groupers and emperor bream.

10.3.3 Freshwater Biodiversity:

The scarcity of freshwater continues to be a major limiting factor to human development and natural biodiversity in Saudi Arabia. Freshwater resources in Saudi Arabia are few and include:

- Natural sources of water such as springs, seasonal streams, pools, wetlands and marshes around which human populations lived.

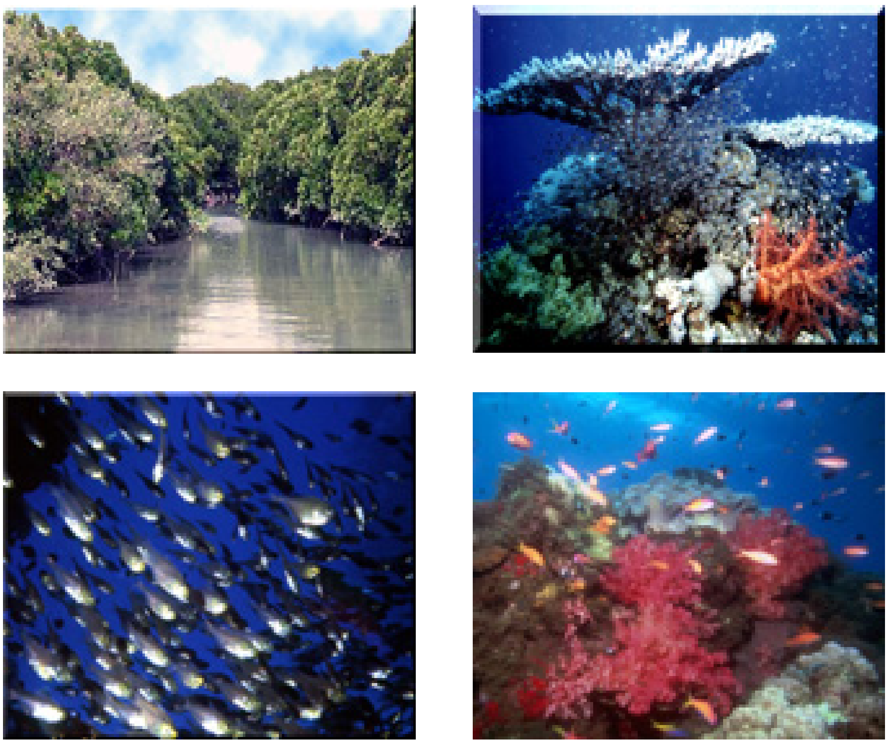

Figure 10.15 Marine Fauna and Flora

- Artificial sources of water; such as wells (of which there are 91,916 private and 5,345 Government wells), dams (about 190), irrigation canals fed by water pumped from deep underground aquifers to supply agricultural irrigation projects and expanding human demands, agricultural drainages and treated effluent outflows.
- There are 30 desalination plants producing 2.8 million m3 of water per day.

Saudi Arabia is the world's highest producer of desalinated water accounting for one third of world production. It is estimated that Saudi Arabia's water demand increased from 2.3 million cubic meters in 1980 to 30 million cubic meters in 2000 due to an accelerated growth in population and vast development in the industrial, agricultural and urban sectors.

10.3.3.1 Status of Freshwater Flora:

Wherever water is naturally available or artificially supplied, the flora flourishes. In distant oases the natural flora can still be found relatively intact, however in areas around the cities and towns a number of introduced flora have established themselves to the detriment of local flora.

Figure 10.16 Freshwater Flora

10.3.3.2 Status of Freshwater Fauna:

Perhaps the most obvious, and certainly the most vulnerable of the key biological sites in the arid landscapes of Saudi Arabia are the natural freshwater wetlands that include ponds, streams and springs as well as artificial wetlands such as reservoirs and effluent streams outside urban areas and agricultural developments. These freshwater wetlands attract and support a diverse assemblage of plants and animals and are important centers of endemism. The distribution of freshwater fish in Saudi Arabia is related to the availability of freshwater dispersal routes. Indigenous species of freshwater fish, of which there are a number in the western mountains, are represented by three genera. The Cyprinian are of Asiatic origin, the Garr of European origin, while the Barbus complex is of an European and afro-Indian origin. Interestingly there is not a single species of freshwater fish common to the eastern and western drainages of the Asir.

All of Saudi Arabia's endemic freshwater fish species have been listed as key species, in view of their rareness, vulnerability and very limited habitats. Acathobrama hadiahensis is known from only one location in Wadi Hadiya in the northern Hijaz, while Barbus apoensis has a very restricted range and is increasingly harvested for food.

10.4 Factors Impacting Biodiversity:

In addition to the climatic factors such as wind pattern, temperature, rainfall and humidity, the potential causes responsible for the deterioration of terrestrial, marine and freshwater biodiversity in Saudi Arabia could be summarized as below:

- Degradation of rangelands
- Uncontrolled cutting of trees and shrubs
- Modern agricultural practices

- Loss of agriculture terraces
- Accelerated developmental programs
- Overgrazing
- Over-hunting
- Over-gathering
- Urban Development
- Land reclamation
- Deforestation
- Dredging and Filling
- Over fishing
- Loss of habitats
- Oil spill
- Solid waste disposal
- Air and water Pollution
- Indiscriminate use of pesticides and fertilizers
- Periodic drought and Desertification

The vulnerability and adaptive capacity of plants and animal communities and their ecosystems to climate change and the possible potential consequences of climate change and the role of various stakeholders and institutional and legal framework in place in the Kingdom are assessed in this report. This report is part of the Second National Communication of Saudi Arabia and the overall goal of this section of the report is to meet Saudi Arabia's obligations under UNFCCC and to set priority actions against global climate change and to integrate climate change concerns into other development plans through making a comprehensive and integrated assessment of impacts, vulnerability and adaptation to climate change.

10.5 Impacts of Climate Change on Biodiversity:

This section will describe the potential impacts of climate change on the various ecosystems in Saudi Arabia.

According to the IPCC AR4, deserts are likely to experience more episodic climate events and inter-annual variability may increase in future, though there is substantial disagreement between projections and across different regions. Continental deserts are likely to experience more severe and persistent droughts. Reduced biomass in deserts is likely to increase the fragility of soils and their vulnerability to erosion. Many desert species are vulnerable to increases in temperature and alteration of the rainfall regime. This will put at risk species that depend on rainfall events to initiate breeding.

Modeling studies suggests that desert systems and their biodiversity are likely to be severely affected by climate change (Wu et al. 2007).

Water is the main limiting resource in arid ecosystems. Desert life is determined in part by the patterns of water availability, e.g. pulses of abundance and adaptation to drought (GEO 2006). Consequently, changes in global or regional precipitation systems could severely affect these ecosystems (Brown, Valen and Curtin 1997). A higher incidence of drought may increase loss of bioproductivity, biodiversity and lead to erosion and deflation leading to desertification (Le Houéro 1996; GEO 2006). Increasing future temperatures may increase evapo-transpiration, which in combination with lower rainfall projected in some arid areas may decrease vegetation cover (GEO 2006). Changes in productivity may also feedback changes in runoff, precipitation regimes and circulation (Lioubimtseva et al. 2004) as modeling suggests vegetation in arid ecosystems is important in the energy, moisture and carbon exchange and the atmosphere (Wang and Eltahir 2000).

A three-year study conducted on desert plants in northern Oman shows that many aspects of these plants phenology (onset of growth, flowering, fruiting) are associated with rainfall (Gazanfar 1997). Changes in temperature extremes may also be important in characterizing differences in phenology between different sites (Elser and Rundel 1999). Changes in rainfall and temperature may therefore have an impact on desert phenology though there is a lack of literature in this area.

Changes to the composition, structure and function of deserts and arid regions have consequences depending on changes that may occur. Desertification leads to land degradation, loss of biodiversity and erosion which ultimately leads to loss of ecosystem services (GEO2006). Increasing aridity and wind speed due to climate change may increase dust emissions from deserts. Although dust from deserts has some positive effect on the productivity of land and oceans, it can also be negative on some ecosystems and human health (GEO 2006). Deserts are not a large carbon sink (GEO 2006). However, if some areas are subject to increased precipitation, changes in vegetation cover may increase carbon sequestration in these areas (Lioubimtseva and Adams 2004).

10.6 Stakeholders:

Several public sector ministries, institutions and departments, committees, associations, societies, private sector entities and non-government organizations (NGOs) play important role in the adaptation, conservation and developmental activities of biodiversity in the Kingdom of Saudi Arabia, which are listed below.

10.6.1 Institutions and Governmental bodies concerned with Conservation of Biodiversity:

Several government organizations are involved in conserving biodiversity in the Kingdom of Saudi Arabia each within their areas of interest.

- Ministry of Defense and Aviation (Military Survey)
- Ministry of Municipalities and Rural Affairs
- Ministry of Interior
- National Commission for Wildlife Conservation and Development
- General Presidency for Meteorological and Environmental Protection
- Ministry of Agriculture
- Ministry of Higher Education (Saudi Universities)
- Ministry of Economics and Planning
- Ministry of Water
- King Abdulaziz City for Science and Technology
- Food and Medicine Commission
- Higher Commission for Tourism and Antiquities
- High Commission of Riyadh Development
- Regional Governorates

In addition, Environmental Council established by the Decision of the Council of Ministers No. 22 dated 29 Muharram 1430 H corresponding to 26 January 2009 under the chairmanship of HRH Prince Turki Bin Nasser Bin Abdulaziz, President of the Presidency of Meteorology and Environment (PME). Environment Council, composed of the concerned sector ministries namely Ministries of: Interior, Foreign Affairs, Finance, Transportation, Health, Agriculture, Municipal and Rural Affairs, Trade and Industry, Water and Electricity, Petroleum and Mineral Resources, Economy and Planning, Culture and Information, King Abdulaziz City for Science and Technology, Saudi Wildlife Commission, Higher Commission for Tourism and Antiquities, is the highest institutional and decision making authority on environmental issues in the Kingdom.

Specialized Research Centers are affiliated to some of these government bodies which are as follows.

10.6.2 Centers affiliated to the National Commission for Wildlife Conservation and Development:

- National Wildlife Research Center (Taif)
- King Khaled Wildlife Research Center (Thumamah)

- Prince Mohammad Al-Sudairy Gazelles Research Center (Qassim)
- Training Center for Conservation of Natural Resources

10.6.3 Centers affiliated to the Ministry of Agriculture:

- National Center for Agricultural Research (Riyadh)
- Range and Animal Wealth Research Center (Al-Jouf)
- Agricultural Research Center (Jazan)
- Horticultural Research Center (Najran)
- Palm-Grove and Dates Research Center (Al-Hassa)

10.6.4 Centers affiliated to the Presidency for Meteorology and Environmental Protection:

- National Center for Meteorology and Environment

10.6.5 Research Centers affiliated to Saudi Universities:

- Prince Sultan Research Center for the Environment, Water and the Desert – King Saud University.
- Research Center – King Fahd University for Petroleum and Minerals
- Water Research Center – King Abdulaziz University
- Prince Sultan Center for Environmental and Touristic Studies – King Khaled University

10.6.6 Centers affiliated to King Abdulaziz City for Science and Technology:

- Natural Resources and Environmental Research Center

10.6.7 Private Entities and Individuals:

- Private reserved areas
- Traditional "Himas"
- Pastoralists
- Fishermen
- Farmers
- Visitors and Tourists

10.6.8 Non-Government Organizations:

- Saudi Biological Society (SBS)
- Saudi Environmental Society (SES)
- Jeddah Ornithology Group (JOG)
- Saudi Diving and Water Sport Club (SDWSC)
- Society of Advocates and Volunteers for Environment (SAVE)
- Saudi Wildlife Fund

10.7 Adaptation Measures:

Based on the above mentioned stresses and factors impacting biodiversity, adaptation measures could be grouped into the following.

- Legal and institutional measures
- Conservation and sustainable use practices
- Strengthening monitoring and evaluation systems
- Strengthening environmental education and awareness at all levels

10.7.1 Legal and Institutional Measures:

Protection of environment and human health, sustainable use of natural resources and conservation of biodiversity are the fundamentals of Saudi Arabia's Basic System of Governance.

The Government of Saudi Arabia issued a number of acts and regulations dealing with environmental protection, conservation and sustainable use of natural resources and to protect public health. Various specialized government agencies are responsible for their implementation.

In spite of the rapid socio-economic, industrial and agricultural development and population increase, the Kingdom has ensured environmental protection and conservation and development of natural resources through the five year development plans. The five year developmental plans take into consideration environmental protection at the feasibility stage. Article 32 of the Kingdom's Basic System of Governance ascertained that the Kingdom should conserve, protect and develop the environment and prevent pollution.

The five year development planning in Saudi Arabia started in 1390 H. These development plans focused on interrelationship between environment and development and the ideal way to use the natural resources without causing fundamental changes in the environment while conserve biodiversity. In the consecutive five year development plans, the general targets of the environment concerned sectors were translated into programs and projects aiming to environment and wildlife protection

In addition to strategic targets and principles contained in these plans which emphasize environment and wildlife protection and how to avoid negative impacts of the rapid development in the Kingdom and ensure environment friendly development. This is accomplished through execution of the development plans concurrently with conserving the natural resources as a means of limiting environmental degradation. The five year development plans have identified the concerned agencies and their roles in protection of environment and conservation of biodiversity. Every one of these plans witnessed the statement of strategies suitable for each agency.

Saudi Arabia has a diversified, highly specialized flora and fauna, but misuse of its natural ecosystems is a serious economic and social threat. Rainfall is limited in most parts of the country and is erratic both spatially and temporally. Soil erosion by water and wind, salinization of soils, deterioration of the natural vegetation of rangelands and forests and sand encroachment contribute to ecosystem and biodiversity degradation.

Practicing conservation and implementing protection of both plants and animals and natural habitats in Saudi Arabia had come into three periodical stages: first during and before the fifties (1950), where emphasis was with traditional and Islamic Sharia' system developed over centuries known as Hima. Secondly the transitional period from old traditional practicing to setting up governmental policies and laws of conservation and protection during sixties and seventies (1960 – 1970s), where Saudi Arabia actively participated in the regional and international fora. Thirdly, the period of eighties and nineties (1980 – 1990s) to date, where emphasis is placed to implement international commitments at national level and to develop rules and regulations and strategies for the conservation and protection of natural resources and their biodiversity. National five year development plans are harmonized with ecological and environmental policies for the conservation and protection of natural habitats. Therefore, strategies of environmental impact assessments for all industrial, agricultural, commercial, and other developmental projects take biological aspects of the ecosystem into considerations (Felemban, 2001).

From a historical perspective, there have been several milestones in the development of institutions in the Kingdom of Saudi Arabia.

The Meteorology and Environmental Protection Administration (MEPA), the forerunner to the current Presidency of Meteorology and Environment (PME), was established in 1981 by a Royal Decree with responsibility of environmental protection and conservation of natural resources. Another Royal Decree created the National Commission for Wildlife Conservation and Development (NCWCD) in 1986. The above Royal Decrees are among the earliest to set up institutions by the Saudi Arabian government addressing environmental, biodiversity and human well-being issues. The Kingdom of Saudi Arabia is the signatory to Convention on Biodiversity, Convention to Combat Desertification and the Ramsar Convention on Wetlands.

There are considerable efforts undertaken by many ministries and institutions to conserve biodiversity in the Kingdom. The Kingdom established a number of authorities whose efforts are related to environmental protection and conservation. While the Ministry of Agriculture (MoA) directly supervises the forest and rangeland sectors, waste agricultural lands, and domestic animal resources, the Ministry of Interior contributes in the protection efforts by implementing the protection laws, the Ministry of Water is responsible for the conservation and development of water resources, the Presidency of Meteorology and Environment (PME) is responsible for environment and its protection. The nature of work of many authorities is related directly or indirectly to trees and plantations. These include the National Commission for Wildlife Conservation and Development (NCWCD), the Ministry of Municipal and Rural Affairs, the Ministry of Transport, the Ministry of Higher Education, the Ministry of Education, King Abdul Aziz City for Science and Technology (KACST), the Supreme Commission for Tourism and others.

Establishment of Ministerial Committee on Environment in 1994 under the Chairmanship of HRH Prince Sultan Bin Abdulaziz, the Crown Prince and Minister of Defense and Aviation, Inspector General and now the Environmental Council under the Chairmanship of HRH Prince Turki Bin Nasser Bin Abdulaziz, President, Presidency of Meteorology and Environment (PME) were to ensure effective coordination among relevant sector ministries and government institutions on environmental protection and conservation issues. Environmental Council is the highest environmental policy-making body in the country. Other ministries and agencies represented in the committee are Ministries of Defense and Aviation, Interior, Petroleum and Mineral Resources, Agriculture, Water and Electricity, Trade and Commerce, Planning, Municipality and Rural Affairs, and KACST. In addition, at the local level, there are permanent committees at the governorate levels under the governor of the region to look into and deal with different local and regional environmental and biodiversity conservation issues.

The MoA supervises forests development through the Natural Resources Administration that implements different programs such as afforestation, forest improvement, sand dunes fixation, forest protection programs and inventory activities. The Administration also undertakes range development and supervision activities in addition to the Management of National Parks and Agriculture activities. The MoA cooperates with other authorities such as the Saudi Wildlife Commission and PME in caring for Mangrove Forests and the conservation of their environment which faces a multitude of pressures, pollution, tree removal, excavation and dredging and filling activities that accompany urban expansion and deteriorate the forest and marine environment.

The Council of Ministers vide decision No. 183 dated 10 May 2010 has supported the recommendations of Ministry of Agriculture vide letter No. 148628 dated 13 May 2009 asking all government sector to work and support the strategic objectives of National Forest Plan and that the ministry of Finance must make necessary budgetary allocations for National Forest Plan and a progress report should be submitted every two years to the council of ministers. PME has also proposed a 'Coastal Zone Management Plan' to control developmental plans in the coastal areas which is in final stages of approval by appropriate authorities. Establishment of Quadruplicate Committee looking after developmental project in coastal areas of Red sea and Arabian Gulf is another way to ensure environment and biodiversity friendly development. New environmental regulations were promulgated in 2001 where responsibility and obligations of each of the concerned public and private sector entities are defined.

Saudi Wildlife Commission in 2001 decided to develop a National strategy to conserve wetlands. The following sections summarize the adaptation efforts undertaken to conserve biodiversity in the Kingdom of Saudi Arabia.

10.7.2 Conservation and Sustainable Use Practices:

Conservation and sustainable use management strategies that maintain and restore biodiversity can be expected to reduce some of the negative impacts from climate change. However, there are rates and magnitude of climate change for which natural adaptation will become increasingly difficult. Options to increase the adaptive capacity of species and ecosystems in the face of accelerating climate change include:

- Reducing non-climatic stresses, such as pollution, over-exploitation, habitat loss and fragmentation and invasive alien species.
- Wider adaptation of conservation and sustainable use practices including through the strengthening of protected area networks.
- Facilitating adaptive management through strengthening monitoring and evaluation systems.

Ecosystem-based adaptation uses biodiversity and ecosystem services in an overall adaptation strategy. It includes the sustainable management, conservation and restoration of ecosystems to provide services that help people adapt to the adverse effects of climate change. Examples of ecosystem-based adaptation activities include:

- Maintenance, development and restoration of mangroves ecosystem and other coastal and marine ecosystems.
- Conservation and restoration of forests.
- Establishment of diverse agro-forestry systems to cope with increased risk from changed climatic conditions.
- Conservation of agro biodiversity (including rangeland) to provide specific gene pools for crop and livestock adaptation to climate change.

The following actions have been taken by different concerned public and private sector entities to develop and conserve biodiversity in the Kingdom of Saudi Arabia at different levels of management.

10.7.2.1 National Parks, Protectorates and Reserves:

The Kingdom of Saudi Arabia has established a policy to create and maintain a system of parks and related reserves. The purpose of this is to ensure that the scenic, natural and cultural resources of the Kingdom will be identified and given protection for the benefit and enjoyment of present and future generations.

- **National Parks:**

Table 10.1 below shows the National and Recreational Parks in the Kingdom, their areas and locations.

Table 10.1 National and Recreational Parks in the Kingdom, their Areas and Locations

Name	Area (km^2)	Location
Asir National Park	45,000	Asir province
Al Hasa National Park	450	20km from Hofuf
Saisad Natioal Park	5,100	Al Taif
Mashar National Park	30	Ha’el
Sa’ad National Park	30	110 km east of Riyadh city.
AI Sudah Park	88.3	25km northwest Abha city.
Al Dalgan Park	44	27km south-west of Abha
Al Gar'aa Park	42	4km from Dalgan Park
Al Hadaba Park	1.0	15km south-east of Abha
Tour Al Maska Park	2.7	South from Al Gar'aa
HRH Prince Sultan Park	26.8	4km from Dalgan Park
AI Shaybani Park	3.5	Near Akeer Port, Al Hasa
Huraimla National Park (Not yet declared)	(Not Known)	80 km NW of Riyadh
Baha National Park (Not yet declared)	(Not Known)	Baha region

Source: Range and Forestry Administration, Ministry of Agriculture, Riyadh, Kingdom of Saudi Arabia.

- **Protectorates:**

Table 10.2 below provides a list of wildlife protected areas, their area, year established and category. The total number of wildlife protected areas is fifteen. Raydah protectorate is part of Asir National Park.

Table 10.2 List of Wildlife Protected Areas, Their area, Year Established and Category

Name of Protected Areas	Date Established	Category	Size of Area (km^2)
Harrat Al-Harrah	1987	SNR / RUR	13,775
Al-Khunfah	1987	SNR / RUR	20,450
Mahazat as-Sayd	1988	SNR	2,141
Ibex Reserve	1988	SNR / RUR	2,369
Al-Tubayq	1989	NR	12,200
Farasan Islands	1989	SNR / SN / RUR	696
Raydah	1989	SNR	9
Umm Al-Qamari	1978	NR	1,600
`Uruq Bani Ma`arid	1994	SNR / RUR	11,980
Majami`Al-Hadb	1993	SNR / RUR	3,400
At-Taysiyah	1995	RUR	4,260
Al-Jandariyah	1995	RUR	1,160
Nafud Al-Urayq	1995	RUR	1,960
Saja Um Al-Rimth	1995	RUR	7,190
Al-Hair Wetland	1988	SNR/NR	250
Total			**83,440**

Source: National Commission for Wildlife Conservation and Development

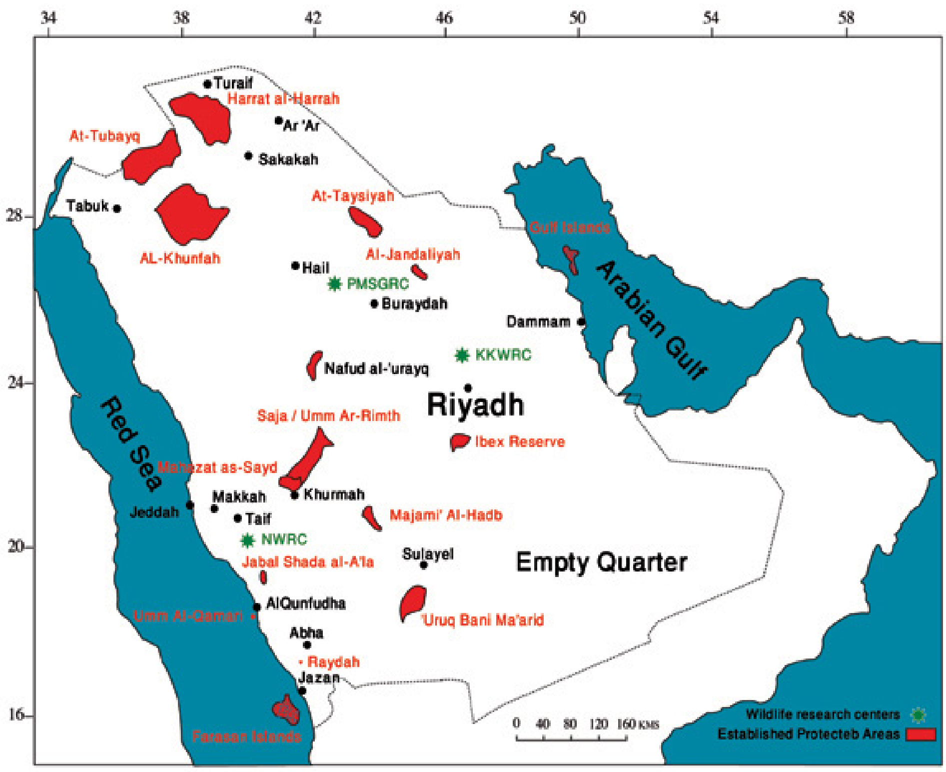

Figure 10.17 Protected Areas in the Kingdom (NCWCD, 2008)

- **Wildlife Reserves :**

The Kingdom started to establish protected areas in 1978 in order to conserve and ensure better use of renewable resources in support of sound socio-economic development. The traditional use of Himas to curb over-exploitation is originated in the Islamic culture going back to the teachings of the Prophet Mohammed (PBUH). The National Commission for Wildlife Conservation and Development (NCWCD) was established by a Royal Decree in 1986 for the purpose of directing national efforts to conserve the Kingdom's natural biodiversity. So far about 8% of the total area of the Kingdom is under protection. Further increase in protected areas has been planned to reach 10%. A system of five broad categories of protected areas was proposed based on the traditional Hima concept and with reference to the IUCN protected area categories.

The following are the Categories of Protected Areas in the Kingdom of Saudi Arabia:

Special Natural Reserves (SNR):

These are prime sites of high biological excellence, constituting the NCWCD's main areas for the conservation of biological diversity. These areas are open for scientific research, education and strictly regulated outdoor recreation, as long as these are compatible with the main purpose of the reserve. Settlements, livestock and cultivation are usually excluded.

Natural Reserves (NR):

These are small areas of high natural excellence, or areas of any size of very high biological importance. The management guidelines for NRs should be similar to those for SNRs, but with greater freedom of public access.

Biological Reserves (BR):

They are smaller sites fulfilling a range of conservation functions, including rangeland reclamation, water catchment protection, or protection of local biological communities e.g. isolated stands of rare trees, mangroves, estuaries, turtle nesting beaches, or vulture breeding colonies. Such sites should be protected from any form of man-related disturbance, except where created for a special purpose, e.g. education or research. BRs would act as an extension of the traditional Hema concept.

Resource Use Reserves (RUR):

These are relatively large areas in which the emphasis is on sound resource management and the integration of renewable resource use and wildlife conservation. Each RUR should be subjected to a negotiated agreement between primary stakeholders (most commonly local communities) and the government. Management of resources should be the responsibility of local communities, with input from relevant government agencies.

Controlled Hunting Reserve (CHR):

These are large areas where the wildlife is managed with the aim of providing improved sustainable hunting at some future point. To be most effective, each CHR should have associated with it one or more fully protected areas to provide sanctuaries for key wildlife populations. CHRs would function as a type of RUR with respect to wildlife and hunting.

The 1990 System Plan identified 103 candidate protected areas (56 terrestrial sites and 47 marine and coastal sites) constitute over 8% of the Kingdom's area, this figure will increase to over 10% as new areas are identified and incorporated into the protected areas system.

By 2006, 16 protected areas had formally been Decreed. The 16 proclaimed protected areas are shown in Table 10.3 below together with their protected area classification. Despite the progress made by the NCWCD, there are still many areas in need of protection, for example several coastal areas are already facing pressure from development.

These reserves represent the natural ecological systems and the biological diversity in the Kingdom.

For the selection of sites as protected areas, the Commission has used a number of ecological and socio-economic criteria. These include:

- Representative coverage of all the Kingdom's biotopes.
- Protection of existing populations of key wildlife species.
- Protection of habitats of key biological importance.
- The potential of the site to provide tangible economic benefits to the local people.
- Sites which are of greatest value for environmental education and awareness.
- Recognition of traditional protection by local people.
- An equitable geopolitical spread of protected areas.

This involves weighing the relative merits of the proposed sites in terms of the criteria described above, in addition to practical considerations such as the degree of local support, presence or absence of conflicting land uses, logistical ease of protection and the urgency of threats to the sites and their wildlife populations.

The main objectives of these reserves are; to conserve natural habitats of wildlife, and application of sustainable use policy in wildlife conservation and development. Geographically the reserves are distributed in the north, central and southern regions of the Kingdom. Some of them are found in the high mountains and some are found in the islands:

- The Northern reserves (Harat ElHara, El Khinfa and El Tubaig).
- The Central reserves (ElWuool, Mahazat El Said and Magami El Hudab).
- The Southern reserve (Uroog bani Maarid).
- The high mountains reserves (Raydah).
- Island reserves (Farasan islands and Um Elgamari).

Table 10.3 Wildlife protected areas in the Kingdom of Saudi Arabia

Name of Protected Areas	Date Established	Category	Size of Area (km^2)
Harrat al Harrah	1987	SNR / RUR	13,775
Al - Khunfah	1987	SNR / RUR	20,450
Mahazat as - Sayd	1988	SNR	2,141
Ibex Reserve	1988	SNR / RUR	2,369
Al – Tubayq	1989	NR	12,200
Farasan Islands	1989	SNR / SN / RUR	696
Raydah	1989	SNR	9
Umm al - Qamari	1978	NR	1,600
`Uruq Bani Ma`arid	1994	SNR / RUR	11,980
Majami`al - Hadb	1993	SNR / RUR	3,400
At - Taysiyah	1995	RUR	4,260
Al - Jandaliyah	1995	RUR	1,160
Nafud al - `Urayq	1995	RUR	1,960
Saja Um Al-Rimth	1995	RUR	7,190
Al Hair Wetland	1988	SNR/NR	250
Total			**83,440**

Source: National Commission for Wildlife Conservation and Development

- **Rangeland Reserves:**

The Ministry of Agriculture started to protect some range sites since 1980 with the following objectives:

- To conserve some of the specific range sites.
- To conserve some rare plant species or the endangered ones or those with special value.
- Improving the quantity and quality of productivity of rangelands.

- To serve as drought reserves for grazing during dry years.
- Research and studies.

The number of range protected sites (through exclosures and/or enclosures) amounted to 37 at the end of 2003 and were distributed all over the Kingdom (Table 10.4). Each site has an area of 150,000 to 87,000,000 m^2 and is dictated by the objective of its protection.

Table 10.4 Rangeland Reserve Locations and Areas till End of 2003

Location	Site	No. of enclosures	Circum. Length km	Area in Km^2
Riyadh	EI-Haysiah	4	15	1.7
	EI-Khomera	1	2	0.5
	Hazwa	1	5,780	4.0
Al Majma'a	Rodat Bana	2	3	0.26
	EI-Kezaima	2	3	0.34
	EI-Ammar	1	2	0.25
	Faidhat EINazim	1	3	0.75
Al Aflag	El Husainiah	1	2	0.25
Shaqra	Wadi EIShams	1	8	4.0
Afif	Shuaib EIMatar	1	3	0.5
Makkah & Taif	Saisad (1)	1	10	4.1
	Saisad (2)	1	9	2.42
	SahlRukba(l)	1	38	87
	Sahl Rukba (2)	1	17	1.8
Al Madinah	El Mustagada	1	1,500	0.15
Eastern	El Dibdiba	2	4	0.5
Asir	Abha	1	7,800	2.0
	Zahran South	1	1,500	0.08
Hail	Subha	2	9,600	3.0
	El Milaihia	1	4	1.0
Tabuk	Wadi Fagr	1	8	2.0
ElBaha	El Shakika	1	4,500	1.0
	El Hinta	1	3	5.0
Northern Borders (ARAR)	El Owaisi	4	8	1.0
	Melahia	1	27	33.85
	Ghoraba	1	8	4.0
Al Jouf	El Tamriat	1	26	26.95
Total		**37**		**20,370**

Source: Reports of the Dept. of Range and Forests, Ministry of Agriculture.

- **Afforestation Efforts:**

Government of the Kingdom has paid great attention and concern towards forests conservation and development. This was reflected in the preparation of the National Forest Strategy (NFS) and National Forest Programme (NFP). Table below shows the afforestation efforts in the Kingdom.

Table 10.5 Afforestation sites in the Kingdom of Saudi Arabia.

Region	Site Name	Area in km^2
Al Baha	Jabel Al Humran	0.25
Al Baha	Abdan	0.56
Al Baha	Al Fath	0.395
Al Baha	Al Malad	0.01
Al Baha	Wadi Al Mandag	0.12
Al Baha	Gulsuma	0.12
Al Baha	Shahba	0.08
Al Baha	Jabal Al Gwaid	0.06
Al Baha	Jabal Al Buraida	0.19
Al Baha	Jabal Mashnia	0.09
Al Baha	Al Shukran	0.10
Al Baha	Jabal Al Ing	0.077
Al Baha	Jabal Al Hash	0.10
Al Baha	Shuab Al Hinta	0.045
Al Baha	Hima Beni Sar	0.18
Al Baha	Al Basim	0.06
Al Baha	Hima Al Sigaita	0.07
Al Baha	Jabal Al Anzia	0.065
Al Baha	Al Sakran	0.085
Total in Al Baha		**2.64**
Beesha		0.98
Asir	Sir Lasan	0.04
Asir	Buhairat Al Sad	0.03
Asir	Muntazah Al Mistaf	0.15
Asir	Garb Abha	0.06
Asir	Abu Sidg	0.25
Asir	Sir Lasan	0.12
Asir	Dulgan	0.22
Asir	Shuab Al Khamira	0.05
Asir	Hawl Abha	0.10
Asir	Ballasmar	0.033
Asir	Al Namas	0.033
Asir	Al Batra	0.15
Asir	Kharif	0.20
Total in Asir		**1.44**
Al Riyadh	Wadi Al Hayssiah	1.33
Al Riyadh	Al Hayssiah (1,2,3)	0.98
Al Riyadh	Muntazah Saad	1.5
Al Riyadh	Rawdat Kheraim	0.90
Al Riyadh	Rawdat Al Tanihat	1.0
Al Riyadh	Al Bobiat	--------
Al Riyadh	Al Ganadiriah	--------
Total in Al Riyadh		**5.71**
Al Taif	Hima Saisad	0.55
Al Taif	Sahl Rukba	0.36
Total in Al Taif		**0.91**
Arar	Tareeg Al Joaf - Arar	**--------**
Al Hassa	Al Hassa	**18.0**
Grand Total		**29.68**

------- Not Known.

Source: Range and Forestry Dept. Reports, Ministry of Agriculture

10.7.3 Strengthening Monitoring and Evaluation System:

National strategy for the conservation and sustainable use of biodiversity developed by the National Biodiversity Committee specifies strengthening of monitoring and evaluation system as one of the critical factors in achieving the goals of the strategy. The strategy has also defined various agencies and organization responsible for monitoring and evaluation of progress made for the biodiversity conservation and development projects and programs in the Kingdom.

The general aspects of the monitoring indicators of these projects and programs could be summarized as under.

- Increase / decrease in the number of officially recognized protected areas and their distribution in Saudi Arabia.
- Increase / decrease in the budget and number of trained and qualified staff to manage each of the protected areas.
- The situation of the protected area in relation to the desired goals set out in the management plan.
- Increase / decrease in the number and health of populations of flora and fauna in each of the protected areas including reintroductions.
- Change in the number of endangered species of terrestrial, marine and freshwater flora and fauna outside protected areas.
- Reappearance and growth of rare species of flora and fauna in terrestrial, marine and freshwater ecosystems.
- Changes in the overall number of species of terrestrial marine and freshwater wildlife and their increase per unit area.
- Level of enforcement of conservation legislations for all wildlife and the effective control of hunting.
- Changes in the value of wild harvested medicinal, aromatic and ornamental plants in comparison to domestically cultivated sources.
- Changes in grazing and wood cutting practices.
- Increase / decrease in new educational and awareness literature about protected areas.
- Increase / decrease in the number of visitors to each of the protected areas and the facilities available for these visitors at each site.
- Increase / decrease in awareness of visitors regarding importance of conservation.

10.7.4 Strengthening Environmental Protection and Biodiversity Conservation Education and Awareness at All Levels:

All environmental regulations and implementation procedures and strategies, biodiversity conservation laws, regulations, and strategies call for inclusion environmental protection and conservation of biodiversity and sustainable use of natural resources in the education curricula at all levels and raising awareness among public regarding these subjects.

Public and private sector are working together to spread education and awareness on the environmental protection and conservation of biodiversity in the society having joint campaigns, literature distribution and waste collection and cleaning campaigns along the beaches and coastal areas.

Actions Needed for the Success of Biodiversity Related Programmes:

Human Resource Development:

There is a need to:

- Establish and effective implementation of training programs.
- Developing the intellectual capacity of those who work in this sector.
- Raising the living standard of those whose livelihood depends on natural resources.

Development of Technology:

- Conducting extensive studies on the local species including their classification, taxonomy, breeding and hybridization to study the ability of species to produce new races.
- Study the development of productivity of species, such as programs that increase the productivity of the active substance in the medicinal plants.
- Monitor the dynamics of change in cultivated species and the way people interact with them.
- Use of technological solutions to meet the increased demand for some species such as the use of tissue culture techniques to reduce the over-gathering of wild medicinal plants.
- Provide technology and technical & scientific potential of different subjects such as environment, ecology, meteorology, agriculture, forestry, wildlife management, economy, water etc.

10.8 Conclusions:

Awareness of climatic variability and change which are not well understood by the public or decision makers must be promoted. Increasing sensitivity to climate issues will facilitate adoption measures to prepare for climate variability and eventually to climate change. A full scale impact of climate change is still not traced out. However, adaptation measures must be put in place in anticipation of the potential effects. Considering that many plant communities and ecosystems in Saudi Arabia are in a highly degraded condition, vulnerability would further lead to un-sustainability.

The permanent changes in climate will have significant impacts on biodiversity in Saudi Arabia. Therefore substantial reduction of heat-trapping gas emissions in developed countries and adaptation strategies are crucial. Reviewing the prediction for different climate change scenarios will be very useful in this critical stage. For example, biodiversity must be managed to ensure that conservation is occurring both inside and outside the protected areas and that adequate habitat is preserved to enable species (plants and animals) to migrate. Therefore comparing observations of annual mean temperature records that were taken from different locations with other predictive records from same locations in Saudi Arabia (See Figures. 6.21, 6.22, 6.24, 6.25, 6.26, 6.27, 6.28, 629, 6.30, 6.31, 6.32, 6.33, 6.39 and 6.40), will also help in decision making.

Following efforts are needed in Saudi Arabia to stop biodiversity degradation:

- Building an integrated database of plant and animal species.
- Establishing a regulation for the consumption of wild species.
- Financing research projects which examined the conservation of land-base genetic origins.
- Studying causes of biodiversity degradation and try to address them.
- Applied protection programs for some rare species.
- Developing a national policy for addressing issues related to alien invasive species.
- Expanding the application of tissue culture techniques for the propagation of threatened plant species.
- Development of marketing strategy for these threatened plants and animals, which may have an economical impact.
- Cooperation between the Gulf States Countries, (GSC) to benefit from the integration of plant and animal species in the region.
- Establishing a biodiversity monitoring system in Saudi Arabia for soil, animals, vegetation and climate-logical changes.
- Establishing a biodiversity management system in the country.

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