First National Communication of the Kingdom of Saudi Arabia

Submitted to

United Nations Framework Convention on Climate Change (UNFCCC)

Presidency of Meteorology and Environment PME
2005

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KINGDOM OF SAUDI ARABIA

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FOREWORD

On behalf of the Government of the Kingdom of Saudi Arabia, I have great pleasure in presenting Saudi Arabia's "First National Communication" in the fulfillment of our commitment under Article 12 of the United Nations Framework Convention on Climate Change (UNFCCC) and in accordance with the relevant Decisions of the Conference of Parties (COP).

The National Communication has been prepared by a National Team of scientists and experts belonging to various disciplines and has been coordinated by the Presidency of Meteorology and Environment.

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.

First and foremost, I would like to express my gratitude to the Crown Prince HRH Prince Sultan Bin Abdulaziz, Deputy Prime Minister, Minister of Defense and Aviation and Inspector General and Chairman of Ministerial Committee on Environment (MCE) for his encouragement, support and guidance. I would also like to thank all scientists, and experts of the National Team for their commendable work. Thanks are also due to different relevant ministries, government agencies, research institutes and academic institutions and universities for their cooperation and coordination during the process of compilation of this report.

Last but not the least; we also thankfully acknowledge the support provided by UNDP-GEF during the course of preparation of this report.

Turki Bin Nasser Bin Abdulaziz
Jeddah

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EXECUTIVE SUMMARY

Executive Summary

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. One effective option that has been adopted by various developed countries to achieve 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 and submit its First National Communication to the Secretariat of the Convention. This report is comprised of three main sections namely: National Circumstances, National Inventory of Anthropogenic Emissions by Sources and Removal by Sinks of Greenhouse Gases, not Controlled by the Montreal Protocol — Base Year 1990 (GHG inventory) and Vulnerability Assessment and Adaptation Measures. Each of the above mentioned sections are divided into sub-sections.

National Circumstances:

The Kingdom of Saudi Arabia comprises about four-fifths (80%) of the Arabian Peninsula, occupies approximately 2,250,000 square kilometers (868,730 square miles) area and bordered on the west by the Red Sea; on the east by the Arabian Gulf, Bahrain, Qatar and the United Arab Emirates; on the north by Jordan, Iraq and Kuwait; and on the south by the Sultanate of Oman and Yemen.

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

Saudi Arabia consists of a variety of habitats such as sandy and rocky deserts, mountains, valleys ('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 population of the Kingdom in 1992 was estimated at 16.9 million with a population density of 7 per square kilometer. Life expectancy at birth in 1991 was 69 for both men and women. Births that year were 37 per 1000 people, and deaths 5 per 1000, with an average annual population growth for 1991-2000 of 3.5%. Seventy-eight percent of the population is concentrated in the urban areas.

Water is a valuable natural resource which plays a critical role in the Saudi development process, as the country is characterized by an extremely limited supply of fresh surface and ground water. Water consumption is estimated at 16,230 million cubic meters/year (cm/y) of which 14,600 million cm were for irrigated agriculture and 1,700 million cubic meters for domestic and industrial purposes There are no perennial rivers in the country; surface water results when rainfall is sufficiently intense to flood the wadis (seasonal water courses). Over 60% of the runoff occurs in the southwestern region, in an area comprising less than 10% of the country's total area. Several dams have been constructed in areas of high surface flows, aimed at utilizing the water flows in agricultural development or for recharging underground aquifers. The amount of non renewable deep groundwater reserves varies between 500,000 and 2,000,000 million cm and the amount of recharge and shallow groundwater aquifer is estimated at 3,850 million cm. According to the Saline Water Conversion Corporation, in 2000 (1420/21 AH) there were 27 desalination plants producing 814 million cubic meters of desalinated water (more than 600 million gallons a day) and providing more than 70 per cent of the required potable water.

Only 2% of the country's land area is considered arable, with the chief agricultural crops including dates, wheat, barley, and fruit. Nonetheless, over the last two decades the total area of land under cultivation has nearly doubled and agricultural production has more than tripled. The Kingdom is currently self-sufficient in wheat and 75% self-sufficient in meat, milk, vegetables, and fruits.

According to the latest estimates (2001), the Kingdom's gas reserves stand at 219.5 trillion cubic feet (6.22 trillion cubic meters), approximately 4% of world reserves while recoverable oil reserves stand at 261.8 billion barrels. This figure represents an increase of 1.8 billion barrels on the 1993 estimate of 260 billion barrels roughly 25% of the world's proven oil reserves. In addition to its vast oil and gas reserves, the Kingdom is rich in mineral deposits as well. Silver and base metal deposits (bauxite, copper, iron, lead, tin and zinc), as well as non-metallic minerals (bentonite, diatomite, fluorite, potash and high-purity silica sand) have also been discovered.

In terms of area, nomadic and semi-nomadic pastoralist constitutes the major form of land use in Saudi Arabia. Most of the rangelands are extremely fragile due to aridity, soil instability, soil infertility, and wind erosion. It is estimated that as many as 70,000 sq. km of rangeland are currently in danger of desertification from removal of shrubs and trees, overgrazing, and surface soil destabilization through inappropriate agricultural practices and resulting erosion.

The educational system has been continuously and systematically expanded to accommodate the ever-growing demand for educational services. The government has devoted vast resources to provide opportunities for primary, secondary and higher education in the Kingdom, providing free education to all. Through this investment, the Kingdom has been able to guarantee equality of opportunity for all and to ensure that the Kingdom's needs for an educated and trained national workforce to carry forward the Kingdom's future development can be fulfilled.

Healthcare has also been one of the important sectors supported by the government. The government provides free healthcare of highest standard for all citizens, a provision extended to all those who visit the Kingdom in pilgrimage. According to statistic, the Kingdom had 324 Hospitals, 46,622 Beds, 31,983 Doctors, 67,421 Nurses, 38,519 Assistant Health Personnel and 3,506 Healthcare centers (1999).

As to the social sector, the social services are designed to redress existing imbalances, to improve living standards and the quality of life of the population, to stimulate citizen participation in community development activities, and to provide remedial care and assistance for the disabled and the deprived. Special attention is given to raising the living standards of the poorest sections of the society, particularly in the villages and the less developed districts of the towns and cities.

The Government, through the public sector, plays a major role in the Kingdom's industrial activity but, in recent years, the private sector has, with the Government's encouragement under the Kingdom's system of free enterprise, become increasingly involved in and responsible for industrial development and diversification. During the last twenty years, Saudi Arabia has witnessed two distinctive phases in its economy; a period of rapid expansion from 1970 to 1980 with an annual GDP percent increase of 10%, followed by a phase of economic contraction from 1980 to 1990 with an annual GDP of 3.2% due principally to a decrease in oil prices; in 1992, the GDP was US$110.7 billion. The GDP is distributed among sectors as follows: agriculture 7%; industry 52%; and services 41%. The economy relies heavily on the oil industry. A key element in the Saudi Arabian government's economic strategy is industrial diversification, a process which has as its primary objective the reduction of the Kingdom's dependence on oil revenues. To this end, the government has encouraged the development of a wide range of manufacturing industries. The government has provided a range of incentives to encourage the private sector to participate in the Kingdom's industrial development efforts. The Kingdom has adopted a free market economic model. The financial, industrial and trade sectors of the economy have made rapid progress, enabling the private sector to play an increasingly important role in the development and diversification of the economy, especially in the fields of construction and farming.

Greenhouse Gas Inventory:

The inventory of anthropogenic emissions and removals by sinks of greenhouse gases has been prepared according to the 1996 Guidelines of the Intergovernmental Panel for Climate Change (IPCC, 1997). The greenhouse gases covered in this inventory included the direct greenhouse gases; namely, carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O).

The process of developing National GHG Inventory passed through various steps as proposed in the 1996 IPCC guidelines including: Identification of the types of data to be collected from each emission source category and sub-sectors, Preparation of a list of government ministries and other governmental, semi-governmental, and private organizations, Development of questionnaires or forms to collect the required information, Collection of inventory data and information, Tabulation of the collected data in the 1996 IPCC prescribed format, Estimation of greenhouse gas emissions/sinks based on methodologies recommended by the 1996 IPCC Guidelines; and, Development of the report and summary of total anthropogenic emissions of greenhouse gases and their removals by sinks.

Input data for the inventory were collected for the period covering 1990 through 1996. However, greenhouse gas emissions were estimated for the base year, 1990, as stipulated in IPCC guidelines. In addition to the questionnaires, various other sources of information were consulted. The emission factors were adopted from the 1996 IPCC Guidelines. Additionally, where more accurate (than the default emission factors suggested in IPCC Guidelines) country-specific information was available, new emission factors were developed and adopted for this study. The major sectors considered were: Energy, Industrial processes, Agriculture, Land-use change and forestry and Waste.

The estimated GHG emission could be summarized as under:

- Total CO_2 emissions in Saudi Arabia in 1990 were 140,958 Gg and CO_2 sinks were 15,240 Gg.
- Energy sector contributed 90% of the total CO_2 emissions, followed by the industrial processes sector (8%) and the agriculture sector (2%).
- Major source categories contributing to these CO_2 emissions (contributions $\geq$2% of the total emissions) were electricity generation (26%), road transport (25%), desalination (15%), petroleum refining (10%), cement production (5%), cement industry (3%), petrochemical industry (3%), aviation (3%) and iron and steel production (2%) .

Greenhouse gas emissions from Industrial Processes Sector include cement production, iron and steel industry, limestone uses, glass manufacturing, soda ash uses, ammonia production, asphalt uses, petrochemical industries, and food/feed industries.

- Cement production and the iron and steel production were the largest contributors to CO_2 emissions and collectively accounted for about 86% of the total emissions of 10,881 Gg. Limestone uses, ammonia production, and soda ash uses contributed 1,473 Gg to the total CO_2 emissions.
- **Chemicals production** was the sole contributor to CH_4 emissions of 9.59 Gg.

Greenhouse gas emissions from Agriculture sector include livestock (enteric fermentation and manure management), agricultural soils, and field burning of crop residues were considered under this sector.

- 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 CH_4 emissions from enteric fermentation, manure management, and field burning of crop residues were estimated at 74.56 Gg, 8.54 Gg, and 4.90 Gg respectively. The N_2O emissions from manure management, agricultural soils (direct and indirect), and field burning of crop residues were estimated at 6.98 Gg, 23.59 Gg, and 0.09 Gg, respectively.
- Field burning of crop residues also emitted 2,692 Gg CO_2.
- For agricultural soils, as per the IPCC Guidelines, only N_2O emissions were estimated.

Land-Use Change and Forestry Sector includes Changes in forest and other woody biomass, forest and grassland conversion to agricultural uses, and emissions or uptake of greenhouse gases by soils as a result of land-use changes were considered. As per the IPCC Guidelines, only emissions or sinks for CO_2 were estimated for this sector.

- Changes in the forest and other woody biomass provided a sink for 93.00 Gg of CO_2.
- Forest and grassland conversion to agricultural uses converted 6,955 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) 8,192 Gg of atmospheric CO_2.
- The total sink from the land-use change and forestry sector was 15,240 Gg of CO_2.
- 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.

Emissions from municipal solid waste management, and industrial, domestic and commercial wastewater management were considered in this sector. As per the IPCC Guidelines, only CH_4 and N_2O emissions were estimated.

- Solid waste management practices emitted 598 Gg of CH_4.
- Municipal and industrial wastewater handling emitted 4.24 Gg of CH_4.
- N_2O emissions from human sewage were estimated to be 2.25 Gg.

Saudi Arabia is a major oil and gas producer and has a relatively large landmass of approximately 2.25 million squares kilometers. Therefore, Saudi Arabia tends to be a large fossil energy-intensive economy since the production and processing of crude oil (drilling and extracting to refining of finished products) is an energy intensive process resulting in relatively high carbon emissions. Since Saudi Arabia has a quarter of the world's oil reserves as well as the world's largest petroleum exporter, it has the responsibility of supplying the world with petroleum which is considered as a strategic resource not only to Saudi Arabia, but to the global economy. Therefore, Saudi Arabia will be limited in its efforts to reduce CO_2 emissions from its oil producing operations.

Saudi Arabia's energy consumption has been on the rise over the past two decades. This is mainly due to the booming oil sector and global oil demand in the 1970s and early 1980s and a continued reliance on a reliable and inexpensive fossil energy. Recognizing the geographical land mass it possesses, Saudi Arabia's industrial and transportation sectors account for approximately 80% of the country's total energy consumption while the residential and commercial sectors account for the remaining 20%. Oil makes up the majority of this consumption at 59% while natural gas accounts for the remainder.

Saudi Arabia's carbon emissions have risen by 55% in the past 20 years. This relatively high increase is not as proportionately significant as other developing nations, which have seen carbon emissions, on the average, double during the same time period. However, in terms of per capita carbon emissions, Saudi Arabia is still one of the highest relative to the developing world. This is mainly attributed to the economic and abundant nature of its strategic crude oil resource.

Vulnerability Assessment and Adaptation Measures

Vulnerability assessment and adaptation measures are comprised of sub-sections namely Climate Change Scenarios, Desertification, Water Resources, Coastal Zone Management (Sea Level Rise), Biodiversity and Socioeconomic Impacts of Annex I Countries Response Measures on Saudi Arabian Economy.

Climate Change Scenarios

The process of assessing the vulnerability of certain sectors, such as agriculture, water resources…etc, to climate change requires the construction of a predicted visions of what the future climate would be under physically reasonable assumptions of greenhouse-gases concentrations. These visions, the climate change scenarios, are to be compared then with a picture representing a non-changed climate, the baseline climate scenario. The results of such comparison can then be used as indicators for the future impacts that might be experienced by the considered sector. In this section, the development of these scenarios for Saudi Arabia will be described.

Based on the length and continuity of records, only 26 synoptic stations were selected to construct the Baseline Climate Scenario. In identifying the climatic baseline period, the optimal (records wise) selection is found to be a twenty six years period (1978-20030.

A comprehensive description of the Kingdom climate can not be produced without first considering the significant variation in its topography, and to the prevailing meteorological systems affecting it. Detailed account of the Kingdom terrain description is given elsewhere. Charts of the seasonal average sea level pressure are drawn for the Kingdom from which the synoptic systems affecting the region were recognized. The Kingdom is greatly influenced by the semi-stationary Pressure Patterns extending from the surrounding regions.

Three climate parameters were selected to describe the general characteristics of the climate in Saudi Arabia during the baseline period. These are: Surface air temperature, precipitation and humidity. Manual analysis of the annually and seasonally averaged values of these three parameters were carried out and displayed in a series of isoline charts. The detailed characteristics of the Kingdom climate were then deduced from these charts, and the climatic zones of the country were identified according to these characteristics.

In order to reveal the climatic trends, the baseline period is divided into two equal parts of 13 years each, and the trends of the parameters were judged from the deference of the mean values corresponding to these two sub-periods for all stations. Results were plotted for the change of the mean annual temperature and the percentage of the precipitation, to show the spatial distribution of these changes.

There is a general warming all over the Kingdom that varies from a minimum of about 0.15^0C (Tabouk, Makkah, Al Ahssa), to a maximum of about 0.75^0C (Khamis Mushait, Wadi Al Dawasser, Yonbu) ,with an average of 0.4^0C.The pattern exhibits a clear systematic distribution with stronger warming area elongating over the interior part of the country (in access of 0.4^{0}C), and an area of weaker warming (less than 0.2^{0}C) along the western and eastern coasts, far north and far south.

As for precipitation trends, there is a vast area of rainfall deficit covering all northern parts of the Kingdom (as low as -40% in Tabouk and Arar). Another area that experienced a decrease in rainfall is the eastern slops of Asir mountains (-14% in Abha). Areas recording maximum increase of rainfall are: the western coasts (92% in Jeddah), the central (45% in Riyadh), the eastern coasts (32% in Dhahran), and the southern (109% in Sharourah).

In creating the Climate Change Scenarios for Saudi Arabia, software called MAGICC/SCENGEN (version 4.1, September 2003), developed originally by the Climate Research Unit at the University of East Anglia of U.K., is utilized.

MAGICC, a coupled gas-cycle/ climate model, is the primary model that has been used in all IPCC assessments to produce projections of future global-mean temperature and global-mean sea level rise.

SCENGEN, a climate scenario generator, uses the output from MAGICC to produce spatial patterns of the climate parameters changes from an extensive database of Atmosphere/Ocean General Circulation Models (AOGCM) data. .

Out of the 47 scenarios available in MAGICC library (it includes now the Special Report of Emission Scenarios-SRES- having wider range of gases), two were selected: P50 as the "Reference" scenario, and WRE350 as the "Policy" scenario.

Output from MAGICC was used to drive SCENGEN. In an initial trail run, all the 17 GCMs incorporated in SCENGEN library were used. However, three GCM models were found to simulate very closely the climatic trends characteristics of Saudi Arabia. Results obtained from running the combination of these three models, for the reference (P50) and the policy (WRE-350) emission scenarios, are given in seasonal and annual changes order.

Many remarkable climate change features can be concluded from these results. Some of these features are as follow:

- 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 (2.2-2.7^{0}C) occurs during summer at the north western region, while the lowest (0.2-0.4^{0}C) occurs, also in summer, but in the south and the southwest.
- The highest precipitation increase occurs in summer in all regions. Obviously, this is trivial for areas having no summer rain. However, in the south and southwest regions, where precipitation regime is characterized by two peaks (one in summer and one in spring), such increase has an important synoptic implication, particularly when compared to the spring change.

In an attempt to get more specific vision of the future climate, the results of the IAP-97 (identified as the best simulating model) were used to construct a 2041 precipitation chart of the Kingdom.

In addition, micro level climate analysis was made by retrieving daily climate data for the region from IPCC databases based on simulation studies conducted using climatic models. Four models namely Hadley model, CCMA model, NCAR model and CCSIRO models were used to retrieve long term simulated records on precipitation, temperature and relative humidity. Various climatic scenarios, as developed by IPCC group were reviewed with main focus on A_2 and B_2 climatic scenario family.

Desertification

Saudi Arabia is particularly vulnerable to climatic change as most of Saudi Arabia has sensitive ecosystem. About 76% of its area is non-arable lands which include 38% of the area as deserts. These areas contain the range lands or pasture areas, which extend over to about 171 million hectare. Most of pastures in Saudi Arabia are scattered herbs and shrubs with low density and low productivity. The rangelands sustain a large number of rural communities through their support for livestock grazing over hundreds of past years. Although, the average annual rainfall in the Kingdom is low, the natural flora has managed in the past to survive under these extreme arid conditions.

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). Dry-land soils such as those of Saudi Arabia often have low organic matter content and are frequently saline and/or alkaline. As such, they are often highly susceptible to accelerated erosion by wind and water. The rainfall distribution map of the Kingdom shows three distinct regions in its rainfall and vulnerability to desertification. Areas with annual rainfall of less than 50 mm, 50-100 mm and more than 100 mm have third, second and first scores in its vulnerability to desertification hazards respectively. The highest vulnerability areas are located mainly in the northwest and southeast areas of the Kingdom. The middle vulnerability is in the central parts and the lowest in the southwestern region mountains.

Most of Saudi Arabia has sensitive ecosystem for any level of climate change especially on desertification processes. Assessment of these impacts indicated clearly that most regions have high vulnerability levels for climate change impacts on desertification processes. The climate change impacts as represented by temperature increase would elevate the levels of reference evapo-transpiration by about 1-4.5% at 1^{o}C increase, and by about 6-19.5% at 5^{o}C increase in most regions. The 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 and more than 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 agricultural sector as a major economic sector in the national economy. Compensation of the crop losses importation from foreign countries represent additional burden on the economy. Furthermore, the agricultural activities represent a major support for about 25% of the national population who still live in rural areas. The deterioration of agriculture for rural communities represents a threat to the social structure and welfare of these communities. The natural plants in range lands and the cultivated crops will suffer from water shortages as the very low annual rainfall in the majority of the regions can not compensate for the elevated plant water requirements. Additionally, the top soil layers in rangelands and in irrigated areas will suffer from salinization and increase of salinity levels by 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. Plant cover will be reduced and lands will be more exposed for erosion and desertification. This will lead to serious effects on social and economic development and sustainability of the national economy and progress of the country. In the process of desertification, factors such as degradation of soil organic and nutrient contents, deterioration of soil structure and salinity built up will lead to more evapo-transpiration and less water supplies to less productive lands to support the rural communities that depend on it. This will be more pronounced in the rangelands which provide natural grazing for animals belonging to rural communities especially the nomads such as sheep and camels in all regions of the Kingdom. The reduction in surface moisture or vegetation 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 is further degraded as a result of erosion and compaction. 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. Substitution of the natural grazing lands by cropped forage will be difficult due to the expected reduction in water supply sources. Importation and supply of forage crops to nomads and rural communities will be very difficult. 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 economies 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.

Water Resources

The quantities of annual runoff are estimated to vary “between” about 5,000 to 8,000 million cubic meters (MCM) of which 780 MCM are produced in the Arabian shelf and the rest are in western coastal parts of the Kingdom. The storage capacity of 215 constructed dams of different shapes and sizes is 833 MCM.

It is estimated that about 1,400 MCM of wastewater was generated in the country in the year 2000. The volumes of collected and treated wastewater are about 534 MCM, which represent about 38% of the total generated wastewater, and 33% of the total distributed domestic water. Presently, about 240 MCM of the treated wastewater is reused annually for landscape and crop irrigation purposes.

The total water production from desalination plants increased from about 200 MCM in 1980 to 540 MCM, 785 MCM and 1050 in 1990, 1997 and 2001 respectively. The desalinated water production is expected to reach about 1600 MCM in 2010 and more than 2500 MCM in 2025. By 2025, the desalination production is expected to be about 54% of the total domestic and industrial demands.

The domestic and industrial water demands have grown from about 220 MCM in 1970 to about 2030 MCM in 2000, and expected to reach 6,450 MCM in 2020. The cultivated areas have expanded from less than 400,000 ha in 1971 to 1.62 million ha in 1992, and started to decrease in 1993 until it reached about 1.21 million ha in 2000. The total irrigation water use has increased from about 6,108 MCM in 1970 to about 9,470 MCM, 18,776 MCM and 19,074 MCM in 1980, 1990 and 2000 respectively.

The total volumes of available renewable water resources from surface water and groundwater recharge are about 6,188 MCM. Non-renewable groundwater resources supplied about 37%, 67% and 66% of the total national needs in 1980, 1990 and 2000 respectively. The dependence on nonrenewable groundwater has increased from 37% of the national demands in 1980 to 67% and 71% in 1990 and 1992 respectively, and then decreased to 66% in 2000 due to increased production of desalination water and reduction in areas for agriculture after 1993.

Any increase in ETo will result in increasing the evaporation rates and decreasing the available water supplies from annual participation by:

- lowering the annual recharge to aquifers
- Lowering the surface runoff.

The calculated total annual recharge to all aquifers in the Arabian Shelf is about 2,762 MCM based on several hydro-geological studies. The annual recharge to shallow aquifers in the Arabian Shield is 1,196 MCM. Thus, the total annual recharge to all aquifers in the Kingdom is about 3,958 MCM. The average increase in reference evapo-transpiration ETo, which reduces the recharge to all aquifers has been defined as 2.3% and 12% of the total annual recharge at 1^{o}C and 5^{o}C increase in temperature respectively. The calculated reduction in the values of total annual recharge is about 91.4 MCM and 475 MCM at 1^{o}C and 5^{o}C increase in temperature respectively.

The reduction in annual surface runoff of 5,000 – 8000 MCM at ETo increase of about 2.3% and 12% at 1^{o}C and 5^{o}C increase in temperature respectively have been calculated . At 1^{o}C increase in temperature, the increase in ETo of 2.3% will result in decreasing the annual surface runoff by about 115 -184 MCM (with an average of 150 MCM). While at 5^{o}C increase in temperature, the increase in ETo of 12% will result in decreasing the annual surface runoff by about 600-960 MCM (with average of 780 MCM). The total annual reduction in water resources equals to reduction in recharge and reduction in surface runoff. Thus, the total water resources reduction will be about 241 MCM and 1,435 MCM at 1^{o}C and 5^{o}C increases in temperature respectively. Total annual increase in irrigation water demand in the Kingdom ranges between 602 MCM at 1^{o}C to 3122 MCM at 5^{o}C respectively. The expected rise in domestic and industrial water demands will range between 75 and 390 MCM at 1^{o}C and 5^{o}C increases in temperature respectively.

The total water stress is equal to the total quantities of decrease in groundwater recharge and surface runoff, increase in irrigation requirements and domestic and industrial demands at 1^{o}C and 5^{o}C increases in temperature. The calculated total water stress ranges between 1520 to 4,947 MCM at 1^{o}C and 5^{o}C increases in temperature respectively.

The costs of the above rises in water demands will represent additional burden on water authorities and citizens as it should be supplied from desalination processes for domestic use. The expected costs will exceed one billion Saudi Riyals annually as the costs of drinking water production and distribution is about SR 4 per cubic meter. This represents about ten percent of the present costs of total national water supplies. The stress on domestic water supplies will be aggravated by the possible decrease in groundwater recharge and surface runoff with temperature increase. This means that the domestic water supplies of 50% from groundwater and surface water will be replaced partially or totally from desalination processes. The related costs of these supplies will exceed SR 4 billions annually. If these increases in domestic and industrial demands are not satisfied then more water supplies problems in rural and urban areas will be experienced. The human, construction, commercial, transportation, education, health and industrial activities will be negatively disrupted. This will lead to serious effects on social and economic development and sustainability of the national economy and progress of the country.

The government has implemented measures to protect the sustainability of water resources. These measures include: execution of a long-term investigation program to assess the availability of groundwater and surface water resources in different regions and supporting the drilling of thousands of wells under the supervision of the Ministry of Agriculture for domestic, agricultural, and industrial purposes. Several other measures undertaken by the government are summarized below.

- The government has supported the construction of 215 dams for water storage and groundwater recharge for domestic and agricultural uses.
- Building of 30 desalination plants to supply about 50% of the domestic water supplies in the Kingdom.
- Establishment of the Ministry of water and Electricity in July 2001 to improve the national water planning and management in the country.
- Development and implementation of water protection and conservation regulations. These include well drilling permission, drilling supervision and specifications, groundwater protection zones, groundwater pumping schemes, protection of groundwater from pollution, surface water development and water conservation.
- Construction of wastewater treatment plants and implementation of wastewater reuse schemes for landscape and crop irrigation in different regions of the Kingdom.

- The introduction and implementation of advanced water conservation support policy at residential level.
- Implementation of modern leakage detection and control schemes in major cities.
- Implementation of advanced irrigation water conservation schemes for large and small farms.
- Modification of water pumping from aquifers by changing the agricultural policies to maintain the long-term sustainability of the aquifers.

Coastal Zone Management: Sea Level Rise

Saudi Arabia extends from the Red Sea on the west which is 1,760 kilometers long; to the Arabian Gulf on the east which is 650 kilometers long.

This chapter is highlighting the main components of addressing vulnerability, impact assessment and adaptation to the Accelerated Sea level Rise (ASLR) including specific vulnerabilities and applied risk assessment techniques to determine environmental area at risk as well as identify economic and social activities that will be impacted by accelerated sea level rise. With the identification of the three scenarios for accelerated sea level rise, the chapter will determine possible impacts on both the environmental and socio-economic activates. For vulnerability and impact assessment, the sensitive areas identified are (a) Water resources, (b) Agriculture (c) Marine life (d) Coastal zone (e) Infrastructures and (f) Tourism. The Accelerated Sea Level Rise Impacts are expressed as Bio-geophysical and Socio-economic impact. Finally an adaptation section has highlighted the Kingdom's effort to combat accelerated sea level rise and present possible options that the Kingdom may utilize to deal with this potential threat. Baseline review was conducted to include sustainable development determents such as marine environment and socio-economic aspects.

Because of the great length of the Saudi Arabian coastline, only vulnerable industrial and populated coastal zone cities that could be affected by ASLR have been included in this study. At the Eastern Coast of Saudi Arabia along the Arabian Gulf, Dammam, Ras Tanura, Jubail and Khafji have been selected as the most vulnerable coastal zone areas. At the Western Coast of Saudi Arabia along the Red Sea, Jeddah, Rabigh, Yanbu and Jizan have been selected as the most vulnerable coastal areas.

A conservative approach based on Intergovernmental Panel for Climate Change (IPCC) and United Nations Framework Convention on Climate Change (UNFCC) predictions for global sea level rise has been used. Three scenarios viz. low, medium and high were applied to assess the impact of ASLR on both the Arabian Gulf and the Red Sea

Socio-economic Impacts of ASLR

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

- For the Low Sea Level Rise Scenario (LSLRS) of 0.2m rise, 401 hectares of sandy beaches are estimated to be lost by the year 2100.
- For the Medium Sea Level Rise Scenario (MSLRS) of 0.49m rise, 984 hectares of sandy beaches are estimated to be lost by the year 2100, and
- For the High Sea Level Rise Scenario (HSLRS) of 0.86m rise, 1,726 hectares of sandy beaches are estimated to be lost by the year 2100.

Considering that the annual coastal development in the Kingdom is 1% and taking into consideration the IPCC Sea Level Rise projection scenarios towards year 2100, and by applying Bruun model to estimate the high risk area subjected to coastal erosion along the Red Sea, it was found that:

- For the Low Sea Level Rise Scenario (LSLRS) of 0.2m rise, 1,087 hectares of sandy beaches are estimated to be lost by the year 2100.
- For the Medium Sea Level Rise Scenario (MSLRS) of 0.49m rise, 2,663 hectares of sandy beaches are estimated to be lost by the year 2100, and
- For the High Sea Level Rise Scenario (HSLRS) of 0.86m rise, 4,674 hectares of sandy beaches are estimated to be lost by the year 2100.

These estimates can be more accurate if high resolution topographical maps and coastal surveys are available, which is proposed to be conducted in futures studies.

Impact SLR on Physical Structures

The socio-economical impact of Accelerated Sea Level Rise (ASLR) on physical structures can be expressed as vertical or horizontal; the vertical impact can affect buildings and recreational facilities along the coastal zone. Horizontal infrastructures include roads, bridges, cables, water and sewer systems.

Currently there is no strong evidence that the Accelerated Sea Level Rise has directly impacted the physical structures along the coastal zone. The Presidency of Meteorology and Environment (PME) is currently regulating the development of facilities along the coastal zones by making Environmental Impact Assessment Study (EIA) a pre-requisite for such development. The high risk facilities, that may encounter socio-economic impacts are facilities located within 200 meters of the coastal zone, are:

- Desalination Plants
- Industries
- Sea Ports
- Roads and causeways
- Recreational Facilities and
- Hotels

Costal Zone Management plan, which promotes integration of climate change consideration and introduces regulations and enforcement frameworks for futures development activities, is considered as the main adaptive measure that will be implemented in the Kingdom to respond to the potential impact of climate change. All levels of the Kingdom's Coastal Zone Management Plans will implement actions and policies established in regional and international agreements to which the Kingdom of Saudi Arabia is signatory.

Biodiversity:

The vulnerability and adaptive capacity of plant and animal communities and their ecosystems to climate change and the possible potential consequences of climate change are assessed in this section of this report.

According to recent estimates, Saudi Arabia contains about 2243 plant species of 132 families, of which about 20% are rare plants. The flora includes 9 species of Gymnosperms and 27 species of Pteridophytes. The number of genera currently stands at 837. Among the families, 37 are represented by a single species. The southwestern mountainous region, from Taif to Yemen border contains about 70% of the floristic elements of Saudi Arabia. Two species of mangroves are also recorded in Saudi Arabia, namely Avicennia marina, the common one, and Rhizophora mucronata.

A checklist of 98 species of mammals has been recorded from the Arabian Peninsula. Of these, 76 species occur in Saudi Arabia. Regarding birds, about 444 species have been recorded in Saudi Arabia, of which about 185 species are known to breed in the Kingdom. There are some ten species of birds indigenous to the Kingdom of Saudi Arabia while hundreds of them are passing through the Kingdom as migratory birds.

The vegetation of Asir mountains is very interesting and comprises of a variety of woodland areas. The top layer of mixed forests on the western slopes consists of Juniperus procera, Nuxia congesta, Tarchonanthus camphoratus, Maesa lanceolata, Teclea nobilis, etc. The second layer consists of small trees or tall shrubs like Olea europaea, Buddleja polystachya, Grewia spp. Dodonaea angustifolia, Debregeasia saenab, Carissa edulis, Ehretia obtusifolia, Canthium spp., etc. The third and fourth layer is formed of a number of short shrubs and herbs.

Natural ecosystems identified as being at risk in Saudi Arabia include wadis, rivulets, various woodlands in mountains, wetlands, raudhas, coastal areas, etc. Anticipated negative impacts of climate change on woodlands of Saudi Arabia over the next 50-100 years include:

(i) Increase in the frequency and changes in the patterns of natural disturbances such as fire.

(ii) Shift toward a younger age class structure of the woodland.

(iii) Reorganization of woodland species composition.

(iv) Woodland decline in species rich areas due to slower dispersal capabilities of plants.

(v) Major changes occurring along woodland and species-rich area boundaries, particularly in the southwestern and northwestern regions.

At present, Saudi Arabia has 15 protected areas which cover approximately 5% of the land area and conserve about 43% of the country's flora. There are 968 plant species, subspecies, and varieties protected in the eight protected areas, majority of which are in the Raydah Nature Reserve. Only 2% occur in more than 5 protected areas. The NCWCD developed a national plan in 1990 after an extensive field survey and a wide range of consultations. According to the plan, 104 sites (both marine and terrestrial) have been identified to declare as protected areas. The sites include areas with key biotopes and landscape features and covering habitats of critical species in the Kingdom.

Climate change is likely to induce vegetation change that will force wild plant and animal species to shift their distribution in response to the new conditions or adapt them to the changing climate. Various degree of pubescence on plants and a variety of changes in the color and size of butterflies, dragonflies, beetles and other migratory insects are reported in various studies conducted by scientists in Saudi Arabia.

As the climate changes, plants will naturally attempt to adapt by migrating into new areas, assuming that the landscape is not fragmented. Since most of the "good" areas are occupied by humans, not all species will be able to migrate. From a conservation point of view, one has to visualize that creating avenues of migration for critical plant groups might be a useful hedge against destructive changes in climate. Unfortunately, most of the species rich areas are located in the mountains of the western side and most of them are highly fragmented and therefore plants have limited options for migration.

In desert ecosystems, protected areas are often located around oasis, which acts as basis for the existence of much of the local fauna. Protected oases often are far apart, so droughts that cause a decline in local forage often cause mass mortality because animals may not be able to move on to adjacent oases. Another impact on extreme climate variation is the result of the disappearance of small pools, seeps and streams in the protected areas, such as the one in Ibex Reserve, near Howtha Bani Tamim. If this happens, it may directly or indirectly affect the wild inmates like Ibex and Gazelles, although these animals can quench their thirst by eating the foliage of wild plants.

To protect the rich biodiversity and endangered species, the government has taken the following addition measures.

- Establishment of a regional drought monitoring and early warning centre within the Presidency of Meteorology and Environment (PME).
- Conservation and reintroduction of animals through National Commission For Wildlife Conservation and Development
- Establishment of National Wildlife Research Center, Taif and King Khalid Wildlife Research Center, Thumamah.

- A collaborative and joint survey conducted by local and scientists with the following objectives.
  - (i) Assessing the current status of the floral and faunal aspects of the reserve.
  - (ii) Assessing the current status of Juniper woodlands in order to find out the causes of die-back phenomenon and
  - (iii) Collecting information in order to draw a management plan of the reserve.

Analysis of Socioeconomic Impacts of Annex 1 Response Measures on Saudi Arabian Economy

Saudi Arabia remains highly dependent on fossil fuel exports while significant demographic pressures continue to tax the government's ability to provide for the needs of its population. The purpose of this chapter 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.

Oil revenues have historically had a direct impact on Saudi government spending and fiscal policy. While 1970's and early 1980's were the years of considerable budget surpluses from oil revenues, the national budget has been running in deficit starting as early as 1983 until the present, only with the exception of 2000 and 2003 which were primarily due to relatively high oil prices. The past two decades, when government expenditures have predominately outstripped government receipts, have resulted in a high domestic debt reaching as much as 100% of GDP in the late 1990s. A remedy to this potential concern would be for Saudi Arabia to diversify its economy sufficiently away from fossil fuels to adapt to the implementation of these Annex I climate change energy policies. However, Annex I countries are obliged to fulfill the needs of vulnerable developing countries like Saudi Arabia in order to meet Annex I county commitments in the climate change convention. 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.

Climate change response measures will impact world oil demand by making fossil-fuel energy more expensive through certain policy measures adopted by Annex I countries (OECD & former Eastern European countries). This will have negative economic impacts as well as adverse impacts on Saudi Arabian welfare since lower incomes can lead to deteriorating socio-economic standards. For example, Saudi real GDP per capita has been decreasing for the past two decades from approximately $28,000/year in the early 1980s to approximately $9,300/year in 2000. This figure is projected to slump even further to $3,000/year by 2010. This is assuming a business-as-usual scenario. However, if climate change response measures were to be implemented by Annex I countries, this would further exacerbate this already tenuous socio-economic situation.

Actions by Annex I countries to reduce greenhouse gas emissions will have adverse impacts on a number of developing countries and considerably greater impacts on countries that are highly dependent on oil revenues, in particular Saudi Arabia. For example, 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. The Intergovernmental Panel on Climate Change (IPCC) in its Third Assessment Report has also projected lower oil demand and revenues for developing countries that are highly dependent on the export of fossil fuels. These economic losses will vary; however, Saudi Arabia, being the largest fossil-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.

Using the climate change convention and the Kyoto Protocol, developed countries have shown a trend of formulating policies and regulations that tend to target oil unfairly for environmental and energy security considerations. The use of effective flexibility mechanisms, (e.g. emissions trading and certain emissions credits and large CDM projects) agreed to in the Marrakech Accord, 7th Conference of Parties, can reduce adverse economic impacts on Saudi Arabia. These mechanisms will promote more cost effective compliance to certain energy policies in industrialized nations that mandate reduction in greenhouse gas emissions. This can include more efficient choices among oil, gas, and coal use globally. In addition, the use of carbon taxation based on carbon content as well as a 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.

Saudi Arabia will require assistance from Annex I countries to diversify its economy in order to adapt to potential climate change related energy 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 resource 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 developed countries for this will be a global benefit to energy security, the global economy, and the environment.

A well-diversified Saudi economy is in the best interest 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 for this will help ensure global energy security.
- Diversification would help Saudi Arabia develop towards a post fossil fuel age over the next several decades and thus may lead to the reduction of the highly greenhouse gas intensive nature of its economy.

- The marginal cost of greenhouse gas emissions abatement in Saudi Arabia (one of the highest carbon intensive economies) 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 fossil fuels while it imports manufactured goods and high tech equipment from certain Annex I countries. Since the fossil 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 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 under.

- 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
- Strong interest in the accession process to the World Trade Organization.

The areas in which Saudi Arabia would require assistance from the Annex I parties in order to diversify its economy are following: power generation, water resources, non-energy use of fossil fuels, and most importantly education.

SECTION 1:

NATIONAL CIRCUMSTANCES

Section 1: National Circumstances

1.1 Location, Topography, Climate and Demographic Characteristics

The Kingdom of Saudi Arabia comprises about four-fifths (80%) of the Arabian Peninsula, a land mass constituting a distinct geographical entity, bordered on the west by the Red Sea, on the south by the Indian Ocean and on the east by the Arabian Gulf.

The Kingdom itself, which occupies approximately 2,250,000 square kilometers (868,730 square miles) is bounded on the north by Jordan, Iraq and Kuwait; on the east by the Arabian Gulf, Bahrain, Qatar and the United Arab Emirates; on the south by the Sultanate of Oman and Yemen; and on the west by the Red Sea.

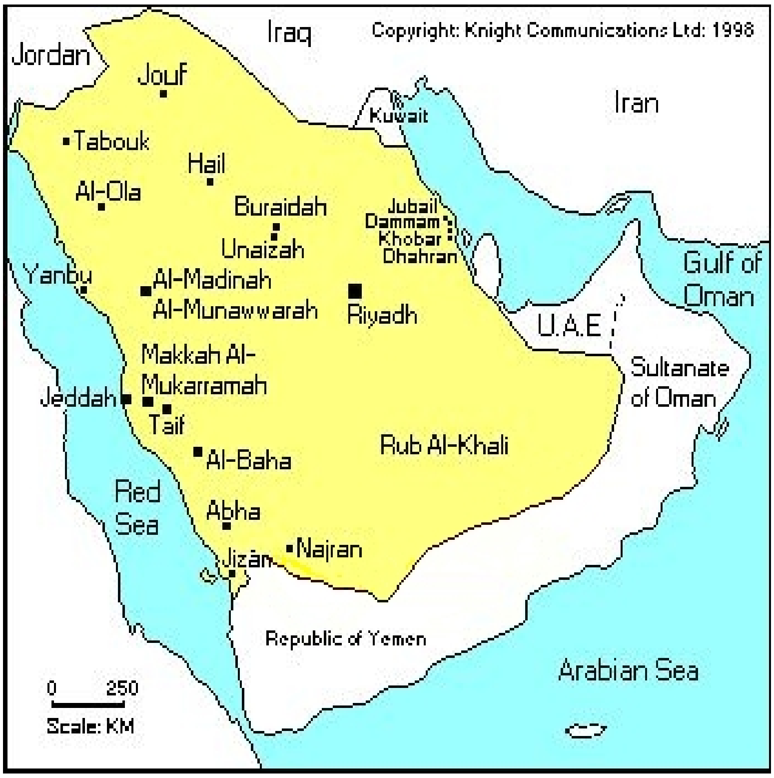


Figure 1.1 Map of Saudi Arabia and its boundaries

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

Located between Africa and mainland Asia, 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 was to become 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.

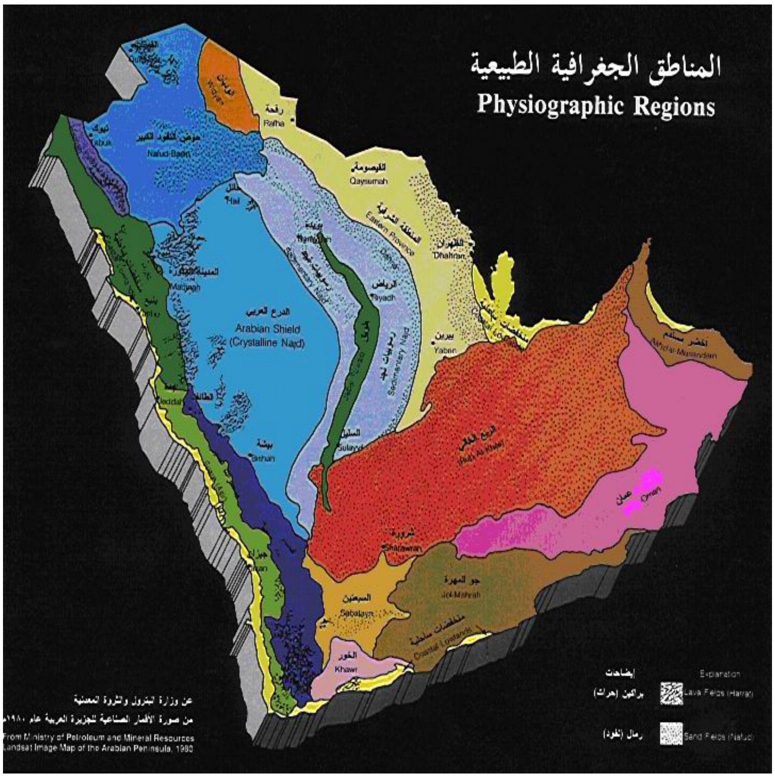


Figure 1.2 Physiography of Saudi Arabia

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

1.2 Water Resources

In a country with the geography and climate of the Kingdom, water is a natural resource which must be highly valued and conserved. The Kingdom draws its water from four main sources:

- Surface water, which is to be found predominantly in the west and south-west of the country. In 1985 (1405/06 AH), surface water provided 10% of the Kingdom's supply.
- Ground water, held in aquifers, some of which are naturally replenished, while others are non-renewable. In 1985 (1405/06 AH), ground water provided 84% of the Kingdom's supply but it is noteworthy that most of this water came from non-renewable aquifers.
- Desalinated seawater, a source of water production in which the Kingdom is now a world leader. Desalination technology, which also produces electricity, has reached an advanced stage of technology in the Kingdom and, by 1985 (1405/06 AH), this source was providing 5% of the Kingdom's supply.
- Reclaimed wastewater, a source of water which is still in its early stages but which offers scope for considerable expansion. In 1985 (1405/06 AH), the reclamation of wastewater provided 1% of the Kingdom's supply.

Water resources play a critical role in the Saudi development process, as the country is characterized by an extremely limited supply of fresh surface and ground water. The environmental aspects of water quality and conservation are intimately connected to the broader concern for management of the country's limited water resources. Water consumption is estimated at 16,230 million cubic meters/year (cm/y) of which 14,600 million cm are for irrigated agriculture and 1,700 million cm for domestic and industrial purposes. The Kingdom relies heavily on non renewable groundwater resources for agriculture.

There are no perennial rivers in the country; surface water results when rainfall is sufficiently intense to flood the wadis (seasonal water courses). Over 60% of the runoff occurs in the southwestern region, in an area comprising less than 10% of the country's total area. Several dams have been constructed in areas of high surface flows, aimed at utilizing the water flows in agricultural development or for recharging underground aquifers.

Groundwater is found in wadi beds, in weathered and fractured rocks, and in sedimentary rock areas, and constitutes a substantial portion of the country's water supply. The amount of non renewable deep groundwater reserves varies between 500,000 and 2,000,000 million cm and the amount of recharge and shallow groundwater aquifer is estimated at 3,850 million cm.

According to the Saline Water Conversion Corporation, in 2000 (1420/21 AH) there were 27 desalination plants producing 814 million cubic meters of desalinated water (more than 600 million gallons a day) and providing more than 70 per cent of the required potable water.

1.3 Agriculture

Only 2% of the country's land area is considered arable, with the chief agricultural crops including dates, wheat, barley, and fruit. Nonetheless, over the last two decades the total area of land under cultivation has nearly doubled and agricultural production has more than tripled. The Kingdom is currently self-sufficient in wheat and 75% self-sufficient in meat, milk, vegetables, and fruits.

1.4 Mineral Resources

In addition to its vast oil and gas reserves, the Kingdom is rich in mineral deposits. Three thousand years ago, the mine known as the Cradle of Gold (Mahad Al-Dhahab), some 180 miles north of Jeddah was a rich source of gold, silver and copper.

According to the Fourth Five Year Development Plan, gold had been discovered at some 600 sites around the Kingdom and a total of 29 prospects have been drilled. The Mahad Al-Dhabab gold mine was re-opened by Petromin with the intention of developing a high-grade underground gold mine with a process capacity of 400 tons of ore per day. This venture encouraged further exploration for gold elsewhere in the Kingdom.

Silver and base metal deposits (bauxite, copper, iron, lead, tin and zinc), as well as non-metallic minerals (bentonite, diatomite, fluorite, potash and high-purity silica sand) have all been discovered, attesting to the wealth that remains, still largely unexploited.

1.5 Oil and Gas Resources

The 1989 (1409/10 AH) Saudi Aramco study put the Kingdom's proven gas reserves at 177.3 trillion cubic feet, an increase of 25% over the last estimate. This figure remained little altered in 1993 (1413/14 AH) when the estimate, now expressed in cubic meters, was 5.2 trillion (approximately 4.2% of world reserves). According to the latest estimates (2001) the Kingdom's gas reserves stand at 219.5 trillion cubic feet (6.22 trillion cubic meters), approximately 4% of world reserves. According to the latest estimates (2001), the Kingdom's recoverable oil reserves now stand at 261.8 billion barrels. This figure represents an increase of 1.8 billion barrels on the 1993 estimate of 260 billion barrels. (An increase in recoverable reserves, despite the daily extraction of millions of barrels of oil, is made possible by the discovery of new oil fields and improved technology in exploiting existing field.)

Current estimates mean that Saudi Arabia has roughly 25% of the world's proven oil reserves.

In the early years of oil exploitation, natural gas from the oil fields was burnt off in gas flares. Conscious of the need to conserve its energy reserves, the Kingdom now gathers the natural gas (methane and ethane) emanating from the oil fields in the

Eastern Region in order to supply the vast industrial complexes at Jubail in the Eastern Region and Yanbu on the western side of the Kingdom. Today, almost all the natural gas at the Kingdom's disposal is effectively utilized.

As techniques for extraction improve and new reserves are found, it is estimated that the oil reserves of the Kingdom of Saudi Arabia will last for some 90 years.

1.6 Flora and Fauna

The stereotype of the Kingdom as a dry, barren desert devoid of almost all flora and fauna is far from correct. Of course, both plants and animals have had to adapt to the rigors of the climate but, for those who look, there is a wealth of wildlife to be discovered, even in the desert regions - and there are parts of the Kingdom, notably the Southern Region, which enjoy ample rainfall and support a wide variety of crops as well as plants and animals.

1.7 Desertification

In terms of area, nomadic and semi-nomadic pastoralism constitutes the major form of land use in Saudi Arabia. Most of the rangelands are extremely fragile due to aridity, soil instability, soil infertility, and wind erosion. In addition, the increasing number of animals and the tendency to stay too long at the same location is contributing to the deterioration of the lands. The problem is being complicated by the provision of supplemental feed and water to livestock which serves to further induce overstocking of rangelands. It is estimated that as many as 70,000 sq. km of rangeland are currently in danger of desertification from removal of shrubs and trees, overgrazing, and surface soil destabilization through inappropriate agricultural practices and resulting erosion.

Figure 1.3 Asir National Park

1.8 Education

Mindful of the need to ensure that the Kingdom's population should be equal to the challenges of the developmental process, the government has devoted vast resources to a program covering primary, secondary and higher levels of education. All of the Kingdom's Development Plans have taken into account the educational aspirations of the Saudi people, providing free education to all. The educational system has been continuously and systematically expanded to accommodate the ever-growing demand for educational services. Through this investment, the Kingdom has been able to guarantee equality of opportunity for all and to ensure that the Kingdom's need for an educated and trained national workforce to carry forward the Kingdom's future development can be fulfilled.

1.9 Health

Of all the benefits that have accrued to the citizens of the Kingdom, none is greater than the provision of free healthcare of the highest standard, a provision extended to all those who visit the Kingdom in pilgrimage.

The decision to embark on plan of inclusive healthcare provision was taken by King Faisal who initiated a massive hospital building programs.

The following statistics, collated for 2001, illustrate the progress made in healthcare sector in the Kingdom.

Table 1.1 Healthcare Statistics

Provision	Number
Hospitals	324
Beds	46,622
Doctors	31,983
Nurses	67,421
Assistant Health Personnel	38,519

1.9.1 Primary Healthcare

By 1988, there were more than 2,000 primary healthcare centers serving the community at local and regional level. By 1989, that figure had risen above 3,000. By 1995, the figure stood at 3,300. By 1999, the figure stood at 3,506.

1.10 Social Services

The Fourth Five Year Development Plan (1405-1410 AH: 1985-1990) set out clearly the philosophy behind the Kingdom's extensive social services program.

The social services are designed to redress existing imbalances, to improve living standards and the quality of life of the population, to stimulate citizen participation in community development activities, and to provide remedial care and assistance for the disabled and the deprived.

There are a number of social service agencies whose task it is to remedy social problems, many of which are created by the process of social development itself.

The government takes the view that poverty and deprivation are not necessarily due to the failure of individuals to meet their own needs. Most of these problems are a result of broader external conditions in society as a whole, and will not solve themselves. Public and private interventions are necessary to improve the conditions of the individual and the community. The Social Services agencies will continue to pay attention to the development of Saudi society, to assist in improving the standard of living, and to take steps to redress some of the social imbalances which have become salient during this period of rapid economic change.

Amongst the social services provided by the state are wide-ranging programs designed to improve living conditions for the population and to smooth the processes related to the rapid transformation of the socio-economic system. There are a number of social rehabilitation, care and remedial services, designed to assist the physically or mentally disadvantaged, to protect vulnerable members of society, and to deal with such problems as juvenile delinquency. Special attention is given to raising the living standards of the poorest sections of the community, particularly in the villages and the less developed districts of the towns and cities.

1.11 Economy

The Government, through the public sector, plays a major role in the Kingdom's industrial activity but, in recent years, the private sector has, with the Government's encouragement under the Kingdom's system of free enterprise, become increasingly involved in and responsible for industrial development and diversification.

Following the peak years of oil revenues in 1980/81 - 1982/83 (1400/01 - 1402/03 AH), it became necessary to undertake a very considerable downward adjustment to the government's level of expenditure. At the same time, the economy as a whole had to come to terms with more modest circumstances.

The most remarkable feature of this process is the relative ease with which both the government and the private sector came to terms with the new circumstances. This is not to say that the process has not been difficult, demanding, even painful. But it is true that a decline in revenues which could have destabilized other economies has been taken as an opportunity to consolidate past achievements and to engender a more commercially realistic and efficient approach to all types of venture.

During the last twenty years, Saudi Arabia has witnessed two distinctive phases in its economy; a period of rapid expansion from 1970 to 1980 with an annual GDP percentage increase of 10%, followed by a phase of economic contraction from 1980 to 1990 with an annual GDP of 3.2% due principally to a decrease in oil prices; in 1992, the GDP was US$110.7 billion. The GDP is distributed among sectors as follows: agriculture 7%; industry 52%; and services 41%. The economy relies heavily on the oil industry; proven recoverable oil reserves in 1993 were 260 billion barrels. The country has 25% of the world's proven oil reserves together with large amounts of associated and non-associated gases, estimated at 183 trillion cubic feet; however, diversification into downstream products in the petroleum industry and into other manufactured and agricultural products is considered an important economic development strategy. Other commercially developed resources include gas, gold, copper, iron and building materials.

1.11.1 Economic Indicators

General Economic Indicators for the Kingdom of Saudi Arabia (percentages) are listed as follows:

Table 1.2 GDP Growth in Saudi Arabia

Year	1996	1997	1998	1999	2000	2001
GDP Growth at constant prices	590,748	617,902	546,648	603,589	706,657	698,403
Percentage Change (%)	-	4.6	-11.5	10.4	17.1	-1.2

1.12 Industrial Development

A key element in the Saudi Arabian government's economic strategy is industrial diversification, a process which has as its primary objective the reduction of the Kingdom's dependence on oil revenues. To this end, the government has encouraged the development of a wide range of manufacturing industries.

The government has provided a range of incentives to encourage the private sector to participate in the Kingdom's industrial effort. Eight industrial estates provide private Saudi manufacturing companies with the necessary infrastructure and services at a very low cost. Credit facilities on generous terms are readily available for such enterprises.

The Kingdom has adopted a free market economic model. The financial, industrial and trade sectors of the economy have made rapid progress, enabling the private sector to play an increasingly important role in the development and diversification of the economy, especially in the fields of construction and farming.

SECTION 2:

NATIONAL INVENTORY OF ANTHROPOGENIC EMISSIONS

Section 2: National Inventory of Anthropogenic Emissions

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 — base year 1990*. This inventory has been prepared in response to the Kingdom's commitment to UNFCCC to submit its National communication which would include national inventory of anthropogenic emissions and removals by sinks of greenhouse gases for Saudi Arabia according to the 1996 Guidelines[1] of the Intergovernmental Panel for Climate Change (IPCC, 1997).

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. 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. The Intergovernmental Panel on Climate Change (IPCC, 1997) has standardized methodologies for the development of national inventories of greenhouse gases by the countries signatory to UNFCCC.

2.2 Objectives

As mentioned above, the overall objective of this section is to present, for Saudi Arabia, a national inventory of anthropogenic emissions by sources and removal by sinks of greenhouse gases that are not controlled by the Montreal Protocol — base year 1990. The greenhouse gas inventory included the direct greenhouse gases; namely, carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). The process of developing this National Inventory passed through the following 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 1996 IPCC Guidelines;
- Preparation of a list of government ministries and other governmental, semi-governmental, 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);

[1] The 1996 IPCC Guidelines refer to the Revised 1996 IPCC Guidelines (1997) in this report.

- Tabulation of the collected data in the 1996 IPCC prescribed format;
- Estimation of greenhouse gas emissions/sinks based on methodologies recommended by the 1996 IPCC Guidelines; and
- Development of the report and summary of total anthropogenic emissions of greenhouse gases and their removals by sinks.

2.3 Data collection and tabulation

2.3.1 Preparation of Questionnaires

The 1996 IPCC Guidelines were utilized in the preparation of questionnaires. The 1996 IPCC 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 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 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.

2.3.2 Selection of Target Organizations/Companies

Based on the input data requirements for calculating greenhouse gas (GHG) emissions for each sector and sub-sector given in the 1996 IPCC Guidelines, a list of potential government departments, private organizations, and industrial companies, from which such information should be available, was prepared. In preparing this list, various government reports, the Saudi Industrial Directory (MIE 1995a, 1995b, 1995c), IIT (1993), SCECO Reports, SWCC Reports, Ministry of Finance and National Economy Reports, Saudi Arabian Statistical Year Books, Kompass Register (1997a, 1997b), and individual company reports were consulted. Literature sources available at the libraries of universities and institutes such as King Fahd University of Petroleum and Minerals and King Saud University, King Abdulaziz City for Science and Technology (KACST) were also consulted.

2.3.3 Inventory Input Data Sources

Input data for the inventory were collected for the period covering 1990 through 1996. However, greenhouse gas emissions were estimated for the base year, 1990, as stipulated in IPCC guidelines.

Custom-made questionnaires were prepared and mailed to each of the listed organizations/companies. The organizations/companies that did not respond within two months of the mailing of the questionnaire were sent reminders. A second reminder was sent to those organizations/companies which did not respond to the earlier requests. The inputs from these organizations/companies were utilized in the calculations of greenhouse gas emissions.

In addition to the questionnaires, various other sources of information were consulted. A complete list of these sources is included in the list of references.

2.3.4 Input Data Collection and Tabulation

The data collected through questionnaires and from other sources were entered into a database. This information was sorted for individual activities for which 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 obtain the missing data.

2.3.5 Selection of Emission Factors and Methodologies for Greenhouse Gas Emissions

In addition to the basic inventory input data, emission factors were needed to calculate greenhouse gas emissions. These emission factors were adopted from the 1996 IPCC Guidelines. Additionally, where more accurate (than the default emission factors suggested in IPCC Guidelines) country-specific information was available, new emission factors were developed and adopted for this study. The calculation procedures for the new emission factors are discussed in appropriate sections of the main report.

Calculation methodologies in the 1996 IPCC Guidelines were followed in estimating greenhouse gas emissions for this study. Calculations for estimating greenhouse gas emissions are presented in the worksheets given in the appendices of Volume II (Part II) of the main report.

2.3.6 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 1996 IPCC Guidelines provide a general table for relative uncertainties associated with emission factors and activity data for CO_2, CH_4 and N_2O emissions.

Uncertainties in emissions estimation basically comes from two major sources: input data and the 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 comes from the fact that the default values provided in the IPCC Guidelines (1997) were established for a certain group of activities that comprises a number of processes. The nature of a group of activity 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 sources and/or sinks 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 can not be quantified precisely because the uncertainties associated with the interpolation and/or averaging procedures also depends on the quality of the relevant data including accuracy.

2.3.6.1 Input Data

The raw data provided by the government organizations were considered to be accurate while the uncertainty of the raw data supplied by the private sectors were considered to be accurate in some cases or vary within 5% 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.

2.3.6.2 Emission Factors

The uncertainties associated with the emission factors used in this study were taken from the IPCC Guidelines (1997) and ranged between 5 and 10%.

2.3.6.3 Overall Emissions Estimation

The overall uncertainty of CO_2 and CH_4 emissions were estimated according to the 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.

2.3.7 Organization of the Section

This study was prepared in accordance with the 1996 IPCC Guidelines for estimating a national inventory of greenhouse gases (IPCC 1997a, 1997b, 1997c). The major sectors considered were as follows:

- Energy
- Industrial processes
- Agriculture
- Land-use change and forestry
- Waste

The methodologies for estimating greenhouse gas emissions from the "Solvent and Other Product Uses" sector have not been developed yet (IPCC, 1997). Therefore, greenhouse gas emissions from this sector were not considered in this report.

The main study is organized in two volumes. Volume I present the methodologies and estimates of greenhouse gas emissions. Volume II contains the input data that were used in developing the inventory (Part I). Part I of Volume II also contains available raw data for the period 1991-1996 for future reference. The worksheets used in emissions calculations are presented in Part II of Volume II.

The sub-sectors and activities in each sector follow closely those recommended in 1996 IPCC Guidelines. The term ‘source categories’ refers to a major activity or a group of activities contributing 2% or more (selected arbitrarily) to the total emissions.

2.4 Summary of Overall Greenhouse Gas Emissions and Sinks

- CO_2 emissions in Saudi Arabia in 1990 were 140,958 Gg and CO_2 sinks were 15,240 Gg. As shown in Table 2.1, the energy sector contributed 90% of the total CO_2 emissions, followed by the industrial processes sector (8%) and the agriculture sector (2%). The major source categories contributing to these CO_2 emissions (contributions $\geq$2% of the total emissions) were electricity generation (26%), road transport (25%), desalination (15%), petroleum refining (10%), cement production (5%), cement industry (3%), petrochemical industry (3%), aviation (3%) and iron and steel production (2%) (Figure 2.1).

Table 2.1 Summary of 1990 Greenhouse gas emissions inventory for Saudi Arabia.

Source Sector	Quantity Emitted (Gg)		
	CO_2	CH_4	N_2O
Energy*	127,385 (90.4)**	87.6 (11)	0.9 (2.7)
Industrial processes	10,881 (7.7)	9.6 (1)	
Agriculture	2,692 (1.9)	88 (11)	30.7 (90.8)
Land-use change and forestry	-15,240*** (14.5)		
Waste		602 (77)	2.2 (6.5)
Total Emissions	**140,958**	**787**	**33.8**
Net Emissions**	**125,718**	**787**	**33.8**

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

Table 2.2 1990 Carbon Dioxide (CO_2) emissions from major source categories

Source Categories	CO_2 (Gg)	Percent of Total
Electricity generation	37,501	26
Road transport	35,139	25
Desalination (FC*)	21,098	15
Petroleum refining	13,923	10
Cement production	6,528	5
Cement industry (FC)	4,772	3
Petrochemical industry (FC)	3,769	3
Aviation-national	3,729	3
Iron and steel production	2,880	2
Others**	11,619	8
Total	**140,958**	**100**

* *Fuel Combustion*

** *Others include the following source categories:*

Field burning of crop residues (2,692 Gg)
Fertilizer industries (2,573 Gg)
Agriculture (1,643 Gg)
Ammonia production (1,457 Gg)
Residential (1,315 Gg)
Navigation-national (986 Gg)
Iron and Steel industries (528 Gg)
Waste management (FC) (253 Gg)
Other industries (116 Gg)
Railways (40 Gg)
Soda ash uses (8 Gg)
Limestone use (7.5 Gg)

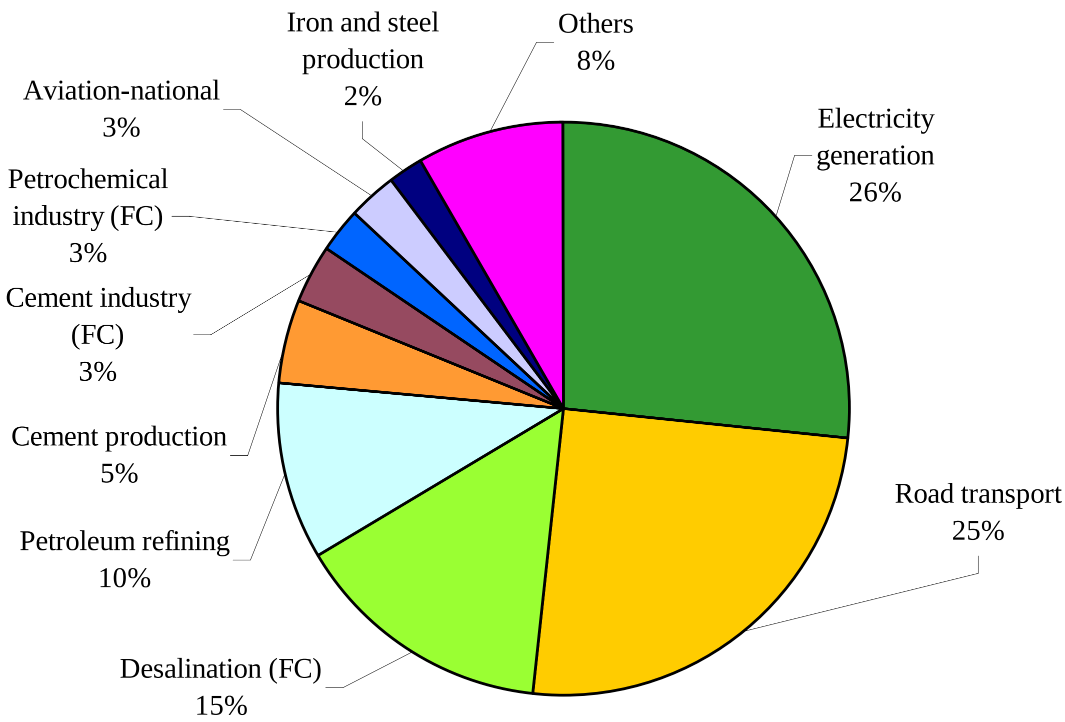


Figure 2.1 Relative contributions of major source categories to 1990 CO_2 emissions of 140,958 Gg

Table 2.3 1990 Methane (CH_4) emissions from major source categories.

Source Categories	CH_4 (tons)	Percent of Total
Solid waste management	597,588	76
Enteric fermentation	74,558	9
Oil & gas processing, production and transport (FE*)	46,759	6
Oil refining (FE)	29,520	4
Others**	38,574	5
Total	**786,999**	**100**

* *Fugitive Emissions*

** *Others include the following source categories:*

Chemicals production (9,589 tons)	*Aviation-national (440 tons)*
Manure management (8,540 tons)	*Petroleum refining (310 tons)*
Road transport (6,624 tons)	*Agriculture (FC) (199 tons)*
Field burning of crop residues (4,895 tons)	*Oil & gas exploration (FE) (123 tons)*
Wastewater Management (4,243 tons)	*Residential (118 tons)*
Electricity generation (1,328 tons)	*Navigation-national (66 tons)*
Desalination (FC) (1,182 tons)	*Waste management (FC) (35 tons)*
Man. industries and construction (880 tons)	*Railways (2.7 tons)*

- CH_4 emissions were 787 Gg. The waste sector contributed 77% of the total CH_4 emissions followed by the agriculture (11%), the energy (11%), and the industrial processes (1%) sectors. The major source categories contributing to CH_4 emissions ($\geq$2% of the total emissions) are shown in Figure 2.2.

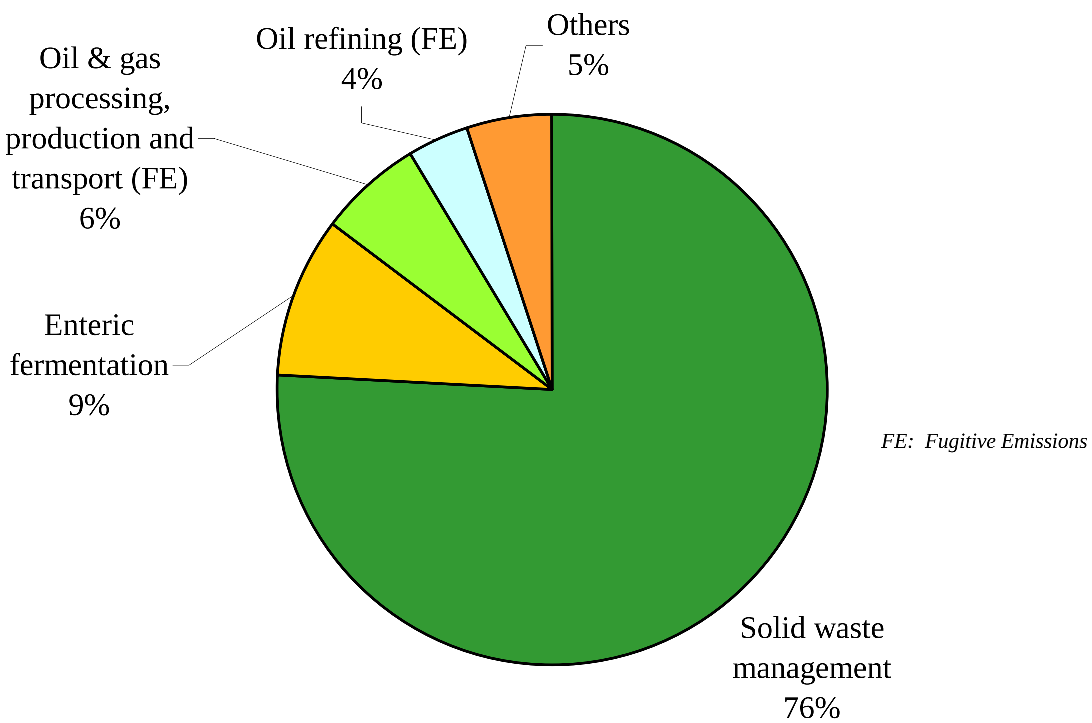


Figure 2.2 Relative contributions of major source categories to 1990 CH4 emissions of 787 Gg

Table 2.4 1990 Nitrous Oxide (N_2O) emissions from major source categories

Source Categories	N_2O (tons)	Percent of Total
Agricultural soils	23,586	69
Manure management	6,983	21
Human sewage	2,246	7
Others*	980	3
Total	**33,795**	**100**

* *Others include the following source categories:*

Road transport (298 tons)
Electricity generation (249 tons)
Aviation-national (121 tons)
Desalination (FC) (111 tons)
Field burning of crop residues (92 tons)
Petroleum refining (44 tons)
Man. industries and construction (39 tons)
Agriculture (FC) (13.4 tons)
Navigation-national (8 tons)
Residential (FC) (2.4 tons)
Waste management (FC) (2 tons)
Railways (0.3 tons)

- N_2O emissions were 33.8 Gg. The agriculture sector was the major contributor with 91%, followed by the waste (6%) and the energy (3%) sectors. Major source categories contributing to N_2O emissions ($\geq$2% of the total emissions) are shown in Figure 2.3.

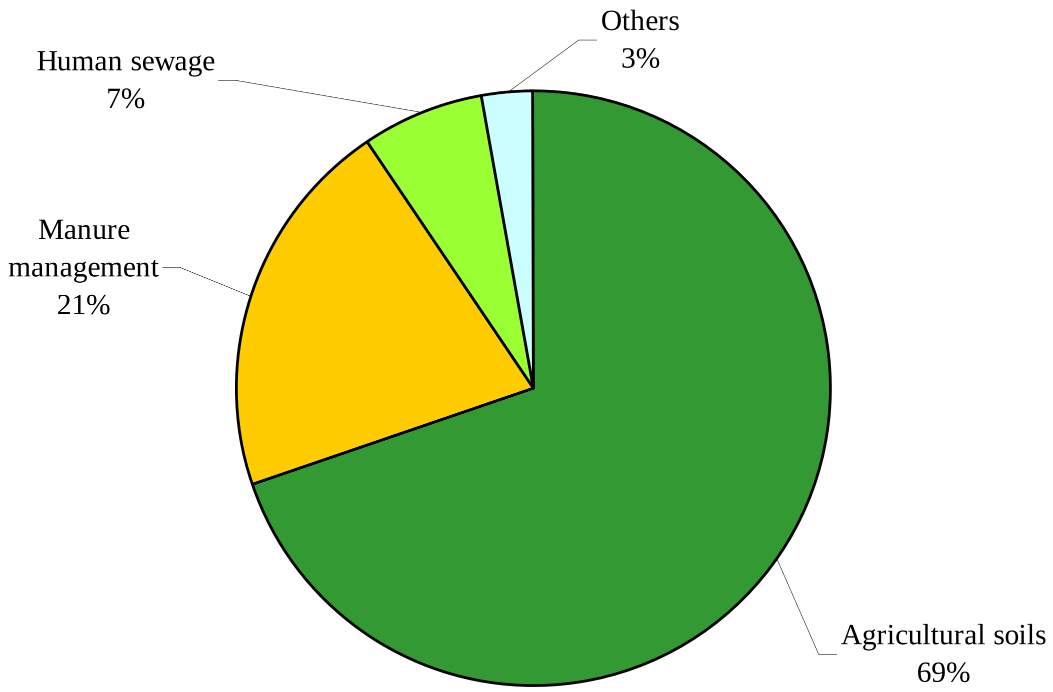


Figure 2.3 Relative contributions of major source categories to 1990 N_2O emissions of 33.8 Gg

2.5 Contributions of Major Sectoral Activities to 1990 GHG Emissions

2.5.1 Energy Sector

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.

2.5.1.1 Emissions from Fuel Combustion Source Categories

- Emissions from the **electricity generation** category were 37,501 Gg CO_2, 1.33 Gg CH_4, and 0.25 Gg N_2O. Crude oil combustion accounted for 43% of CO_2 emissions, followed by diesel oil (32%), and natural gas (25%). About 53% of N_2O emissions were contributed by the combustion of crude oil, followed by the combustion of diesel oil (40%).

- The petroleum refining category encompasses 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 13,923 Gg CO_2, 0.31 Gg CH_4, and 0.04 Gg N_2O. Fuel combustion associated with oil refining activities was the major contributor to CO_2 emissions, followed by those generated by the fuel combusted in the gas processing activities. The emissions of CH_4, and N_2O from different activities of petroleum refining followed trends similar to those of CO_2 emissions. Other activities, such as oil and gas production, oil and gas transportation, and oil and gas exploration contributed insignificantly to greenhouse gas 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 11,758 Gg CO_2, 0.88 Gg CH_4, and 0.04 Gg N_2O. Activities related to the cement industry were the largest contributors to most types of greenhouse gas emissions from the industrial processes sector.

- The road transportation category was the major source of greenhouse gas emissions. Automobiles emitted 35,139 Gg CO_2, 6.62 Gg CH_4, and 0.30 Gg N_2O. Gasoline combustion was the major contributor to all greenhouse gas emissions.

- The aviation category was divided into national and international bunker combustion sources. The greenhouse gas emissions from domestic combustion sources were 3,729 Gg CO_2, 0.44 Gg CH_4, and 0.12 Gg N_2O. The emissions from international bunker combustion sources were 493 Gg CO_2, 0.08 Gg CH_4, and 0.04 Gg N_2O. The emissions from the international bunker combustion for aviation category were not included in the 1990 greenhouse gas emissions inventory as per the 1996 IPCC Guidelines.

- The navigation category was divided into national and international bunker combustion sources. The emissions from domestic combustion sources were 986 Gg CO_2, 0.07 Gg CH_4, and 0.01 Gg N_2O. The emissions from international bunker combustion sources were 4,447 Gg CO_2, 0.29 Gg CH_4, and 0.04 Gg N_2O. The emissions from the international bunker combustion for navigation category were not included in the 1990 greenhouse gas emissions inventory as per the Revised 1996 IPCC Guidelines.

- The desalination plants combust crude oil, diesel oil, and natural gas. Emissions from fuel combustion in the desalination plants category were 21,098 Gg CO_2, 1.18 Gg CH_4, and 0.11 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 in estimating the greenhouse gas emissions (from fuel combustion only). Emissions from the agricultural category were 1,643 Gg CO_2, 0.20 Gg CH_4, and 0.01 Gg N_2O.

- Emissions from the solid waste and wastewater management category (from fuel combustion only) were 253 Gg CO_2, 0.03 Gg CH_4, and <0.01 Gg N_2O.

2.5.1.2 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** (87%) and accounted for about 76.40 Gg CH_4. Oil refining, gas processing, oil and gas production, transportation, exploration, and venting and flaring were considered in the above estimate. Approximately 53% of CH_4 emissions in this sector were generated from oil and gas processing, production and transportation related activities. Fugitive emissions from oil refining activities accounted for 34% of CH_4 emissions. All other activities accounted for about 13% of CH_4 emissions. Gas flaring and venting emitted 87% of total fugitive CH_4 emissions while the non-combustion emissions accounted for 13%. Saudi Aramco, one of the largest oil producing companies in the world, has installed a master gas collection network throughout the Kingdom's oil and gas fields. Instead of flaring, the gas is collected, processed, and utilized through the network. This capability has significantly lowered CH_4 emissions from the Kingdom's oil and gas fields.

2.5.2 Industrial Processes Sector

Greenhouse gas emissions from the cement production, iron and steel industry, limestone uses, glass manufacturing, soda ash uses, ammonia production, asphalt uses, petrochemical industries, and food/feed industries were considered under this sector.

- **Cement production** and the **iron and steel production** were the largest contributors to CO_2 emissions and collectively accounted for about 86% of the total emissions of 10,881 Gg. Limestone uses, ammonia production, and soda ash uses contributed 1,473 Gg to the total CO_2 emissions.

- **Chemicals production** was the sole contributor to CH_4 emissions of 9.59 Gg.

2.5.3 Agriculture Sector

Greenhouse gas emissions from livestock (enteric fermentation and manure management), agricultural soils, and field burning of crop residues were considered under this sector.

- 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 CH_4 emissions from enteric fermentation, manure management, and field burning of crop residues were estimated at 74.56 Gg, 8.54 Gg, and 4.90 Gg respectively. The N_2O emissions from manure management, agricultural soils (direct and indirect), and field burning of crop residues were estimated at 6.98 Gg, 23.59 Gg, and 0.09 Gg, respectively.

- Field burning of crop residues also emitted 2,692 Gg CO_2.

- For agricultural soils, as per the IPCC Guidelines, only N_2O emissions were estimated.

2.5.4 Land-Use Change and Forestry Sector

Changes in forest and other woody biomass, forest and grassland conversion to agricultural uses, and emissions or uptake of greenhouse gases by soils as a result of land-use changes were considered. As per the IPCC Guidelines, only emissions or sinks for CO_2 were estimated for this sector.

2.5.4.1 Sinks

- Changes in the forest and other woody biomass provided a sink for 93.00 Gg of CO_2.
- Forest and grassland conversion to agricultural uses converted 6,955 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) 8,192 Gg of atmospheric CO_2.
- The total sink from the land-use change and forestry sector was 15,240 Gg of CO_2.

2.5.4.2 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.

2.5.5 Waste Sector

Emissions from municipal solid waste management, and industrial, domestic and commercial wastewater management were considered in this sector. As per the IPCC Guidelines, only CH_4 and N_2O emissions were estimated.

- Solid waste management practices emitted 598 Gg of CH_4.
- Municipal and industrial wastewater handling emitted 4.24 Gg of CH_4.
- N_2O emissions from human sewage were estimated to be 2.25 Gg.

SECTION 3:

VULNERABILITY ASSESSMENT AND ADAPTATION MEASURES

Section 3: Vulnerability Assessment and Adaptation Measures

This section of the report represents a major effort undertaken by the lead authors. The conclusions of this section are highly qualitative and require further build up in the next National Communication. There is a need for capacity building and funding for major long term ecological studies and development of local predictive models in order to improve the quality of the findings of this section. Therefore the predicted impacts need to be viewed with consideration to high uncertainty of the conclusions. The following elements are examples of some of the main limitations in the analysis and results contained in different sections of the national communications, in particular the section on vulnerability assessment

- There was major lack of measured data and appropriate local and regional models to fully assess the local impacts of climate change.
- The report heavily relied on data and scenarios from the Intergovernmental Panel for climate Change (IPCC).
- Changes in the climatic conditions namely temperature, relative humidity and precipitation were based on global models, which don't take into account regional and national circumstances.

3.1 Climate Change Scenarios

3.1.1 Introduction

The process of assessing the vulnerability of certain sectors, such as agriculture, water resources and biodiversity etc, to climate change requires the construction of predicted visions of what the future climate would be under physically reasonable assumptions of greenhouse-gases concentrations. These visions, *the climate change scenarios*, are to be compared then with a picture representing a non-changed climate, *the baseline climate scenario*. The results of such comparison can then be used as indicators for the future impacts that might be experienced by the considered sector.

In this section, an overview of Saudi Arabian meteorological network, variations in meteorological conditions in different regions, steps involved in developing baseline climatic data, and development of climatic scenarios for Saudi Arabia will be described. The section will also cover statistical methods used in the trend analysis of selected meteorological parameters in the region. A comparative evaluation is presented to assess change in temperature, relative humidity and rainfall under different scenarios by comparing with the baseline data.

Within the effort of the Presidency of Meteorology and Environment (PME) for implementing Saudi Arabia's commitments to the UNFCCC, a study on the climatic change scenarios was conducted. Out of the 63 stations of the Saudi Arabian meteorological network, data from only 26 selected synoptic stations were utilized in this study. These selected stations with their coordinates in terms of latitudes and longitudes, elevation above mean sea level, and record lengths are listed in Table 3.1.1 and depicted in figure 3.1.1. The selection of 26 stations was dictated by the length

Table 3.1.1 Locations of meteorological stations used for climatic change scenario study

STATION NAME	WMO NO.	LATITUDE (N)	LONGITUDE (E)	ELEVATION (M)	STARTING date (M.Y)	OBS / DAY	REMARKS
Turaif	40356	31 41	38 44	852	04 . 1970	7	
Arar	40357	30 54	41 08	549	04 . 1970	8	
Guriat	40360	31 24	37 17	504	06 . 1984	8	
Al-Jouf	40361	29 47	40 06	669	1970	7	
Rafha	40362	29 37	43 30	449	1969	7	
Al-Qaisumah	40373	28 19	46 08	538	1969	8	
Tabuk	40375	28 22	36 36	766	1964	8	
Hail	40394	27 26	41 41	1002	05 . 1964	8	
Al-Wajh	40400	25 12	36 29	24	04 . 1964	8	
Al-Gassim	40405	26 18	43 46	647	1966	8	
Al-Dahran	40416	26 16	50 10	17	01 . 1955	8	
Al-Ahsa	40420	25 18	49 29	178	07 . 1982	8	(HOFUF)
Al-Madinah	40430	24 33	39 42	636	02 . 1956	8	
Riyadh -2	40437	24 56	46 43	614	11 . 1983	8	K. K. I. A.
Riyadh -1	40438	24 43	46 44	620	01 . 1952	8	OLD
Yenbo	40439	24 08	38 31	10	05 . 1966	8	
Jeddah	41024	21 43	39 11	17	01 . 1951	8	K. A. I. A.
Makkah	41030	21 26	39 52	240	01 . 1980	8	
Al-Taif	41036	21 29	40 33	1453	05 . 1960	8	
Al-Baha	41055	20 18	41 39	1652	09 . 1982	8	
Wadi Al-Dawasser	41061	20 26	44 41	701	03 . 1970	8	
Bisha	41084	19 59	42 38	1162	06 . 1969	7	
Abha	41112	18 14	42 40	2093	12 . 1977	8	
Khamis Mushait	41114	18 18	42 48	2056	09 . 1966	8	
Najran	41128	17 37	44 25	1212	09 . 1973	8	
Sharorah	41136	17 28	47 06	725	09 . 1970	7	
Gizan	41140	16 54	42 35	7	01 . 1963	8	

and continuity of their meteorological records. In identifying the climatic baseline period, the best compromising (records wise) selection is found to be a twenty six years period, from 1978 to 2003. Data were retrieved from the computer of the Scientific Information and Documentation Centre (SIDC) of PME. It consists of the monthly mean values of the sea level pressure, surface air temperature and humidity, total rainfall and the average number of rain days. Upon inspection of the collected data, few missing or erroneous values were found. These were treated and adjusted by applying the WMO accepted statistical methods in estimating missing data, and supported by a graphical interpolation. A complete data set of the selected baseline period was copied into a CD-ROM and kept as database for any subsequent climate change studies.

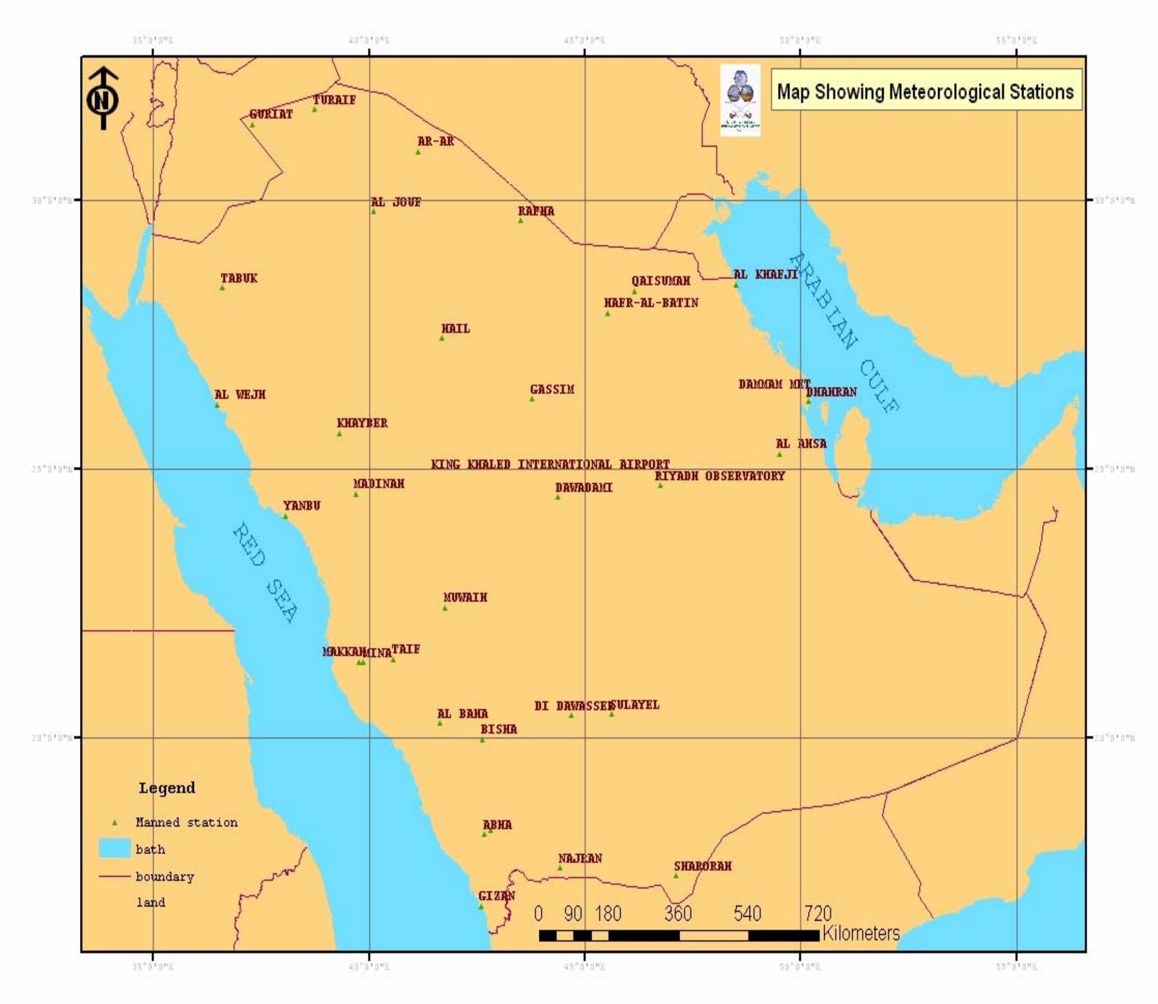


Figure 3.1.1 Manned synoptic meteorological station in Saudi Arabia

3.1.2 Baseline Climate conditions

Saudi Arabia is a vast country with an estimated area of 2,250,000 km^2. Its climate varies from one region to another not only because of its vastness, but also due to the influence of the significant variation in its topography, and prevailing meteorological systems. A comprehensive description of climate cannot be produced without considering these factors.

Map showing various types of Kingdom's terrain was obtained (figure 3.2.2) showing the coastal pains, plateaus, sandy deserts and the western heights of the country. The southern part of southwestern heights is the most significant topographical feature of the Kingdom, having peaks in access of 3,200m.

Charts of the seasonal average sea level pressure are drawn for the Kingdom from which the synoptic systems affecting the region were recognized. The Kingdom is greatly influenced by the extension of the “Siberian high” to the northern, central and eastern parts, and the extension of the “Sudan low” to the southwest and the west in winter. The Kingdom is almost totally dominated by the extension of the “South west Indian monsoon” and the developed “Saudi Arabian Summer heat low” in summer. Spring and autumn are transitional seasons; during spring e.g., the prevailing pressure system in winter undergoes changes into the pressure pattern of summer, and vice versa during autumn.

Three climate parameters were selected to describe the general characteristics of the climate in Saudi Arabia during the baseline period. These are: surface air temperature, precipitation and humidity. The first two parameters are commonly used in all climate change studies. The humidity parameter however, is not that common, but in a dry country like Saudi Arabia, where desert shrubs and trees, depend vitally on the atmospheric humidity for their survival; the consideration of the future trend of this parameter became quite obvious. Analysis of the annually and seasonally averaged values of these three parameters were carried out and displayed in a series of isoclines charts. The detailed characteristics of the Kingdom climate were then deduced from these charts as briefly discussed in the following paragraphs.

The climate of Saudi Arabia is generally characterized by a high surface air temperature, except on the northern edges of Al – Nafud basin and in Al Asir heights. The warm period is usually from April through September, but the variation in the monthly mean temperature is greater in the interiors than along the coastal areas. As shown in the isothermal chart of the seasonal and yearly averaged temperature (Figures 3.1.2 and 3.1.3), there is a systematic increase in temperature as moving southward to Rub Al Khali. Temperatures at the western coasts are the highest yearly average, and higher than those at the eastern coasts. Mild temperatures are prevailed on Asir heights with very strong temperature gradient at both sides of the mountain.

As for precipitation, which is clear from the seasonal and annual average precipitation contours (Figures 3.1.4 and 3.1.5), the rainfall in the Kingdom is generally low and occurs mainly during winter and spring, except in the southwest region, where rainfall is highest in the Kingdom. The rainfall varies from season to season and year to year. An interesting configuration of the rainfall distribution is the area of maximum yearly average total precipitation extending from Makkah in the west to Qaisumah in the northeast of the Kingdom.

In general, as may be concluded from the seasonal and annual average relative humidity isoline plots (Figures 3.1.6 and 3.1.7), the relative humidity is at its maximum in the month of January in winter and minimum during summer month of July (Figure 3.1.6). Relative humidity exhibits a maximum seasonal variation in the inland and at the eastern coast areas, but along the Red sea coasts, the relative humidity is high all year round (Figure 3.1.7).

The climatic zones of the country were identified according to these characteristics, and a choice of certain stations to represent these zones was made as follows:

1. Tabuk for the northern region
2. Sharourah for the southern region
3. Dhahran for the eastern coast
4. Jeddah for the western coast
5. Qassim for the central region, and
6. Khamis Mushait for the mountainous region.

3.1.2.1 Observed Climatic Trends during Baseline Period

Three approaches were used to determine trend in temperature, precipitation, and relative humidity.

(a) Annual average value
(b) Ordinary least square approach (OLS)
(c) Mann-Kendall Trend Analysis

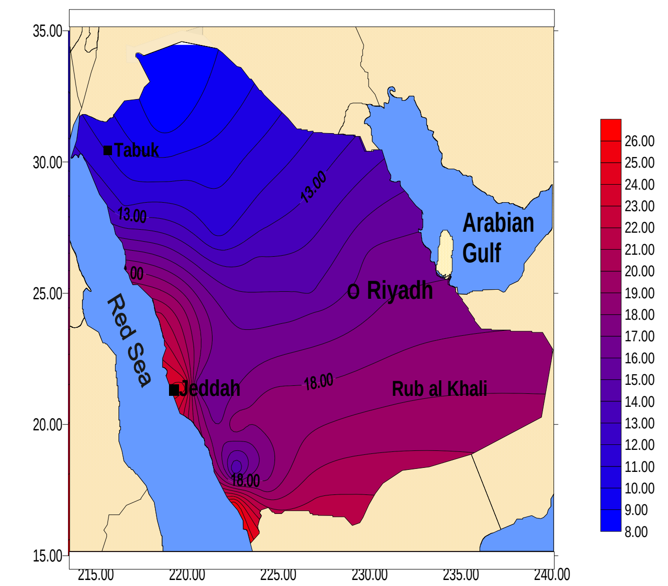
Method (a) is briefly discussed below, while methods (b) and (c) are discussed in the main report.

3.1.2.1.1 Annual Average value Approach

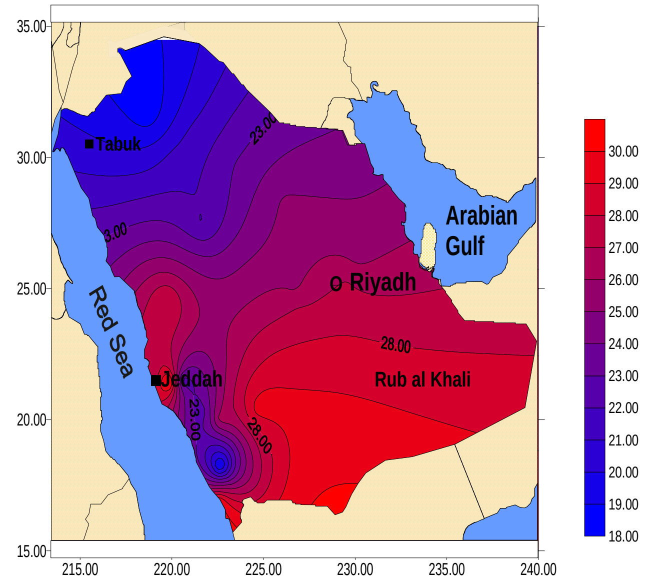
In order to reveal the climatic trends during the baseline period, the annual mean values of the three climate parameters were plotted in temporal graphs for the stations representing the identified climatic zones. The baseline period is divided into two equal parts of 13 years each, and the trends of parameters were judged from the difference of the mean values corresponding to these two sub-periods for all stations. Results were then plotted and analyzed in maps to show the spatial variations of temperature and precipitation trends in the Kingdom.

As can be seen from the pattern of temperature trends (figure 3.1.8), there is a general warming all over the Kingdom that varies from a minimum of about 0.15^0C (Tabuk, Makkah, Al Ahssa), to a maximum of about 0.75^0C (Khamis Mushait, Wadi Al Dawasser, Yanbu), with an average of 0.4^0C for the whole country. Apart from the odd large values at Yanbu and Dhahran, the pattern exhibits a clear systematic distribution with stronger warming area elongating over the interior part of the country (in access of 0.4^0C), and an area of weaker warming (less than 0.2^0C) along the western and eastern coasts, far north and far south.

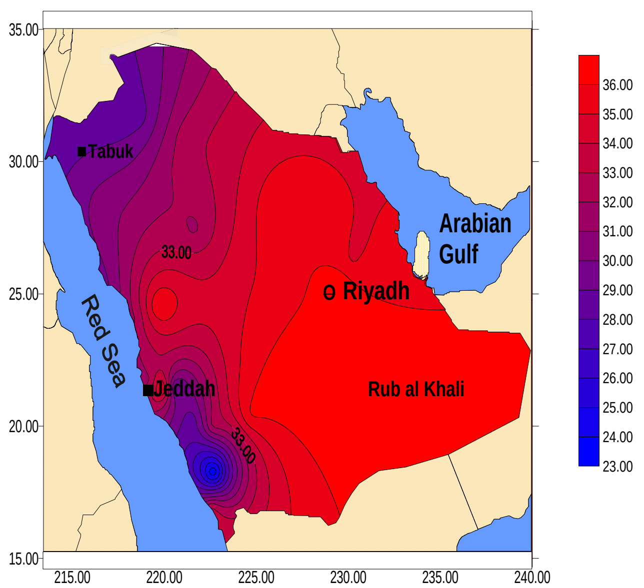
As for precipitation trends (figure 3.1.9), there is a vast area of rainfall deficit covering all northern parts of the Kingdom (as low as -40% in Tabuk and Arar). Another area that experienced a decrease in rainfall is the eastern slope of Asir mountains (-14% in Abha). Areas recording maximum increase of rainfall are: the western coast (92% in Jeddah), the central region (45% in Riyadh), the eastern coast (32% in Dhahran), and the southern region (109% in Sharourah).



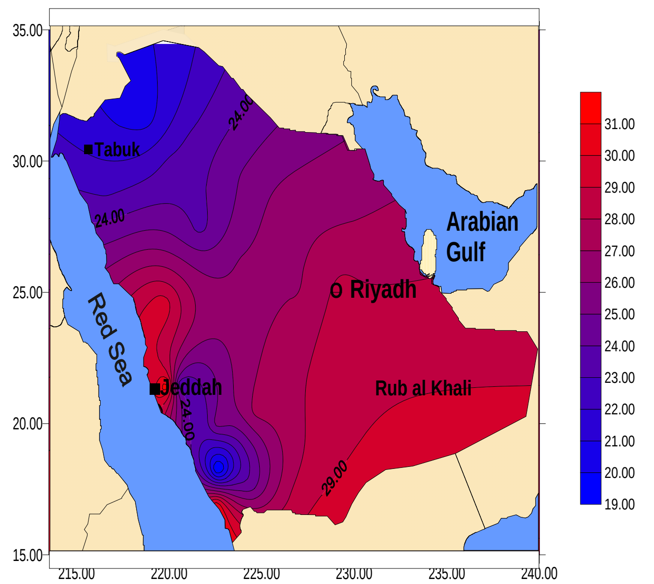
(a) Temperature – Winter



(b) Temperature- Spring

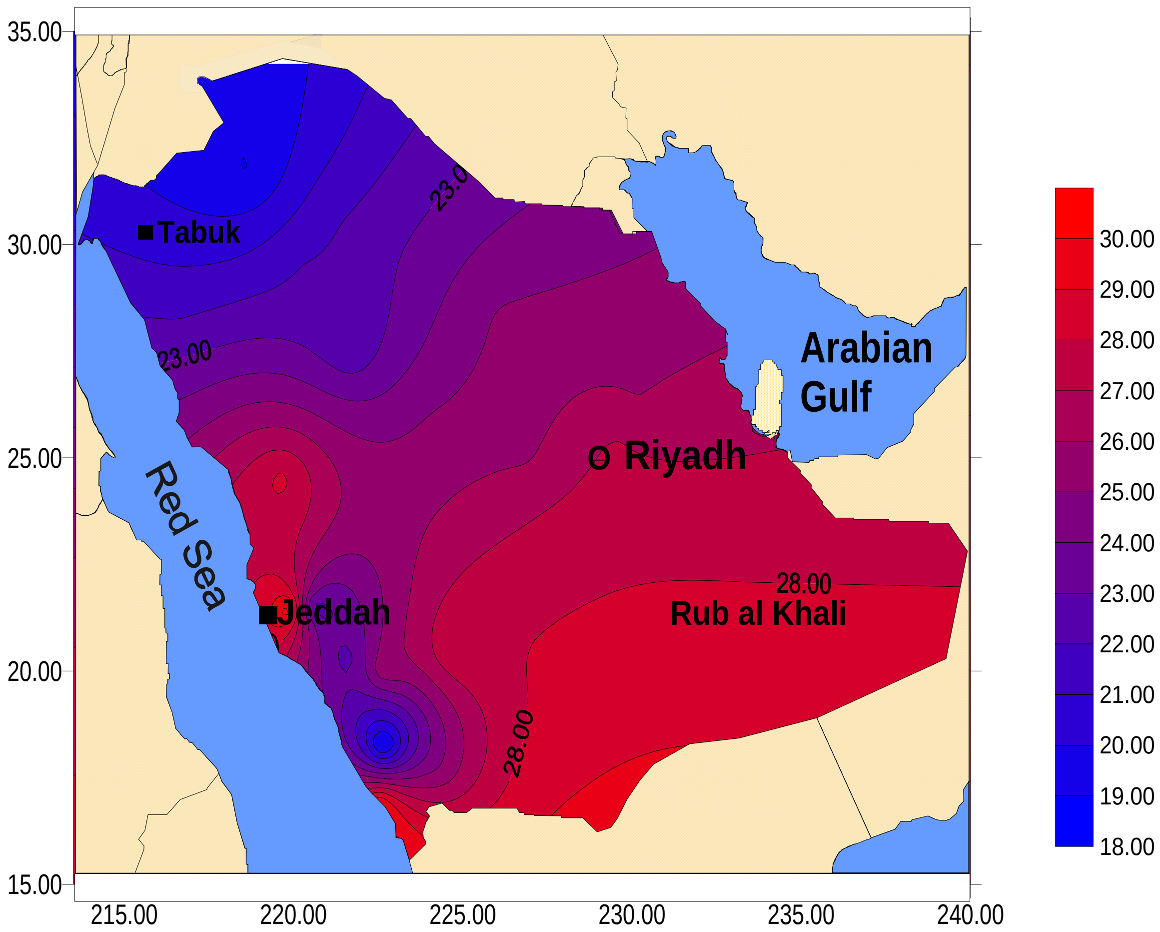


(c) Temperature – Summer



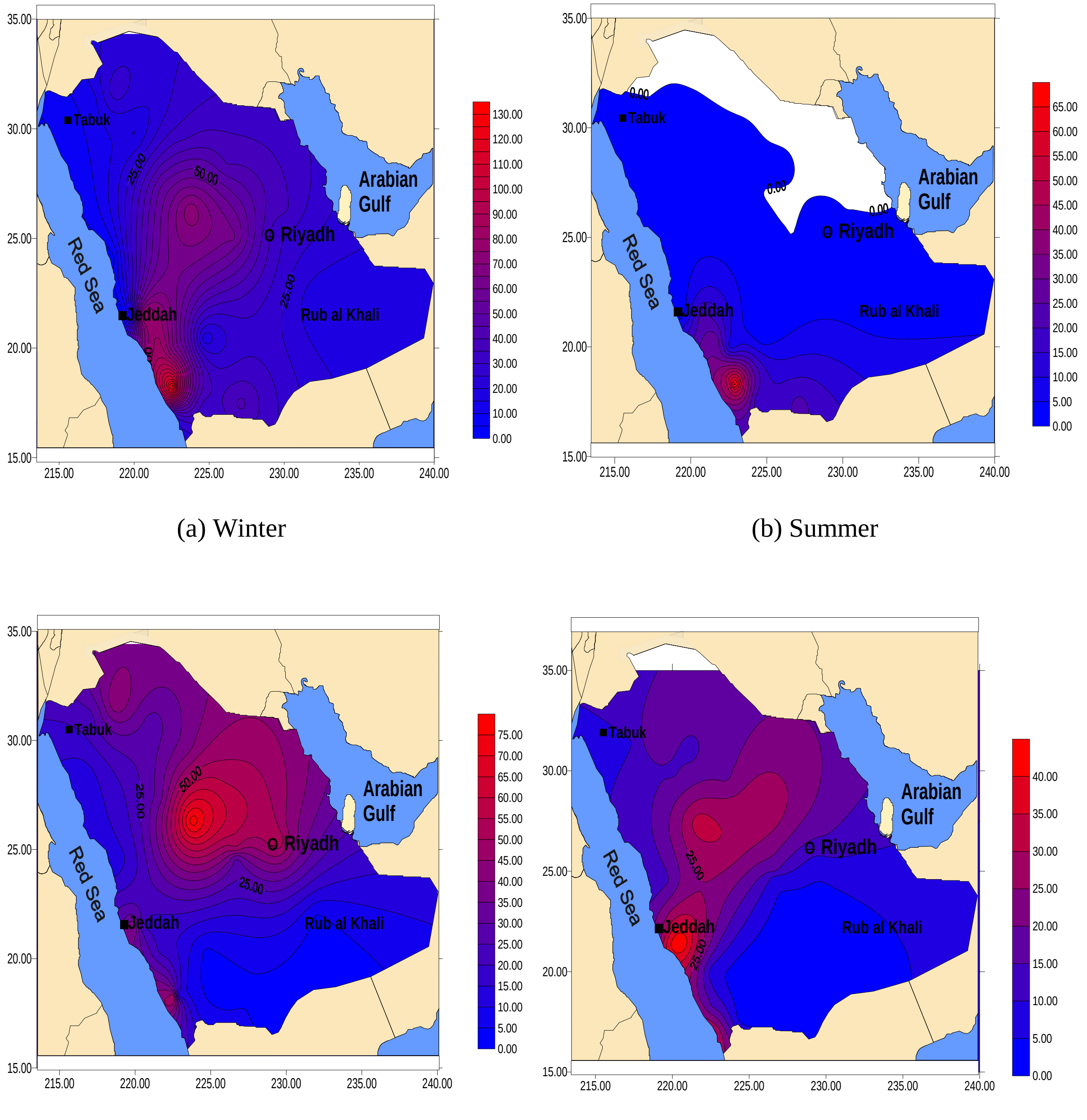
(d) Temperature Autumn

Figure 3.1.2 – Spatial variation in temperature in different seasons



(a) Average annual temperature

Figure 3.1.3 Temperature variations (1970-2003)



(a) Winter (b) Summer

(c) Spring (d) Autumn

Figure 3.1.4 – Seasonal spatial variation of precipitation in Saudi Arabia

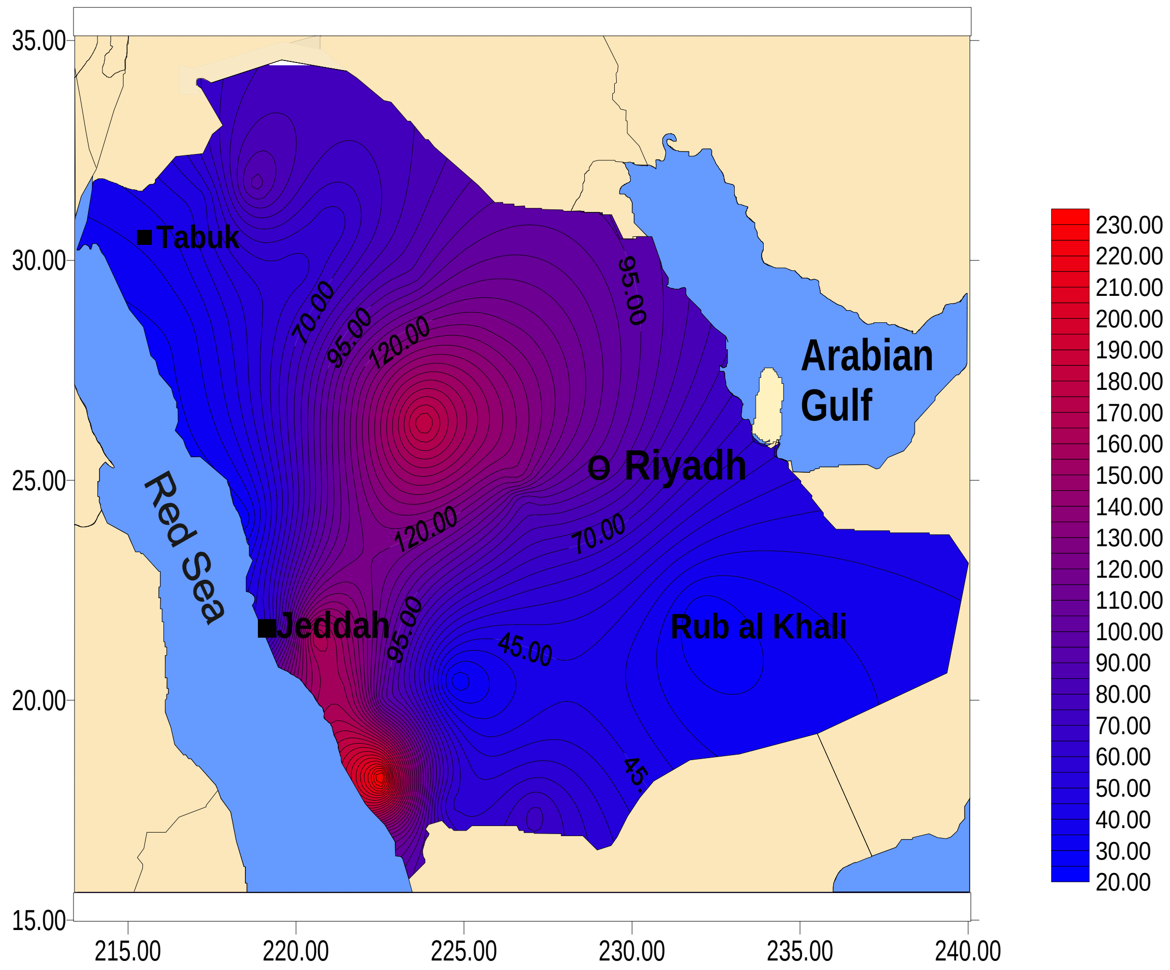
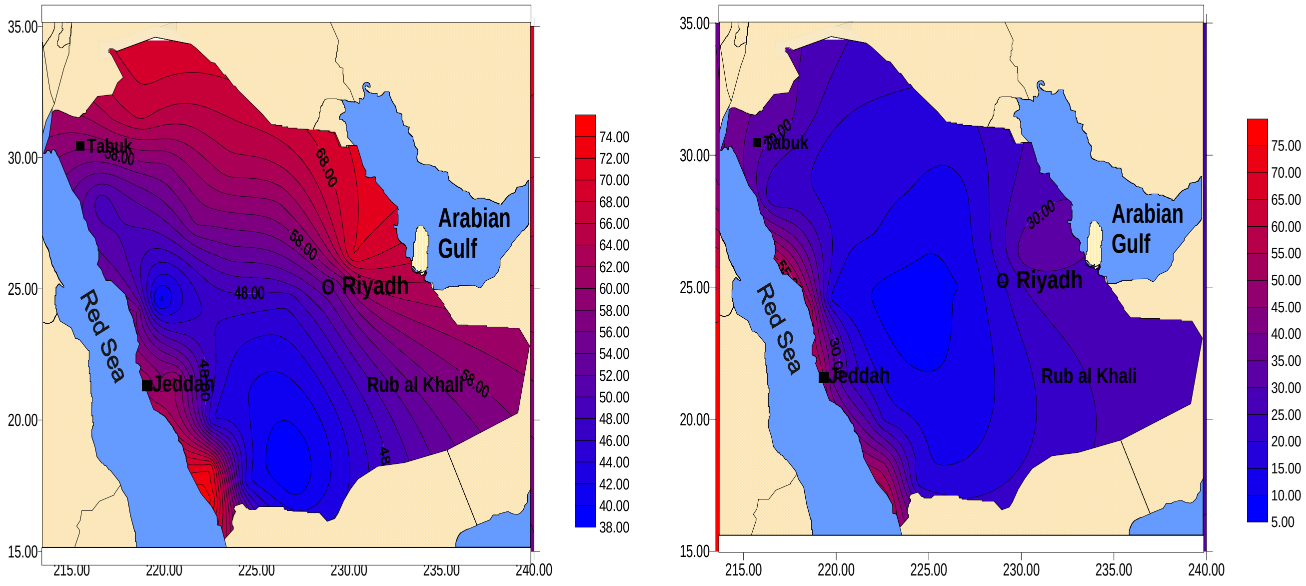


Figure 3.1.5 - Spatial variations in total yearly precipitation in Saudi Arabia



(a) January – Relative Humidity (b) July - Relative Humidity

Figure 3.1.6 Spatial variations in relative humidity in winter and summer

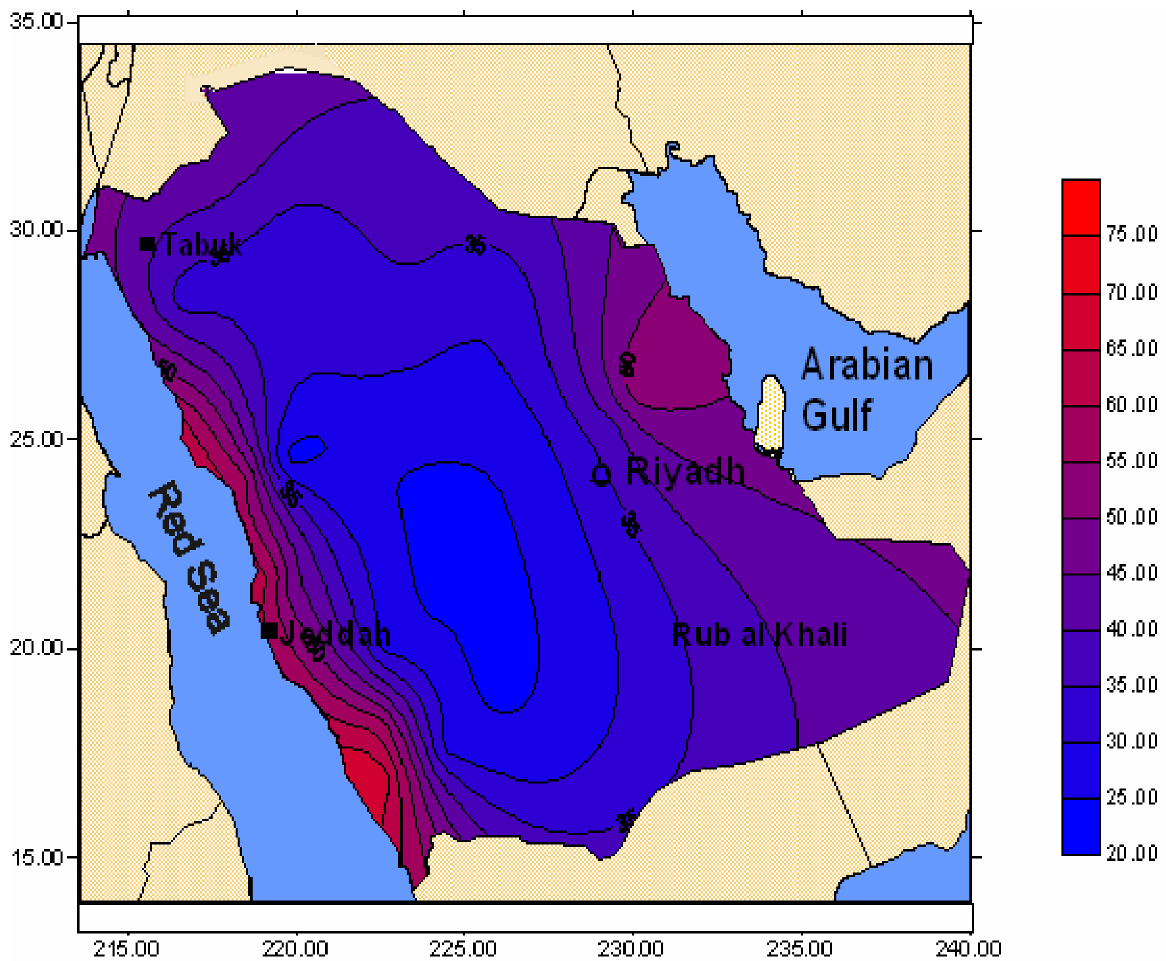


Figure 3.1.7 Yearly relative humidity spatial variation

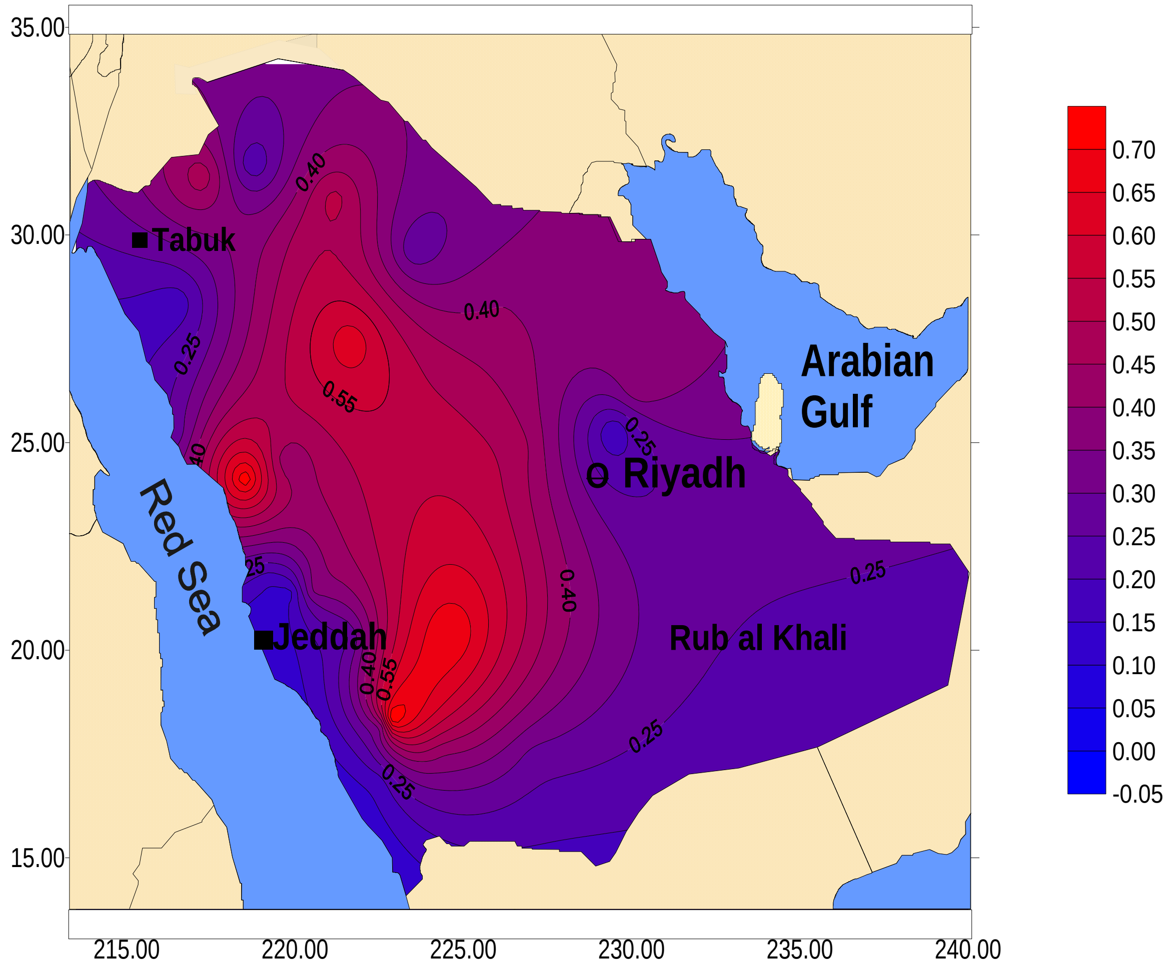


Figure 3.1.8 Change in temperature (1991-2003)

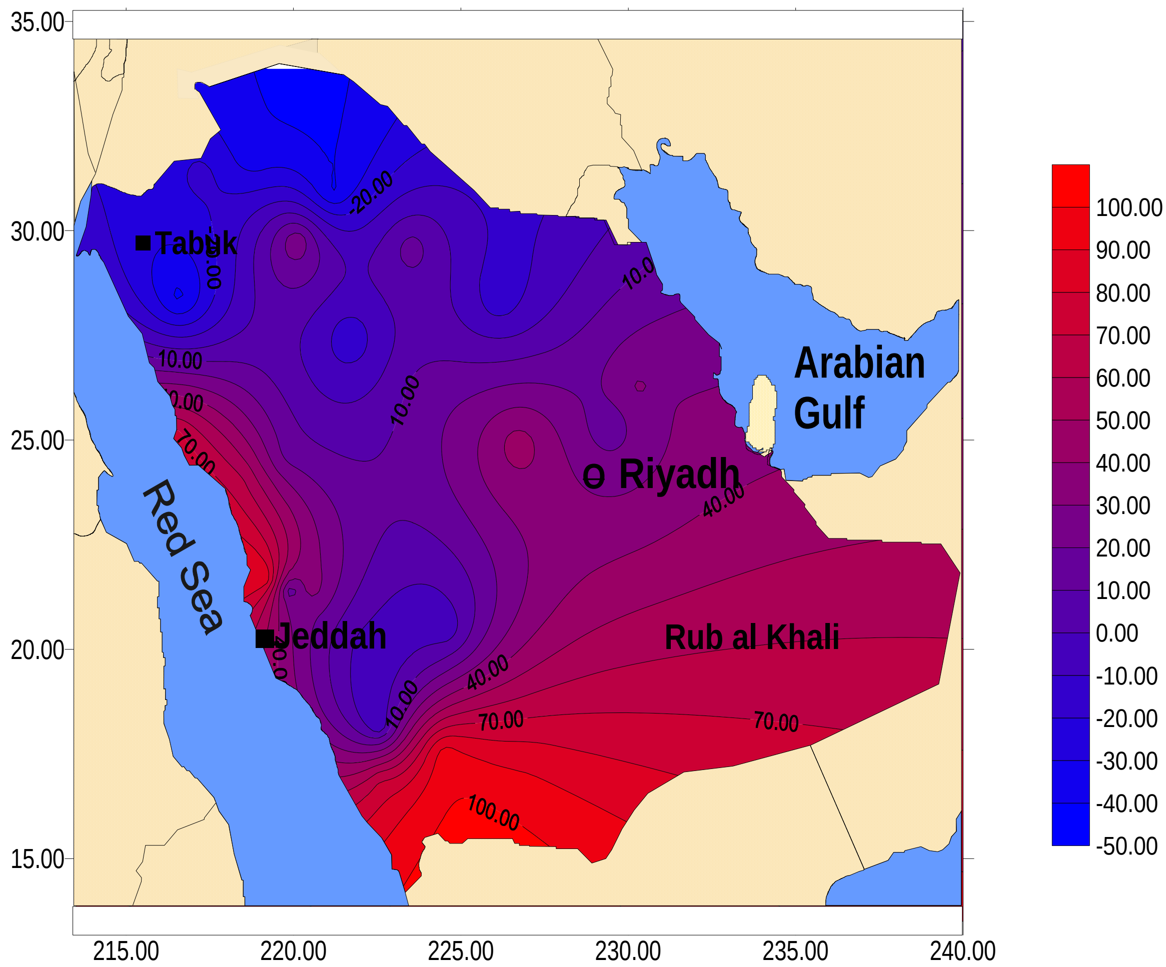


Figure 3.1.9 Precipitation trend change in percentage (1970-2003)

3.1.3 Climate Change Scenarios

Climatic change scenarios were developed to predict temperature, precipitation and relative humidity values in 2050 and 2100 using two different models. MAGICC was used for 2020-2050 prediction while predicted data by global models were retrieved from IPCC data base to predict for 2070-2100. These models are described below:

3.1.3.1 Application of MAGICC/SCENGEN

In creating the climate change scenarios for Saudi Arabia, software called MAGICC/SCENGEN (version 4.1, September 2003), originally developed by the Climate Research Unit at the University of East Anglia, U.K., was utilized.

MAGICC, a coupled gas-cycle/climate model, is the primary model that has been used in all IPCC assessments to produce projections of future global-mean temperature and global-mean sea level rise. The recent modifications to MAGICC were developed to update its science to that of IPCC Third Assessment Report (TAR). An important new feature in MAGICC-4.1 is the inclusion of climate feedback effects on its carbon cycle.

SCENGEN, a climate scenario generator, uses the output from MAGICC to produce spatial patterns of the changes in climate parameters from an extensive database of Atmosphere/Ocean General Circulation Models (AOGCM) data. The SCENGEN improvements allow, among other things, to produce area-average output for selected regions for direct input to the impact components of integrated assessment models.

The method of using MAGICC/SCENGEN begins by selecting the emissions scenarios. Out of the 47 scenarios available in MAGICC library (it includes now the Special Report of Emission Scenarios (SRES) having wider range of gases), two scenarios were selected: P50 as the "Reference" scenario, and WRE350 as the "Policy" scenario. P50, the median of SRES scenarios, is in use now instead of IS92a, which has been used with the old versions of MAGICC. IS92a scenario was used by many neighboring countries of Saudi Arabia such as Yemen, Sudan, Iran and others in their national communications. The policy scenario WRE350 is also a SRES scenario having a CO_2 concentration which stabilizes at 350 ppm in the year 2150. It should be mentioned here that the predicted global rise of sea surface level in the year 2041 was 11 and 14 cm for policy and reference cases respectively.

Output from MAGICC namely, global-mean time series of gas emissions, gas concentrations, temperature and sea level, for both reference and policy cases, were used to drive SCENGEN. In an initial trial run, all the 17 GCMs incorporated in SCENGEN library were used to produce seasonal and annual temperature (^{0}C) and precipitation (%) changes in the year 2041, i.e. 50 years from the central year of the adopted baseline period. The aim of this trial was to select, based on a thorough comparison of output with baseline climatic trends, the best single or combination of GCM models to fit Saudi Arabian climate peculiarities.

The output of SCENGEN comes out as an array (Latitude-Longitude) of 5 x 5 deg. grid for the whole globe. For the purpose of comparison and subsequent analysis, nine grid cells that cover the Kingdom territory were identified (figure 3.1.10). The extracted results for each of these cells are tabulated in seasonal and annual order in table 3.1.2.

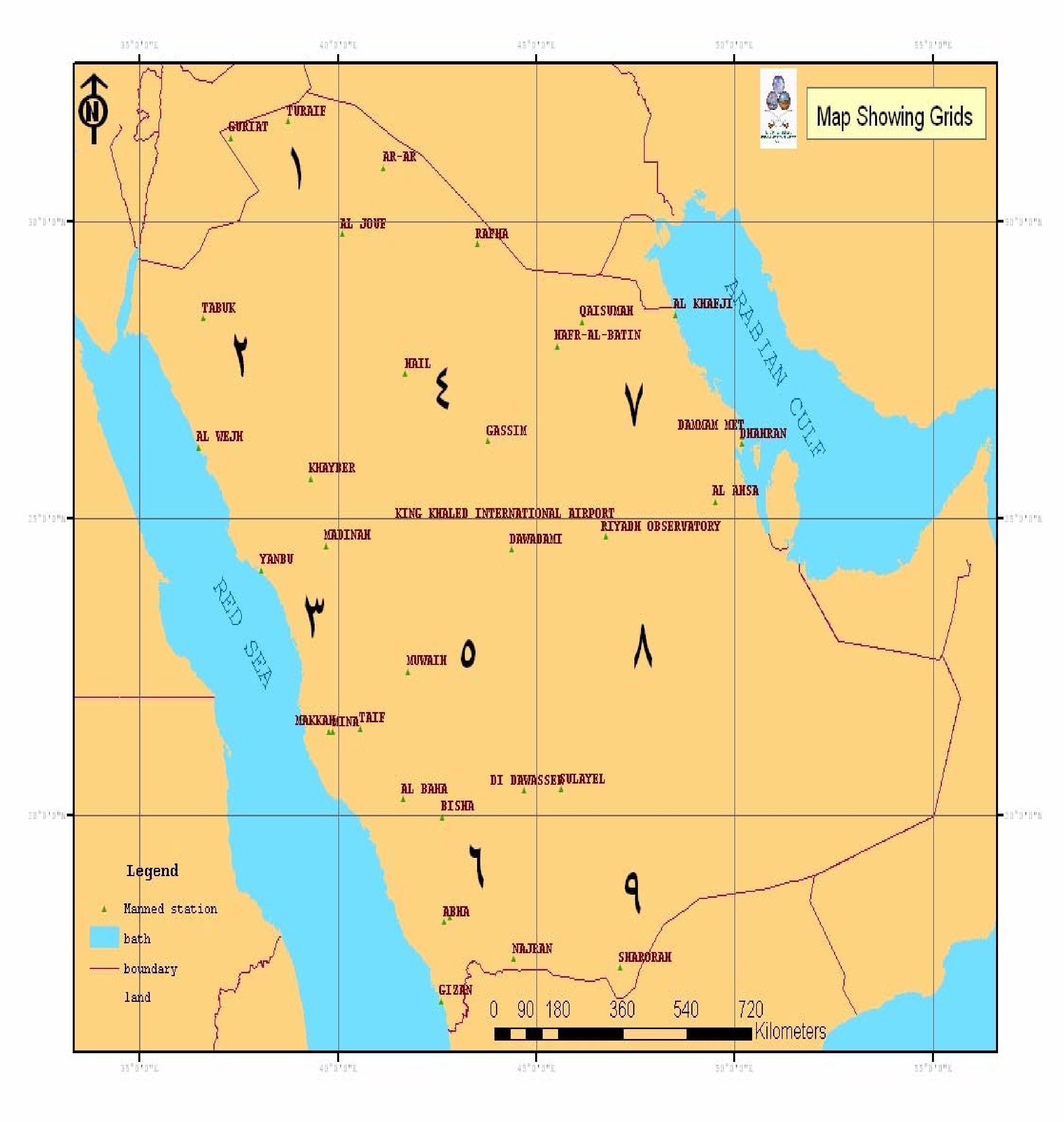


Figure 3.1.10 Grid cells covering Saudi Arabia

Table 3.1.2 Changes in temperature and relative humidity in each grid cell as predicted by GCM

Zones	1		2		3		4		5		6		7		8		9	
	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	
Models	**T**	**R**	**T**	**R**	**T**	**R**	**T**	**R**	**T**	**R**	**T**	**R**	**T**	**R**	**T**	**R**	**T**	**R**
All(17)	2.2	-16.1	2.3	33.9	1.9	43.5	2.4	34.1	2.0	64.5	1.4	31.5	2.4	22.7	2.1	36.9	1.5	28.8
BMRC98	2.4	-17.3	2.8	76.1	2.8	40.0	3.1	46.3	2.8	231.9	2.0	96.3	3.2	37.6	2.7	238.0	1.6	84.9
CCC199	2.3	-20.3	2.4	13.1	1.9	29.0	2.5	11.9	2.2	29.4	1.2	32.3	2.5	7.6	2.2	32.1	1.5	38.4
CCSR96	2.5	-19.0	2.4	22.7	1.9	51.3	2.4	11.5	1.7	57.8	1.0	43.5	2.4	5.4	1.6	55.9	1.0	47.7
CERF98	2.2	-19.4	2.3	20.2	1.9	43.0	2.5	11.2	2.1	32.9	1.3	48.7	2.5	-2.4	2.3	22.4	1.7	39.8
CSI296	2.3	-27.0	2.4	19.7	2.2	5.1	2.6	-15.2	2.2	-0.4	1.6	-6.0	2.6	-1.0	2.2	-2.4	1.6	-6.4
CSM_98	2.2	-5.4	2.2	15.9	1.8	9.2	2.3	32.7	1.9	87.4	1.4	42.4	2.4	40.4	2.1	269.7	1.6	39.9
ECH 395	2.7	-39.4	2.9	265.2	2.8	355.8	3.2	366.4	2.9	391.6	2.3	110.6	3.3	214.4	2.8	262.1	2.1	89.5
ECH 498	2.2	-16.1	2.5	-8.6	2.3	-5.4	2.8	-16.1	2.4	-1.9	1.5	-9.0	2.9	-12.3	2.8	-13.6	2.0	1.2
GFDL 90	2.0	-6.4	1.9	15.5	1.7	23.9	2.0	12.1	1.7	29.9	1.8	22.5	2.1	12.6	1.7	26.3	1.3	24.9
GISS 95	2.5	-19.6	2.3	45.7	1.6	55.1	2.4	26.0	1.4	63.1	0.9	39.5	2.5	41.0	1.8	45.0	1.1	27.9
HAD295	2.1	-16.5	2.2	25.4	1.7	41.1	2.3	10.2	2.1	25.6	1.5	16.0	2.1	-0.8	2.1	11.5	1.8	5.4
HAD300	1.9	-17.4	1.9	-13.0	1.4	7.0	2.0	-15.5	1.8	2.9	1.2	8.7	1.8	-9.7	1.8	2.0	1.6	1.1
IAP_97	2.0	-17.7	1.9	-7.4	1.9	-1.2	2.1	-10.5	2.0	24.5	1.7	20.0	2.1	-9.2	2.0	29.8	1.7	21.5
LMD_98	2.2	-18.4	2.0	4.1	1.8	-1.2	2.1	-8.0	1.8	9.5	1.5	9.4	2.3	-9.7	1.9	9.5	1.5	7.4
MRI_96	1.9	-12.7	1.9	23.8	1.5	28.1	1.9	12.2	1.4	33.2	0.9	24.1	1.8	7.4	1.4	31.4	1.0	25.8
PCM_00	2.2	-4.3	2.2	82.0	1.9	34.9	2.4	95.1	2.1	51.6	1.4	14.6	2.3	67.7	2.0	39.8	1.6	22.1
WM_95	2.1	2.5	2.4	15.9	2.2	23.8	2.4	9.6	2.0	27.0	1.4	21.5	2.4	6.4	1.9	23.3	1.3	19.0
MAX.	2.7	2.5	2.9	265.2	2.8	355.8	3.2	366.4	2.9	391.6	2.3	110.6	3.3	214.4	2.8	269.7	2.1	89.5
MIN.	1.9	-39.4	1.9	-13.0	1.4	-5.4	1.9	-16.1	1.4	-1.9	0.9	-9.0	1.8	-12.3	1.4	-13.6	1.0	-6.4

Three GCM models were found to simulate very closely the climatic trend characteristics of Saudi Arabia. These are CCSR96, IAP-97 and MRI-96. Results obtained from running the combination of these three models, for the reference (P50) and the policy (WRE-350) emission scenarios, are shown in table 3.1.3 for each of the nine grid cells and given in seasonal and annual change order.

Remarkable climate change features were concluded from these results, which included the following.

- 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 (2.2-2.7^{0}C) occurs during summer at the northwestern region (cells 1 and 2), while the lowest (0.2-0.4^{0}C) occurs in summer in southern and southwestern regions (cells 6 and 9).

Table 3.1.3 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 (^{0}C)
Referance (P 50%) Global-mean dt:1.1(^{0}C) **Year** : 2041

- The highest increase in precipitation occurs 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.

In an attempt to get more specific vision of the future climate, the results of the IAP-97 (identified as the best simulating model) were used to construct a 2041 precipitation chart of the Kingdom.

Table 3.1.4 shows the calculated average annual rainfall for all meteorological stations for the year 2041, using the average rate of change deduced from the model as follows:

AV 41=AV 91 (1 + RC/100)

Figure 3.1.11 shows the spatial distribution of averaged changes in Annual precipitation (mm) in the year 2041. An interesting feature can be noticed in this map is the future increase of precipitation over Asir mountains as opposing the decrease of about 15% in Abha during the baseline period, which may be considered as a logical compensation for a dynamically suitable area for high precipitation.

Figure 3.1.12 shows the resultant annual rainfall for the year 2041 according to the above relation. As can be noticed, the general pattern has not changed from that of the baseline period, but there is change in value and a noticeable shift southwards of the central maximum from Qassim towards Riyadh. Another feature of importance is the further expansion of the northwest area of minimum rainfall northeastwards.

3.1.4 Prediction for different scenarios using global modeling data

Since the grid interval to retrieve information using this approach is quite coarse, 5 degree latitude and 5 degree longitude, it was difficult to interpolate information at micro-level in the Kingdom. Therefore efforts were concentrated in retrieving daily data for the region from IPCC databases. These databases are maintained by IPCC and are based on the simulation studies conducted using global climatic models. These databases store data at global level for different climatic scenarios up to the year 2100. Various climate change scenarios, as developed by the IPCC group, were reviewed and the main focus of the study for this first communication report was on A2 and B2 climate scenario families.

Under the scenario family A2, the world will be very heterogeneous. The main emphasis will be on the family values and preserving local traditions and cultural identities. The global population under this scenario will increase continuously with a less concern on economic development. The B2 scenario family, on the other hand, describes a heterogeneous world with less rapid, and more diverse technological change but a strong emphasis on community initiative and social innovation to find local, rather than global solutions. It is a world with continuously increasing global population at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than other scenarios. While the scenario is also oriented toward environmental protection and social equity, it will also focus on local and regional levels of development.

In order to assess long-term impact globally in the next hundred years, global climatic models were used to simulate changes in temperature, precipitation, relative humidity, solar radiation, and wind circulation. For this study, long-term simulated records on precipitation, relative humidity and precipitation were retrieved from the following four models with main focus on Hadley Centre Global model.

1. Hadley Centre Global Model, U.K. known as Hadley model
2. Canadian Climatic Centre Model known as CCCMA
3. Global climatic model by National Center For Air Research (NCAR), USA known as NCAR model
4. Australian global model known as CCSIRO model

Table 3.1.4 Annual total rainfall for the year 2041 from the model IAP_97

Station Name	Average 1991 (mm)	Rate of Change (%)	Average Change (mm)	Average 2041 (mm)
TURAIF	93.5	-18.0	-16.8	76.7
ARAR	61.2	-18.0	-11.0	50.2
GURIAT	46.0	-18.0	-8.6	39.4
AL-JOUF	56.4	-11.0	-6.2	50.2
RAFHA	92.4	-11.0	-10.2	82.2
QAISUMAH	123.6	-9.0	-11.1	112.5
TABUK	31.2	-7.0	-2.2	29.0
HAIL	115.2	-11.0	-12.8	102.4
WEJH	27.6	-7.0	-1.9	25.7
GASSIM	181.2	-11.0	-19.9	161.3
DHAHRAN	92.4	-9.0	-8.3	84.1
AL-AHSA	92.4	-9.0	-8.3	84.1
MADINAH	62.4	-1.0	-0.6	61.8
RIYADH	102.8	30.0	30.8	133.6
YENBO	27.6	-1.0	-0.3	27.3
JEDDAH	56.4	-1.0	-0.6	55.8
MAKKAH	106.8	-1.0	-1.1	105.7
TAIF	166.8	25.0	41.7	208.5
AL-BAHA	151.2	25.0	37.8	189.0
WADI ALDAWASSER	25.2	30.0	7.6	32.8
BISHA	94.8	20.0	19.0	113.8
ABHA	246.0	20.0	49.2	295.2
KHAMIS MUSHAIT	201.6	20.0	40.3	241.9
NAJRAN	62.4	20.0	12.5	74.9
SHARORAH	72.2	22.0	15.9	88.1
GIZAN	116.4	20.0	23.3	139.7

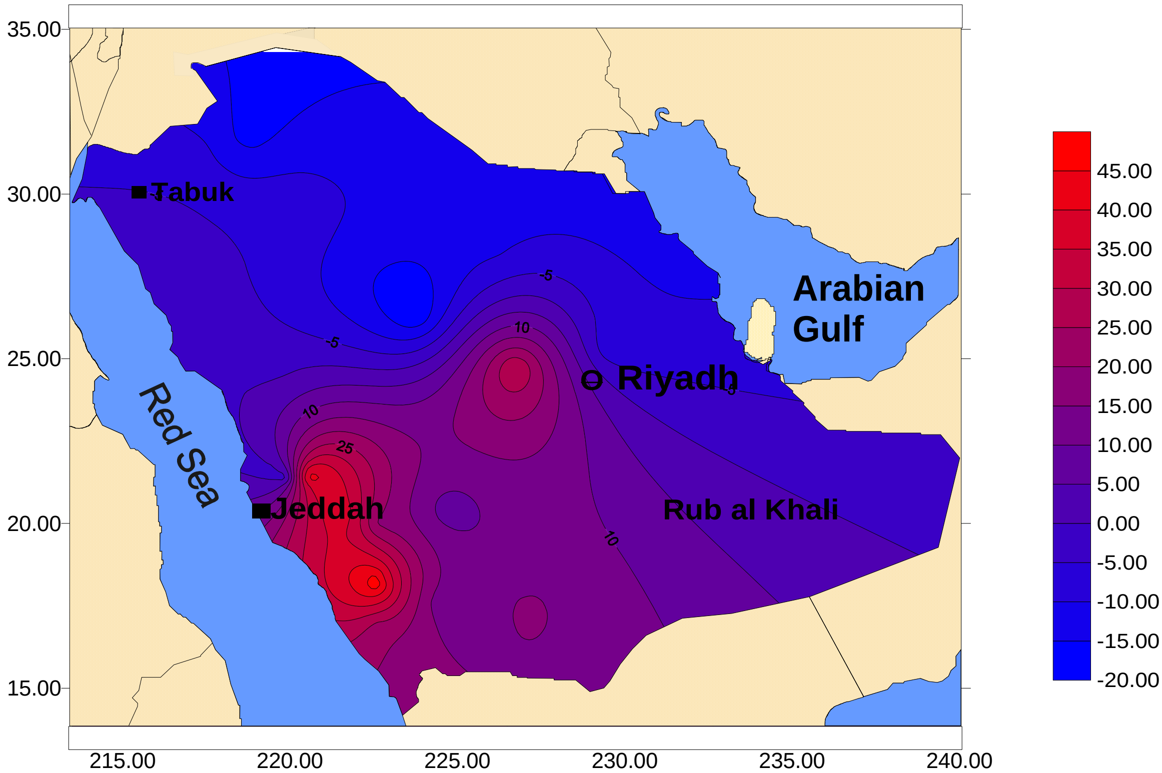


Figure 3.1.11 Average changes in annual precipitation in the year 2041 (mm)

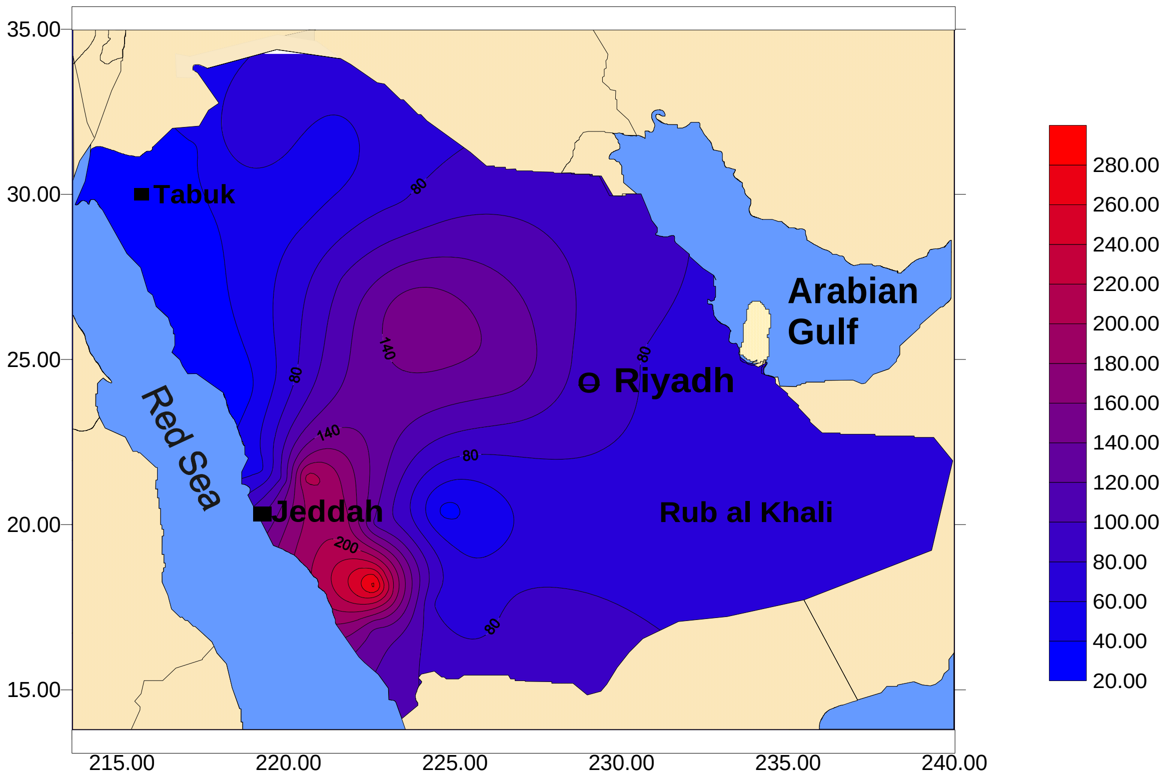


Figure 3.1.12 Average of total annual precipitation in the year 2041 (mm)

A2 and B2 scenarios are the main scenarios among all the scenarios developed by the IPCC and have been used by most of the global climatic models for climatic change predictions. These two scenarios also cover most of the predicted climatic changes in the next century. It was therefore decided to concentrate on these two scenarios to study temperature, humidity and precipitation changes in the Kingdom of Saudi Arabia between 2070 and 2100 in reference to baseline values between 1970 and 2000.

Table 3.1.5 Maximum changes in precipitation and temperature in 2041

Seasons	Change in temperature (^{0}C)		Change in total annual precipitation (mm)	
	Minimum	Maximum	Minimum	Maximum
Winter	1.2	3.2	-54.8	374.2
Spring	1.1	2.6	-58.4	759.9
Summer	-0.1	3.9	-100	704.7
Autumn	0.5	4.1	-100	743.0

Using GCM run data stored in IPCC Data Centre, monthly time series data was retrieved for Longitude 15^0 N to 35^0 N and 32.5^0 E to 60^0 E covering the Kingdom of Saudi Arabia. Data was retrieved from 1970 to 2100 for mean monthly temperature, precipitation, and relative humidity for all grids covering the above ranges of latitudes and longitudes.

Using average of 1970 to 2000 values as baseline, the change in temperature, relative humidity and precipitation were estimated for the period 2070 to 2100 with respect to average values obtained from 1970 to 2000 as base values. These changes were then plotted on the map to see variation in the monthly temperature (Figure 3.1.13 for A2 scenario and figure 3.1.14 for B2 scenario), change in the relative humidity on monthly basis (Figure 3.1.15 for A2 scenario and figure 3.1.16 for B2 scenario) and change in the precipitation on monthly basis (Figure 3.1.17 for A2 scenario and figure 3.1.18 for B2 scenario). The findings are summarized in the following sub-sections:

3.1.4.1 Change in Temperature

Although analysis was conducted using all four models but only the results obtained for scenarios A2 and B2 using Hadley model are presented in this section.

3.1.4.1.1 A2 Scenario

Based on the spatial variations on monthly basis as shown in Figure 3.1.13, the change in the temperature at various locations as predicted by the Hadley model for A2 scenario are as follows:

(i) The minimum monthly temperature increase is expected as 1.8^{0}C in May while maximum increase of 4^{0}C is expected in September.

(ii) In January, temperature change varies from a minimum of 2.15^{0}C on the eastern coast to a maximum value of 2.95^{0}C in north, southwest and south of Saudi Arabia.

(iii) In February and March, increasing trend from southwest (1.9^{0}C) to northwest near Tabuk (4^{0}C).

(iv) Between April and July, central region extending from eastern coast on the Arabian Gulf to the western coast near Jeddah will experience a minor increase in temperature while in the northern and southern regions, an increasing trend is predicted.

(v) In northern and southern parts of the Kingdom, an increase of 4^{0}C is expected during the summer months.

(vi) Relatively minor temperature increase is expected in November and December.

3.1.4.1.2 B2 Scenario

Based on the spatial variations on monthly basis as shown in Figure 3.1.14, change in temperature at various locations as predicted by the Hadley model for B2 scenario are as follows:

(a) Minimum temperature increase of 1.5^{0}C is predicted in February on the eastern coast of Saudi Arabia while maximum temperate increase of 3.5^{0}C is predicted in September in Rub Al-Khali.

(b) B2 scenarios show lower temperature rise in interior regions covering major cities like Riyadh and Qasim and extending to the costal cities like Jeddah on the west and Dhahran on the eastern coast. However, in northwest and southeast regions of the Kingdom, higher temperature rise of up to 3.50C is expected.

(c) From February to April, temperature increase in the east and southeastern regions would be lower than that in the northern and western regions. On the eastern coast extending from Kuwait border to Oman and in the interior regions extending to Riyadh and Qassim, a moderate increase of 1.50C would be expected.

(d) Maximum increase in temperature close to 2.50C is expected in the northwestern region near Tabuk and southeastern region covering Rub Al-Khali.

3.1.4.2 Change in Relative Humidity

Similar to temperature, predicted 100 year data by Hadley model was retrieved to study changes in the relative humidity in 2070 to 2100. These changes on monthly basis are presented in Figures 3.1.15 and 3.1.16 and the findings are summarized below:

3.1.4.2.1 A2 Scenario

(i) As shown in Figure 3.1.15, an overall decrease in relative humidity in the whole region is expected between October and January in 2070 and 2100 compared to the base average values between 1970 and 2000. Considering hot and arid climatic conditions, desert ecosystem and its sustainability could be very vulnerable to such very small change.

(ii) Humidity in summer in the coastal areas and in central region of the Kingdom will increase by 1.5% to 3.0%.

3.1.4.2.2 B2 Scenario

(a) A decrease in the relative humidity in the range of 1% to 2% is expected in the northwest and northern regions near Tabuk in December and January (Figure 3.1.16).

(b) In February, the increase in relative humidity will be at its highest level of 2-2.5% near Jeddah. This increase will extend through the central region and towards the eastern coast near Dhahran where the increase in humidity in the month of February is expected by 1%. In the northern region, a decrease in humidity by 1% is expected in the month of February (Figure 3.1.16).

(c) In March, there will be a slight increase in humidity on the coastal regions and a shift of increasing trend towards north on the western coast near Yanbu.

(d) In April, a slight shift in humidity trend is expected on the eastern cost with a maximum increase by 1.5% near Dhahran. This trend will be extended to south-east where an increase of 1% in the relative humidity is expected.

(e) In May and June, there would be an overall increase in the humidity in the entire Kingdom except in the north where a decreasing trend is expected.

(f) Between July and October, a decreasing trend in the humidity in the range of 1.5% to 2.0% is expected in the northwestern and southeastern regions while in the central, eastern, and southwestern regions, higher increase in humidity in the range of 2% in August to 3% in September is expected.

(g) A decreasing trend in humidity will be experienced in October and an increase in the humidity will be shifted towards northeast with a maximum increase near Kuwait border by 1.5%.

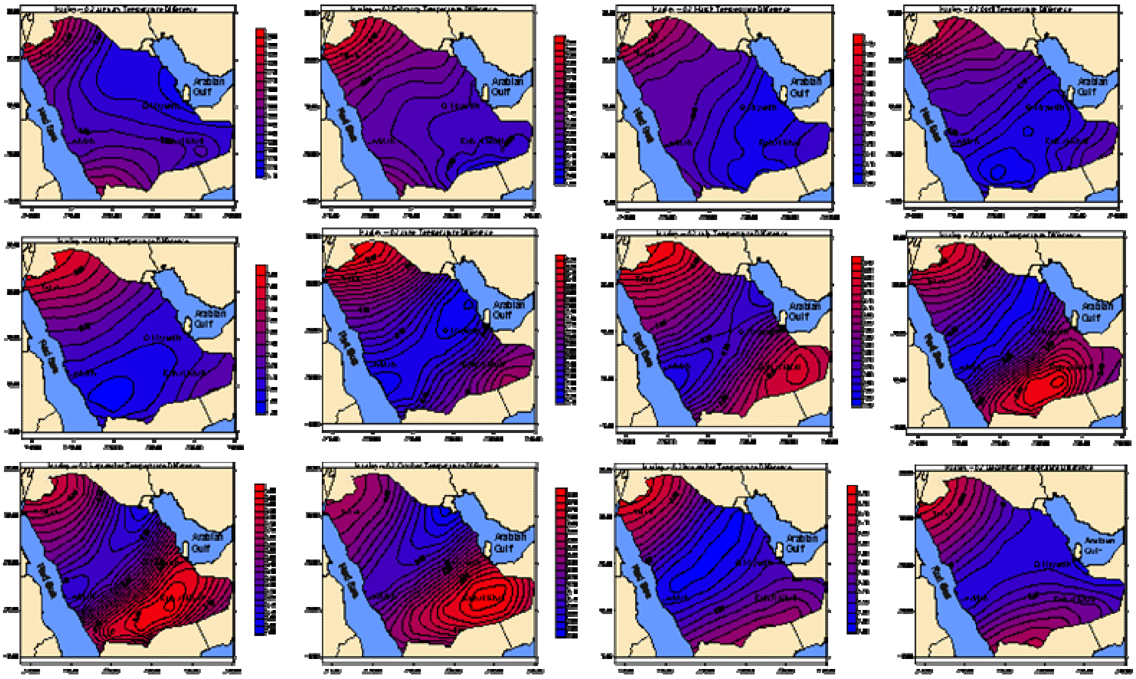


Figure 3.1.13 Monthly temperature changes for A2 scenario – Hadley Model

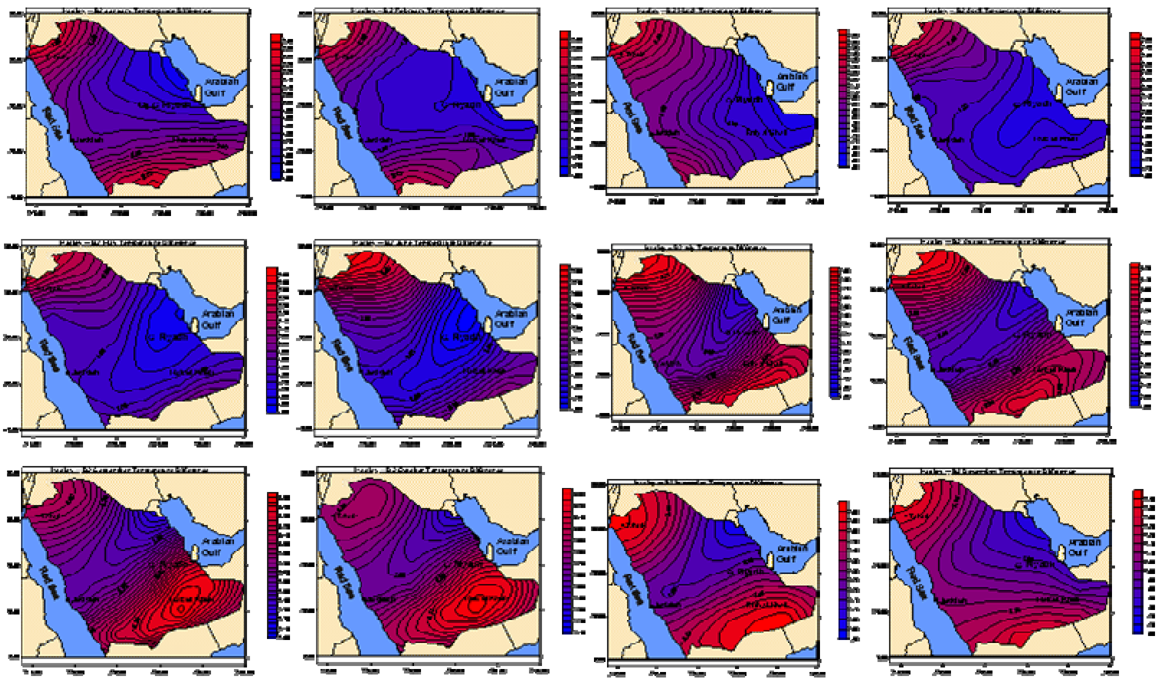


Figure 3.1.14 Monthly temperature changes for B2 scenario – Hadley Model

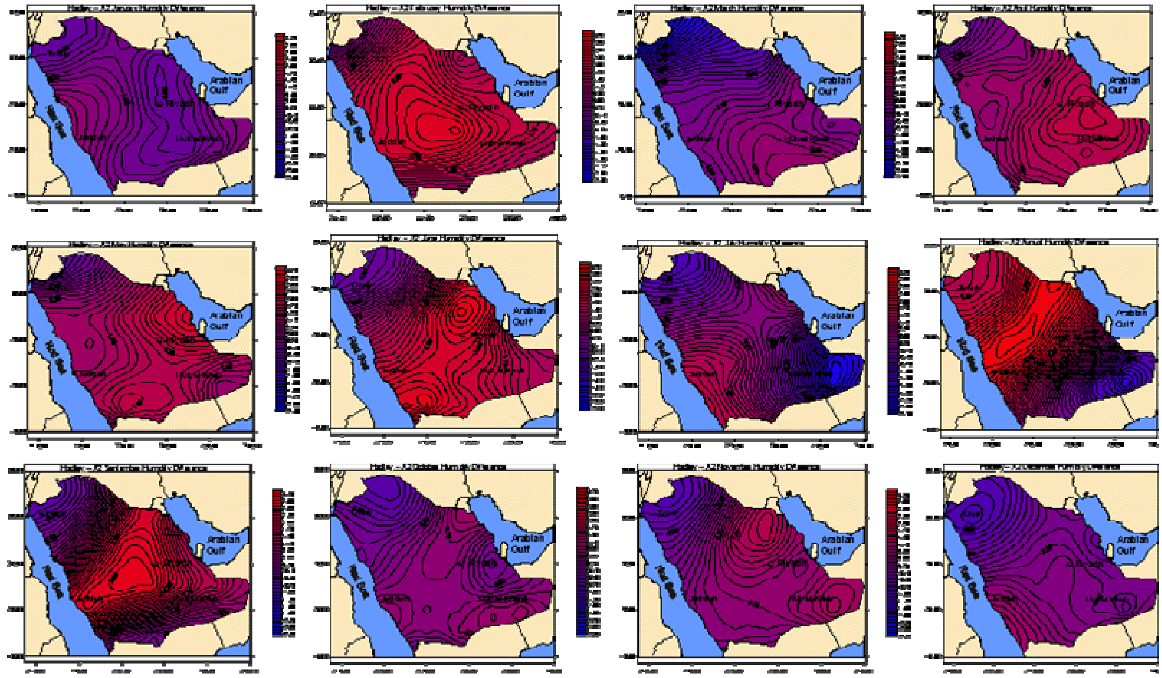


Figure 3.1.15 Monthly humidity changes forA2 scenario – Hadley Model

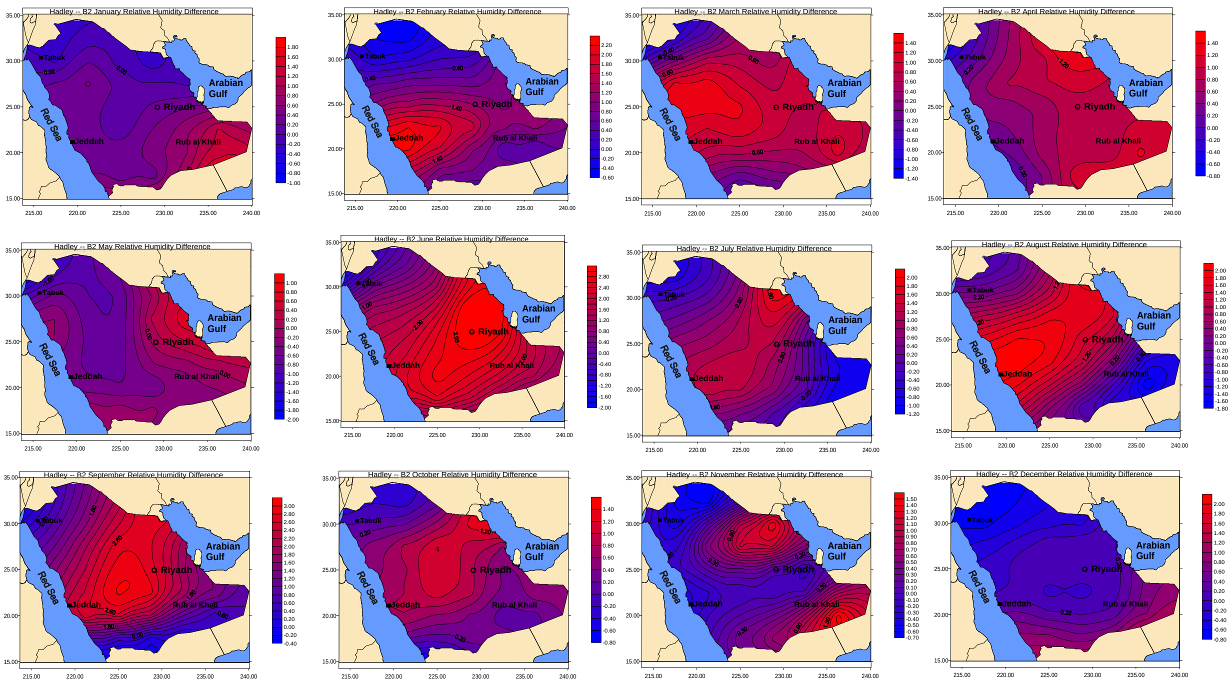


Figure 3.1.16 Monthly humidity changes for B2 scenario – Hadley Model

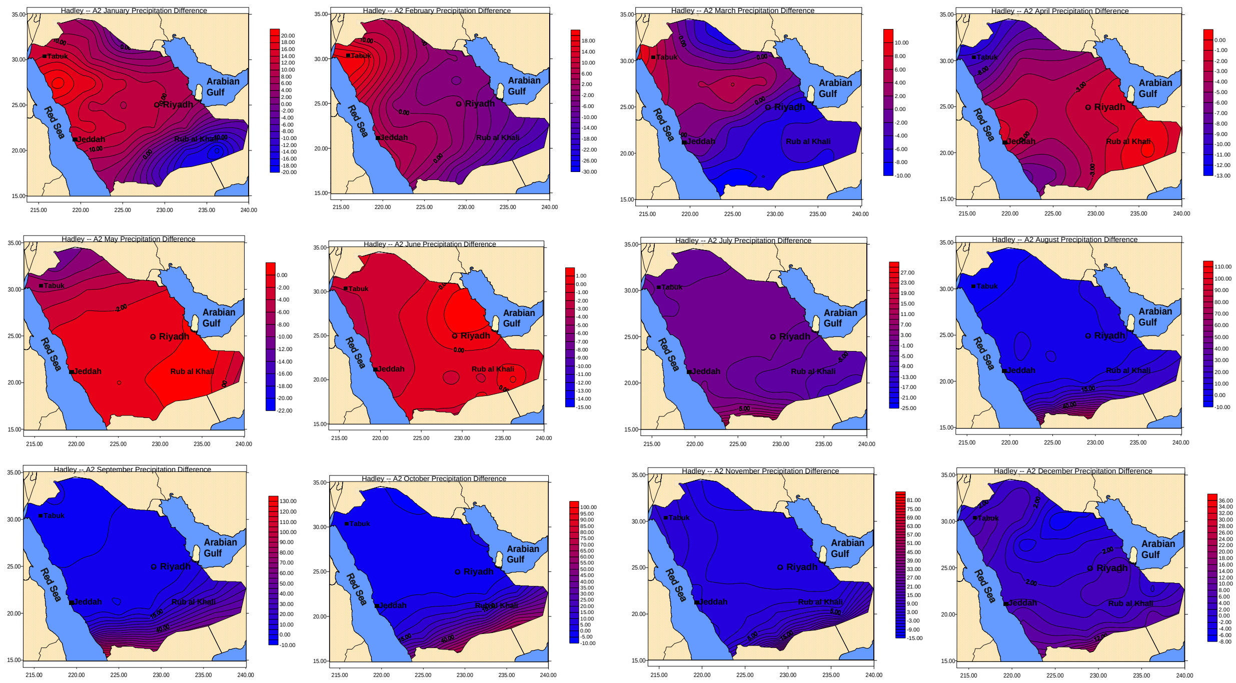


Figure 3.1.17 Monthly precipitation changes for A2 scenario – Hadley Model

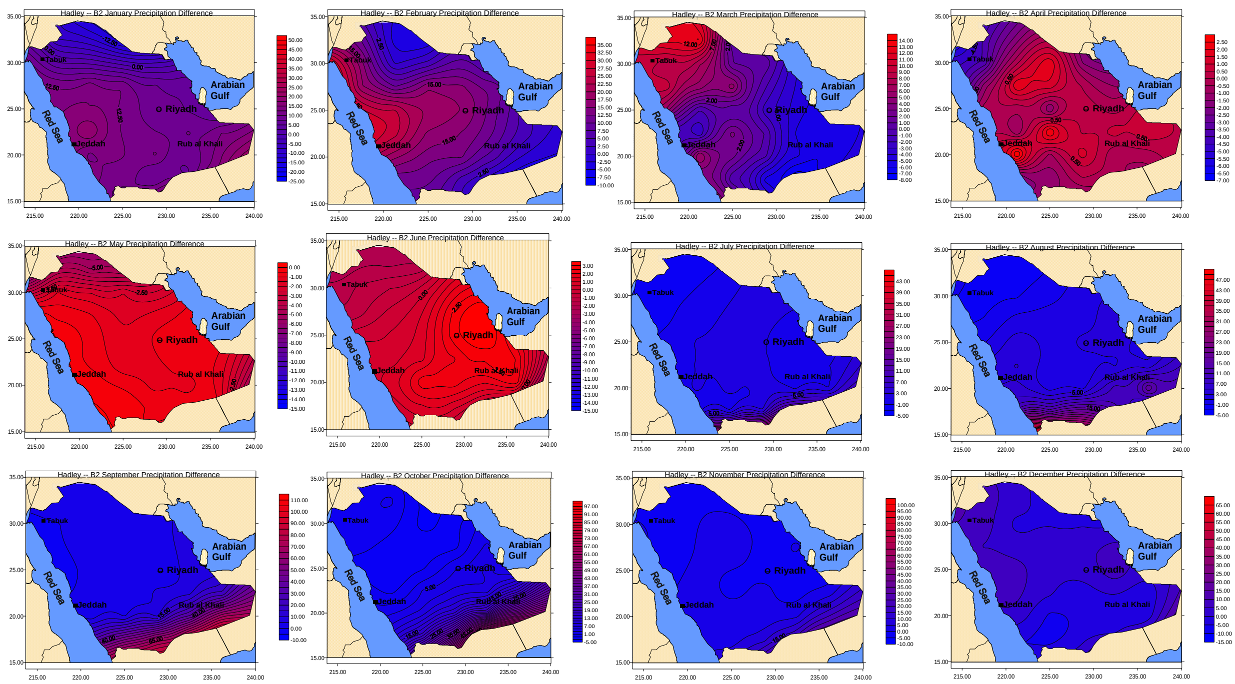


Figure 3.1.18 Monthly precipitation changes for B2 scenario – Hadley Model

3.1.4.3 Change in Precipitation

Figure 3.1.17 and 3.1.18 present monthly changes in the precipitation as predicted by Hadley Model between 2070 and 2100. The changes for scenario A2 are presented in Figure 3.1.17 while figure 3.1.18 shows changes for B2 scenario. The findings are highlighted in the following sections:

3.1.4.3.1 A2 Scenario

- In January and February, southern region will experience a decrease in the precipitation by 10 mm on average while the precipitation is expected to increase in the northwestern region near Yanbu by 20 mm. In the central and coastal regions near Jeddah and Dhahran, an increase of 10 mm rain is expected in January and February. In the remaining lower part of the country, a slight decrease in precipitation is expected.
- During March and April, there would be an overall decrease in the precipitation in the Kingdom except in the southern and northeastern regions, which will experience drought situation with a decrease in the precipitation by 10 mm.
- During summer, a 15-20 mm decrease in the precipitation is expected affecting western coast and northern regions near Tabuk.
- There will be no appreciable change in the precipitation trends during July and August except a slight increase in precipitation (5- 10 mm) in the southern part of the country near Yemen border.
- In September and October, an increase in the precipitation is expected covering larger area in the south. Northern and eastern regions will experience drought conditions with lower rainfall.
- In November and December, an overall decrease in the total precipitation in the larger part of the country is predicted except a 5-10 mm increase in the southern region bordering Yemen. The central part of the country may not be affected but a portion in the south and northwest regions may receive 10-15 mm higher rainfall.

3.1.4.3.2 B2 Scenario

- A decrease of 12.5 mm precipitation is predicted in the northern and northeastern regions in January while an increase of 12.5-25 mm is expected in the southwestern region with a maximum increase near Jeddah.
- In February, a slight decrease in the precipitation (by 5 mm) is expected in south, southeast and northeast regions while southwestern region will receive higher rainfall. Near Jeddah, the total rainfall increase in February would be between 15mm to 25 mm. The rainfall front in the southwestern region may move towards northwestern region and as a result, whole western coast may experience increase in the precipitation with maximum increase near Tabuk (approximately 12 mm).
- A slight decrease in the precipitation is expected in March throughout the Kingdom.

- During summer months (i.e. from May to August), a decreasing trend in precipitation is expected in the whole country except in the southern region. Such decrease may be insignificant as the range of decrease vary between 3mm to 5mm.
- From August to October, a larger part of southern region bordering Yemen may receive higher rainfall with a maximum in August (about 45mm) followed by September (35mm).
- The front moving from the Arabian Gulf may cover a larger part of the region which is expected to move to the central region in November and then towards the southwestern and eastern regions in December. A 10 mm increase in the total precipitation in the central region is expected in November, which may shift to the southwestern and eastern regions, with an increase in December by 15mm.

3.1.4.4 Comparative Evaluation of Models

This section covers a comparative evaluation of the changes in temperature and precipitation in 100 years as predicted by four global models i.e., Hadley Center, NCAR, CCCMA, and CCSIRO global models. Trend analysis of observed meteorological data using Mann-Kendall method is added as a model known as Sen slope method. The results as predicted by these five models are presented in Figures 3.1.19 for temperature and 3.1.20 for precipitation. As shown in these Figures, there is no consistent prediction and the changes also vary significantly.

3.1.4.4.1 Change in Temperature

Hadley center model predicts an increase in the temperature from a minimum of 2.5^{0}C in the central region to a maximum of 3.05^{0}C in the northwestern region near Tabuk. An increase of 2.75 ^{0}C is expected in the southern part of the country.

The Canadian global climatic model (CCCMA) predicts the temperature increase in the range from 2.10^{0}C to 3.30^{0}C in 2100. A maximum increase of 3.30 ^{0}C is predicted near Riyadh while in the southern part, an increase of 3.0^{0}C is expected in 2100. The increase of temperature in the northwestern region is predicted as 2.20^{0}C.

The Australian global climatic model (CCSIRO) predicts temperature increase in the range of 3.45^{0}C in the south near Gizan and Sharorah to 4.10^{0}C near Tabuk in the northwestern region. Most of the interior region and central part of the country will experience an increase between 3.75 ^{0}C and 3.85 ^{0}C.

NCAR global model predicts relatively low increase in the temperature (i.e. between 1.20^{0}C and 1.58^{0}C) in 2100. The maximum increase (1.58^{0}C) is predicted in the southern and south-eastern regions while the lowest increase is expected on the western coast near Yanbu and in the northwestern region near Tabuk. In the interior region, temperature increase in 2100 as predicted by NCAR model would be in the range of 1.30^{0}C to 1.50^{0}C.

The extrapolation of the trend analysis using Mann-Kendall method shows a range of temperature from –1.0^{0}C to 5.5^{0}C in 2100. The negative value indicates cooling effect in a small area near southern border with Yemen. The temperature increase in Riyadh is predicted as 2^0C with the decrease towards southern side. In the northwestern part of the country, an increase in the range of 0.5 ^{0}C and 2.0 ^{0}C is predicted by this approach. Highest increase (between 5.0^0C and 5.50^0C) is predicted near Qassim, in the area between Riyadh and Dhahran, and in the northeastern region near Arar.

3.1.4.5 Change in annual precipitation

Hadley Center model predicts an increase in the annual precipitation throughout the Kingdom, extending from the central part (increase by 40mm) to the southern coast and southern parts of the country (an increase up to 120mm) annually. The Hadley model has also predicted maximum increase of up to 120mm in the northern region. In the interior part of the country, an increase of only 30mm to 40mm annually is predicted. No appreciable change in the north-eastern part is predicted by the model.

Canadian global model ‘CCCMA’ predicts entirely different patterns of precipitation with the highest annual increase of up to 300mm annually in the northeastern region near Tabuk. In the central part of the country, extending from the western coast near Jeddah to the eastern coast near Dhahran, the model predicts an increase of 50mm to 150mm in the total annual precipitation. Comparing these increases with average precipitation of 80 mm in Saudi Arabia, CCCMA model over-predicts such increases and requires further investigation. CCCMA model also predicts a decrease in the annual rainfall by 20-30mm in the south and southeastern regions of the Kingdom.

CCSIRO, the Australian global climatic model, predicts maximum increase in the precipitation in the southern part near Gizan and Sharourah . Such increase in 2100 is estimated to be in the range of 50-100 mm annually. No significant increase in the precipitation is expected in the southeastern part near Rub Al Khali. Northeastern parts of Saudi Arabia may receive an increase in the rainfall by 10-20mm annually. The central and northeastern parts will experience a decrease in the precipitation in the range of 50-80mm annually according to the CCSIRO model prediction.

NCAR model, supported by the United States Atmospheric Research Group, predicts lower increase of precipitation with the maximum increase of up to 45mm on a small area in the southwestern region. On a large area, extending from the central part of the Kingdom to the south-eastern region, no significant changes in the precipitation are expected. However, in the northeast and northwest, a decrease in the range of 15-60mm is predicted with the maximum reduction near Tabuk.

Extrapolation of the trend analysis using Mann-Kendall method shows a high variability in the precipitation data. Zones of high precipitation are found in the south and south-eastern regions with an increase by 50-80mm annually. A reduction of 15mm to 35mm is predicted in a smaller area in the north-eastern region. In the northwestern part of the country (near Tabuk), an increase in the annual precipitation by 80mm is expected.

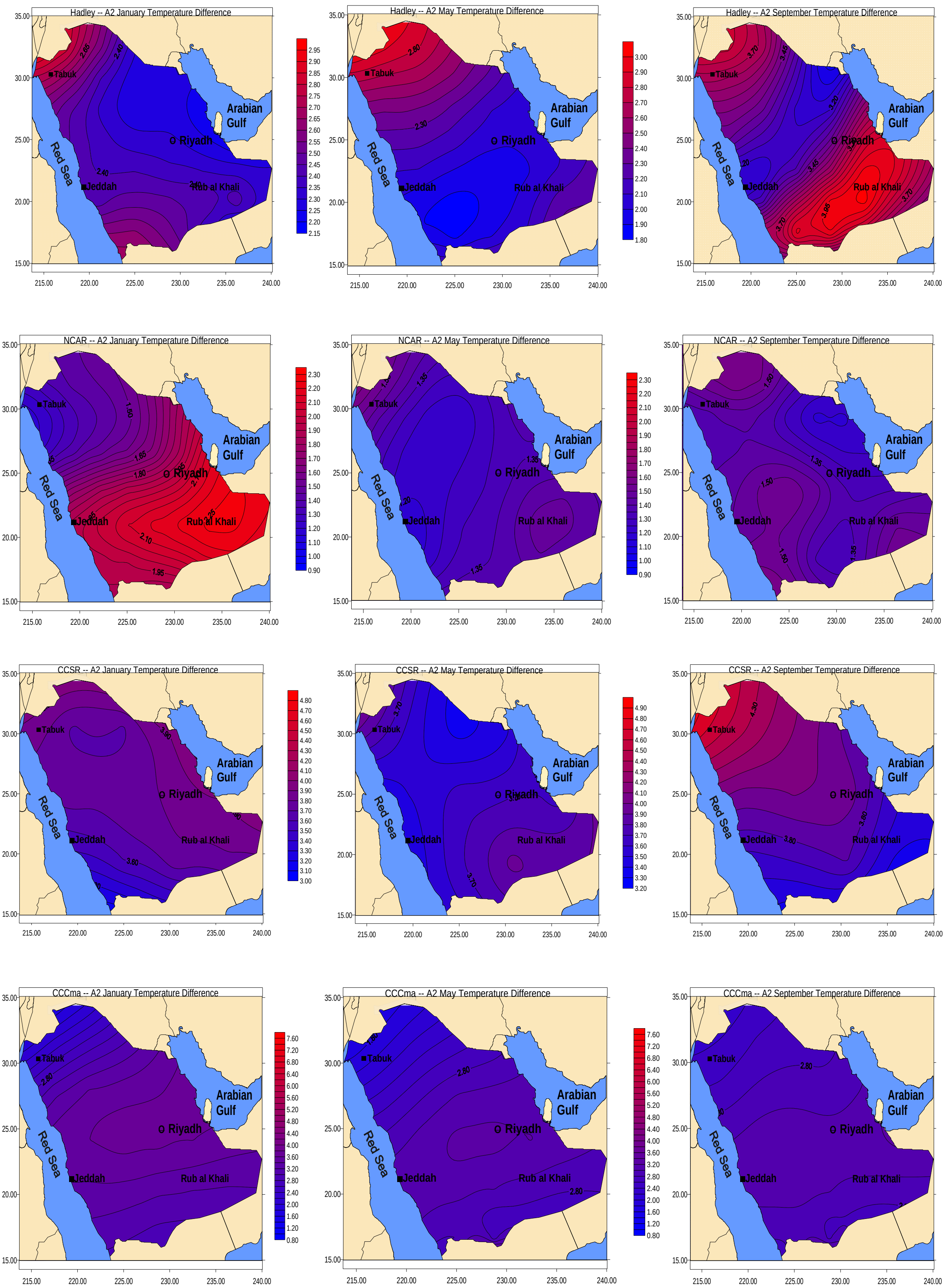


Figure 3.1.19 Comparative evaluation of four global models in assessing temperature increase in 2070-2100 – A2 Scenario

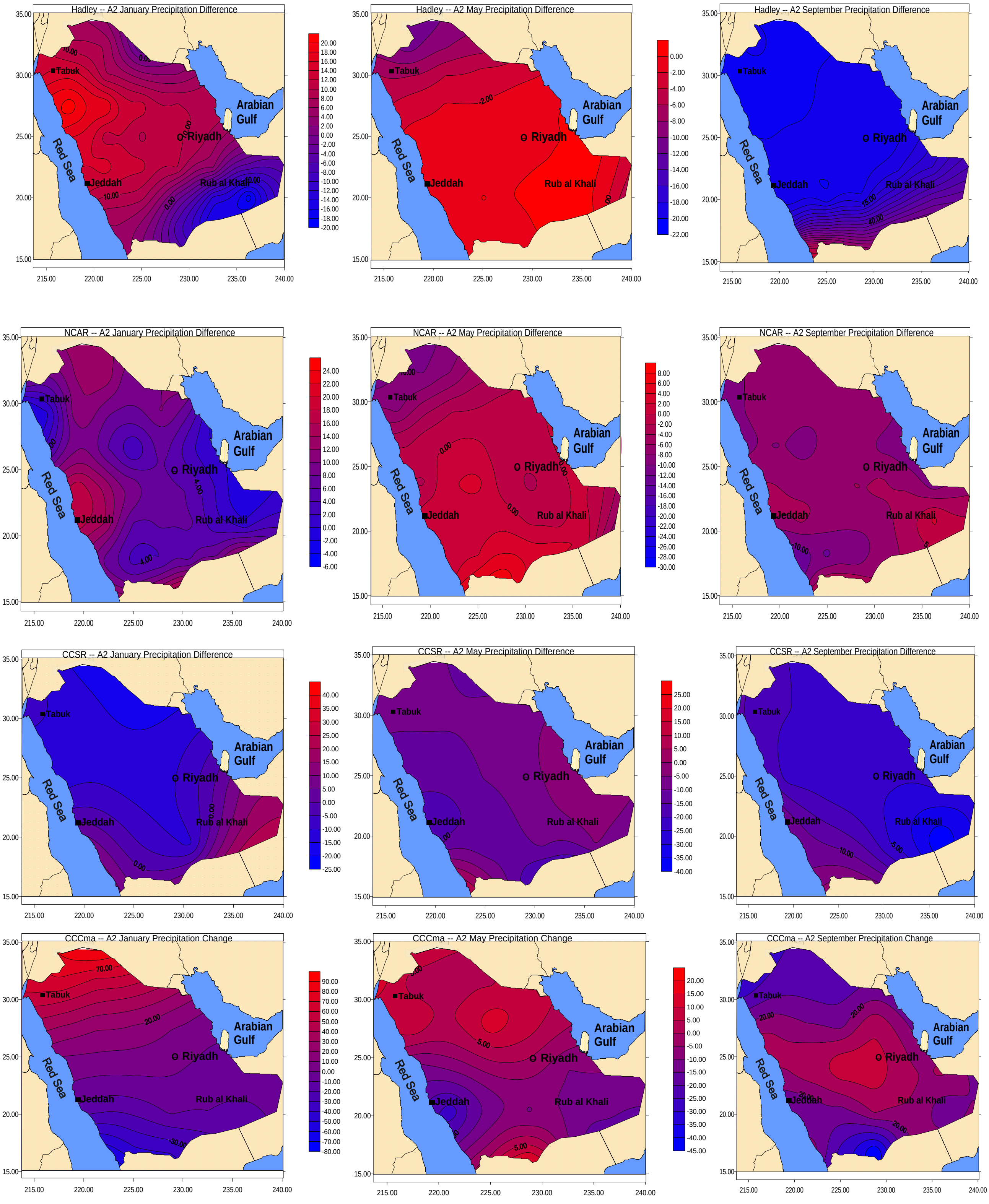


Figure 3.1.20 Comparative evaluation of four global models in assessing precipitation increase in 2070-2100 – A2 Scenario

3.2 Desertification

Saudi Arabia is particularly vulnerable to climatic change as most of Saudi Arabia has sensitive ecosystem. About 76% of its area is non-arable lands which include 38% of the area as deserts. Theses areas contain the range lands or the pastures areas which extends over about 171 million hectare. Most of pastures in Saudi Arabia are scattered herbs and shrubs with low density and low productivity. The rangelands sustain a large number of rural communities through their support for livestock grazing over hundreds of past years. Although, the average annual rainfall in the Kingdom is low, the natural flora has managed during the past years to survive under these extreme arid conditions. Much of the country (except for southwestern region), has an average annual rainfall of less than 150 mm. Renewable surface water is very limited, and there are no lakes or rivers in the Kingdom. Groundwater resources from local aquifers (mostly non-renewable) are the major water supply source for domestic, agricultural and industrial purposes. Thus, water scarcity is common and changes in the water balance would have substantial implications for, amongst other things, sensitive desert ecosystem, and agriculture and water resources.

This study will assess potential impacts of climate change on desertification and water resources and its implications for sustainable socio-economic development in Saudi Arabia.

3.2.1 Background Information

3.2.1.1 Location, Climate, Population, Landform and Land Use

Saudi Arabia is situated at the furthermost part of the southwestern Asia, and it occupies about four-fifth of the Arab Peninsula, with a total area of 2.25 million square kilometers of which about 40% are desert lands. It lies within Latitudes 16^{o} and 32^{o} 12' N, and longitudes 34^{o} 36'E. Saudi Arabia extends mostly in the dry tropical desert range west of the continents. The climate of Saudi Arabia varies among regions due to its topographical features. Consequently, the summer is hot, dry in the interior regions, and more humid in the coastal regions. The winter is cool in the interior regions and mild in the coastal regions. The seasonal variation in temperature may range from below zero to more than 40^{o}C. The mountainous highlands of the southwestern region have moderate climate with lower temperature. The average annual rainfall ranges from less than 50 - 100 mm in the central and northern regions, and is about 25 mm in southern and northwestern areas (MAW 1988) (Figure 3.2.1). In the southwestern mountains, the rainfall occurs during summer and winter and a maximum annual rainfall of over 600 mm was recorded. The average annual evaporation ranges from 2500 mm to about 4500mm.

In Saudi Arabia, the population of the Kingdom has increased from about 7.7 million in 1970 to about 21 million in 2000, and expected to reach about 40 million by 2020. The urban population has increased from about 3.74 million or 50% of the total population in 1970 to about 15 million (71%) in 2000 respectively.

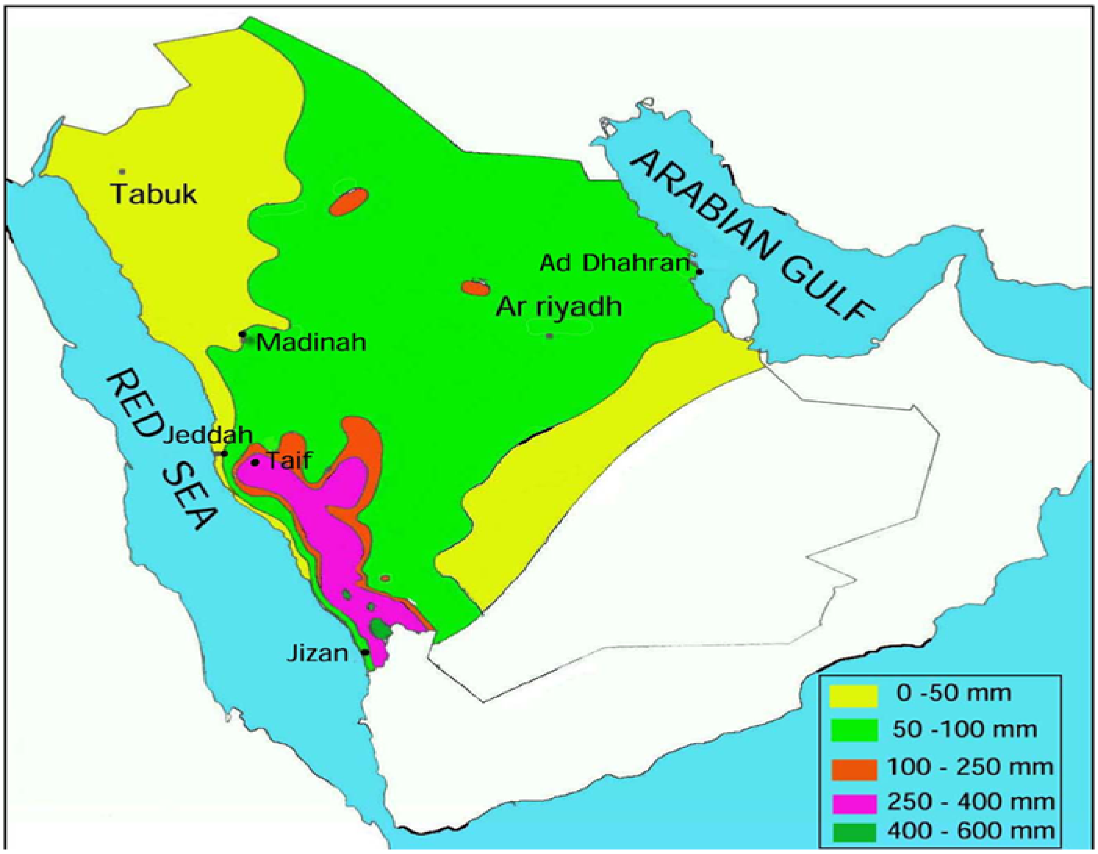


Figure 3.2.1 Average annual rainfall distribution regions in Saudi Arabia

The Kingdom consists of five distinct landforms namely: desert, plain, plateau, mountains, and lava flows (Figure 3.2.2). The desert mainly covers the Ar Rub Al-Khali, Aldahna, and Great Nafud deserts. About 30% of the Arabian Peninsula is covered with sand in the form of sand-seas. The three major bodies of sands are the Great Nafud in the north, the Empty Quarter (including the Al-Jafurah sand) in the south and rather crescent-shaped body of sand known as Dahna or Ad-Dahna connecting the two great bodies of sand. 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 great 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 AI-Jafurah. In contrast with the reddish hues of sands in the Nafud, the Dahna and rest of the Empty Quarter, the sands of AI-Jafurah are buff to tan in colour. Plain form covers the costal area of Saudi Arabia. The Plateau covers the middle part of Saudi Arabia.

The mountains are located in the Southwestern part of Saudi Arabia. Lava flows covers the West and Northwestern parts of Saudi Arabia.

The total arable lands of the Kingdom are 52.68 million hectares (ha) or 23.4% of total area of the Kingdom. In 2000, about 1.12 million ha or 2.2% of the arable lands are cultivated

Figure 3.2.2 Landforms of Saudi Arabia

3.2.2. Impacts on Flora Distribution

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). More reasonable definition is “collapse of the ecosystems and socio-economic structures following severe land degradation resulting from natural causes and/or human activities”. In the process of desertification, biologically and economically productive land becomes less productive and less able to support the communities that depend on it. Desertification is a term that has long been associated with dry-lands, which cover 40% of the land surface of the globe. Desertification has become increasingly apparent in the dry sub-humid regions of the world, where mean annual rainfall ranges from 750 to 1500 mm, and where the majority of the human inhabitants of the dry-lands now live. Current best estimates suggest that roughly 70 per cent of all agriculturally used dry-lands are considered to be experiencing differing degrees of desertification.

3.2.3 Vulnerability Levels

Dry-land soils such as those of Saudi Arabia often have low organic matter content and are frequently saline and/or alkaline. As such, they are often highly susceptible to accelerated erosion by wind and water. The rainfall distribution map of the Kingdom shows three distinct regions in its rainfall and vulnerability to desertification (Figure 3.2.3). Areas with annual rainfall of less than 50 mm, 50-100 mm and more than 100 mm have third, second and first scores in its vulnerability to desertification hazards respectively. The highest vulnerability areas are located mainly in the northwest and southeast areas of the Kingdom. The middle vulnerability is in the central parts and the lowest in the southwestern region mountains.

The distribution of the rangelands according the annual rainfall as shown in Table 1 indicate that about two third of pastures receive rainfall less than 100 mm/year. These regions have different types of flora and landforms as appear in figures 3.2.3. Furthermore, these areas are located within the highest vulnerability level to desertification in the country according to desertification vulnerability map of Saudi Arabia (Figure 3.2.3)

Table 3.2.1 Distribution of rangelands according the annual rainfall

Annual Rainfall (mm/year)	Area of rangelands (million ha)	Percentage
0 -100	117	68.4
100 -200	48	28.1
> 200	6	3.5

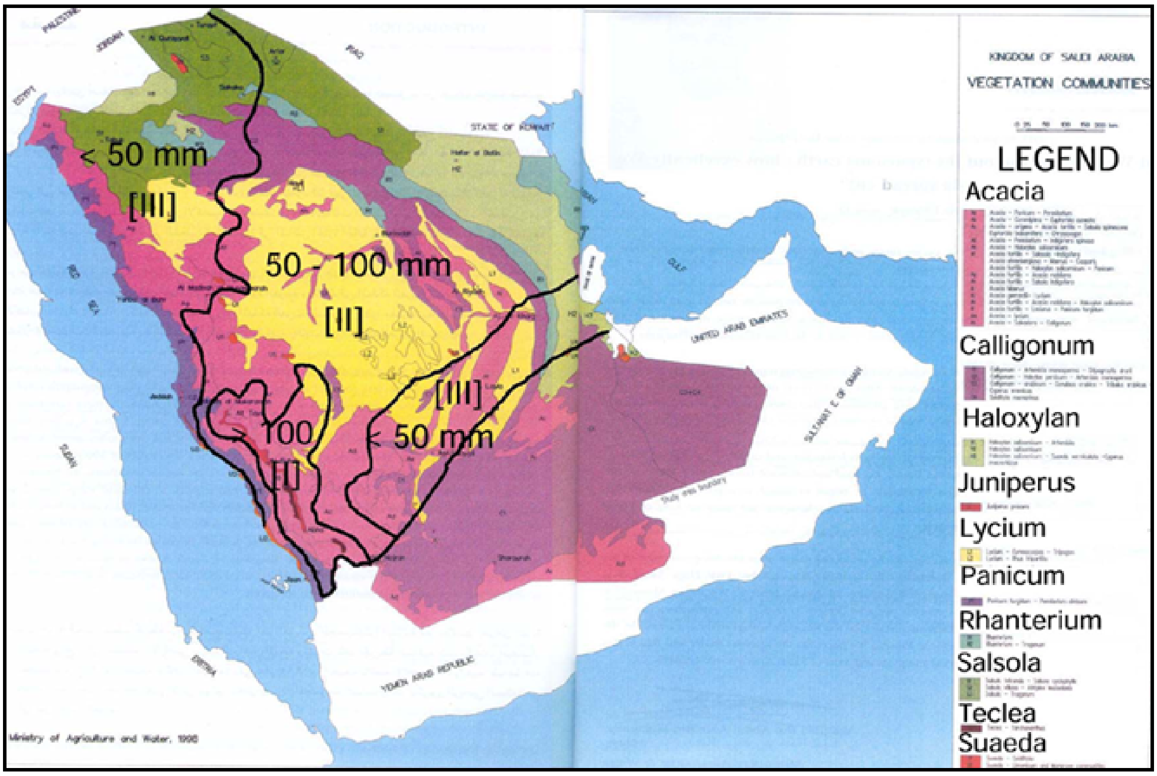


Figure 3.2.3 Desertification vulnerability classes as indicated by annual rainfall in different regions overlapping the flora distribution map of Saudi Arabia.

The predicted increase in temperature would most probably have the effect of increasing potential evapo-transpiration rates in the dry-lands, and in the absence of any large increases in precipitation, many dry-lands are accordingly predicted to become more arid in the 21st century. As soils dry they become more susceptible to wind erosion, especially where there is no vegetation cover or the area is cultivated - this could ultimately generate "dust bowl" conditions in some areas. Higher temperatures could result in a reduction in soil fertility due to higher rates of decomposition and losses of organic matter, and could affect nutrient cycling. A general decrease in precipitation or increase in evaporation will cause an increase in the area affected by saline conditions. Coastal areas could be more directly affected by Salinization due to the increased penetration of salt water into the groundwater. Increasing temperatures and drier conditions could give rise to more forest fires, although the extent to which land degradation results will vary.

3.2.4 Impacts of Increase in Reference Evapo-transpiration

The possible increase in temperature will have detrimental impacts on growth and survival of different types of flora in Saudi Arabia as it induces increase in the level of reference evapo-transpiration (ETo) and plant water requirements under the water scarce conditions in different regions of the Kingdom. The effects of a temperature increase from $1C^{o}$ to $5\ C^{o}$ on plant water requirements have been evaluated in different areas in Saudi Arabia. A comprehensive literature review was carried out including analyses of weather data for twenty one weather stations representing different agricultural regions of the Kingdom (Figure 3.2.4). These stations include the following: Abha, Aflag, Bishah, Hail, Haradh, Hofuf, Jizan, Madina, Maqala, Najran, Qurayyat, Riyadh, Sakakah, Sarrar, Shaqra, Sulayyil, Sylkabir and Taif.

In this study, the effect of air temperature increase on reference crop evapo-transpiration and irrigation demand was assessed, assuming no change in other climatic parameters. The effects of a temperature increase from 1^{0}C to 5^{0}C on plant water requirements were evaluated in twenty different areas in Saudi Arabia. The Penman-Monteith method was introduced by ASCE in 1990 and 1996 to predict ETo (ASCE, 1990 and Allen et al 1996). This method was tested and found to be the best for calculating ETo under the prevailing conditions of Al-Hassa, Sarrar, and Al-Fadhly when compared with the measured ETo value among all the above methods. Consequently, the Penman-Monteith method was selected for the calculation of ETo in this study. A special computer program was developed and used to calculate the change in the values of reference crop evapo-transpiration (ET_{O}) and the irrigation requirement (IR) by increasing the temperature by 1, 2, 3, 4, and 5^{0}C in the twenty two areas. The crop water requirement (IR) was calculated from the recommended method by Doorenbos and Pruitt (1984).

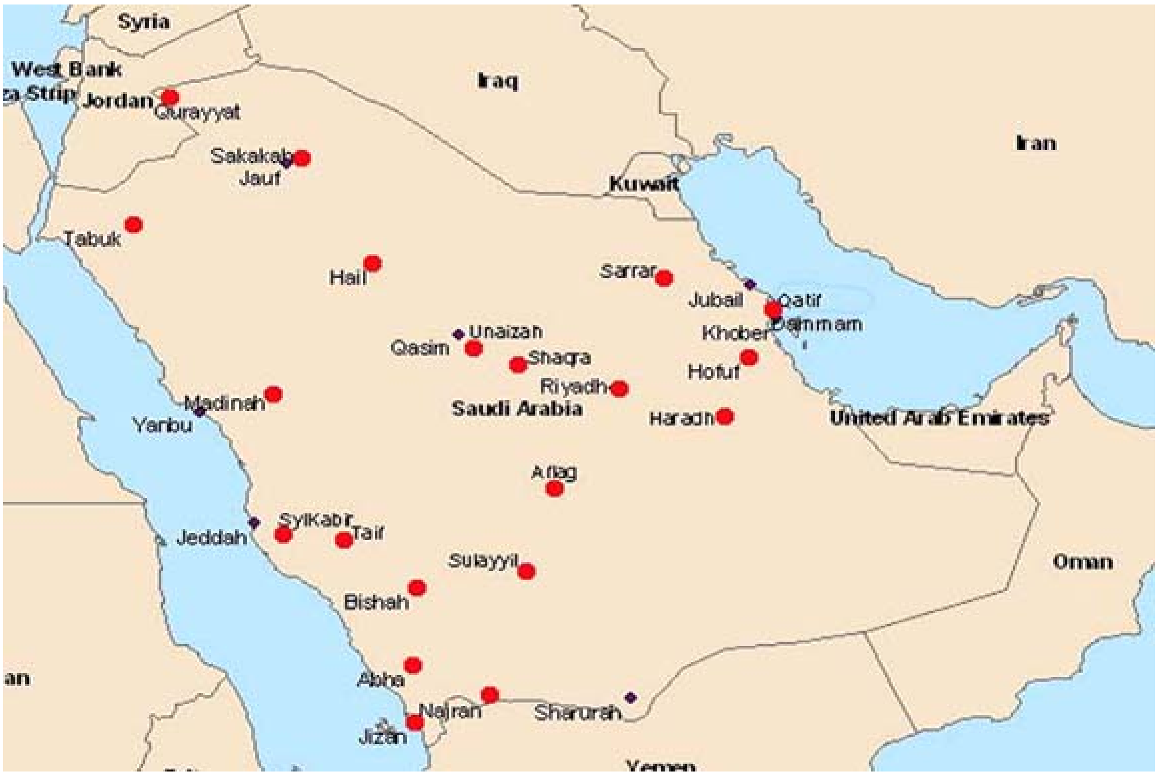


Figure 3.2.4 Distribution of selected stations for the assessment of possible temperature increase on reference evapo-transpiration and water requirements.

The available measured meteorological data provided by the Ministry of Agriculture and Water (1975-1985) were used in the calculation of ET_o values. The data includes: temperature, humidity, solar radiation, sunshine hours, and wind speed. The increase in IR value is equal to 1.54 times the increase in ET_o value, as the average irrigation efficiency value E_p is considered to be 0.65 in Saudi Arabia. It is clear from figures 5 that the increase of 1^oC has resulted in increasing the reference evapo-transpiration and plant water requirements by about 1-4.5% in most of the regions. While, the increase of 5^oC has resulted in increasing the reference evapo-transpiration and plant water requirements by about 6-19.5% in most of the regions (figure 3.2.6). This high increase occurs during winter season from November –March, while the low increase occurs during summer season from May-September. In general, the increase in temperature resulted in increasing the ET_o and IR values in the selected regions by different ratios. The increase in ET_o and IR values in the selected regions during winter season (November-March), were greater than summer and autumn seasons (April-October). In the coastal area (Qatif), 1^0C increase in temperature resulted in increasing the ET_o and IR by values ranged from 2.2% in June to 4.4% in January. An increase of 5^0C in temperature resulted in increasing the ET_o and IR by values ranged from 10.8% in June to 20.0% in January. In the oasis area (Hofuf), 1^0C increase in temperature resulted in increasing the ET_o and IR by 2.1% in August and 3.5% in January. An increase of 5^0C in temperature resulted in an increase in the ET_o and IR by 10.7% in August and 18.2% in January. In the central area (Riyadh), 1^0C increase in temperature increased ET_o and IR by 1.7% in July to 3.1% in January. An increase of 5^0C in temperature resulted in increasing the ET_o and IR by values ranged from 8.2% in July to 15.8 in January. In Tabuk area, 1^0C increase in temperature resulted an increase in ET_O and IR values by 2.1% in July and 3.5% in January. An increase of 5^0C increase in temperature resulted in increasing the ET_O and IR by values ranging between 10.5% in September to 18.0 in January. In Madina area, 1^0C increase in temperature resulted in increasing the ET_O and IR by values ranged from 1.9% in July to 3.0% in December. An increase of 5^0C in temperature resulted in increasing the ET_O and IR by values ranging between 8.9% in September to 15.0 % in January. In Sulayyil area, 1^0C increase in temperature resulted in increasing the ET_O and IR by values ranging between 1.7% in August to 3.4% in December. An increase of 5^0C in temperature resulted in increasing the ET_O and IR by values which ranged between 8.3% in August to 17.6% in January. The increase in water requirements of plants by about 16-19% during winter season will have detrimental effects on plant growth and survival especially during the plant development and growth season. This will contribute to enhancement of vulnerability levels of different regions for desertification in the Kingdom especially in dry winter seasons. This has been experienced in specific regions of the Kingdom such as Taif, Abha and Waha where the average annual rainfall has been dropped since 1985 to less than one third of the rainfall levels of 1985 (Figure 3.2.5). For example, in Abha, the average annual rainfall has dropped from about 253 mm in 1985 to less than 87 mm in 2003 as evident from PME rainfall records. The impact of this drastic drop in annual rainfall has resulted in significant detrimental impacts on the flora (trees and grass) as observed in Abha region, and similarly in Waha and Taif. This will enhance desertification processes by serious land degradation and soil erosion processes.

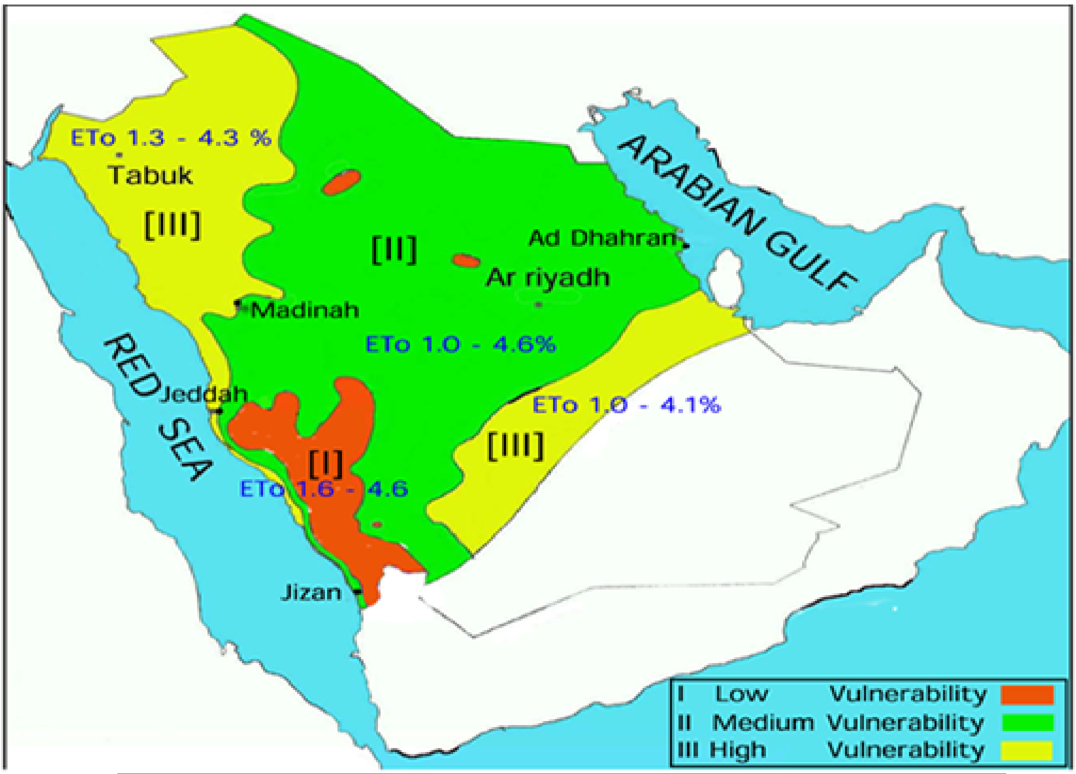


Figure 3.2.5 Increase in values of ETo caused by 1^oC increase in temperature overlapping the flora distribution map of Saudi Arabia.

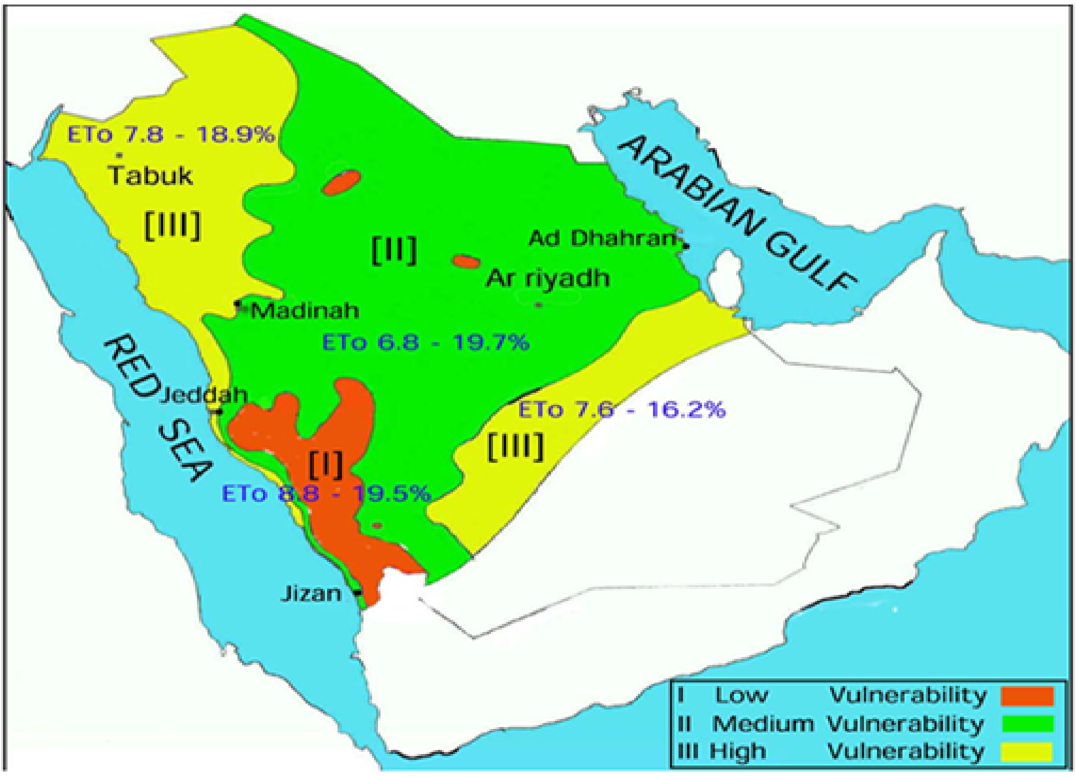


Figure 3.2.6 Increase in values of ETo caused by 5^{o}C increase in temperature overlapping the flora distribution map of Saudi Arabia.

3.2.5 Increase in Plant Water Requirements on Elevating Soil Salinity

There is an indirect effect of water shortages on the soil salinity of the root-zone in irrigated and desert areas. The increase in plants' water demand will lead to more water consumption by plants from the root zone. This will minimize the available water for leaching the accumulated salinity levels in the roots of natural and cultivated plants. With increasing plant water requirements, the plants consume these additional demands from the available irrigation water and from the leaching fraction. This will result in increasing the soil salinity and will cause more deterioration in plant growth and survival and its vulnerability to diseases and partial or complete death. The resultant increase in soil salinity level by increasing the plant water requirements is calculated. Assuming that the additional demand, are taken from the leaching fraction then the percent increase in ET0, and the increase in soil salinity can be calculated. For example, if leaching fraction is 0.2 and the increase in ET0 is 15%, the increase in soil salinity will be 2.8 times of the original value. The desert plants survive mostly on <100 mm/year of water from annual rainfall. The desert plants in the six areas have good growth in desert soils with measured salinity levels of 8.5 to 25 mmhos/cm (ECe levels of saturation extract of soil layer). Table 3.2.2 shows some desert plant communities and their salt tolerance levels in the deserts of coastal, oasis, and central areas.

Table 3.2.2 Measured salt tolerance levels of some common desert plants in Saudi Arabia

Plant Community	Salinity of Soil EC_e in mmhos/cm *
Calligonum comosum	8.5
Cyperus conglomerates	14.8
Haloxylon salicornicum	14.0
Panicum turgidum	14.0
Pennisetum divisum	25.0
Eragrostis barrelieri	14.3
Phoenix dactylifera	12.5
Hammada elegans	14.0

*: EC_e values of measured electrical conductivity of saturation extract of soil layer (0-50 cm).

The expected increase in ETcrop will result in decreasing the soil moisture contents in the root zone and in increasing the salinity levels by more than 3 times the original soil salinity especially during dry winter seasons (Ayers and Wescot, 1985). This will increase the soil salinity to about 25 to 75 mmhos/cm ECe value. Some species might not tolerate that high level of salinity and will be damaged partially or completely. This will result in major reduction in the vegetation cover in different land forms of the country. It is well known that more than 40% sand movement is suspended and controlled by vegetation cover. Thus, possible reduction of plant communities and intensities to less than the above ratio will enhance the soil erosion and collapse of the ecosystem of different land forms which lead to desertification of more areas in the Kingdom. This will be especially pronounced in regions with high vulnerability to desertification processes in the north and central regions, and in the southwestern regions including high lands around Abha, Taif and Baha, that have already experienced major reduction in annual rainfall since 1985.

Future climate change is likely to both reduce the productivity of rangelands and change the areas amenable to livestock production. The extensive urbanizations, industrial and agricultural developments in different regions of the Kingdom during the last three decades have created new local conditions to varying extents such as micro climates, salinized soils, water logged lands, and water stress environments. The resultant climatic changes and water stresses by local and regional causes on natural vegetation are:

- Small Size Plants
- Much Smaller Leaves
- Density of pubescence will be much higher
- Develop thick cuticle on leaves to reduce the transpiration rate
- Produce only a few flowers
- Produce only a few seeds, most of which are not viable
- Early shedding of leaves

- Increased pathogen attack (As climate changes pests and pathogens also migrate to new areas
- Absence of pollinators and seed dispersers
- Disrupt the timing of fruit maturation

Moreover, a reduction in moisture availability would change the species composition in favor of woody, less palatable, plants. A further effect of a shift of carbon storage from soil to biomass is that it is likely to adversely affect soil stability and increase its erosion. As climate change, the areas suitable for rangeland will change in response to changes in the water balance.

3.2.6 Impact on Climate

Biomass burning is a common practice in the tropics and sub-tropics, and dry-land fires are significant sources of atmospheric aerosols and tract gas emissions. The total biomass burning contributes about 40 percent of gross emissions from all sources, the contribution from dry-land burning is conservatively estimated to be around 10 percent. Lands in arid regions such as Saudi Arabia are widely recognized as sources for crustily-derived aerosols (dust) that are transported by the atmosphere. The impact of atmospheric dust on the surface and atmospheric energy balance is complex. However, warming generally occurs in the dust layer and cooling generally occurs beneath them near the surface. The overwhelming effect of desertification on the surface and atmospheric energy balance comes from disruptions to the hydrological cycle. In many cases, removal of vegetation leads to increased runoff and potential evapo-transpiration rates due to higher surface and near-surface temperatures, higher near-surface wind speeds and lower near-surface atmospheric moisture levels. The increase in runoff and evapo-transpiration rates then leads directly to a decrease in soil moisture and a rapid decrease in amount of energy used to evaporate or transpire water into the atmosphere. When less energy is consumed in the latent heat, more energy is available for heating the ground, or heating the air. Phillips (1993) summarized this by suggesting that soil moisture levels in dry lands are directly related to vegetation cover, precipitation and water erosion; and negatively related to albedo, temperature and Aeolian erosion.

3.2.7 Socio-Economic Impacts of Climate Change On Desertification

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 less natural 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 an increase in the area affected by 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 soil becomes further degraded through erosion and compaction. The changes in 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 reduce both 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 (as described before). Substitution of the natural grazing lands for supporting the cattle in different regions of the Kingdom by cropped forage will be difficult and unsustainable due to the expected reduction in water supply sources. Importation and supply of forage crops to nomads and rural communities will be very difficult and economically unviable.

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 survival and structure 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 are forced out from their homelands as a result of desertification, poor harvests and water supply stresses. National economies 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. Quantitative estimates of financial costs are expected to suffer larger relative economic damages.

3.2.8 Adaptation Measures

The Kingdom, since its establishment, has been active in adopting and executing several measures to combat the impacts on desertification. This issue has been on top of the priorities of the government because most of country is existed within sensitive terrestrial ecosystem, which includes vast areas of deserts in different regions. Furthermore, the severe climatic conditions and the low precipitation have made the soils and plants very vulnerable for any change in climatic parameters such as temperature and rainfall. Various types of measures have been taken by different governmental agencies especially during the last three decades in all regions of the Kingdom to minimize effects of desertification processes on plants, soils and natural plantation. These measures have been successful in combating desertification processes. These include:

- Assessment of the natural resources: several studies were executed by several agencies such as soil classification, distribution of Flora in the Kingdom, climate atlas of the Kingdom, survey of range lands and forests in the Kingdom, assessment of the impacts of protection measures on wild life and plants in the protected zones, annual survey of cultivated crops in the Kingdom. These studies have helped in providing concrete baseline for further investigations on the impacts of climate change on desertification.

- Research studies on combating sand encroachment on agricultural and urban facilities helped in minimizing the advancement of drifting sands.
- Implementation of a comprehensive agricultural development program especially 1974 onwards. With major support of the government, the green cultivated areas have increased from less than 200,000 hectares in 1970 to more than 1.2 million hectares in 2004 and vast areas of desert lands have been converted into green areas. These new cultivated areas are expected to help in improving the climatic conditions in terms of temperature, humidity and rainfall around these areas.
- Management and development of rangelands in different regions has helped in protection of these lands and in retardation of desertification processes.
- Cultivation of eroded soils and highlands in different regions of the kingdom.
- Development of national parks by plantation of millions of trees annually in different regions such as Aseer, Al-Hassa, Al Baha, and Khorais.
- Establishment of Wild Life Protection and Development Agency, the National Commission For Wildlife Conservation and Development (NCWCD), in 1986. This agency has helped in defining more than ten protection zones in the Kingdom. This measure has helped in minimizing the impacts of desertification processes within and around these zones on the wild life and natural resources including natural plantation and soils.
- Development and implementation of effective regulations for the protection of soils, natural plants, rangelands, forests and wild life.

3.2.9 Conclusions

Most of Saudi Arabia has sensitive ecosystem for any level of climate change especially on desertification processes. Assessment of these impacts indicated clearly that most regions have high vulnerability levels for climate change impacts on desertification processes. The climate change impacts as represented by temperature increase would elevate the levels of reference evapo-transpiration by about 1-4.5% at $1^{o}C$ increase, and by about 6-19.5% at 5 ^{o}C increase in most regions. The 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 and more than 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 agricultural sector as a major economic sector in the national economy. Compensation of the crop losses importation from foreign countries represent additional burden on the economy. Furthermore, the agricultural activities represent a major support for about 25% of the national population who still live in rural areas. The deterioration of agriculture for rural communities represents a threat to the social structure and welfare of these communities. The natural plants in range lands and the cultivated crops will suffer from water shortages as the very low annual rainfall in the majority of the regions can not compensate for the elevated plant water requirements. Additionally, the top soil layers in rangelands and in irrigated areas will suffer from salinization and increase of salinity levels by 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. Plant cover will be reduced and lands will be more exposed for erosion and desertification. This will lead to serious effects on social and economic development and sustainability of the national economy and progress of the country. In the process of desertification, factors such as degradation of soil organic and nutrient contents, deterioration of soil structure and salinity built up will lead to more evapo-transpiration and less water supplies to less productive lands to support the rural communities that depend on it. This will be more pronounced in the rangelands which provide natural grazing for animals belonging to rural communities especially the nomads such as sheep and camels in all regions of the Kingdom. The reduction in surface moisture or vegetation 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 is further degraded as a result of erosion and compaction. 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. Substitution of the natural grazing lands by cropped forage will be difficult due to the expected reduction in water supply sources. Importation and supply of forage crops to nomads and rural communities will be very difficult. 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 economies 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. Quantitative estimates of financial costs are expected to suffer larger relative economic damages.

3.3 Water Resources

The low rainfall quantities in most of the Kingdom are expected to create limited surface water. The quantities of the annual runoff are estimated to vary “between” about 5,000 to 8,000 million cubic meters (MCM) of which 780 MCM are produced in the Arabian shelf and the rest are in western coastal parts of the Kingdom. The storage capacity of 215 constructed dams of different shapes and sizes is 833 MCM (personal communications, 2004). These dams were constructed for groundwater recharge, surface storage and flood control purposes. The available surface water for use is about 2230 MCM including the dams’ storage.

Groundwater is stored in more than 20-layered principal and secondary aquifers of different geological ages (Figure 3.3.7). The Arabian Shelf includes the deep sedimentary aquifers which are formed mostly of limestone and sandstone that overlay the basement rock formation known as the Arabian Shield, and covers about two third of Saudi Arabia or 1.485 million km^2 . These aquifers crop out in the western parts of the Shelf and extend towards the eastern parts. The isotopic analyses showed that the fossil groundwater in the above aquifers is 10,000-32,000 years old. Large volumes of groundwater are stored in the sedimentary aquifers. The renewable groundwater resources are mainly stored in the shallow alluvial aquifers and within Basalts, which extends mostly in the southwestern parts of Saudi Arabia with varying thickness and width. These aquifers store about 84 BCM with an average annual recharge of 1,196 MCM. The total national groundwater reserves in the shallow and deep aquifers to a depth of 300m below ground surface are about 2,259 (BCM). These assessments need to be updated because they were mostly based on investigations carried out before more than fifteen years.

It is estimated that about 1,400 MCM of wastewater was generated in the country in the year 2000. The volumes of collected and treated wastewater are about 534 MCM, which represent about 38% of the total generated wastewater, and 33% of the total distributed domestic water. Presently, about 240 MCM of the treated wastewater is reused annually for landscape and crop irrigation purposes.

The total water production from desalination plants increased from about 200 MCM in 1980 to 540 MCM, 785 MCM and 1050 in 1990, 1997 and 2001 respectively. The desalinated water production is expected to reach about 1600 MCM in 2010 and more than 2500 MCM in 2025. The present production represents about 50% of the total domestic and industrial demands, and the rest is from limited surface water and mostly from groundwater resources in shallow and deep aquifers. By 2025, the desalination production is expected to be about 54% of the total domestic and industrial demands. The available water resources in the country from conventional and non-conventional resources are summarized in Table 3.3.3.

3.3.1 Water Supply and Demand Overview

The domestic and industrial water demands have grown from about 220 MCM in 1970 to about 2030 MCM in 2000, and expected to reach 6,450 MCM in 2020. The industrial demands represent less than 10% and 2% of the total domestic and industrial demands, and the national demands respectively (table 3.3.4). The growing domestic and industrial water demands are mainly satisfied from desalination plants and from the non-renewable groundwater resources. The cultivated areas have expanded from less than 400,000 ha in 1971 to 1.62 million ha in 1992, and started to decrease in 1993 until it reached about 1.21 million ha in 2000. The total irrigation water use has increased from about 6,108 MCM in 1970 to about 9,470 MCM, 18,776 MCM and 19,074 MCM in 1980, 1990 and 2000 respectively (Tables 3.3.4).

The total volumes of available renewable water resources from surface water and groundwater recharge are about 6,188 MCM. Non-renewable groundwater resources supplied about 37%, 67% and 66% of the total national needs in 1980, 1990 and 2000 respectively (Table 3.3.8). The domestic and industrial water use depends mainly on desalination processes in satisfying about 50% of the demands while the other 50% is supplied by groundwater from the local aquifers near cities and towns. It is clear from table 3.3.6 that the dependence on nonrenewable groundwater has increased from 37% of the national demands in 1980 to 67% and 71% in 1990 and 1992 respectively, and then decreased to 66% in 2000 due to increased production of desalination water and reduction in areas for agriculture after 1993. The reuse of treated wastewater especially for irrigation has been very low (less than 1%), and is expected to grow significantly in the near future with improvement of water management as will be discussed below.

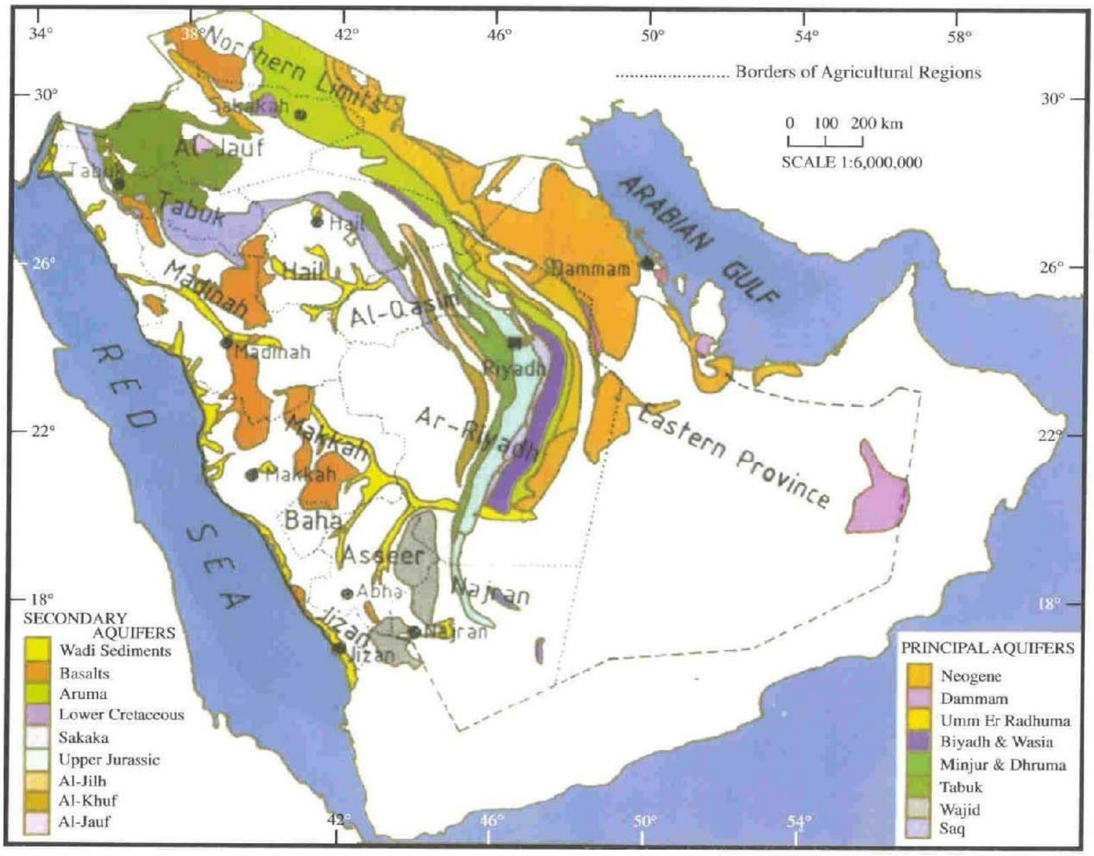


Figure 3.3.1 Extension of the outcrop areas of principle and secondary aquifers in agricultural regions in Saudi Arabia

Table 3.3.1 Available water resources in Saudi Arabia in 2001-2003(MCM)

Surface water	5,000-8,000 (2,230 available for use)
Groundwater resources	2,269,000 (84,000 renewable groundwater in shallow aquifers)
Groundwater recharge	3,958 (1,196 to shallow aquifers and 2,762 to deep aquifers in the Arabian Shelf)
Desalination	1,050
Treated wastewater	240

Table 3.3.2 Growth of water use in Saudi Arabia between 1970 and 2000 (MCM)

YEAR	Domestic and Industrial			Agriculture	Total
	Domestic	Industrial	Total		
1970	200(3.2%)	20(0.3%)	220	6,018(69.5%)	6,238
1980	446(4.4%)	56(0.6%)	502	9,470(95.5%)	9,972
1990	1508(7.4%)	190(0.9%)	1,698	18,776(91.7%)	20,474
1995	1550(6.7%)	230(1.0%)	1,780	21,498(92.4%)	23,278
2000	1800(8.5%)	290(1.4%)	2,090	19,271(90.2%)	21,361

Table 3.3.3 Water supply in Saudi Arabia (MCM)

Water source	1980	1990	1992	2000
Treated wastewater effluents	110 (1%)	110 (0.5%)	110 ((0.4%)	240 (1.1%)
Desalination	200 (2%)	540 (3%)	540 (2%)	1050 (5%)
Surface water & and recharge to shallow and deep aquifers (renewable water)	6,000 (60%)	6,000 (29%)	6,000 (26%)	6,000 (28%)
Groundwater(nonrenewable)	3,662 (37%)	13,824 (67%)	16,628 (71%)	14,071 (66%)
Total	**9,972**	**20,474**	**23,278**	**21,361**

3.3.2 Assessment of Impacts of Climate Change on Water Resources

3.3.2.1 Impacts of Climate Change on Groundwater Recharge and Surface Water

Any increase in ETo will result in increasing the evaporation rates and decreasing the available water supplies from annual participation by:

- lowering the annual recharge to aquifers
- Lowering the surface runoff.

The calculated total annual recharge to all aquifers in the Arabian Shelf is about 2,762 MCM based on several hydro-geological studies. The annual recharge to shallow aquifers in the Arabian Shield is 1,196 MCM. Thus, the total annual recharge to all aquifers in the Kingdom is about 3,958 MCM. The average increase in reference evapo-transpiration ETo, which reduces the recharge to all aquifers has been defined as 2.3% and 12% of the total annual recharge at 1°C and 5°C increase in temperature respectively. The calculated reduction in the values of total annual recharge is about 91.4 MCM and 475 MCM at 1°C and 5°C increase in temperature respectively.

3.3.2.2 Impacts of Climate Change on Surface Water

The reduction in annual surface runoff of 5,000 – 8000 MCM at ETo increase of about 2.3% and 12% at 1°C and 5°C increase in temperature respectively have been calculated . At 1°C increase in temperature, the increase in ETo of 2.3% will result in decreasing the annual surface runoff by about 115 -184 MCM (with an average of 150 MCM). While at 5°C increase in temperature, the increase in ETo of 12% will result in decreasing the annual surface runoff by about 600-960 MCM (with average of 780 MCM). The total annual reduction in water resources equals to reduction in recharge and reduction in surface runoff. Thus, the total water resources reduction will be about 241 MCM and 1,435 MCM at 1°C and 5°C increases in temperature respectively.

3.3.2.3 Impacts of Climate Change on Irrigation Water Demands

The calculated increase in ETo has been used to calculate the increase in irrigation requirements of various crop types in different regions of the Kingdom at 1°C and 5°C increases in temperature. Total annual increase in irrigation water demand in the Kingdom ranges between 602 MCM at 1°C to 3122 MCM at 5°C respectively.

3.3.2.4 Impacts of Climate Change on Domestic and Industrial Demands

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

3.3.2.5 Prediction of Total Water Stresses

The total water stress is equal to the total quantities of decrease in groundwater recharge and surface runoff, increase in irrigation requirements and domestic and industrial demands at 1°C and 5°C increases in temperature. The calculated total water stress ranges between 1520 to 4,947 MCM at 1°C and 5°C increases in temperature respectively (Figure 3.3.8).

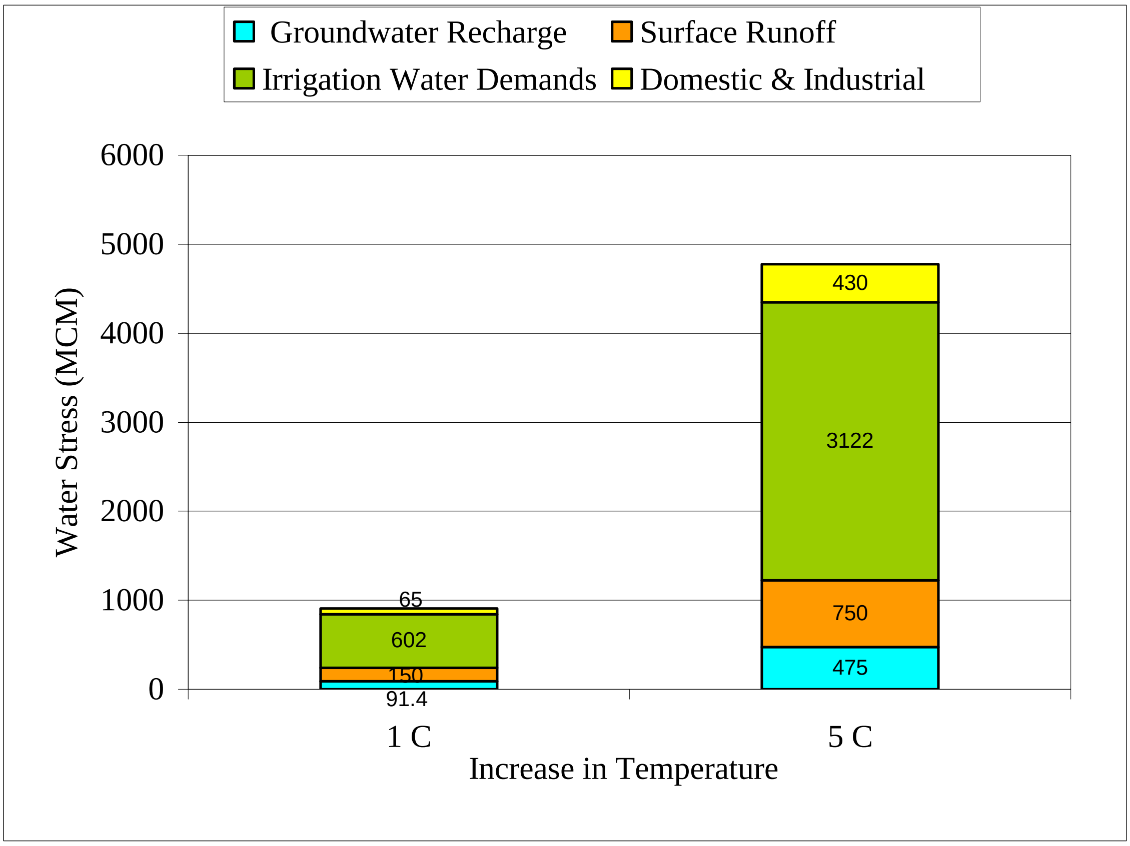


Figure 3.3.2 Stress on water resources as a result of climatic change

3.3.3. Socio-economic Impacts

The described impacts of climate changes in above sections on water resources in Saudi Arabia are expected to have significant effects on socio-economic conditions in the Kingdom. The welfare, development and survival of urban and rural communities and the sustainability of the national economy are directly affected by the impacts of climate change on water resources. These impacts can be explained in the followings:

3.3.3.1 Socio-Economic Impacts from Increasing Water Demands

The possible climate change is expected to induce significant increase in water demands for domestic, industrial and agricultural purposes and simultaneously a major reduction in water supply conditions in terms of qualities and quantities. The domestic and industrial water demands of about 2030 MCM in 2000 are expected to increase by 75 and 390 MCM at 1°C and 5°C increase in temperature respectively. The costs of the above rises in water demands will represent additional burden on water authorities and citizens as it should be supplied from desalination processes for domestic use. The expected costs will exceed one billion Saudi Riyals annually as the costs of drinking water production and distribution is about SR 4 per cubic meter (personal communication with the Ministry of Water and Electricity). This represents about ten percent of the present costs of total national water supplies. The stress on domestic water supplies will be aggravated by the possible decrease in groundwater recharge and surface runoff with temperature increase. This means that the domestic water supplies of 50% from groundwater and surface water will be replaced partially or totally from desalination processes. The related costs of these supplies will exceed SR 4 billions annually. If these increases in domestic and industrial demands are not satisfied then more water supplies problems in rural and urban areas will be experienced. The human, construction, commercial, transportation, education, health and industrial activities will be negatively disrupted. This will lead to serious effects on social and economic development and sustainability of the national economy and progress of the country.

3.3.3.2 Socio-Economic Impacts due to Increase in Agricultural Water Demands

The government used the agricultural development for accomplishing several objectives. In addition to contribution to food security, socio-economic developments and national gross domestic product (GDP), it has been important mean for the protection of the structure of local communities and minimization of impacts of urbanization on rural areas, by the improvement of standard of living through a stable and better source of income, training and settling the nomads into agricultural and prosperous communities, and by the introduction of effective public services such as health and education, and commercial facilities. The total given loans between 1973 and 1998 were 178,624 loans for a total value of SR 29.5 billion ($7.7 billion). The total given support for wheat and barley production has been about SR 55,459 billions (US$14.87 billions) between 1979 and 2000. About SR 16.659 billions (US$ 4.44 billions), SR 3.808 billions (US$ 1.015 billions) and SR 7.884 billions (US$ 2.102 billions) have been given for imported barley, poultry feed and agricultural inputs such as fertilizers and machinery respectively during 1974 and 2000. The total given supports is SR 83.81 billions (US$ 22.34). The values of given total supports in addition to loans are SR 113.31 billions (US$ 30.216 billion). New agricultural infrastructure including wells, pumps, sprinkler irrigation and drip systems were introduced in these remote areas, and as a result, hundreds of thousands of hectares of desert lands were reclaimed and converted into productive farms.

The comprehensive agricultural developments especially after 1974 have contributed in achieving self sufficiency in five agricultural commodities. These are poultry meat and eggs, milk, wheat, dates and most types of vegetables. In 1999, the agricultural sector accounted for 6.7% of the total Gross Domestic Product (GDP), and equivalent to the GDP of the industrial sector. The value of agricultural GDP to total GDP in percentage has grown from 1.1% in 1974 to about 6.7 in 1999. The agricultural GDP has grown from SR 994 millions in 1969 to SR 34,443 millions in 1999 or by 994%, while, the national GDP has grown from SR 16,611 millions to SR 512,354 millions or by 31% during the same period. The value of agricultural GDP in 2000 at current prices was SR 35,600 millions. All above values indicate clearly that the agricultural sector became an essential productive sector which has been contributing significantly to the national economy even after the reduction of supports and incentives to agriculture between 1984 and 2000.

The total irrigation water use has increased from about 6,108 MCM in 1970 to about 19,074 MCM in 2000. The climate change will result in increasing the annual irrigation water use by about 602 and 3,122 MCM at 1^oC and 5^oC increase in temperature respectively. It will be difficult to compensate this demand under decreasing surface runoff. The expected rise in irrigation demands will lead to losses in crop yield if not compensated. These 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 agricultural sector as a major economic sector in the national economy. Compensation of the crop losses importation from foreign countries represent additional burden on the economy. Furthermore, the agricultural activities represent a major support for about 25% of the national population who still live in rural areas. The deterioration of agriculture represents a threat to the social structure and welfare of rural communities.

3.3.4 Adaptation Measures

The government has been instrumental in supporting different programs for minimizing the impacts of possible climate changes on water supplies for satisfying the growing demands for domestic, agricultural and industrial purposes. The available groundwater resources in deep and shallow aquifers and limited surface water have been utilized to satisfy about 90% of the total national demands. The rest of demands have been supplied from seawater and brackish desalination processes. Advanced measures have been implemented to protect the sustainability of water resources and to satisfy the demands in urban and rural areas for different purposes. These measures include:

The government has executed a long-term investigation program to assess the availability of groundwater and surface water resources in different regions and has adopted the development of aquifers and surface water on the basis of these studies.

The government has supported drilling of thousands of wells under the supervision of the Ministry of Agriculture for domestic, agricultural, and industrial purposes (as explained in Section 3.4.1.B). Several other measures undertaken by the government are summarized below.

- The government has supported the construction of 215 dams for water storage and groundwater recharge for domestic and agricultural uses (as explained in Section 3.4.1.A).
- Building of 30 desalination plants to supply about 50% of the domestic water supplies in the Kingdom (as explained in Section 3.4.2.B).
- Establishment of the Ministry of water and Electricity in July 2001 to improve the national water planning and management in the country.
- Development and implementation of water protection and conservation regulations. These include well drilling permission, drilling supervision and specifications, groundwater protection zones, groundwater pumping schemes, protection of groundwater from pollution, surface water development and water conservation.

- Construction of wastewater treatment plants and implementation of wastewater reuse schemes for landscape and crop irrigation in different regions of the Kingdom.
- The introduction and implementation of advanced water conservation support policy at residential level.
- Implementation of modern leakage detection and control schemes in major cities.
- Implementation of advanced irrigation water conservation schemes for large and small farms.
- Modification of water pumping from aquifers by changing the agricultural policies to maintain the long-term sustainability of the aquifers.

3.3.5 Conclusions

Most of Saudi Arabia has limited renewable water resources in addition to groundwater in deep and shallow aquifers. These limited water resources are very sensitive to climate change. Assessment of the impacts on water resources indicated clearly that most regions have high vulnerability levels for climate change impacts on water resources. The total annual reduction in recharge and surface runoff will be about 241 MCM and 1,435 MCM at 1^{o}C and 5^{o}C increase in temperature respectively. On the other hand, the climate change will also increase the domestic and industrial water demands by about 75 and 390 MCM at 1^{o}C and 5^{o}C increase in temperature respectively. This will lead to increased domestic, industrial and agricultural demands. The costs of the above rise in water demands will represent additional burden on water authorities and citizens as it should be supplied from desalination processes for domestic use. The expected costs will exceed one billion Saudi Riyals annually as the costs of drinking water production and distribution is about SR 4 (personal communication with the Ministry of Water and Electricity). This represents about ten percent of the present costs of total national water supplies. The stress on domestic water supplies will be aggravated by the possible decrease in groundwater recharge and surface runoff with temperature increase. This means that the domestic water supplies of 50% coming from groundwater and surface water will be partially or totally fulfilled from desalination processes. The related costs of these supplies will exceed SR 4 billions annually. If this increase in domestic and industrial demands is not satisfied then more water supplies problems in rural and urban areas will be experienced. The human, construction, commercial, transportation, education, health and industrial activities will be negatively affected. This will lead to serious impacts on social and economic development and sustainability of the national economy and progress of the country. Deterioration of water supplies, rainfall, surface runoff and aquifer recharge will be having serious impacts on the social survival and structure in rural areas. Welfare of these communities will be seriously threatened. Consequently, sustainability of economic development and social structure in rural areas will be under serious challenges. 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. Quantitative estimates of financial costs are expected to suffer larger relative economic damages.

3.4 Coastal Zone Management: Sea Level Rise

3.4.1 Coastal Characteristics

Saudi Arabia lies at the crossroads of three continents, Europe, Asia and Africa. It extends from the Red Sea on the west which is 1,760 kilometers long; to the Arabian Gulf on the east which is 650 kilometers long (Figure 1).

Figure3.4.1 Saudi Arabian Coastal Cities

3.4.1.1 Saudi Arabian Coastal Cities

There are 17 coastal cities along the Arabian Gulf (Table3.4.1) and 34 along the Red Sea (Table 3.4.2)

Table 3.4.1 Arabian Gulf Coastal Cities

The Arabian Gulf of Saudi Arabia		
Eastern Province		
Al Khafji	As Shfaniyah'Al-Jibai	Al-Ugayr
Ras al Zawr	Al Jubail	Munifah
Al Jaemar	Ras Tannurah	Ar Rubayiyah
Snabis	Darin	Safwa
Al Dammam	Al Dhahran	Qudaya
		Al-Khobar
		Salwah

Table 3.4.2 Red Sea Coastal Cities

The Red Sea Of Saudi Arabia		
Sakkakah province	Haql	
Medina Province		
Yanbu Al Bahr	Ar Rayis	
Makkah Province		
Masturah	Rabigh	Thuwal
Dhabban	Jeddah	Mastabah
Al Laith	Al Wasqah	Muqal Al Ulya
A Muzayif	Ajah	Al Qunfudah
Al Quz	Al Kidasah	Unnykir Al
Al Fariq	As Salamah	Al Ma'aysah
Makhshush	A Maq	Al Birq
Gizan Province		
Al Tirq	Al Qamah	As Shuqaiq
Gizan	Al Hanashali	Tuhamah
As Sahi	Qulinah	Al-Ka'ashm
Farasan		

3.4.1.2 Study Basis

This chapter is highlighting the main components of addressing vulnerability, impact assessment and adaptation to the Accelerated Sea level Rise (ASLR). Three main scenarios were used based on literatures assessed by the Intergovernmental Panel for Climate change (IPCC). Before the application of the three scenarios, baseline review was conducted to include sustainable development determents such as marine environment and socio-economic aspects. In addition, a baseline for meteorological aspects for the Kingdom was developed. The baseline studies will assist in the evaluation of climate change and sea level rise. It will also be used for future determination of more accurate impacts for coastal zone biota and socio-economic impacts.

The chapter then will focus on specific vulnerabilities and applied risk assessment techniques to determine environmental area at risk as well as identify economic and social activities that will be impacted by accelerated sea level rise. With the identification of the three scenarios for accelerated sea level rise, the chapter will determine possible impacts on both the environmental and socio-economic activates. For vulnerability and impact assessment, it is now an accepted practice to identify the most sensitive sectors in the economy. In the case of Saudi Arabia, the sensitive areas identified are (a) Water resources, (b) Agriculture (c) Marine life (d) Coastal zone (e) Infrastructures and (f) Tourism. The Accelerated Sea Level Rise Impacts are expressed as Biogeophysical and Socio-economic impact

Finally an adaptation section will highlight the Kingdom's effort to combat accelerated sea level rise and present possible option that the Kingdom may utilize to deal with this potential threat.

3.4.2 Baseline & Vulnerability Aspects:

3.4.2.1 Baseline Information:

3.4.2.1.1 Marine Resources:

Coral Reefs represent the most significant habitat found along the Saudi shores (both Red Sea & Arabian Gulf). These reefs as well as the Mangrove forests form the basic framework of tropical habitats and provide shelter and food for wide array of marine life. More than 194 species of coral reefs form about 74 genera have been recorded, with the highest coral diversity occurring in the central Saudi Arabian Red Sea area. Coral reef harbors a longstanding and important artisan fishery.

3.4.2.1.1.1 Arabian Gulf Coral Reefs

Among the most spectacular manifestations of life on this planet are coral reefs, some of which represent by far the largest structure made by living organisms. The high salinities and wide temperature range fall well outside the optimum range for coral reef development; and consequently Arabian Gulf coral reefs support far fewer species of both corals and associated fauna than the reefs of Red Sea or Western Indian Ocean. The limiting effects of the Gulf environment now appear, however, to be much less severe than had been supposed previously. During a relatively cursory examination of the Saudi Arabian reefs, twice as many genera of reef corals have been recorded as the total recorded by previous investigations in the Gulf.

3.4.2.1.1.2 Arabian Gulf Mangroves

The seaward edge of the halophyte zone is marked by abrupt "step" or drop in the level of the mud, at the transition from the firm halophyte "turf" to wet mud of much sorter consistency. The uppermost levels of these wetter sediments are usually occupied by a belt of black mangroves "*Avicennia marina*", forming a thicket of dark green bushes one to two meters high. Mangroves trap sediments and bind them together with an extensive root system; thus gradually extending the tidal flat seaward. The wet, fine-grained mud is rich in organic matter and devoid of oxygen below the surface; and the mangrove roots are able to survive only by means of pneumatophores, which project above the mud surface at regular intervals and conduit oxygen to the buried portions of the root system.

3.4.2.1.1.3 Arabian Gulf Sanctuaries

Al-Jubail Marine Wildlife Sanctuary

Al-Jubail Marine Wildlife Sanctuary is located on the east coast of Saudi Arabia, North of Jubail industrial town and occupies an area of 2,300 square kilometers. The sanctuary was established in 1993 as nature reserve and managed by National Commission for Wildlife Conservation and Development (NCWCD). The main objective of the management plan is to protect the coastal habitat and reintroduce the mangrove trees in the area.

The sanctuary consists of two shallow gulfs namely Dawhat Al-Wafi and Dawhat Al-Musalamiyah; a coastal stretch between Abu-Ali and Raas Al-Zoor; five coral islands namely Harkosi, Karan, Kareen, Jana and Juraid. A diversified flora species is present in different habitats (Figure 3.4.2). As for the Fauna species, it’s present in different habitats e.g. 260 bird species which represent more than 70% of the birds found in the Gulf Region. Some of the islands are important breeding ground for green turtle, and various species of terns.

3.4.2.1.1.4 Red sea Coral Reefs

Coral reefs of the Red Sea are among the most spectacular in the world. Most are situated along the coast and surrounding offshore islands and are in relatively good condition. However, along some stretches, such as the coast surrounding Jeddah and the industrial city of Yanbu, coral reefs are increasingly becoming affected by development.

There are 194 species of corals recorded along the Saudi Arabian coast of Red Sea with the greatest diversity in the central portion. Five areas along the coast are noted for their extensive coral reefs: Tiran island area, Wajh bank, area north of Yanbu, coastline between Obhur and Tuwwal north of Jeddah; and outer Farasan bank.

Coral reefs play an important role in the coastal ecosystem. They provide habitats for a wide variety of marine species and protect coastal lands from erosion and storm damage. In the red sea, coral reef communities generally form extensive and productive reef flats which create protected habitat from many juvenile species as well as lagoon with also serve this purpose

3.4.2.1.1.5 Red Sea Mangroves

Mangroves generally grow in water logged and saline soil of the inertial zone and are often associated with areas of runoff. Only two species have been recorded along the red sea coast, *Avicemnia marina*, which is widespread, and *Rhizophora mucronata*, found only at six sites. They are found in such areas as broad coastal plains, protected shores, over shoals and spits, and in lagoons.

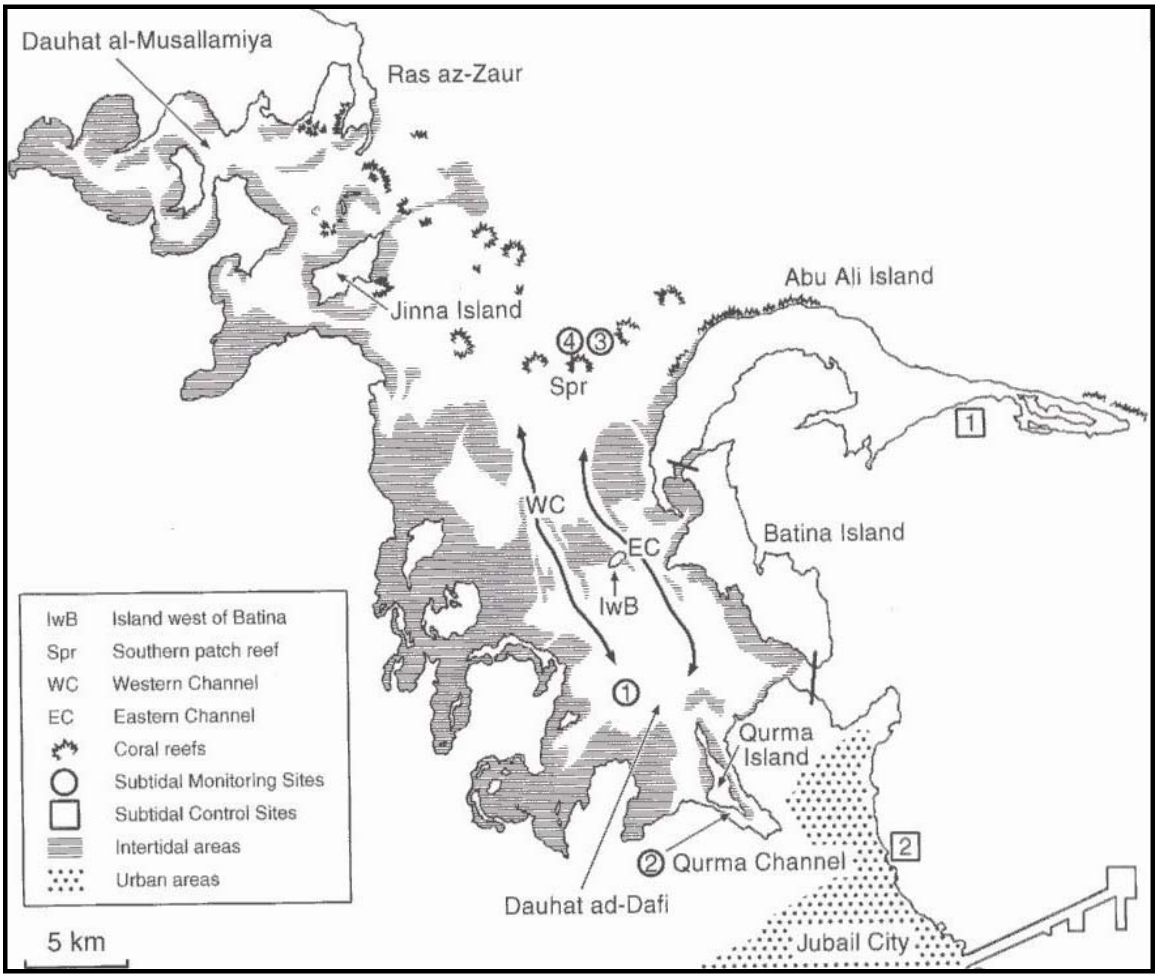


Figure 3.4.2 Ras Abu Ali marine sanctuary

While mangroves are found scattered along much of the Red Sea Coast, the major concentration is in the southern red sea where factors such as increased sediments create an environment more conducive to their development. Agricultural development, properly planed and managed, could be beneficial to certain coastal habitats such as mangroves. Mangroves have a variety of values: they provide food in the form of detritus, shelter for numerous organisms (such as mollusks, crabs, shrimps, and fish), fodder for camels and goats, and fuel for human use. Mangroves are also important nesting sites for several species of birds.

Development of coastal recreational facilities and coastal villages in Ras Hatiba area north of Jeddah and shrimps aquaculture along the southern Red Sea coast have contributed to the decline of Saudi Arabia's Coastal mangroves.

3.4.2.1.1.6 Red Sea Marine Sanctuaries

Farasan Sanctuary

The Farasan Island group is a large archipelago of Red Sea coral islands lying 40 km offshore from Jezzan, with many low-lying islands and islets. Some islands are bare and surrounded by coral, while others are sandy. The largest island is Farasan Kabir, being 66 km long and 5-8 km wide, and the highest point does not exceed 72 m. It has the greatest biological diversity of any site in the Saudi Arabian Waters of the Red Sea.

Farasan Sanctuary is located in Southern Red Sea of Saudi Arabia and occupies an area of 696 square kilometers. It was established in 1989 as a natural reserve. The sanctuary is managed by the National Commission for Wildlife Conservation and Development (NCWCD) to protect the Mangroves, Dugong and Gazelles.

There are several dense stands of mangrove, mostly the black mangrove, Avicennia marina and red mangrove, Rhizophora mucronata, seven species of sea grass present in the surrounding waters. The important plant communities include Commiphora, Acacia and Salvadora. About 231 species of fish, 49 species of reef building coral, 3 species of Dolphin, wide diversity of mollusks, crustaceans, large numbers of breeding seabirds as well as populations of breeding Ospreys Pandion haliaetus and Sooty Falcons Falco concolor are also of considerable importance. A remnant population of endangered Dugong Dugong dugon and the only known confirmed breeding site for Crab Plover Dromas ardeola also exist on the red sea coast of Arabia. The Islands include the largest wild population of gazelles, Gazella gazella farasani (an endemic subspecies of the idmi gazelle).

3.4.2.1.2 Physical and Chemical Properties:

3.4.2.1.2.1 Physical Properties

Arabian Gulf

The surface water temperature in the Arabian Gulf varies between 12°C in winter and >35°C in summer. The temperature difference between summer and winter is greatest (>20°C) in the north-western part and least (<11°C) at Hormuz.

Due to high rate of evaporation, salinity increases gradually from southern to northern parts of the region with lower salinity along the eastern coast. In summer, the surface salinity varies from 34 ppt off the Omani coast on the Arabian Sea, to 37 ppt in the Gulf of Oman and up to 42 ppt just off Bahrain. Salinities as high as 70 ppt have been repeated in the Gulf of Salwah at its extreme southern extremity. In winter, the salinity is somewhat higher than in early summer in the upper NW, apparently due to the variation of fresh water influx from Shatt Al-Arab and meteorological effects, particularly evaporation.

A surface flow of water of high temperature >28°C and low salinity about 37 ppt enters the Sea Area through the Straits of Hormuz during the summer season. This flow is also observed in the winter with temperature >20°C and salinity 39 ppt. The annual seawater temperature variations in the area, which reaches down to 20 m depth in May and to deeper depths in February, might be related to air temperature and the vertical mixing intensity. The strong mixing in February leads to a vertical homogeneity and changes extended to deeper-layers. In May, the thermo-cline acts as a barrier and limits the variation to the upper 20 meters.

Tides in the Arabian Gulf are complex and vary from semi-diurnal to diurnal. The tidal range is large with values greater than 1m everywhere. The dimensions of the inner are such that resonance amplification of the tides can occur and the result is that the semi-diurnal constituents have two amphidromic points while the diurnal constituents have one amphidromic point, in the central region of the Arabian Gulf. The tides in the Arabian Gulf are basically semi-diurnal. Tidal range is least in the central basin of the area, being about 1 to 2 meters in the central region. In the northwest, at Shatt Al-Arab delta, tides are normally about 2.5 meters, and in the South (in the Gulf of Oman), the range is about 2 meters.

The tidal regime in the southern region is predominantly of the mixed, prevailing semi-diurnal type i.e. there are two high waters and two low waters per day with a large diurnal inequality in high and low water levels.

Red Sea

Surface waters of the Red Sea are always warmer than the deep waters and there is evidence on an intermediate layer between them. Deep water temperatures in the Red Sea are remarkably high compared to those formed in the deep water of the ocean at the same depth. The deep water temperature is about 21°C at 1000 m. The Red Sea can be characterized in terms of three water layers: **mixed layer,** which develops because of mixing induced by the wind stress and is formed immediately beneath a thin surface water layer. The water temperature in the mixed layer is almost constant. During the summer months, the mixed layer is about 50 m deep and it becomes deeper with the increased strength of wind field in the winter season; **thermocline layer** is formed beneath the mixed layer and is found to extend from 50-100 m to about 700 m. The temperature gradient is large in this layer because of the fairly rapid decrease in temperature with depth. During the winter this layer deepens because of the increase in the vertical mixing processes in the upper layers; **deep layer** occupies most of the depth of the Red Sea, extending from about 700 m to the seabed. The water temperature in this layer is almost constant (21°C), throughout the year.

Tides in the Red Sea are semi-diurnal and are simply represented by a standing wave having a single central node. Period of tidal oscillation is approximately 12.8 hours for a depth of 500 m and length of 1600 km. The average spring tidal range is about 0.5 m at either end of the Red Sea, but the magnitude decreases towards the central region. South of the Strait of Bab Al-Mandab, the time of high water changes by several hours, and the spring tidal range increases to about 1.0 m. The Red Sea is an ideal sea to test the dynamical theories of the tide because of its long narrow shape.

3.4.2.2 Vulnerability Aspects

More than 50 percent of the population of Saudi Arabia lives within 100 km of the Saudi coastline. The coastal region houses cities, towns, and myriads of factories and processing plants. The interface between the land and sea is the main site for the import and export of goods and services essential for the wellbeing and economic prosperity of the country. Coastline is the location of desalination plants that supply the bulk of the country's drinking water, oil refineries and petrochemical factories, and a number of cement plants in the Kingdom in addition to ongoing recreational and tourism industry. Because of the great length of the Saudi Arabian coastline, only vulnerable industrial and populated coastal zone cities that could be affected by ASLR have been included in this study. At the Eastern Coast of Saudi Arabia along the Arabian Gulf, Dammam, Ras Tanura, Jubail and Khafji have been selected as the most vulnerable coastal zone areas. At the Western Coast of Saudi Arabia along the Red Sea, Jeddah, Rabigh, Yanbu and Jizan have been selected as the most vulnerable coastal areas.

3.4.2.2.1 Arabian Gulf

Considering the socioeconomic aspects, there are four main coastal cities that could be impacted by ASLR along the Arabian Gulf, namely Dammam, Ras Tanura, Jubail and Khafji. Other coastal cities and towns viz. Safaniya, Munifah, Ras Al-Zawr, Safwa, Azawar, Sanabis Darin, Al Rabiyah, Al Ugayr and Salwa are scattered along the coastal zone and have less socio-economic importance compared to Dammam and Jubail area (Figure 3.4.3).

Dammam Area (Dammam, Al Khobar and Dhahran)

The development, which took place in the Kingdom, linked the three cities (Al-Khobar, Dhahran and Ras Tanura) into almost a single area, known as Dammam Area (Figure 3.4.4) and run by a single municipal administration with total area of 718 square kilometers (277 square miles), also have local administrations. Each city has its own special characteristics and role in giving the area its present shape. The simultaneous growth of Dammam, Dhahran and Al-Khobar brought the three jurisdictions into physical contact, with the result that the triangle which connects the cities is now one large urban and industrial mass. This entire region, covering some 300 square miles of land, is now known as the Dammam Area and is run by a single municipal entity.

Located in the Kingdom’s Eastern Province, Dammam Area is surrounded by the Arabian Gulf to the north, east and south and extends westward to Dahna desert. It lies on a longitude of $50^{0}6'$ and latitude of $26^{0}6'$, on a broad coastal plain with an extensive tidal area, sloping slightly towards the Arabian Gulf Coast. Dhahran area abounds in rocky outcrops and hills reaching 144 meters (470 feet) in height in some parts and about 200 meters (600 feet) in areas to the north of Dhahran. Sand shifted around by the frequent winds in the Southern area forms dunes up to 30 meters (100 Feet) high.

Dhahran, Ras Tanura, Jubail and Kafji are the most important economical and industrial zone in Saudi Arabia, whereby most of the petroleum and petrochemical industries that support the Saudi economy is within this zone. The discovery of new oil fields to the south, west and north of Dammam in the 1940s and 1950s, which now account for a quarter of the world's proven oil reserves, triggered a building boom.

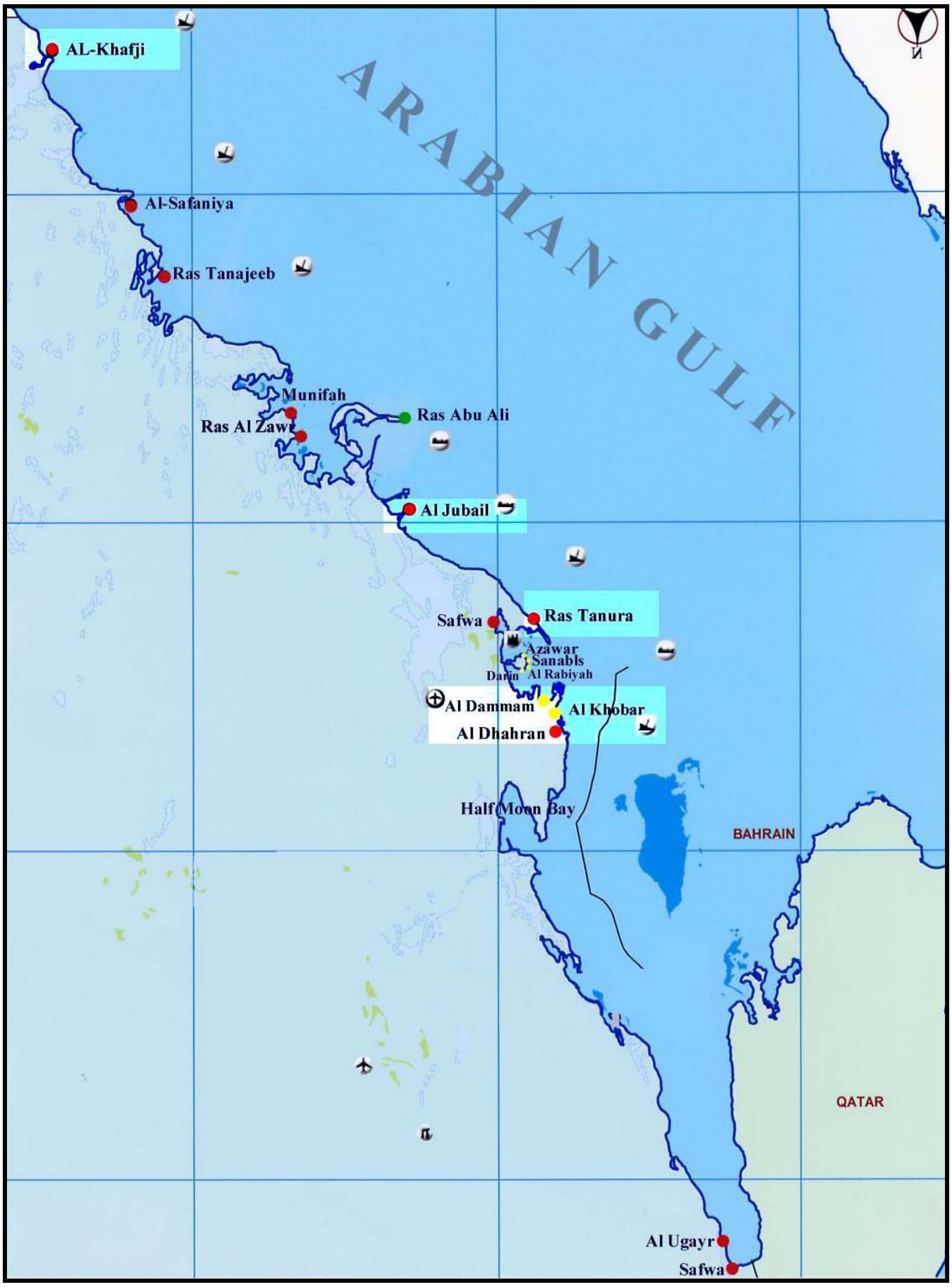


Figure 3.4.3 and 3.4.4 Arabian Gulf Coastal Cities

Figure 3.4.5 Dammam City Coastal Zone

The growth of the oil industry in the region had a similar impact on the small fishing village of Dammam and the hamlet of Al-Khobar. Within two decades of the discovery of oil, Al-Khobar briefly became the shipping point for Saudi Arabian crude oil to the refinery in Bahrain. Service industries sprouted up to support the oil industry and meet the needs of people living in the Dammam Area. As a result, the population has grown to over 500,000, growing at a pace of over five percent a year.

Al Jubail, industrial city and port city

There is no doubt that the advanced infrastructure of Jubail (Figure 3.4.5) is the cornerstone, which has allowed various industrial, commercial and social sectors to establish themselves through integrated action. The biggest industrial complex in jubail is Saudi Arabian Basic Industries Corporation (SABIC). SABIC was established in 1976 to add value to Saudi Arabia's natural hydrocarbon resources. Today, SABIC is among the leading petrochemical companies in terms of sales and product diversity. It’s also one of the Middle East's largest non-oil industrial companies.

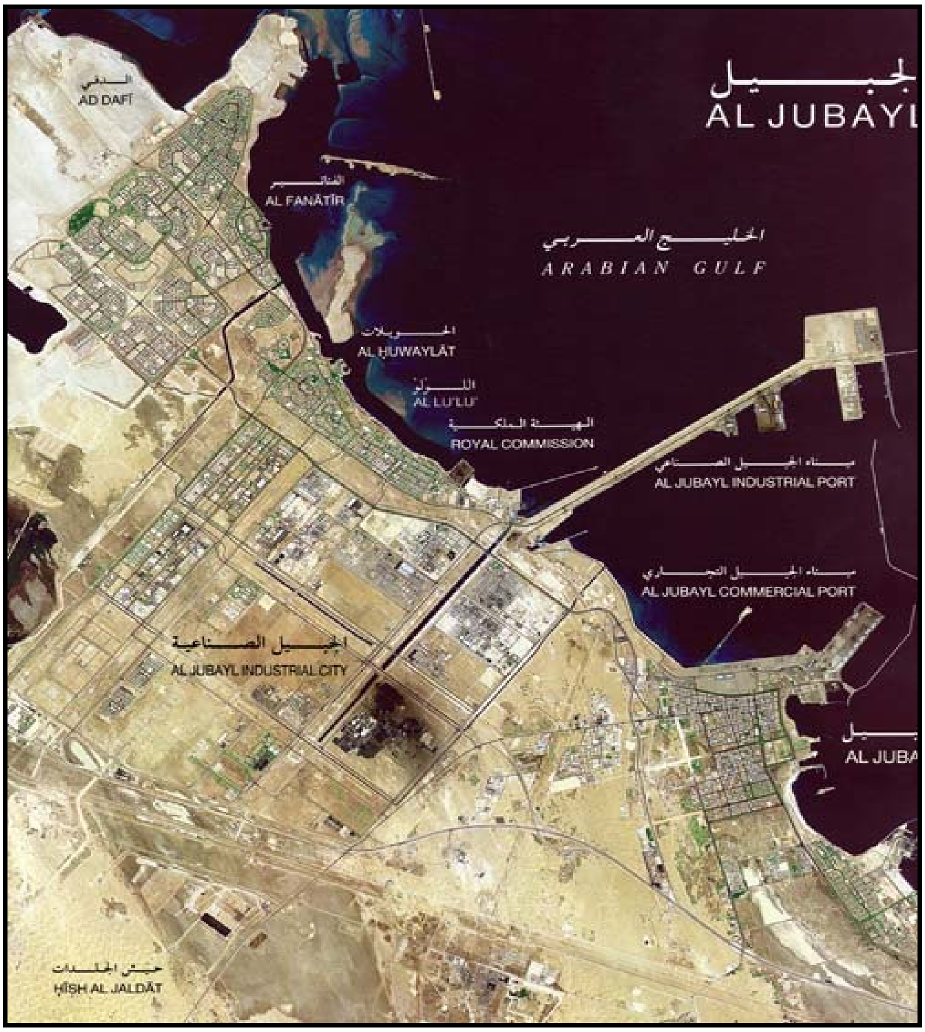


Figure 3.4.6 Jubail City Coastal Zone

3.4.2.2.2 Red Sea

Four coastal cities have been selected as the most venerable cities to Accelerated Sea level Rise (ASLR) along the Red Sea namely Jeddah, Rabigh, Yanbu and Gizan (Figure 3.4.6). The selection of these cities was based on the population growth, socio-economic activities and historical and cultural importance to the Kingdom. The other coastal cities or towns namely Haql, Duba, Al-Wajih, Umluj, Masturah, Thuwal, Al Lith and Qunfudhah) have less socio-economic importance.

Jeddah City

Jeddah city has an important position for being the gateway of the two Holy Cities of Makkah Al-Mukarramah and Madinah Al-Munawwara (Air, Sea, and Land). It is a commercial industrial and scientific city. History proved that Jeddah is considered as one of the oldest cities inhabited by (Bani Qudaah Tribe) in 115 B.C. after the downfall of Maarib Dam in Yemen. Jeddah (Figure 3.4.7) is situated in the middle of the eastern coast of the Red Sea (Tihama Plain) in the western region of Saudi Arabia, bordered by a group of small hills on the east followed by disconnected chains of mountains parallel to the high mountains of Hijaz and bordered by the Red Sea on the west.

The Red Sea port of Jeddah, located mid-way along the western coast of the Kingdom, is a bustling, thriving city and seaport. Its location on the ancient trade routes and its status as the seaport and airport for hajjis visiting the Holy City of Makkah have ensured that Jeddah is the most cosmopolitan of all Saudi Arabia's cities. By the end of the 1970s, the population of Jeddah was estimated to be close to one million. By 1986, the estimated population was 1.4 million. With an estimated growth rate in excess of 10%, the population by 1993 had passed two million.

Rabigh City

Rabigh is one of the important industrial cities in the Kingdom. It is located along the Red Sea coast. From socio-economical point of view, one of the largest oil refineries in Saudi is located in Rabigh. In addition to that many fishing and agricultural activities are present in Rabigh.

Yanbu Industrial City

This city was developed as an industrial city on the coast of Red Sea. It comprises petrochemical & non hydrocarbon facilities plus a refinery & also the terminal of the East-West pipeline. Yanbu' al Bahr (Arabic, “spring by the sea”), industrial and port city in Saudi Arabia, located on the Red Sea coast in Madinah Province, about 350 km (about 220 mile) north of Jeddah. About one third of the city’s 185 square kms consists of industrial city. Yanbu is very near to the Suez Canal opening it to the European market for its products. Yanbu is in the middle of Americas and the Far East. The city is located far off from the major oil fields of the Kingdom but intra-country pipelines convey crude oil and natural liquefied gas to the petrochemical industries. Yanbu City is the second largest industrial city in Saudi Arabia, whereby large petroleum and petrochemical industries exist within the Royal Commission for Jubail and Yanby area.

Yanbu Port includes the facilities that enable it export more than three (3) million barrels/day. The services required by the residents such as the housing, industrial, health, education, recreational and public services are provided in Yanbu in the greatest amount and in line with the highest levels of life.

Gizan City

West of Abha on the tropical Red Sea coast is the town of Gizan, located in southwestern Saudi Arabia. Gizan covers an area of 40,000 square kilometers, including some 5,000 villages and cities. Attached to it are 100 islands, including the important island of Farasan. Jezzan is the third most important seaport on the Red Sea.

Jezzan area consists of fertile plains, forests and mountains. The fertile plains, which extend behind the coastal swampland, have been created by the alluvial deposits brought down from the mountains by river and flood. The forest region (the Alhazoun district), which is also subject to flooding, consists of forest interspersed with some areas of rich pasture.

Figure 3.4.7 Red Sea Coastal Cities

The mountain region is part of the Al Sarawat mountain range which constitutes the jagged backbone of the Arabian Peninsula. The highest peak in Gizan is the Fifa Mountain which rises 11,000 feet. Gizan is one of the Kingdom's richest agricultural regions, remarkable for both the quality and variety of its agricultural produce. It is notable for its production of coffee beans, grain crops (barley, millet and wheat) and fruit (apples, bananas, grapes, lemons, mangoes, oranges, papayas, plums and tamarinds).

Figure 3.4.8 Jeddah City Coastal Zone

3.4.3 Impact of Accelerated Sea Level Rise

All sectors of activities in the Kingdom with varying degrees will have potential climate change and sea level rise impacts.

Table 3.4.3 ASLR Scenarios

Accelerated Sea Level Rise of the Arabian Gulf and Red Sea					
Year	**1990**	**2020**	**2050**	**2075**	**2100**
Scenario 1 (Low) cm	0	3	7	13	20
Scenario 2 (Med.) cm	0	8	20	33	49
Scenario 3 (High) cm	0	16	39	62	86

3.4.3.1 Selection of ASLR Scenario

A conservative approach based on Intergovernmental Panel for Climate Change (IPCC) and United Nations Framework Convention on Climate Change (UNFCC) predictions for global sea level rise has been used. Three scenarios were applied (low, medium and high) to assess the impact of ASLR on both the Arabian Gulf and the Red Sea (Table 3.4.3).

3.4.3.1.1 Induced ASLR Risks

The potential consequences of Sea-Level Rise will be felt world wide, but countries at low altitude will be more affected, such consequences include:

- Increased frequency and extent of flooding
- Rearrangement of coastal unconsolidated sediments and soils
- Increased soil salinity
- Changes of wave climate
- Dune and beach erosion
- Salt water intrusion to water table
- and wetland vegetation

Many of the coastal lines of the Arabian Gulf and Red Sea have low lying areas. These areas are being backfilled or elevated for development projects. The backfills became prime land with major commercial development which could be vulnerable to sea level rise. Many of these first order impacts are linked and will be influenced by feedback from changes to other environmental parameters such as increased temperature, humidity and changed rainfall and/or wind patterns. As consequences of first order impacts in coastal zones, a variety of second order impacts can be identified which include the following:

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

3.4.3.1.1.1 Potential Bio-geophysical Impacts of ASLR

The above scenarios were taken and applied in both the Arabian Gulf and the Red Sea. The following potential impacts were identified.

(a) Impacts of ASLR on Water Resources

Salt Water Intrusion

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

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

(b) Impacts of ASLR on Agricultures

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

(c) Impacts on the Marine Environment

Coral Reefs Bleaching

Red Sea reefs are only affected in a minor way by human activities. Consequently the reefs are in near-pristine condition. However, few threats loom on the horizon. Reefs on the Arabian Sea coast are heavily influenced by cool upwelling, which limit coral growth and favor the growth of large algae. These reefs are only marginally affected by human activities, and remain in good condition. The shallow fringing reefs in the Arabian Gulf are impacted by high sediment, and large fluctuations in temperature and salinity, hence they are not well developed. Also they have been severely impacted by coral bleaching in recent years. The degree and cause of bleaching has to be investigated in the future studies. There is little active coral-reef management in the region, however, there are projects to increase management capacity and conserve some valuable reefs. An imminent threat to these reef systems is oil pollution from increasing tanker traffic in addition to any potential sea level rise.

Mangroves

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

Impacts on the Shoreline

Coastal Erosion

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

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

An important limitation for the quality of data available for this assessment has been the data on coastal topography to the required scale of accuracy. The Risk Zone has been defined as the area within the coastal zone and below 2 m contour. Available topographic data for the affected areas is usually from 1: 5,000 scale maps. Unfortunately, accurate detailed contour maps are not available at present. Future studies on ASLR will be more comprehensive when such data is available.

By modeling, the first and best-known model relating shoreline retreat to an increase in local sea level is that proposed by Bruun [1962; 1988]. The analysis by Bruun assumes that with a rise in sea level, the equilibrium profile of the beach and shallow offshore moves upward and landward. Following a number of assumptions, Bruun derived the basic relationship for the extent of shoreline recession R, due to an increase in sea level, S: $R = (L/B + h) S$, where L is the cross shore distance to the water depth h taken by Bruun as the depth to which near shore sediment exist (depth of closure), and B is the height of the dune. The analysis is two-dimensional and assumes:

1. The upper beach is eroded due to the landward translation of the profile;
2. The material eroded from the upper beach is transported immediately into the offshore and deposited, such that the volume eroded is equal to the volume deposited; and
3. The rise in the near shore bottom as a result of deposition is equal to the rise in sea level, thus maintaining a constant water depth in the offshore [SCOR, 1991].

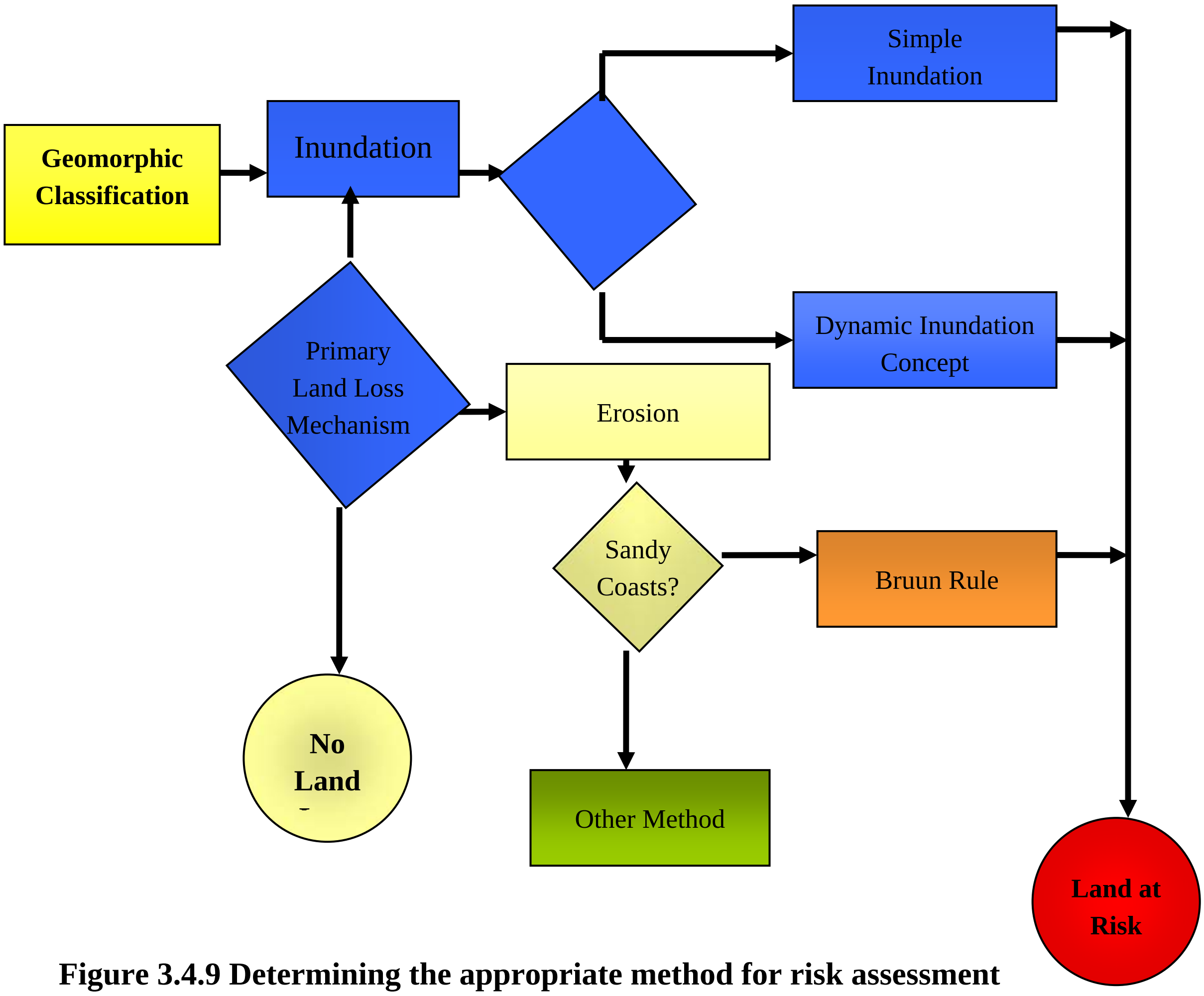


Figure 3.4.9 Determining the appropriate method for risk assessment

<u>Coastal Inundation</u>

Along the sheltered coasts, rising sea level often causes direct inundation or submergence of the upland. This impact results in higher water table and boggy soils, as well as invasion of salt-tolerant species displacing farmer's crops. There is also an eventual die-off of trees because of saltwater intrusion. While there can be some edge erosion, land loss is a simple function of slope; smaller the slope, the greater the inundation. High water is often selected as the primary inundation contour, and all land loss is measured relative to this datum.

Most of the Saudi Arabian coasts have small slopes; therefore the inundation level as a result of Accelerated Sea Level Rise is expected to be high and will effect the existing structures and agricultural activities as well as the groundwater table. The extent of such damage has to be investigated in futures research.

3.4.3.1.1.2 Socio-economic Impacts of Accelerated Sea Level Rise

Several general analyses of the potential impact of sea level rise on the Red Sea and Arabian Gulf coasts have been carried out. As a result, areas of high vulnerability in both the Eastern Province (Arabian Gulf) and Western Province (Red Sea) and possible socio-economic impacts have been generally defined. These high-risk areas include Dammam, Ras Tanura, Jubail Industrial City and Khafji along the Arabian Gulf and Jeddah, Rabigh, Yanbu and Gizan Cities along the Red Sea.

Accurate, up to date information on elevation, land use and socio-economic characteristics is still needed for an integrated assessment of possible impacts. As a result, a complete quantitative, high resolution analysis and assessment has not yet been finalized. The socio-economic impact has been assessed based on the available data collected from different sources. A comprehensive coastal survey on both the Arabian Gulf and Red sea has to be conducted in order to drive with more accurate results on socio-economic impacts.

However it has been estimated that 20% of Saudi Arabian coastal areas have been subjected to development, 130 KM along the Arabian Gulf coasts and 352 KM along the Red Sea coasts. A conservative scenario of 1% annual coastal development was applied on the Arabian Gulf and Red Sea coasts (Table 3.4.4). This scenario was applied on the coastal erosion model to estimate the area of sandy beaches that may demolish as a result of sea level rise

Table 3.4.4 Projected coastal development

Projected Coastal Development Along the Saudi Arabian Coastal Cities (1% Annual Coastal Development)		
Year	**Arabian Gulf (KM)**	**Red Sea (KM)**
2005	130	352
2020	151	409
2050	203	551
2075	261	706
2100	335	906

(a) Loss of Sandy Beaches

Arabian Gulf Coastal Cities

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

- For the Low Sea Level Rise Scenario (LSLRS) of 0.2m rise, 401 hectares of sandy beaches are estimated to be lost by the year 2100.

- For the Medium Sea Level Rise Scenario (MSLRS) of 0.49m rise, 984 hectares of sandy beaches are estimated to be lost by the year 2100, and
- For the High Sea Level Rise Scenario (HSLRS) of 0.86m rise,1,726 hectares of sandy beaches are estimated to be lost by the year 2100 (Figure 3.4.9).

These estimates can be more accurate if high resolution topographical maps and coastal surveys are available, which are proposed to be conducted in future studies.

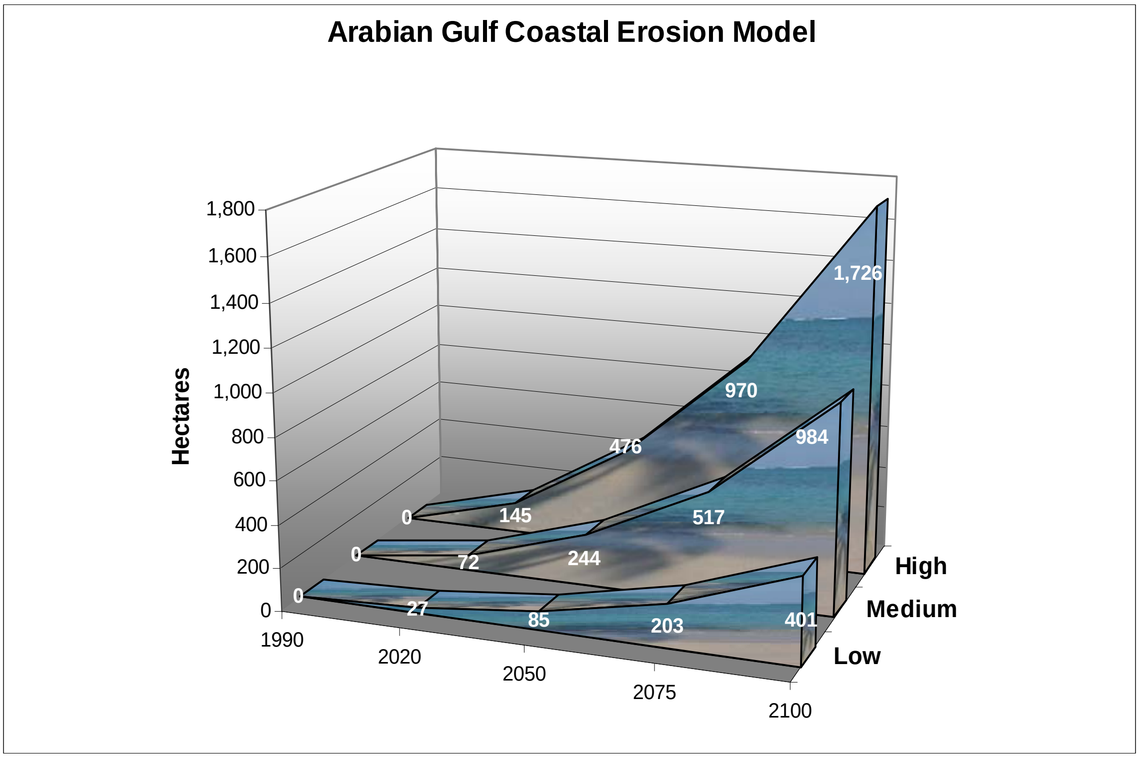


Figure 3.4.10 Arabian Gulf Coastal Erosion Model

Red Sea Coastal Cities

Considering that the annual coastal development in the Kingdom is 1% and taking into consideration the IPCC Sea Level Rise projection scenarios towards year 2100, and by applying Bruun model to estimate the high risk area subjected to coastal erosion along the Red Sea, it was found that:

- For the Low Sea Level Rise Scenario (LSLRS) of 0.2m rise, 1,087 hectares of sandy beaches are estimated to be lost by the year 2100.
- For the Medium Sea Level Rise Scenario (MSLRS) of 0.49m rise, 2,663 hectares of sandy beaches are estimated to be lost by the year 2100, and

- For the High Sea Level Rise Scenario (HSLRS) of 0.86m rise, 4,674 hectares of sandy beaches are estimated to be lost by the year 2100 (Figure 3.4.10).

These estimates can be more accurate if high resolution topographical maps and coastal surveys are available, which is proposed to be conducted in futures studies.

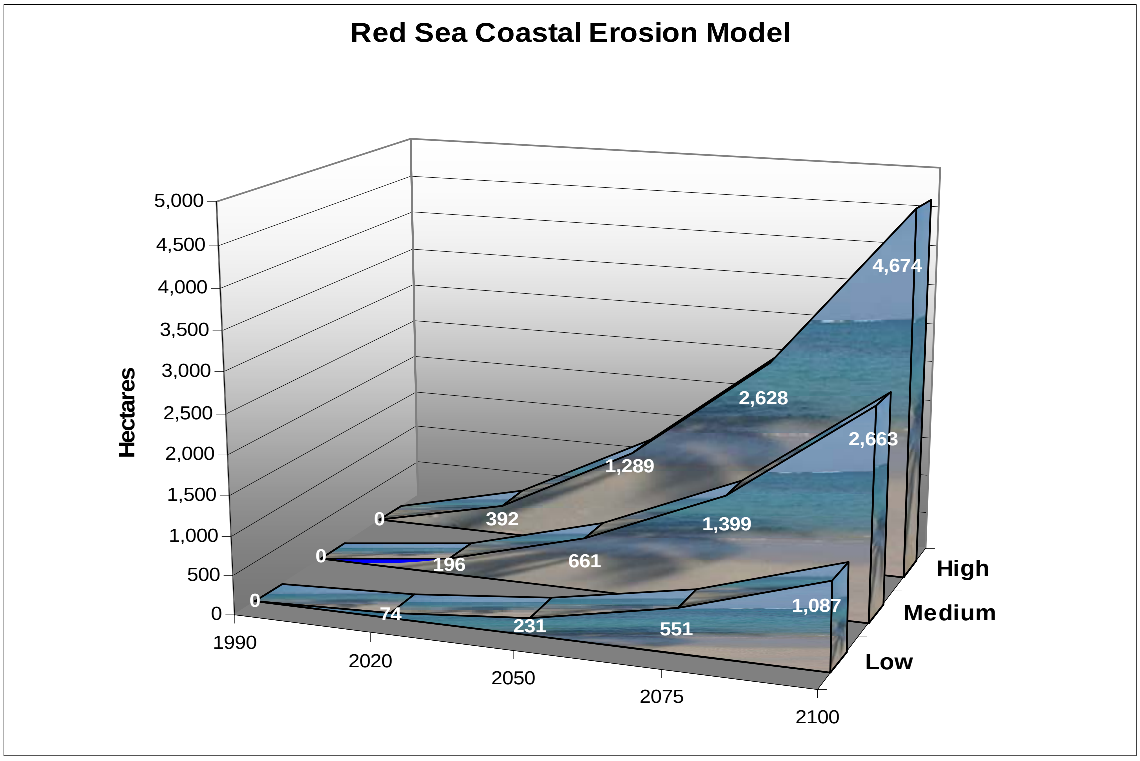


Figure 3.4.11 Red Sea Coastal Erosion Model

(b) Impact on Physical Structures

The socio-economical impact of Accelerated Sea Level Rise (ASLR) on physical structures can be expressed as vertical or horizontal; the vertical impact can affect buildings and recreational facilities along the coastal zone. Horizontal infrastructures include roads, bridges, cables, water and sewer systems.

Currently there is no strong evidence that the Accelerated Sea Level Rise has directly impacted the physical structures along the coastal zone. Like many other countries, there is no monitoring program for sea level rise in Saudi Arabia.

Most of the existing structures along the Arabian Gulf and the Red Sea coastal zone has been designed and constructed to resist the salt water intrusion caused by tidal movement. As per the Saudi civil construction code, prior to the construction of any facility, a comprehensive soil analysis has to be conducted to examine the stability of the structures and impact of external factors on its integrity. Further more, the

Presidency of Meteorology and Environment (PME) is currently regulating the development of facilities along the coastal zones by making Environmental Impact Assessment Study (EIA) a pre-requisite for such development. The EIA shall consider the impact of the facility on the Bio-geophysical environment and vice versa. The impact of sea level rise on infrastructure is expressed as inundation and erosion. Major facilities that may encounter socio-economic impacts are facilities located within 200 meters of the coastal zone. The high risk facilities are:

- Desalination Plants
- Industries
- Sea Ports
- Roads and causeways
- Recreational Facilities and
- Hotels

According to IPCC, impact of Sea Level Rise shall be considered as a potential threat impacting the development and socio-economical activities along the coastal zone in the next decades. Therefore, sea level rise shall be incorporated in the Costal Zone Management Plan. The Kingdom of Saudi Arabia has developed a Coastal Zone Management Plan (CZMP) and one of its objectives is to regulate the development of the coastal zones to attain the sustainable development strategy of the kingdom.

(c) Impact on Water Resources

Management of water resources has become a priority issue in the Kingdom. As a result of population increase and industrial and agricultural development, demand on potable water is increasing. 60% of the domestic water demand in the Kingdom is met from desalination plants and 40% groundwater and surface water. The high concentrations of Total Dissolved Solids (TDS) of groundwater limit its uses for domestic and industrial activities. Therefore it is mixed with desalinated water to meet the demands for quality and quantity.

As a result of sea level rise, seawater is intruded into aquifers. This intrusion results in increasing groundwater salinity affecting its quality. Considering the population and industrial development expansion, the demand on potable water will double in the next decade. This increased demand will have to be eventually supplied from desalination plants, which will need more investment and economical burden. Besides high construction and operational costs of desalination plants, many environmental issues such as air pollution and impact on marine environment also pose a serious challenge.

The Kingdom of Saudi Arabia represented by the Ministry of Water is currently evaluating other alternatives to meet the water demands in the future. These alternatives are summarized as:

- Reuse of domestic wastewater for agricultural irrigation purposes.

- Investigation of aquifers in the Al-Rub Al-Khali desert.

(d) Impact on Agricultures

Most of the agricultural activities in the Kingdom are concentrated in the central region. Limited activities are present along the coastal zones (Figures 3.4.11 & 3.4.12), namely in Gizan city along the Red Sea and Qatif city along the Arabian Gulf. In the past few years soil salinity has been increased in these cultivated areas.

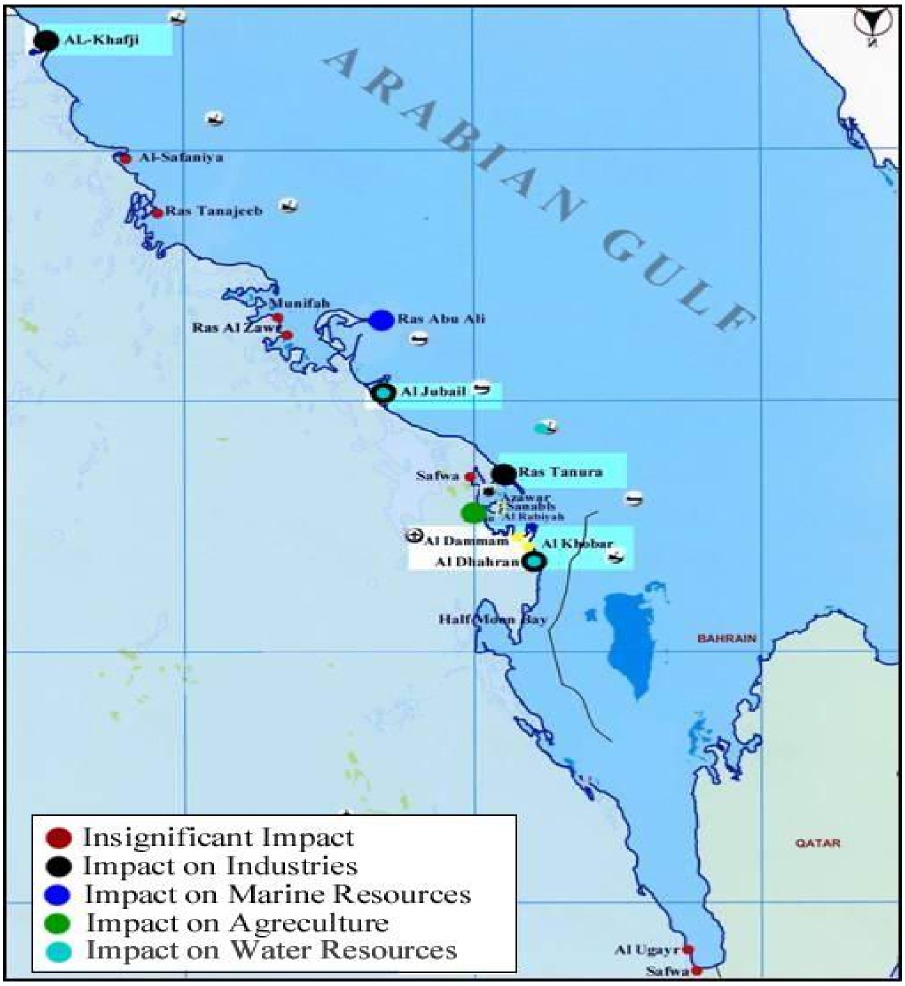


Figure 3.4.12 ASLR Impact on Arabian Gulf Coastal Cities

Figure 3.4.13 ASLR impact on Red Sea Coastal Cities

The Ministry of Agricultures is conducting studies to investigate the cause of soil salinity. The increase of soil salinity could be related to desertification, use of inorganic fertilizers or salt water intrusion. More studies have to be conducted to investigate the impact of Sea Level rise on the agricultural activities.

3.4.4 Adaptive Measures

Costal Zone Management plan is considered as the main adaptive measure that will be implemented in the Kingdom to respond to the potential impact of climate change. There are two components that the plan promotes. First is the integration of climate change consideration into coastal zone management plan. Second is the introduction of regulation and enforcement frameworks for futures development activities. The following is an illustration on how the current coastal zone management plan is considered as an effective future adaptive measure.

3.4.4.1 Costal Zone Management

3.4.4.1.1 Need for Coastal Zone Management

Saudi Arabia's coastal zone is rich in a variety for natural, commercial, recreational, ecological and aesthetic resources of immediate and potential value to the present and future well-being of the Kingdom. Unprecedented economic development which has taken place within the Kingdom has created increasing and competing demands upon the lands and waters of the coastal zone. In addition to these competing demands, potential sea level rise resulting from climatic changes is a main concern that needs to be integrated in a coastal zone management plan.

It requires cooperation among all affected interests. If successful cooperation and coordination provided for, Presidency of Meteorology and Environment’s (PME) proposed coastal zone management plan will lead to development of land and water use programs for the coastal zone and unified policies for dealing with land and water use decisions of more than local significance.

3.4.4.1.2 Existing Coastal Area Status

Various land reclamation and dredging activities carried out within coastal zone are of great concern. In spite of increasing trends of land ownership along the coastal area, still there are public owned areas along the coastal strip which have not yet experienced any land reclamation and/or dredging projects.

3.4.4.1.2.1 Findings of Coastal Area Status

The topography of coastal line is not adequately regulated due to coastal land reclamation which resulted in semi-enclosed and/or isolated areas along the coastline. Such areas contribute to concentration of pollutants and algal blooms that adversely affects the coastal marine environment.

The land reclamation processes have contributed to destruction of some environmentally sensitive areas, threatening many coastal natural resources which have been considered as the essential primary food web for marine living organisms. Accordingly, fish catch yields and reserves are likely to be affected.

3.4.4.1.2.2 National Coastal Zone Management

As in many other countries around the world, early 1980s in Saudi Arabia were a time of growing awareness and concern over degradation of environment and resources. Sections of the coasts were showing visible signs of this pressure which generated considerable discussion as to how we should deal with it. The preservation of valuable coastal resources appeared to be an important issue. This led to fruitful collaboration between PME and IUCN which resulted in the Assessment of National Coastal Zone Management Requirements.

Pollutants originating from land-based sources are of particular concern to the marine environment since they exhibit toxicity, persistence and bio-accumulation in the food chain.

3.4.4.1.2.3 General Policy for Coastal Zone Management

Effective management of coastal resources will require that the national government should assist agencies, provincial governments and municipal authorities in the development of coastal zone management programs for their respective areas.

The role of national environmental protection agency, PME with responsibility for coordination between local coastal zone management programs would focus on ensuring that the goals and objectives of these programs (Local Area Coastal Zone Management Plans) are consistent with national policy as determined by the decisions of the Ministerial Committee for Environment (MCE) or by Royal Decree.

In this regards, individual Local Area Coastal Zone Management programs should have as priorities, the following goals:

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

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

- The protection of natural resources, including sharms, coral reefs, beaches, dunes, islands, fish and wildlife and their habitat, within the coastal zone.
- The 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 water intrusion resulting from poorly planned and managed coastal development.

- Priority consideration being given to coastal-dependent uses and orderly processes for sitting major facilities related to national defense, energy, fisheries development, recreation, ports and transportation., and the location, to the maximum extent practicable of new commercial and industrial development in or adjacent to areas where such development currently exists.
- Public access to the coasts for recreational purposes.
- Assistance in the redevelopment of deteriorating urban waterfronts and ports, and sensitive preservation and restoration of historic, cultural and aesthetic coastal features.
- 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.
- Assistance to support comprehensive planning, conservation, and management of living marine resources, including planning for the sitting of pollution control and aquaculture facilities within the coastal zone.

(c) 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.

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

Climate change concerns need to be integrated in the general policy for coastal zone management as an adaptation. Coastal zone management can be used as a tool for adaptation for coastal zone management in order to avoid future socio-economic difficulties caused by sea level rise resulting for climate change. For action related to adoption to climate change need to be integrated in these plans.

3.4.4.1.2.4 Process of Coastal Land Reclamation and Dredging

The projects of any alteration and negative affect either sea-ward and/or land-ward along the coastal line is prohibited by regulation, however it is permitted under special conditions.

3.4.4.1.2.5 Development of the Coastal Private Water Frontage Area

The development of coastal area particularly along the shoreline is not allowed with exception of special conditions pertaining to national interests, security, economy and public utilities undertaken by designated governmental sectors. The application of the developer to the municipality will include four copies of development activities and coastal land deed along with EIA study indicating the effect of the development on surrounding environment with its alternative solutions and/or remediation of any impact. Upon the approval of the study by PME, it should consider the designation of the coastal line boundaries of built-up area along the shoreline within which establishment of green area and playing area is permitted. In order to minimize future socio-economic impacts resulting from sea level rise, PME need to conduct many studies to investigate the extent of impact of sea level rise on the coastal zones and communicate the results of these studies to different sectors that may use these results to integrate in their designs and futures development.

3.5 Biodiversity:

3.5.1 Introduction

The earth's climatic conditions are being changed because of human activities. Throughout the world air temperatures are increasing at the rate of 0.7^0 C in every century. These changes are unavoidably leading to more and more world records being set. As for example 1988 was the warmest year of the last century while 2001 was the warmest year since 1000 AD. Although these changes have created profound impact on the life of all living things, only a few organizations have taken this problem seriously. In many countries, especially in the developing world, the likely impact of global warming on plants, animals and their ecosystems remains inadequately understood. It has recently been realized that historical records of the year-by-year behaviour of plants can provide valuable measures of a plant's sensitivity to climate change. The Royal Botanic Garden at Edinburgh (RBGE) is one of the oldest botanic gardens in the world that is capable of holding such records. In 2002, the RBGE re-established its tradition of phenological recordings and is currently monitoring some 300 individual plants on a daily basis. Preliminary studies suggest that around two thirds of RBGE plants are sensitive to temperature.

In order to accomplish the commitments arising from the United Nations Framework Convention on Climate Change (UNFCCC), several organizations in Saudi Arabia, particularly the National Commission for Wildlife Conservation and Development (NCWCD) and the Presidency of Meteorology and Environment (PME) have taken special interest in assessing the vulnerability and adaptation of plants and animals to the current climatic change. These assessments generally are associated with the performance of vulnerability studies aimed at defining the potential impacts of climate change on the biodiversity of this country and on the well-being of human societies. The resulting information is designed to assist the Government of Saudi Arabia in better understanding the urgency of developing and collecting more information on impacts and adaptation strategies as a tool for minimizing negative impacts and taking the best possible advantage of new opportunities under changing climatic conditions and for achieving sustainable development practices.

Saudi Arabia is one of the most vulnerable countries in the region to climate change. There are many reasons for these vulnerabilities which are explained in the climate change 2001 (Third Assessment report of the Intergovernmental Panel on Climate Change (IPCC)). The report established how human activity (burning fossil fuels and changes in land use) is modifying the global climate with temperature rises projected for the next 100 years that could affect human welfare and the environment. The climatic record of this region for the past five years showed that there were fluctuations in the temperature and a decrease in rainfall over large portions of Saudi

Arabia. In the 21st century, this warning trend, and changes in precipitation patterns are expected to continue along with a potential rise in sea level and increased frequency of extreme weather events (for details, refer to sections 3.1 and 3.4 respectively).

Saudi Arabia's biodiversity is under threat from multiple stresses. Climate change is one of the several pressures. There are several other factors operating on the ecosystems and their plant and animal communities. All these negative trends lead to habitat loss and fragmentation of species-rich ecosystems.

Although climate changes will have consequences all over Saudi Arabia, not all regions will be affected equally, nor all regions equally vulnerable to those impacts. Saudi Arabia, being located in the arid part of the world is expected to experience faster warming due to climate change than countries located in the tropical or temperate regions. However, significant variation can be anticipated due to the large size of the country, its diverse landscapes and also due to its Red Sea coast on the western side and the Arabian Gulf on the eastern side. The vulnerability and adaptive capacity of plant and animal communities and their ecosystems to climate change and the possible potential consequences of climate change are assessed in this section of this report.

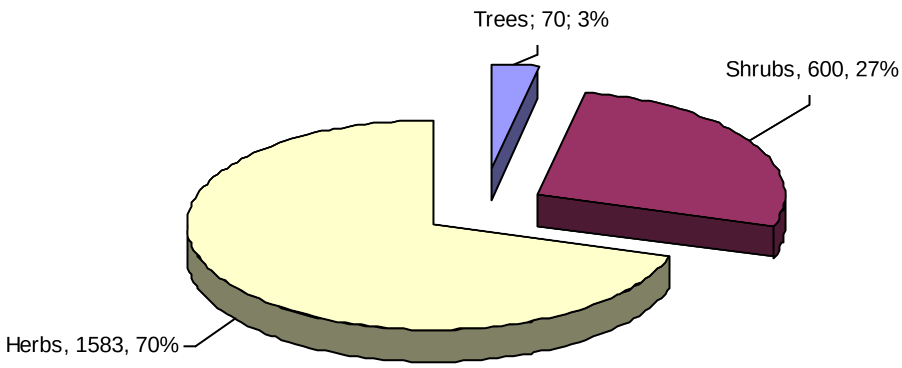


Fig. 3.5.1 Flora of Saudi Arabia

3.5.2 Brief Account of the Flora of Saudi Arabia

According to recent estimates, Saudi Arabia contains about 2243 plant species of 132 families, of which about 20 % are rare plants. The flora includes 9 species of

Gymnosperms and 27 species of Pteridophytes. The number of genera currently stands at 837. Among the families, 37 are represented by a single species. The southwestern mountainous region, from Taif to Yemen border contains about 70% of the floristic elements of Saudi Arabia. Two species of mangroves are also recorded in Saudi Arabia, namely *Avicennia marina*, the common one, and *Rhizophora mucronata*.

Phyto-geographical studies show that there are three chorological units present within Saudi Arabia; namely Saharo-Sindian regional zone, Somali-Masai regional centre of endemism and Afro-montane archipelago-like regional centre of endemism. Saharo-Sindian zone is again divided into two sub zones – Arabian and Nubo-Sindian. The vegetation of the Saharo-Sindian region is sparse with few exceptions and about 60% of the vegetation, mainly in the low lying areas, is represented by annuals and their density of populations varies from year to year, depending on the amount of rainfall and the amount of seed deposits from previous years. The Nubo-Sindian local centre of endemism covers the entire northern Hijaz Mountains and the western Najd. The floristic elements of "Somali-Masai regional centre of endemism" can be seen in the southwestern highlands at altitudes between 500-1500m.

Unlike many other countries, the percentage of rare and endangered species is very high in Saudi Arabia. About 600 species are considered as rare or endangered. The loss of flora and fauna in Saudi Arabia is probably higher than any other country in the Middle East. The Kingdom of Saudi Arabia is passing through a series of socio-economic changes as part of her development programs. As a result of these developments, large areas of virgin land in the mountainous regions and the range lands in the Northern, Eastern and Central regions are being turned into urban and agricultural lands. In addition to this, the dramatic fluctuations in climate, which resulted in periodic drought, have made it much more difficult for plants to survive in their habitats.

3.5.3 Brief Account of Terrestrial Fauna

A checklist of 98 species of mammals has been recorded from the Arabian Peninsula. Of these, 76 species occur in Saudi Arabia. Regarding birds, about 444 species have been recorded in Saudi Arabia, of which about 185 species are known to breed in the kingdom.

There are some ten species of birds indigenous to the Kingdom of Saudi Arabia while hundreds of them are passing through the Kingdom as migratory birds. In the winter birds of prey, including falcons, arrive in the Kingdom. Other seasonal migratory birds include Doves, Ducks, Geese, the Houbara, Kingfishers, Martins, Owls, Pipits, Quail, Swallows, Vultures of various types and Warblers. Crows, Black Kites and, above all, a number of Sparrows, encouraged by more plentiful sources of water, thrive within the Kingdom. The Southern Region has the richest bird population than in any other part of the Kingdom. Bustards, Eagles, Goshawks, Linnets, Magpies, Partridges, Thrushes and Woodpeckers are amongst the species to be found there at some time of the year.

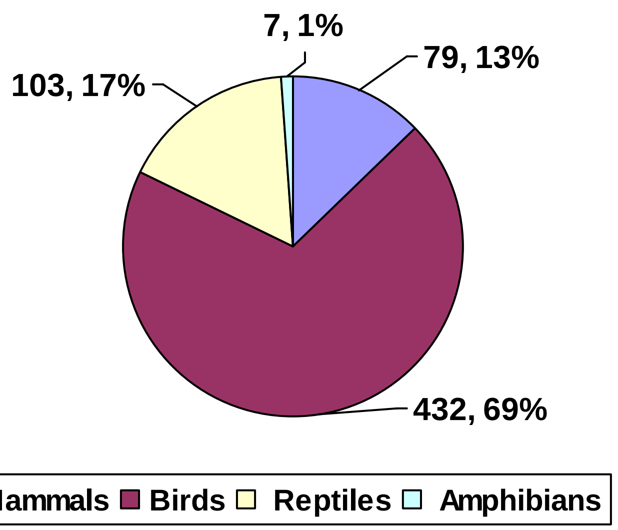


Fig. 3.5.2 Fauna of Saudi Arabia

Mammalian life is equally rich. Antelopes, Bats, Baboons, Honey Badgers, Camels, Cats, Dormice, Foxes, Gazelles, Gerbils, Goats, Hamsters, Hedgehogs, Hyenas, Jackals, Jerboas, Leopards, Mongooses, Porcupines, Rats, Sheep, Shrews, and Wolves are amongst those mammals still to be found in some parts of the Kingdom. The Oryx, an endangered species, was saved by the determined efforts of the National Commission for Wildlife Conservation and Development (NCWCD).

To add to this list is a wide variety of lizards (some 100 species) and snakes (53 species, including some highly venomous sea-snakes) are also present in Saudi Arabia. Zoological analysis of Arabian and Middle Eastern butterflies reveals species with palaearctic, Afro-tropical and oriental affinities. About 8 endemic species in Asir and 23 endemic sub-species in Hijaz, Central and Eastern Saudi Arabia and Asir regions have been recorded.

Table 3.5.1 Distribution of fauna of Saudi Arabia

Groups	Family	Genera	Species
Lizards	7	21	60
Snakes	8	24	34
Turtles	5	9	9
Amphibians	3	4	7

3.5.4 Asir Mountains and Valleys

Asir Mountains in the southwestern Saudi Arabia with its dense *Juniperus* population is a good example of a biome (Climax vegetation). Within the broad climatic zones, local topographic factors can cause major departures from the expected climate and most areas comprise a mosaic of microclimates, which affect the plants profoundly. Thus the west facing slopes and east facing slopes of Asir Mountains have climatic differences, which allow the development of dense vegetation on one side and a scrub on the other. Unlike in other parts of Saudi Arabia, the region maintains a large number of tree species that include species with tropical, arid and temperate affinities. The mountain ranges are characterized by moderately cool temperate climate at altitudes between 2500-3000 m. The coastal plain (Tihama region) and foothills at elevations ranging from 100-200 m is characterized by their semitropical to arid or semi arid climate. The regions between these altitudes, (i.e. between 300-2500), on the other hand, are characterized by a mixture of varied topography with steep slopes, deep valleys and extremely variable moisture and temperature regimes. A Considerable number of publications have been reported in the past to demonstrate the climate and vegetation of Asir Province (Vesey-Fitzgerald, 1955; Abulfatih, 1979; 1981 a & b; 1984; 1991; 1992; Konig, 1988; Collenette, 1999, Chaudhary, 1999-2001).

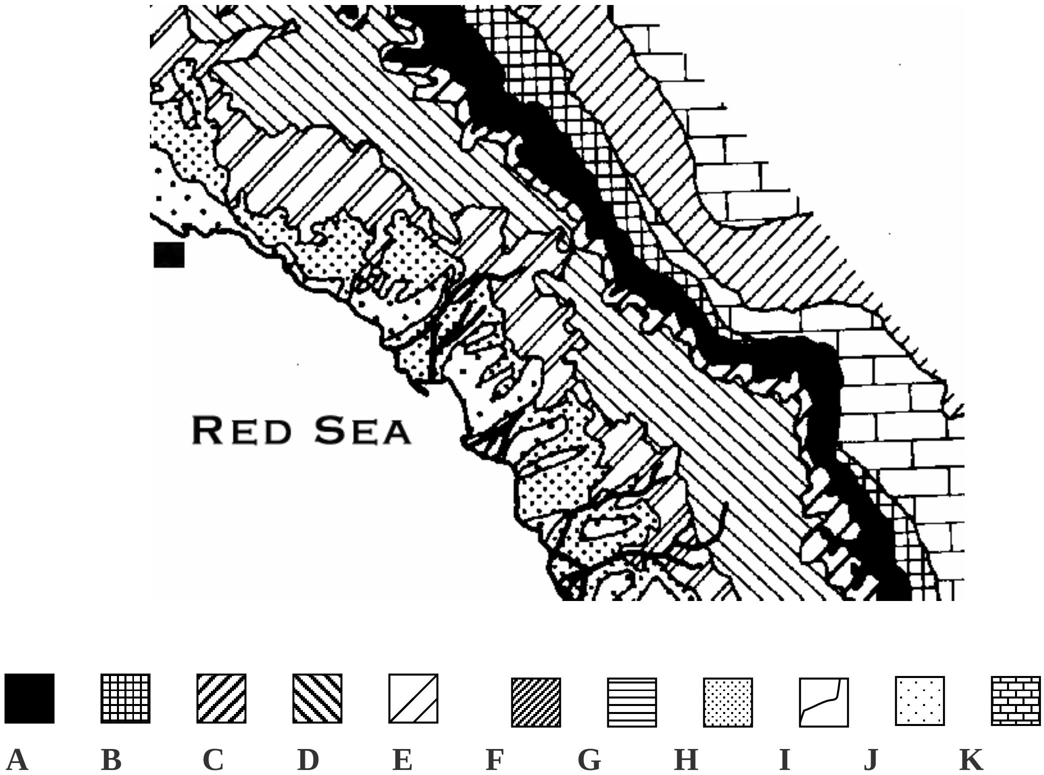


Figure 3.5.3 Diagrammatic representation of the climax vegetation of Saudi Arabia

A. Montane Wood vegetation (*Juniperus procera-Olea europaea-Acaia origena* community).

B. Evergreen open xeromorphic scrub.

C. Acacia etbaica xeromorphic woodland.

D. *Acacia asak-Commiphora* xeromorphic woodland.

E. *Acacia tortilis-Commiphora* and *Euphorbia cuneata* woodland.

F. *Acacia- Commiphora* xeromorphic woodland.

G. *Acacia tortilis- Acacia ehrenbergiana* xeromorphic woodland.

H. Wadi woodland communities (*Acacia ehrenbergiana* and *Acacia tortiis-Hyphaene thebaica* community.

I. *Acacia ehrenbergiana-Leptadenia pyrotechnica* and *Acacia tortilis-Maerua crassifolia* xeromorphic woodland**.**
J. *Panicum turgidum* grassland.
K. Semi desert vegetation of the eastern slopes.

The vegetation of Asir Mountains has been selected as one of the prototype climax vegetation for long-term ecological monitoring programs. The National Commission for Wildlife Conservation and Development (NCWCD) and the Presidency of Meteorology and Environment (PME) are working closely to ensure that the monitoring of climate change in the ecosystem of Asir region is ecologically relevant, cost-effective and statistically sound.

The vegetation of Asir mountains is very interesting and comprises of a variety of woodland areas. The west facing escarpment and the top are subjected to fog/cloud condensation in addition to rainfall. The vegetation is rich in this area. The woodlands have three or more layers of vegetation. The top layer of mixed forests on the western slopes consists of *Juniperus procera*, *Nuxia congesta*, *Tarchonanthus camphoratus*, *Maesa lanceolata*, *Teclea nobilis*, etc. The second layer consists of small trees or tall shrubs like *Olea europaea*, *Buddleja polystachya*, *Grewia spp. Dodonaea angustifolia*, *Debregeasia saenab*, *Carissa edulis*, *Ehretia obtusifolia*, *Canthium* spp., etc. The third and fourth layer is formed of a number of short shrubs and herbs. The density of vegetation varies from very dense in narrow west facing gullies to open and sparse on exposed slopes. The density of *Juniperus* trees decreases eastwards of the escarpment. On the eastern slopes of mountains, the vegetation is sparse, mostly dominated by *Acacia* trees and some other xerophytes such as *Euphorbia*, *Adenia*, *Aloe*, etc.

Following is a consolidated list of species present in various habitats of the Asir Mountains. This list is based on previous, preliminary studies conducted in the study area, and is not necessarily reflect the true characteristics of the Asir Mountains.

Low altitude areas (Foot hills- 300-1000m).

a. Slopes

Acacia asak	*Acacia ehrenbergiana*	*Acacia etbaica*
Acacia hamulosa	*Acacia mellifera*	*Acacia tortilis*
Adenium obesum	*Aerva javanica*	*Anisotes trisulcus*
Barleria bispinosa	*Berchemia discolor*	*Buddleja polystachya*
Cadaba glandulosa	*Combretum molle*	*Commiphora kataf*
Commiphora myrrha	*Euphorbia cuneata*	*Gomphocarpus sinaicus*
Grecia tenax	*Justicia flava*	*Maerua crassifolia*
Premna resinosa		

b. Runnels, disturbed ground, plains

Abutilon bidentatum	*Aloe officinalis*	*Argemone mexicana*
Calotropis procera	*Cassia italica*	*Ceropegia spp.*
Cordia ovalis	*Blepharis ciliaris*	*Datyloctenium scindicum*
Heliotropium longiflorum	*Ricinus communis*	*Sida ovata*

Solanum incanum

Altitude between 1000-1600m

a. Slopes

Acacia asak	*Acacia etbaica*	*Acacia tortilis*
Acalypha racemosa	*Adenia venenata*	*Pupalia lappacea*
Anisotes trisulcus	*Barleria trispinosa*	*Blepharis ciliaris*
Buddleja polystachya	*Cenchrus ciliaris*	*Danthoniopsis barbata*
Dichrostachys cinerea	*Eragrostis papposa*	*Euclea schimperi*
Ficus cordata ssp.	*Ficus plamata*	*Ficus sycamorus*
Hibiscus diflersii	*Hyparrhenia hirta*	*Kleinia odora*
Leucas glabrata	*Pennisetum setaceum*	*Polygala tinctoria*
Pulicaria crispa	*Tephrosia pumila*	*Terminalia brownie*
Tetrapogon villosus		

b. Water course community

Acacia laeta	*Aloe sabea*	*Alternanthera pungens*
Astragalus atropilisulus	*Astragalus corrugatus*	*Centaurea pseudosinaica*
Cissus rotundifolia	*Coccinea grandis*	*Combretum molle*
Commicarpus plumbagineus	*Datura stramonium*	*Picus cordata ssp.*
Salicifolia	*Ficus vasta*	*Hibiscus vitifolius*
Nuxia oppositifolia	*Ocimum americanum*	*Plumbago zeylanica*
Tamarindus indica	*Themeda triandra*	*Verbascum bottae*
Withania somnifera	*Ziziphus spina-christi*	

Altitude between 1600-2200m

Abutilon bidentatum	*Acacia albida*	*Acacia etbaica*
Acacia negrii	*Acacia seyal*	*Achillea biebersteinii*
Acokanthera schimperi	*Aloe spp.*	*Argyrolobium arabicum*
Asparagus africanus	*Barleria acanthodes*	*Barleria proxima*
Cadia purpurea	*Campanula edulis*	*Cluytia myricoides*
Commicarpus grandiflorus	*Conyza incana*	*Cordia Africana*
Dichrostachys cinerea	*Diospyros mespiliformis*	*Dodonaea angustifolia*
Euclea schimper	*Euphorbia Amman*	*Gomphocarpus fruticosus*
Heliotropium longiflorum	*Hyperium rovolutum*	*Jasminum grandiflorum*
Justicia flava	*Justicia odora*	*Kleinia odora*
Lycium shawii	*Maerua crassifolia*	*Moringa peregrine*
Olea chrysophylla	*Otostegia fruticosa*	*Plicosepalus curviflorus*
Pulicaria glutinosa	*Pulicaria schimperi*	*Rhus retinorrhoea*
Rosa abyssinica	*Ruellia patula*	*Senecio asirensis*
Teclea nobilis	*Trichodesma calathiforme*	*Verbascum yemense*

High altitude areas (between 2200-3100m)

Acacia negrii	*Achyranthes aspera*	*Anagyris foetida*
Anarrhinum orientale	*Asparagus africanus*	*Buddleja polystachya*

Cadia purpurea	*Celtis Africana*	*Cenchrus ciliaris*
Centaurothamnus maximum	*Crinum album*	*Dodonaea angustifolia*
Dracaena serrulata	*Juniperus procera*	*Lavandula dentata*
Lonicera etrusca	*Marrubium vulgare*	*Maytenus undata*
Micromeria imbricate	*Minuartia filifolia*	*Nepeta deflersiana*
Nuxia oppositifolia	*Olea chrysophylla*	*Otostegia fruticosa*
Pennisetum villosum	*Pistacia falcata*	*Rumex nervosus*
Scadoxus multiflorus	*Senecio asirensis*	*Senecio hadiensis*
Tagetus minuta	*Teucrium yemense*	

Rainshadow regions of the Eastern slopes (between 1600-2000m)

Acacia ehrenbergiana	*Acacia seyal*	*Acacia tortilis*
Adenium obesum	*Aerva javanica*	*Calotropis procera*
Citrullus colocynthis	*Cocculus pendulus*	*Cordia sinensis*
Ecbolium gymnostachym	*Echinops sp.*	*Euphorbia spp.*
Indigofera spinosa	*Lycium shawii*	*Salvadora persica*
Ziziphus spina-christi		

3.5.4.1 Evaluation of the study area

Asir Region has long history of research on vegetation and wildlife, their interactions and human impacts on vegetation. In order to have a meaningful monitoring on the vegetation of these areas, these studies are, perhaps, valuable in developing initial management models to a certain extent. The vegetation component of the long term monitoring in the Asir region can be generally divided into two categories, 1) developing and 2) implementing protocol for long term monitoring. The primary goal of this endeavor will be to develop a method of monitoring vegetation that could detect large-scale changes in the region. Several methods may be needed in such a monitoring programme, such as satellite imaging (remote sensing) combined with more intensive field work to collect data.

Woodland vegetation of Asir Mountains appears to receive sufficient winter and summer precipitation in certain years to recharge a deep soil reservoir of water. Deep soil water is seemingly needed to balance the potential evapo-transpiration during the growing season. If the quantity of winter rain is large enough, the area would support a dense forest (dense woodland as in the case of certain parts of Asir region). An intermediate amount of precipitation will support an open forest or sparsely vegetated Juniper woodland, while areas with scanty rain will support a shrub-land. In short, sufficient amount of deep soil water and less runoff rainwater is inevitable for the healthy growth of woodlands. However, regional runoff patterns reported from Asir region suggest that the deep soil reservoir is depleting each year due to excessive transpiration and increased runoff.

According to observations carried out in other parts of the world (Neilson et al, 1989, Stephenson, 1990), excess water present in deep soil layers at the end of the growing season (say Spring season) combined with the nutrient rich habitat (if it so), will increase the biomass and leaf area of the plants in subsequent seasons. This will eventually increase the withdrawal of the deep soil water. In other words, if the leaf-area of the vegetation on a mountain-slope were so high then the rate of water withdrawal from deep soil would also be very high. This will eventually result in the death of plants itself or result in excessive defoliation and peeling of the bark. Thus theoretically speaking, ecosystems should be in a state of balance as far as the water content of the soil and the atmospheric temperature are concerned. As a rule, woody plants require deep soil water while grasses require sufficient surface soil moisture for their growth. If winter rains are accompanied by high spring rains or high mid-summer rains, surface soil remain moist and thereby increases the growth of grasses. This is evident in certain parts of Asir Mountains and the extreme southwestern region of Saudi Arabia.

3.5.4.2 Data Collection

There are now a substantial number of observational and experimental studies that demonstrate the link between climate and biological or physical processes in the ecosystems. In Saudi Arabia, so far, a monitoring program for analyzing the vegetation structure and the impact of climate on vegetation has not been developed.

Several vegetation studies have taken place in the Asir area (Vesey Fizgerald, 1955, Abulfatih, 1979, 1981, 1984, 1992). These studies should be considered with respect to relevance for current objectives. Mainly three points will be included in the monitoring program.

(i) Analysis, summarization and evaluation of existing vegetation data.

(ii) Routine collection and archiving of field data from the study sites and

(iii) Development and modification of vegetation monitoring goals, protocols and procedures.

3.5.4.3 Methods

The first and foremost goal of this sub-section is to develop a method of monitoring and detection of variations in the vegetation in the Asir region.

3.5.4.3.1 Field Sampling Techniques

- Climatic data for the past 10 years or so will be collected from weather stations located at Taif, Abha, Baha, Khamis Mushait, and Bisha.
- Data related to temperature, humidity, precipitation, wind direction, etc. will be collected regularly during the monitoring period.
- Responses to increased atmospheric CO_2 can be detected in increased stomata densities in the leaves.
- Several observation sites will be identified at various altitudes to record various data. This will be carried out for a period of approximately 10 years. (Data such as leaf size, flowering period, approximate quantity of fruit/seed production from each species, etc. will be collected from these sites).
- Yearly increases in the diameter of woody species in the vegetation plot at various altitudes will be recorded by dendrometers.

- Select quadrates (say 50x50 m.) in different transects to study the tree height, crown diameter, number of trees per quadrates.

The above data should be collected and analyzed for a period of at least 10 years. Although the guidelines mentioned above are only preliminary, the monitoring program for detecting the effect of climate changes on the vegetation in the study area can be taken as a right step in this direction. The initial effort is to identify and establish permanent monitoring sites along an elevation gradient, with a site located in three different vegetation types (i.e. low altitude area, riparian vegetation or vegetation in runnels, high altitude area). At each monitoring site the initial structure and composition of the tree, shrub and herbaceous strata have to be documented to provide baseline data for comparison in future years.

3.5.4.3.2 Identify the impacts on communities

In order to assess the changes caused by human activities, effective and reliable monitoring systems are required to recognize and predict hazardous effects. Biological methods can be successfully applied in predicting the impact of human activities particularly of pollutants well in advance since they present effective and reliable method of evaluating the effect of anthropogenic substances on the living organisms. Thus microbes, plants, animals, populations, biotic communities and ecosystems show different levels of sensitivity and can be successfully employed as ecological indicators (bio-indicators) to asses and predict environmental changes in a timely manner.

It is thus evident that every plant is a product of the conditions under which it grows and is therefore, a measurement of environment. Dominant species in an area are most important indicators, as they receive the full impact of the habitat for over long-periods. Consequently, plant communities are more reliable indicators than individual plants. Plants are indicators of conditions, processes and uses. Large species serve as better indicators than small species

Comparing various ecosystem models for finding out the future climate change is one of the steps that most researchers follow to determine whether plant species will keep up with the present climate variations. Some believe that species may migrate 8-60m upward in elevation/decade or 10-15 km in a pole ward direction. Species such as *Maerua oblongifolia*, *Orthosiphon pallidus*, *Indogofera oblongifolia*, *Dobera glabra*, etc which are usually found in the low lying Tihama areas are now reported from higher altitudes ranging from 300-800m above sea level. This type of migrations can possibly be attributed to climate change.

3.5.4.3.2.1 Effect of temperature and water stress on plants:

- Plant remain small in size
- Leaves will be much smaller
- Density of pubescence will be much higher
- Develop thick cuticle on leaves to reduce the transpiration rate
- Produce only a few flowers
- Produce only a few seeds, most of which are not viable.

Assessing the long-term climatic change in a species population density or its distribution range is sometimes difficult, primarily for two reasons: 1). Both climate and biological factors vary greatly every year and these annual variations often mask long-term trends, making them difficult to detect, 2) factors such as habitat loss, hunting pressure, grazing, competition with other native and exotic species and pollution are simultaneously affecting species population size and distribution along with climate change so that it is difficult to determine definitively the effect of any one cause. However, the present altitudinal range, distribution area, population size, conservation status, ecology, genetic and phenotypic diversity are some of the parameters to take into consideration when assessing the general response of a species or of a particular population to climate change. Drought in consecutive years definitely poses a threat to vulnerable plants. Such plants, if suffer from water stress at the seedling stage remain small in size, produce only a few flowers, set a few viable seeds and die away, whereas, in the case of sufficient moisture, the stature of such plants will be large and produces enough flowers and seeds for the next season. The physiological activities in perennial plants such as shrubs and trees during adverse climatic conditions are also not different from that of annual plants. Several plants seen in the arid and extra arid parts of Saudi Arabia have characteristic structural modifications associated with methods of water conservation. As the climate varies the structural modifications like the density of pubescence also vary to a certain extent. The most important plant population (*Acacia*) has small leaves to reduce transpiration rate. The other common structural modifications (not only in *Acacia* but in other species as well) include, a thick cuticular layer all over the surface of the aerial parts. Sometimes the aerial parts, especially the leaves are covered with a wax-like substance (e.g. *Calotropis*, *Rhanterium*, *Capparis*, etc.) which cuts down water loss through the epidermis when the stomatas are closed. Sunken-stomata is another feature commonly seen in plants living in extreme climatic variations. This feature helps minimize the water loss during transpiration. In Saudi Arabia about 50-60% of plants are annuals and are able to complete their life cycle in a relatively short period in order to escape from the seasonal changes. After shedding their seeds, such plants undergo long periods of dormancy period either in the form of seeds (*Diplotaxis*, *Picris*, *Spergula*, etc.) or as curled-up vegetative balls during the dry months of the year (*Anastatica heirochuntica*). During adverse climatic conditions, *Enneapogon desvauxii* or *Gymnarrhenia micrantha* produce underground flowers, immediately after developing their first few leaves. These underground flowers are capable of producing seeds. As and when the seeds get enough moisture the seeds germinate into a normal plant.

3.5.4.3.2.2 Effect of climate change on plant communities

(a) Early shedding of leaves
(b) Increased pathogen attack
(As climate changes, pests and pathogens also migrate to new areas)
(c) Absence of pollinators and seed dispersers
(d) Disrupt the timing of fruit maturation

There are three possible methods in which plants may respond to climate change such as 1) persistence in the modified climate, 2) migrating into better adaptable climate and 3) extinction. Changes can take place in the first category in which three types of persistence are possible, phenotypic plasticity, gradual genetic adaptation of population or ecological changes. However evidences show that during adverse climatic conditions, species are tend to migrate to a more suitable place rather than adapt genetically. Overall, species having a great potential for adaptive responses through genetic diversity, phenotypic plasticity, high abundance or significant dispersal capabilities are least at risk of extinction. Extra arid desert, mountain ranges or shore lines, sometimes, block the easy migration of several species. Climate change will have drastic impact on such species.

Some categories of plants would appear to be more vulnerable. Fragmentation of population is of particular importance for endemics. Due to climatic variations, if they cannot persist or adapt, species showing a fragmented distribution may see their range become even more fragmented, with local disappearances. Locally or regionally, climate change may even weaken dominant species such as *Acacia* spp., *Lycium shawii*, etc through defoliation.

The effects of temperature on plants are often difficult to assess because they are closely dependent on the available water supply. There are various adaptations to overcome very high temperature, such as vertically arranged narrow leaves or drooping leaves (e.g. *Ficus salicifolia*), or thick white dense hairs (e.g. *Teucrium polium*). According to scientists, an increase in nitrogen deposition and atmospheric CO_2 concentration will favour groups of species that share certain physiological or life history traits that are common among invasive species (*Argemone mexicana, Tridax procumbens, Nicotiana glaucum, Opuntia* spp.) that allow them to dominate in a locality. As far as the distribution of plants is concerned, there are ups and downs in the response towards climate change. Studies show that dispersal would not be a significant problem for most species in the changing climate, provided the platform of suitable habitats was not altered. Unfortunately this privilege cannot be taken as granted as far as the situation in Saudi Arabia is concerned. Most of the habitats in Saudi Arabia and elsewhere in the Arabian Peninsula are highly fragmented due to human activities and therefore the opportunities for migration and establishments will be limited and restricted to less than 50% of the floristic elements present in Saudi Arabia.

Climate change and atmospheric CO_2 increase may affect the relation between plants and pollinators. According to scientists, elevated CO_2 may affect flowering (time, number of flowers) and nectar quality (amino acids).

In areas in and around Jabal Tallan, Jabal Warjan, etc, there are signs of significant microclimate change. In these mountains, the lower slopes are covered with immense stands of totally dead *Juniperus* trees along with many dead Dragon trees (*Dracaena ombet*). Now most of the vegetation in these mountains is present only in sheltered gullies and ravines where water is lingering after rain. According to Collenette "in 1977, among the many endemic plants which grow on this mountain (Jabal Dibbagh) there were some twenty-five plants of a *Phlomis* species new to science, about the same number of shrubs of *Daphne linearifolia*, and a number of gravel pans in a limited areas were carpeted with *Tulips*. In 1985, nearly all the large *Junipers* had been removed, the number of *Phlomis* plants had been reduced to five, most of the *Daphne* bushes were dead or dying and the number of tulip plants had been reduced by over half. People living in the area, especially near Sawawin camp, commented on how seldom the mountain was wreathed in cloud compared to previous years".

Distributions, population sizes, population density, etc. have been affected directly by the changes in vegetation in most parts of Saudi Arabia. Many communities are expected to be placed at greater risk because of unsuitable habitats and various obstacles in species migration due to change in land uses and thereby the fragmentation of habitats. Due to improper management, these obstacles or pressures will cause some species currently placed as "critically endangered" to become extinct and a majority of those labelled as “endangered or vulnerable” to become rarer and thereby closer to extinction in the next few decades.

The woodlands of *Juniperus procera* was in a healthy condition for many centuries. Unfortunately extensive decline has been reported in the last two decades or so. The decline is characterized by die back at the lower altitudinal ranges of the woodlands. However, the woodlands in high altitude are generally in a healthy condition. A study has been conducted on the die back issue of Juniper trees and will be presented here as a case study.

3.5.4.3.2.3 Impacts of climate change on Ecosystems

Prolonged droughts have serious repercussion on various ecosystems in Saudi Arabia. If there is no rain, ground water level will fall considerably, wet-land areas and the seasonal springs in Saudi Arabia will dry up. As a result of these impacts there will be a drastic change in the vegetation cover and this will affect the infiltration rate, increased run off and soil erosion and a decline in ground water recharge. Natural ecosystems identified as being at risk in Saudi Arabia include wadis, rivulets, various woodlands in mountains, wetlands, raudhas, coastal areas, etc.

In some cases, such as in coastal areas, habitat may simply be lost as a result of factors such as sea-level rise, with no potential area for species to migrate. Farasan group of islands, off Jizan coast is one of the finest habitats for two important mangrove spp. (*Avicennia marina* and *Rhizophora mucronata*). These islands are also a resting place for a number of migratory birds such as sooty Gulls, Black headed Gulls, Boobies, Terns, Egrets, Pelicans, etc. The coastal mangrove forests also provide a breeding ground for a number prawns and fish. The presence of these mangrove communities and birds may be threatened by the disappearance of coastal marshes as a result of increases in sea level caused by climate change.

Species occurring in the Hijaz Mountains are also at risk of losing habitat as a result of changes in climate. Extreme temperature conditions may cause these areas to undergo major changes, to an extent due to high rates of variation in habitat structure that naturally occur on mountain ranges as a result of changes in steepness, slope and exposure. Besides loss of habitat, wild species are at risk from fire hazards. It is now well known that the kind of vegetation in a region is the basic factor involving all types of fire hazards. Other main factors to be considered in fire-hazard potential are the relative humidity and temperature. Many dominant grass species such as *Themeda triandra, Cenchrus ciliaris,* etc. are dominant in areas of high species density. Dried plants of such species are a tremendous fire hazard.

The rangelands and their components are the most important natural resource in the Northern parts of Saudi Arabia. After establishing several protected areas, a range monitoring programme has been started by the Range and Animal Development

Centre at Al-Jouf to determine the effects of climate and the recovery of vegetation. Their study shows that despite the prevention of grazing, the vegetation in several areas (except Harrat Al-Harra) remain as stunted, primarily due to lack of rain and extreme heat. The system used by the investigating team could be utilized by range managers to adjust livestock numbers according to the range trend.

In most parts of Saudi Arabia, the term 'rare plants' has an important significance when referring to the flora. It is basically due to rainless years, severe heat and the unsustainable use of natural resources. In many countries, the rare plants constitute only 5-15% whereas in Saudi Arabia, the rare category which also includes the endangered species constitutes about 33%. Most of the hillocks in the Najd Area is devoid of any appreciable plant cover. According to plant collectors, several areas visited by them especially in the north western regions, contained an appreciable vegetation cover. However, those areas when revisited appear to be completely deforested after a few years.

Anticipated negative impacts of climate change on woodlands of Saudi Arabia over the next 50-100 years include:

(i) Increase in the frequency and changes in the patterns of natural disturbances such as fire.
(ii) Shift toward a younger age class structure of the woodland.
(iii) Reorganization of woodland species composition.
(iv) Woodland decline in species rich areas due to slower dispersal capabilities of plants.
(v) Major changes occurring along woodland and species-rich area boundaries, particularly in the southwestern and northwestern regions.

3.5.5 Present Conservation Status in Saudi Arabia

3.5.5.1 Drought Warning System

A regional drought monitoring and early warning centre has been established within the Presidency of Meteorology and Environment (PME) in May 2003 to coordinate the results of all climate related studies. In addition, the 14th meeting of the IPCC held in Geneva agreed in principle to support the centre with all available expertise. The main goal of the centre is to finalize strategies on various climate changes in order to slow down the increasing risk of drought and also to prepare a work plan to protect the environment and its natural resources. The main objective of the centre is to monitor and analyze the climate data of the past, present and future periods. It also systematically observes the atmospheric, terrestrial and oceanic parameters so as to predict the climate changes in the environment.

3.5.5.2 Assessing the Vulnerability of protected areas

Degradation and extinction of population or a population decline can still be expected as a result of changes in environmental conditions related to climate change or widespread pollution, even after an area has been set aside as a protected habitat. At present, Saudi Arabia has 15 protected areas which cover approximately 5% of the land area and conserve about 43% of the country's flora. There are 968 plant species, subspecies, and varieties protected in the eight protected areas, majority of which are in the Raydah Nature Reserve. Only 2% occur in more than 5 protected areas (Robertson, 1996). The NCWCD developed a national plan in 1990 after an extensive field survey and a wide range of consultations. According to the plan, 104 sites (both marine and terrestrial) have been identified to declare as protected areas. The sites include areas with key biotopes and landscape features and covering habitats of critical species in the Kingdom.

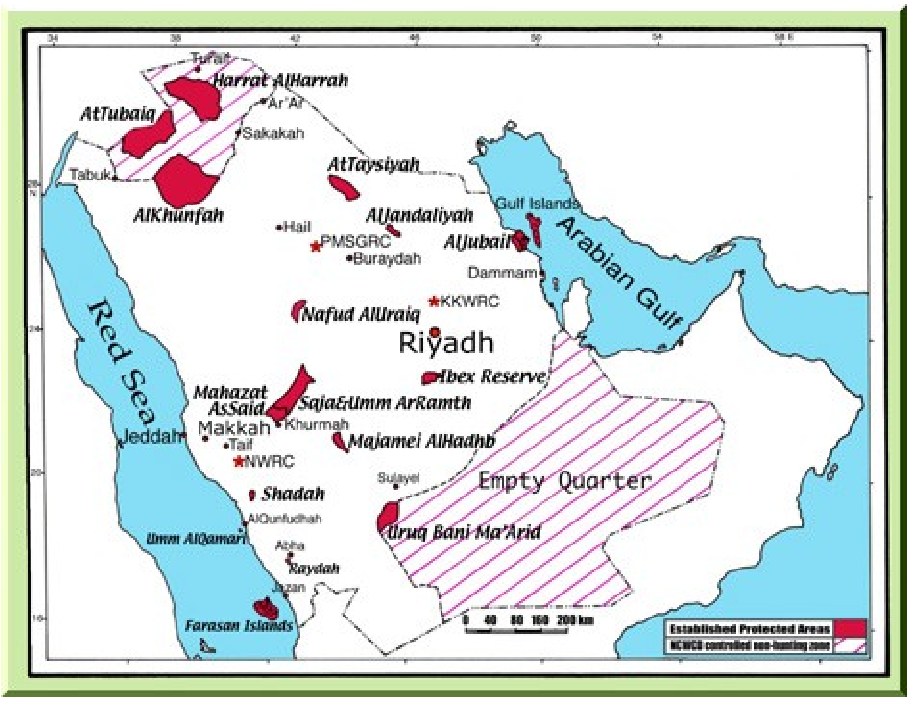


Figure 3.5.4 Protected areas in Saudi Arabia

Climate change is likely to induce vegetation change that will force wild plant and animal species to shift their distribution in response to the new conditions or adapt them to the changing climate. Various degree of pubescence on plants and a variety of changes in the color and size of butterflies, dragonflies, beetles and other migratory insects are reported in various studies conducted by scientists in Saudi Arabia. If the protected area is not large enough to contain an area that will be suitable under the new climate conditions, a species may become locally extinct. On the other hand, if the protected areas are large enough, the species make adjustments within the habitat as and when conditions change.

As the climate changes, plants will naturally attempt to adapt by migrating into new areas, assuming that the landscape is not fragmented. Since most of the "good" areas are occupied by humans, not all species will be able to migrate. From a conservation point of view, one has to visualize that creating avenues of migration for critical plant groups might be a useful hedge against destructive changes in climate. Unfortunately, most of the species rich areas are located in the mountains of the western side and most of them are highly fragmented and therefore plants have limited options for migration.

In desert ecosystems, protected areas are often located around oasis, which acts as basis for the existence of much of the local fauna. Protected oases often are far apart, so droughts that cause a decline in local forage often cause mass mortality because animals may not be able to move on to adjacent oases. Another impact on extreme climate variation is the result of the disappearance of small pools, seeps and streams in the protected areas, such as the one in Ibex Reserve, near Howtha Bani Tamim. If this happens, it may directly or indirectly affect the wild inmates like Ibex and Gazelles, although these animals can quench their thirst by eating the foliage of wild plants.

3.5.5.3 Reintroduction of Animals, Research Centers and Botanical Gardens:

3.5.5.3.1 **Reintroduction of animals:** NCWCD has actively involved in the conservation and reintroduction of endangered animals in the Kingdom.

3.5.5.3.2 **Research Centers:** NCWCD is running two important research centers namely:

- National Wildlife Research Center, Taif.
- King Khalid Wildlife Research Center, Thumamah**.**

Objectives of Research Centers

- To breed endemic species of Saudi Arabia, particularly endangered ones.
- To reintroduce those species into the wild, notably in protected areas established by the Commission.
- To undertake scientific research on those species.
- To undertake research on habitat rehabilitation associated with reintroduction programs to enhance the success of those operations.

Captive breeding programs have been developed on species such as Idmi, Oryx and Rheem. Both Centers are actively involved in the reintroduction of Arabian Oryx and Houbura Bustard in their respective habitats.

3.5.5.3.3 **Botanical Gardens and Green Houses**

For the past few decades, universities and colleges and organizations have launched nationwide campaigns to promote environmental education and awareness and conservation activities in the Kingdom. Development of botanical garden at King Saud University (KSU), Riyadh and green houses associated with the department of Botany & Microbiology, KSU are two such institutions that have been used effectively in the fight for the conservation of nature. Several feasibility studies have also been conducted in the Kingdom with the active collaboration of Botanic Garden Conservation International (BGCI) to establish a National Botanic Garden on the outskirts of Riyadh City in order to protect the endangered and vulnerable plants of Saudi Arabia. The purpose of ex-situ conservation through Botanic Gardens is to provide protective custody of material for introduction into damaged habitats and to enhance populations as part of ecosystem management.

3.5.5.4 Dieback phenomenon in Juniper woodlands: A Case study

The genus *Juniperus* is one of the largest coniferus genera widely distributed in the temperate regions of the Northern Hemisphere. *Juniperus procera* is one of the most widespread species in its genus occurring in the Eastern Mediterranean, from Turky to Himalayas, Saudi Arabia, Oman, Yemen and in many parts of East Africa. The woodlands of Junipers are very important to conserve the biodiversity of a region, ranging from mammals to microorganisms as well as various other plant species. The woodlands in the southwestern region of Saudi Arabia consist of ***Juniperus procera***, one of the main dominant plants at elevations above 1500 meters. A few decades ago, these woodlands were the most dominating and luxuriously growing plant groups in Saudi Arabia. However, in recent years, a serious die back phenomenon has been observed in a large area of Juniper woodlands of Asir Mountains. Dieback is a process in which the tips of the Juniper branches start dying and carry on until the whole-branch is killed. The status of the Juniper trees in other mountains of southwestern region such as that of Taif, Ballasmar, Jabal Tallan, Jabal Fayfa, Jabal Qahar and Jabal Hashar is also not different from that of the Asir Mountains.

The populations of ***Juniperus phoenicea,*** another species present in the Nothern Hijaz is also in a highly degraded state. Though there are no Juniper woodlands in the Northern Hijaz Mountains, the presence of this Mediterranean species in the isolated mountains of North western region is highly remarkable and the loss of this dominant plant can cause irreversible damage to biodiversity of these mountains. According to Collenette (1989), “Juniper is especially valuable as its cool foliage is capable of condensing drifting clouds into drops of water. This can be observed in the Juniper zone of high Asir during summer, when the steamy Tihama plain is high in humidity. Cloud tears over the lip of the escarpment, through Acacias, shrubs and Junipers but only the Junipers are dripping as if it were raining and the ground immediately under them is soaking wet. Each time a Juniper tree is felled, it is like turning off a small water tap”.

Scientists have various opinions about the cause of the die-back of Juniper trees. Some are of the view that the major cause of the poor regeneration of these trees was due to the infection of a Tortricid moth, *Strepsicrates cryptosema* on the female cones (Hajar et al, 1991). This view has been discarded since long-lived Junipers, bearing thousands of cones can produce sufficient number of viable seeds every year and that at least a few of them can escape the infection (Gardner and Fisher (1994).

Figure 3.5.5 Dead or partially dead trees of *Juniperus procera* in Jabal Hashar, Gizan

Others are of the view that, this might be a cyclical phenomenon concerning the Juniper woodlands growing under extremely critical conditions. As the trees in the Asir Mountains and elsewhere are of the same age, the death of these trees also might have happened at the same period in recent years. All these views were discarded for one reason or the other. According to a study conducted on *Juniperus excelsa* (*Juniperus procera*) in the northern mountain range of Oman, the possible factors for the poor regeneration of the Juniper trees could possibly be due to human disturbance, grazing pressure or climatic change (Gardner and Fisher, 1994).

3.5.5.4.1 Initiatives to overcome the dieback problems

The die-back phenomenon of Juniper woodland is a matter of concern to the Government of Saudi Arabia in general and to the National Commission for Wildlife Conservation and Development (NCWCD) in particular. Since 1994, NCWCD has undertaken preliminary researches on the ailing Juniper trees of the southwestern region, assisted by Japanese Scientists from JICA. In 1999, a joint research between NCWCD and JICA has been initiated to identify the problems facing Juniper trees in the Asir-mountains, and to conserve the entire Juniper Woodlands from further deterioration.

A preliminary survey was carried out in 1994 (Yoshikawa and Yamamoto, 1995) by a team of Japanese and local scientists to carry out the following objectives.

(i) Assessing the current status of the floral and faunal aspects of the reserve.

(ii) Assessing the current status of Juniper woodlands in order to find out the causes of die-back phenomenon and

(iii) Collecting information in order to draw a management plan of the reserve.

The analysis on the characteristics of physiological adaptation of *Juniperus procera* to drought environment was one of the essential items in the research. The research team also studied the competition among inter and intra species in the Juniper woodlands, apart from the forest structure and plant population dynamics of Juniper stand and water balance in Juniper tree under fluctuation of environmental conditions. The studies on the die-back phenomenon of Asir mountains during the 1994-95 period have concluded that die-back phenomena of woodland trees was highly related to environmental stress factors including water deficit, low temperature, lack of nutrients, air pollutants, insect attack, over grazing by herbivorous animals, erosive ground and diseases. The team also gathered several data to estimate the possible cause, which include various topographical factors such as different altitudes, slope directions, slope degrees. In order to follow up the survey, two Japanese experts on floral and faunal aspects visited the site and conducted surveys with the close collaboration of NCWCD counterparts in April and May, 1995. The report of the study team overviews the results and recommends a 5-year plan for the management and research of the reserve.

Fisher (1997) proposed four possible hypotheses (all involving climate changes), concerning the dieback problems of Raydah Reserve. They are:

a. Overgrazing by livestock has altered local vegetation structure, causing woodland decline at lower altitudes through effects on microclimate.
b. The global temperature rise of the twentieth century with elevated Spring temperatures in the Middle East is causing woodland decline through temperature-induced dieback at the lower juniper ecotone.
c. Dieback caused by periodic droughts combined with long regeneration cycles, is more marked at the lower, hotter elevations.
d. The present arid phase in the climate of Saudi Arabia, which began between 4000 and 6500 years ago is still developing, causing woodland dieback through a long-term increase in aridity.

Based on the above field studies and in line with the discussions from other scientists attending a symposium (1995) on Juniper die-back, the research team had come up with several **preliminary conclusions.** However, scientists have the view that a long-term study on the tree growth and temperature along an altitudinal gradient across the dieback zone is necessary to prove the accuracy of various hypotheses. Factors suspected to be the cause of partial or complete damage to juniper trees are as follows.

(1) Global warming
(2) Drought stress
(3) Biotic factors
(4) Human activities
(5) Physical damage
(6) Ageing

In order to overcome the dieback problems facing the Juniper woodlands of Saudi Arabia, the National Commission for Wildlife Conservation and Development (NCWCD) has initiated a joint research in cooperation of the Japanese International Cooperation Agency (JICA).

3.5.6 Socio-economic impact

It is now proved beyond any doubt that serious climatic changes predicted due to global warming have far reaching implications to the biodiversity, human welfare and socio-economic systems on a global scale. Biodiversity and its natural resources are important to most of the nomadic communities of Saudi Arabia. The Saudi societies in general and the tribal communities in particular are vulnerable to the biodiversity loss that could result from climate change. The socio-economic impacts in Saudi Arabia can be summarized as:

a. Increase of temperature and lack of rain hamper the effort of farmers who practice terraced cultivation in the southwestern region.
b. Successive drought periods will have drastic impact on nomadic communities as they heavily depend on animal husbandry.
c. Air borne dust levels and land soil salinity will be affected (increased).
d. Successive droughts will change the vegetation structure from Mesophytes to Xerophytes.

These socio-economic impacts could be summarized as under.

3.5.6.1 Impact on agriculture

Tribal communities in the southwestern region are heavily depended on rain-fed agriculture. Lack of sufficient rain or untimely rain will often hamper the efforts of these people to improve their agriculture demands. Studies on evapo-transpiration (ET_0), irrigation water demands, soil salinity and desertification conducted in various agriculture regions in Saudi Arabia proved that an increase in temperature of 1^0 C will result in increasing the ET_0 and water demands by values range between 1 - 4.5% and an increase in temperature of 5^0 C will result in increasing the ET_0 and water demands by values range between 6 – 19.5% (section 3.2). The expected water shortage will increase the soil salinity by about 3.0 times of the original salinity level (section 3.2) and this eventually causes a water stress on desert plants.

Ground water is the main irrigation resource in most parts of Saudi Arabia particularly in the Central, Eastern and Northern regions. Ground water is highly salty in many parts of the Kingdom. Regular use of ground water for irrigation purposes will turn the agriculture land into a salty land. A considerable number of agriculture lands have been abandoned in Saudi Arabia as a result of the constant usage of saline ground water. Increase in temperature leads to increased sand, soil and dust movements. Increased dust in the atmosphere has negative impacts on the health of all living beings. Temperature rise associated with increased wind speed also enhances sand dune movements. The impacts of climate change in the agriculture sector in this country can be summarized as follows.

- Increase of temperature and prolonged drought will reduce crop yield and increase the number and variety of pests.

- Successive drought will affect farmers particularly the small income farmers; and as a result they have to abandon their marginal land.
- Shortage of water resources will force farmers to shift their cultivation from one crop to another and from one area to another. The practice increases desertification.
- Successive drought will result in job loss, and loss of income.

3.5.6.2 Effect on Nomadic Community

The nomadic communities are highly vulnerable to climate change. The loss of grazing sites in one area due to severe drought force them to shift their dwelling places and move their flocks of sheep and herds of camels from one region to another.

3.6 Analysis of Socioeconomic Impacts of Annex 1 Response Measures

3.6.1 Objectives

The purpose of this chapter 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 fossil fuel 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 away from fossil fuels to adapt to the implementation of these Annex I climate change energy policies. However, Annex I countries are obliged to fulfill the needs of vulnerable developing countries like Saudi Arabia in order to meet Annex I county commitments in the climate change convention. 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.

3.6.2 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 energy 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.*

3.6.3 Introduction

The implementation of certain climate change policies by Annex I countries will undoubtedly impact the economies of oil-exporting nations. These energy policies will include measures to reduce emissions of carbon dioxide. This can translate into a reduction of fossil fuel demand, of which petroleum is the largest global contributing source of greenhouse gases. There are not only economic impacts but also social implications as well for Saudi Arabia. A substantial portion of the Gross Domestic Product (GDP) is a result of revenues from oil export sales (Figure 3.6.1).

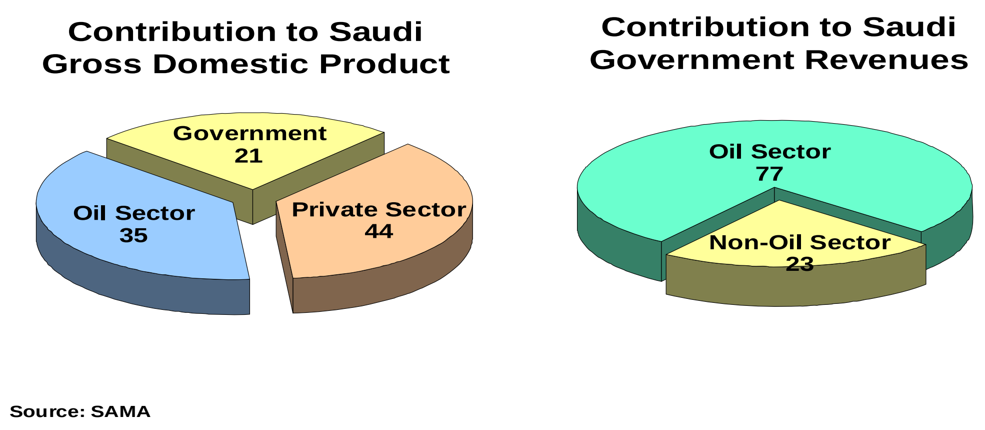


Figure 3.6.1 Contribution of oil sector in 2002 (% of Total)

The overall economic growth rate of the Saudi economy, which will depend mainly on the non-oil sector, has not kept up with the population growth rate of the country. While real crude oil export revenues remained flat, significant demographic pressures have continued to burden the domestic economy resulting in unemployment, thus causing the real GDP per capita in the country to shrink over time. Therefore, it is critical for Saudi Arabia to take these Annex I country response measures seriously, since these climate change related energy policies may further erode Saudi Arabia's oil revenue base, which is a large contributing factor to the economic welfare of this country.

3.6.4 Economic Impacts of Response Measures on the Saudi Economy

Climate change response measures will impact world oil demand by making fossil-fuel energy more expensive through certain policy measures adopted by Annex I countries (OECD & former Eastern European countries). This will have negative economic impacts as well as adverse impacts on Saudi Arabian welfare since lower incomes can lead to deteriorating socio-economic standards. For example, Saudi real GDP per capita has been decreasing for the past two decades from approximately $28,000/year in the early 1980s to approximately $9,300/year in 2000. This figure is projected to slump even further to $3,000/year by 2010 (Figure 3.6.2). This is assuming a business-as-usual scenario. However, if climate change response measures were to be implemented by Annex I countries, this would further exacerbate this already tenuous socio-economic situation.

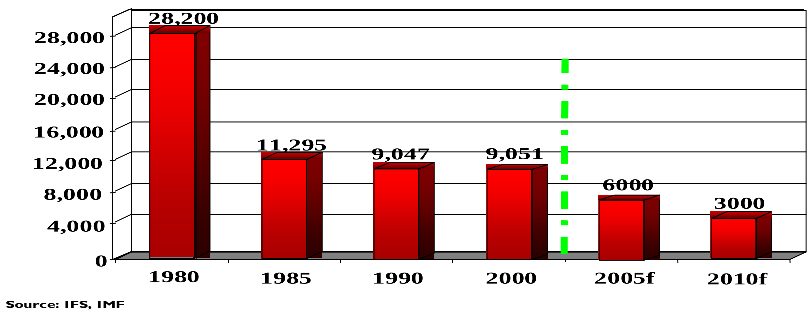
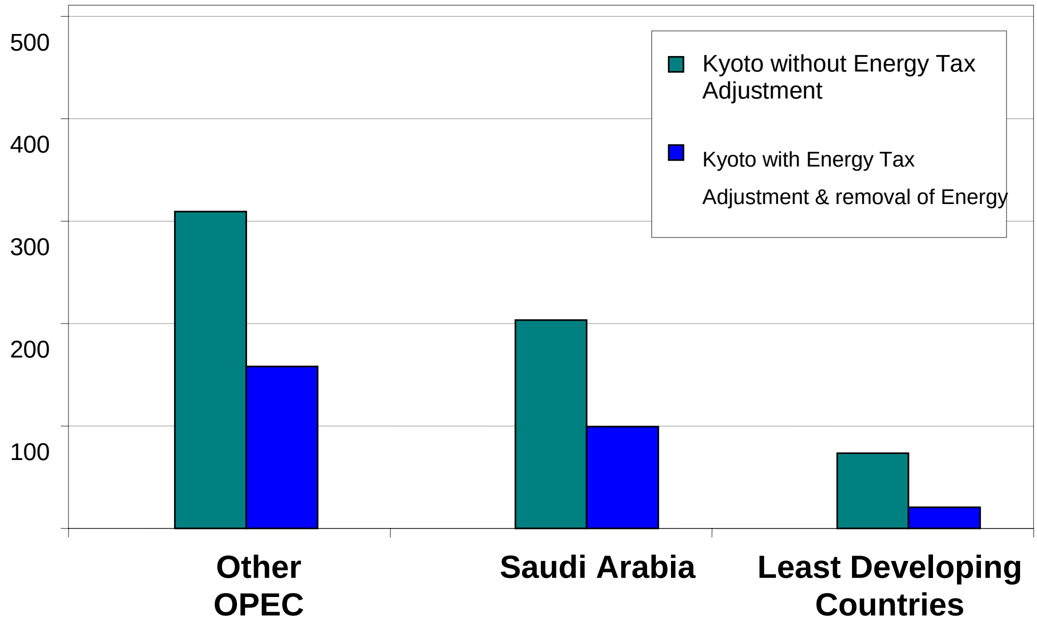


Figure 3.6.2 Average GDP Per Capita

Actions by Annex I countries to reduce greenhouse gas emissions will have adverse impacts on a number of developing countries and considerably greater impacts on countries that are highly dependent on oil revenues, in particular Saudi Arabia. For example, 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. The Intergovernmental Panel on Climate Change (IPCC) in its Third Assessment Report has also projected lower oil demand and revenues for developing countries that are highly dependent on the export of fossil fuels. These economic losses will vary; however, Saudi Arabia, being the largest fossil-exporting economy, will experience disproportionate losses to its economic welfare compared to other developing countries (Figure 3.6.3). 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.



Source: Charles River Associates

Figure 3.6.3 Net Present value of cash compensation

Since the economy of Saudi Arabia is dependent on oil exports, which account for approximately 35% of GDP and 77% of government revenues, sufficient considerations must be given to the impact of Annex I climate change policies on the Saudi Arabian economy (See Figure 3.6.1). A mandate to address the impact of response measures is clearly stated in Articles 4.8 and 4.10 of the climate change convention and Articles 2.3 and 3.14 of the Kyoto Protocol. Countries whose economies are dependent on exports of fossil fuels are mentioned explicitly in Article 4.8 (h).

3.6.5 Implications of Energy Policies

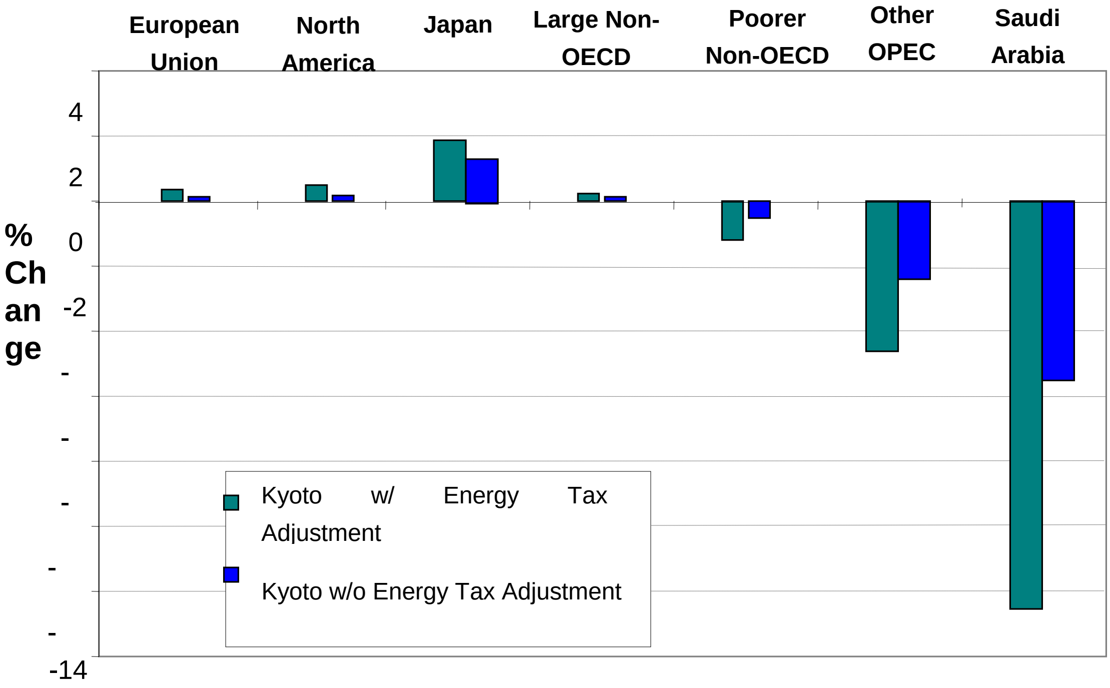
The introduction of energy policies to reduce greenhouse gas emissions, in particular CO_2, could depress the global economy, especially developing countries economies that rely on energy intensive industries. This can lead to economic welfare losses in developing countries, thus retarding economic development and further increasing the gap between industrialized nations and developing countries. This especially holds true for oil producing developing countries since there are already unilateral domestic taxes in OECD countries on transportation fuels.

Using the climate change convention and the Kyoto Protocol, 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 are both environmentally unfriendly and have adverse impacts on economic growth of developing countries, in particular oil exporting countries like Saudi Arabia. Thus, this contradicts the aim of assisting economic development and world sustainable growth and contravenes the requirements of Articles 4.8 and 4.10 in the climate change convention.

Actions by Annex I countries can have adverse impacts on developing countries. These impacts are transmitted by changes in the terms of trade between the developed and developing world, and by changes in the volumes of imports and exports. However, oil-exporting developing countries will be disproportionately affected. Oil demand from Annex I countries will fall due to limits on carbon emissions and a higher tax effectively on oil use. This lower oil demand will negatively impact Saudi oil export earnings.

Terms of trade changes, as a result of the implementation of these energy policies, can also produce spillover effects. As developed country industrial and service sectors adjust to climate change related energy policies, they will use more expensive inputs of production (i.e. less greenhouse intensive processes) to produce exportable goods and services; therefore, the cost of producing these goods and services will be higher. Thus, terms of trade will move against Saudi Arabia and other poorer developing countries as oil demand decreases and import prices for goods and services rise (Figure 3.6.4).

The use of effective flexibility mechanisms, (e.g. emissions trading and certain emissions credits and large CDM projects) agreed to in the Marrakech Accord, 7th Conference of Parties, can reduce adverse economic impacts on Saudi Arabia. These mechanisms will promote more cost effective compliance to certain energy policies in industrialized nations that mandate reduction in greenhouse gas emissions. This can include more efficient choices among oil, gas, and coal use globally. In addition, the use of carbon taxation based on carbon content as well as a 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: Charles River Associates

Figure 3.6.4 Percentage change in terms of trade in 2010

3.6.6 Saudi Arabian Economy

Oil revenues have historically had a direct impact on Saudi government spending and fiscal policy. While 1970's and early 1980's were the years of considerable budget surpluses from oil revenues, the national budget has been running in deficit starting as early as 1983 until the present, only with the exception of 2000 and 2003 which were primarily due to relatively high oil prices (Figure 3.6.5). The past two decades, when government expenditures have predominately outstripped government receipts, have resulted in a high domestic debt reaching as much as 100% of GDP in the late 1990s (Figure 3.6.6) This continuous pattern of annual budget deficits will more than likely persist for the foreseeable future unless the Saudi economy can find sources of revenues other than its crude oil exports.

The loss of oil revenues, due to climate change energy policy, will be much more difficult to replace for specialized oil exporters like Saudi Arabia. This is due to the fact that the 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 Annex I country energy policies taken as a response to climate change. In addition, Annex I mitigation measures would reduce demand for oil and would further exacerbate the current economic conditions, thus impeding foreign investment and may precipitate capital flight.

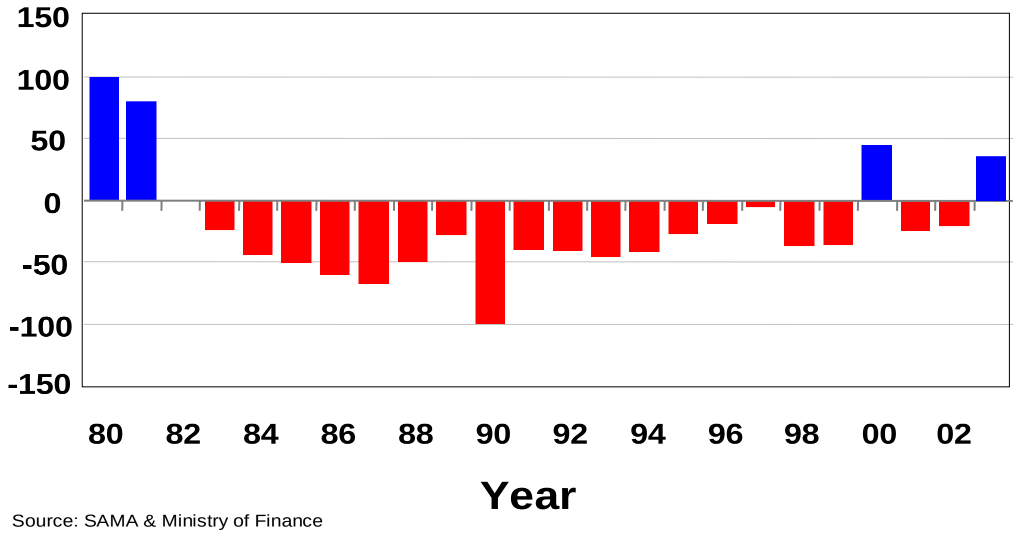


Figure 3.6.5 Saudi Government Budget Balances

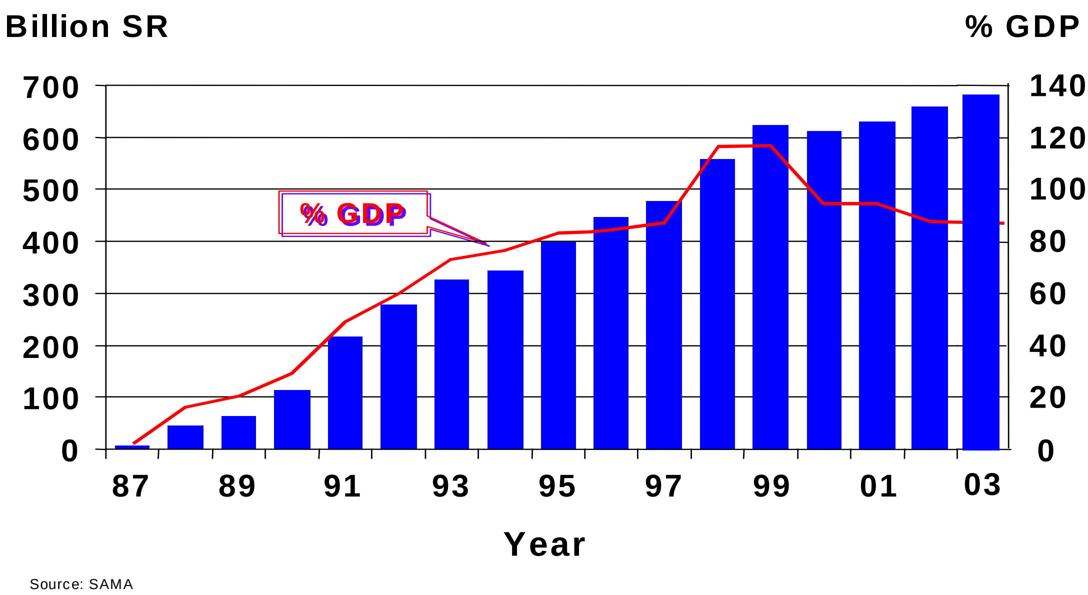


Figure 3.6.6 Saudi Domestic Debt

Even though Saudi Arabia has established robust oil and petrochemical industries, its economy has not been sufficiently diversified, remaining largely reliant on the oil sector. This lack of economic diversity places Saudi Arabia's economic development at risk especially if industrialized countries implement energy policies to curb greenhouse gas emissions. However, the diversification of the Saudi economy can offer a more stable revenue base than the country's current high dependency on crude oil production.

3.6.7 Demographic Implications

According to the 1992 census, the total population of Saudi Arabia was approximately 17 million. In 2003, Saudi Arabia's population exceeds 22 million of which Saudis make up 75% of the total. During the past two decades, the average annual growth rate of the Saudi population was approximately 3.9%. 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 29 million, suggesting an annual average growth rate of 3.1%. (Figure 3.6.7) Even though this population growth rate may slightly recede this decade, it is still amongst the highest in the world compared to developing and industrial country population growth rates at 1.7% and 0.7%, respectively, in the 1990s.

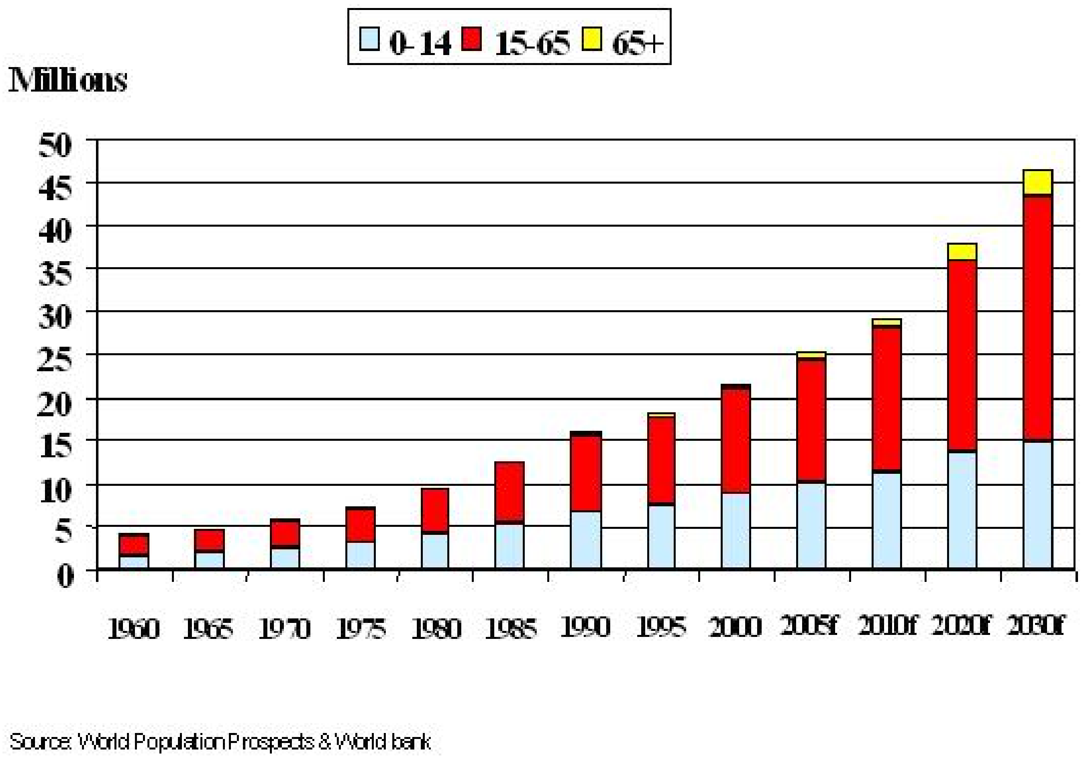


Figure 3.6.7 Population growth in Saudi Arabia

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 has now changed as the once booming oil economy slowed due to a sharp fall in oil prices in the following decade. 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 has become a serious concern for the government; namely, increasing financial burdens due to a growing population in the face of declining oil revenues. Another concern is that 65% of the growing Saudi population is below the age of 25. Another demographic statistics suggests that the median Saudi population is 14.7 years of age. (Figure 3.6.8) Therefore, the challenge that the Saudi government currently faces is as follows: Can the Saudi economy generate sufficient employment opportunities for this burgeoning labor force?

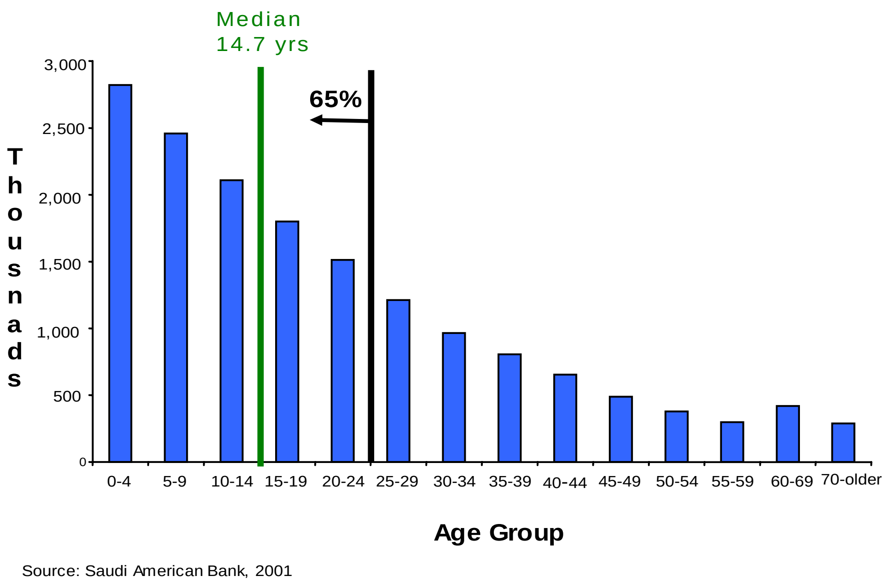
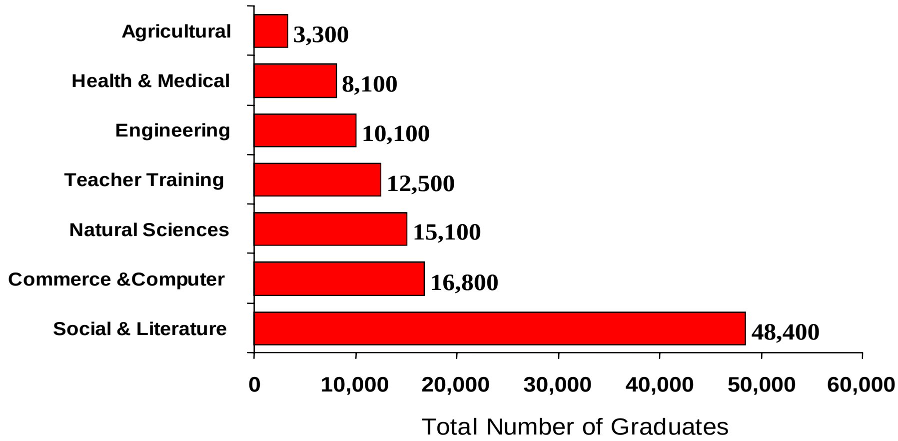


Figure 3.6.8 Saudi demographic youth bulge

During the five-year period between 1995 and 1999, it was estimated that the total number of university graduates in Saudi Arabia reached 114,000, or approximately 22,800 per annum. Not only is this number considered small, but most graduates were in fields not demanded by the private sector. For example, engineering graduates over this five-year period were estimated at 10,100, while literature and social studies graduates were almost five times larger (Figure 3.6.9). The nature and quality of this current education will yield inadequate labor skills among Saudis. This has resulted in a lack of private sector participation among Saudis in the labor force. Therefore, as the competition for available jobs intensifies in this potentially demanding job market, so must the skills and quality of education of this young Saudi workforce.



Source: Ministry of Finance and National Economy

Figure 3.6.9 University Graduates by field of specialization

There is a need for capacity building through 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.

3.6.8 Saudi Arabia's Adaptation Requirements for 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 energy policies on developing countries that are heavily reliant on fossil fuel 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 provide assistance to Saudi Arabia as an adaptation measure to offset the economic impacts of Annex I 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 they can adapt to future climate change policies. If Saudi Arabia fails to diversify its economy sufficiently away from its fossil fuel dependent 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 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 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 political 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 for this will help ensure global energy security.
- Diversification would help Saudi Arabia develop towards a post fossil fuel age over the next several decades and thus may lead to the reduction of the highly greenhouse gas intensive nature of its economy.
- The marginal cost of greenhouse gas emissions abatement in Saudi Arabia (one of the highest carbon intensive economies) 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 fossil fuels while it imports manufactured goods and high tech equipment from certain Annex I countries. Since the fossil 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 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 under.

- 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

- Strong interest in the accession process to the World Trade Organization.

The areas in which Saudi Arabia would require assistance from the Annex I parties in order to diversify its economy are following: power generation, water resources, non-energy use of fossil fuels, and most importantly education.

3.6.8.1 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 Saudi Arabia's low cost of energy and its growing population:

- 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 into residual gasification through CDM projects can produce environmental friendly power.

3.6.8.2 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 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.

3.6.8.3 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: 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 barriers in order for its end products to reach the desired markets.
- 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 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.

3.6.9 Saudi Energy Consumption and CO_2 Emissions

Saudi Arabia is a major oil and gas producer and has a relatively large landmass of approximately 2.25 million squares kilometers. Therefore, Saudi Arabia tends to be a large fossil energy-intensive economy since the production and processing of crude oil (drilling and extracting to refining of finished products) is an energy intensive process resulting in relatively high carbon emissions. Since Saudi Arabia has a quarter of the world's oil reserves as well as the world's largest petroleum exporter, it has the responsibility of supplying the world with petroleum which is considered as a strategic resource not only to Saudi Arabia, but to the global economy. Therefore, Saudi Arabia will be limited in its efforts to reduce CO_2 emissions from its oil producing operations.

Saudi Arabia's energy consumption has been on the rise over the past two decades. This is mainly due to the booming oil sector and global oil demand in the 1970s and early 1980s and a continued reliance on a reliable and inexpensive fossil energy. Recognizing the geographical land mass it possesses, Saudi Arabia's industrial and transportation sectors account for approximately 80% of the country's total energy consumption while the residential and commercial sectors account for the remaining 20%. Oil makes up the majority of this consumption at 59% while natural gas accounts for the remainder.

Saudi Arabia's carbon emissions have risen by 55% in the past 20 years. This relatively high increase is not as proportionately significant as other developing nations, which have seen carbon emissions, on the average, double during the same time period. However, in terms of per capita carbon emissions, Saudi Arabia is still one of the highest relative to the developing world. This is mainly attributed to the economic and abundant nature of its strategic crude oil resource.

3.6.10 Conclusions

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 CO_2 emissions. This will reduce oil demand in these countries and directly reduce Saudi Arabia's crude oil exports which comprise a large portion of its GDP. However, Saudi Arabia can 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 and the Kyoto Protocol.

Saudi Arabia will require assistance from Annex I countries to diversify its economy in order to adapt to potential climate change related energy 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 resource 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 developed countries for this will be a global benefit to energy security, the global economy, and the environment.

SECTION 4:

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