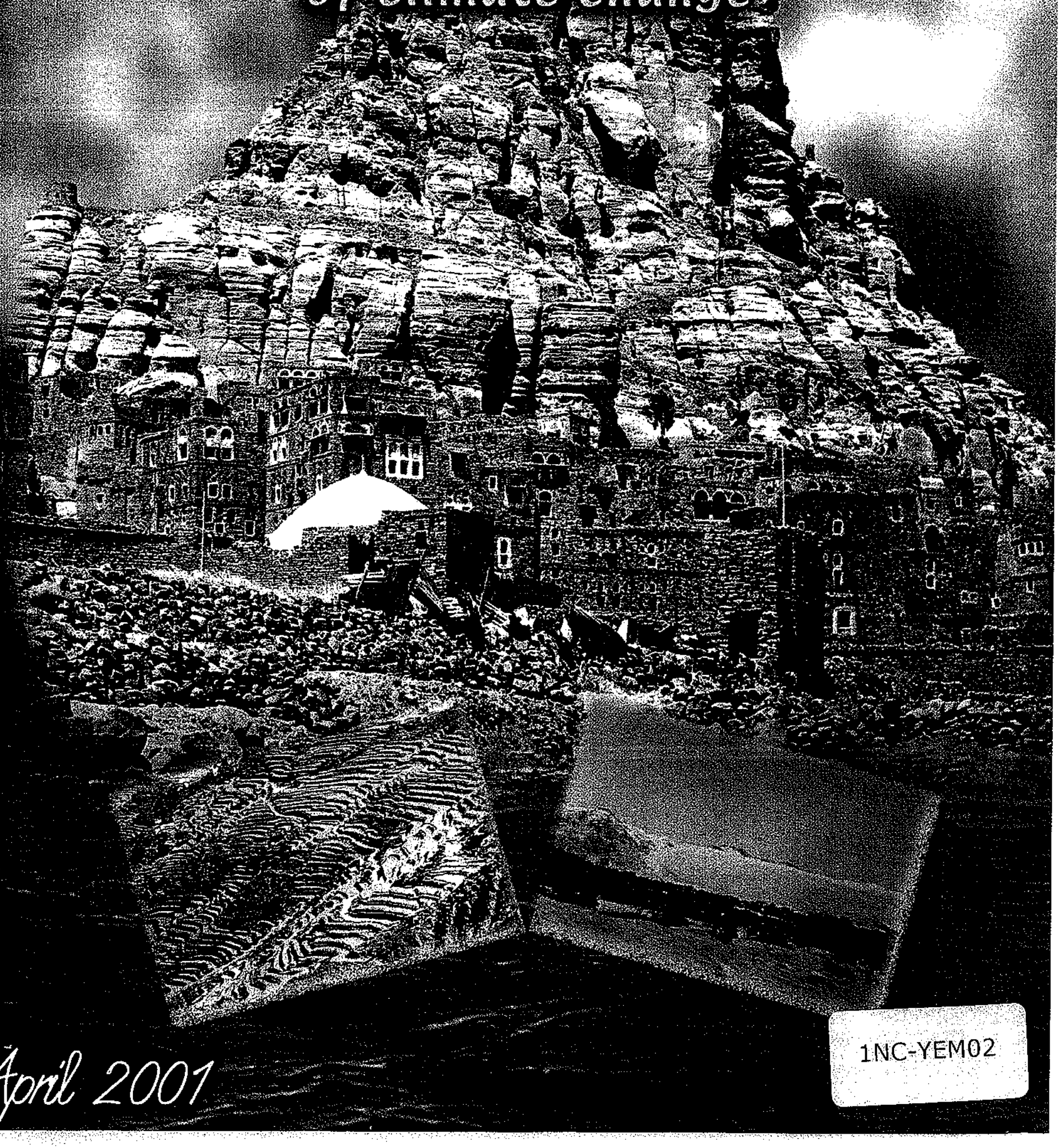
REPUBLIC OF YEMEN

Initial National Communication Under United Nation Framework Convention Of Climate Change



April 2001

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ENVIRONMENTAL PROTECTION COUNCIL

REPUBLIC OF YEMEN

PREFACE & FORWARD

Following signing of the UN Framework Convention on Climate Change (UNFCCC) at the Earth Summit in 1992, Rio de Janeiro, and in response to the Conference of parties, the parties are required to submit their Initial Communication which should include a national inventory of sources and sinks of greenhouse gases, identification of vulnerable sectors and actions to be taken for sustainable future development.

Recent increasing in Government commitment towards achieving the objectives of better protection of the environment and the rational management of resources has been reflected in submission of the national communication within three years of availability of financial resources. As the fund made available for the initial national communication was on early 1998 through the Global Enviornment Facility (GEF) and the Netherlands Climate Change Studies assistant programm (NCCSAP) during 1998.

Climate change is a new subject in Yemen. Capacity to assess topics on climate change, particularly the main focal areas of inventories, mitigation analysis, vulnerability assessment remains rudimentary and restricted to a few institutions. Long-term institutional capacity building is considered critical to overcoming technical difficulties relating to methods, models and data. Introduction of abatement activities would require first a national policy position to support industrial energy conservation and the transfer or development of environmentally sensitive technology. Ensuring the success of such a policy requires specific policy instruments to enable productive sectors to adopt appropriate abatement practices. The introduction of such instruments in turn requires some policy and technical capacity to monitor emission for purposes of enforcing reduction instruments. Therefore developing a practical national response program requires skills in many technical and social disciplines.

As anticipatory measures are also often more cost-effective than reactive adaptation measures, Yemen is presenting several cost-effective measures

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LIST OF ABBREVIATIONS AND ACRONYMS

AREA	Agricultural Research and Extension Authority
ASLR	Accelerated Sea Level Rise
B/D	Barrels a Day
BAU	Business As usual
CAMA	Civil Aviation and Meteorological Authority
CCGT	Combined-Cycle Gas Turbine
CH_4	Methane
CHP	Combined Heat and Power
CO	Carbon monoxide
CO_2	Carbon dioxide
CoP	Conference of Parties
COZMIS	Coastal Information System
CSO	Central Statistical Office
ECHAM3TR	Max Plan Institute
EFARP	Economic, Financial and Administrative Reform
EPC	Environmental Protection Council
Eto	Potential evaporation
Etp	Potential evapotranspiration
FAO	Food and Agriculture Organization
GAREW	General Authority for Rural Electrification and Water
GCM	General Circulation Model
GDP	Gross Domestic Product
GEF	Global Environment Facility
GHG	Green House Gas
GIS	Geographical Information System
GNP	Gross National Product
GWh	Gega Watt per hour
IPCC	Intergovernmental Panel on Climate Change
ITCZ	Inter-Tropical Convergence Zone
IVM	Institute for Environmental studies
Kv	kilo volt
LDC	Least Developed Country
LNG	Liquefied Natural Gas
LPG	Light Petroleum Gas

LIST OF ABBREVIATIONS AND ACRONYMS

m.a.s.l.	Meter above sea level
MCM/Mm^3	Million Cubic Meter
MEW	Ministry of Electricity and Water
MGJ	Million Gega Joule
MOMR	Ministry of Oil and Mineral Resources
MPD	Ministry of Planning and Development
MW	Mega Watt
N2O	Nitrogen dioxide
NCCSAP	the Netherlands Climate Change Studies Assistance Programme
NGO	Non-Governmental organization
NIR	Net Irrigation Requirement
NMVOC	Non-methane volatile organic compounds
NO	Nitrous Oxides
NWRA	National Water Resources Authority
°C	Degree Celsius
OSU	Oregon State University
P	Precipitation
PEC	Public Electricity Corporation
PMU	Project Management Unit
PV	Solar Home System
RH	Relative humidity
RSCZ	The Red Sea Convergence Zone
SCOMR	Supreme Council for Oil and Mineral Resources
SO_2	Sulphur dioxide
SSD	Sunshine duration
TOE	Tonne oil equivalent
UKHI	United Kingdom Meteorological Office
UNDP	United Nation Development Progrmme
UNFCCC	United Nation Framework on Climate Change Convention
V&A	Vulnerability and Adaptation
WHO	World Health Organization
WS	Wind speed
YLNG	Yemen Liquefied Natural Gas Company
YR	Yield Reduction

Executive Summary

Introduction

As Yemen became a party to the United Nation Framework Convention of Climate Change (UNFCCC), it should prepare its initial National Communication which is considered as the first step in the actual implementation of the UNFCCC in Yemen.

National circumstances

The national circumstances of Yemen during 1994 are summarized in Table ES.1. Yemen has high susceptibility to natural disaster which is exhibited in the tectonic processes that formed the mountains of Yemen. The high vulnerability of mountain ecosystem creates large difficulties in the economic use of territory and requires constant realization of complex protective measures, especially when it is augmented by possible climate change. A consequence of the country's geographical location with respect to the equator, Yemen is located in arid and semi arid zone, which is considerably vulnerable to climate change. Redistribution of precipitation and increasing frequency and intensity of drought with the possible increase in air temperature in the country entail negative consequences, particularly in water resources management and agriculture.

Table SE.1 - National Circumstances

Criteria	Unit	1994
Area	000 Km^2	555
Population	000,000	14.9
Urban population as percent of total population	%	23.2
Land area used for agricultural purposes, (cultivable land)	000 Km^2	16.6
Population in absolute poverty	%	20-30
Life expectancy at birth	Years	57.5
Literacy rate	%	44
GDP	000,000 USD	5291.1
GDP per capita	USD $	355
Estimated share of the informal sector in the economy in GDP	%	20-30*
Share of industry in GDP	%	20.66
Share of services in GDP	%	36.1**
Share of agriculture in GDP	%	21.7
Livestock population		
Cattle	000	1,151
Sheep and goats	000	6,940
Camels	000	171
Forest area	000 Km^2	24

Source: The Republic of Yemen Statistical Year- Book, 1996.

* Informal sector in Yemeni economy, Ministry of Planning, Sana'a, March 1996

** Services sector includes: trade, restaurant, hotel, transport, storage, communication, supply, insurance, personal services and society services.

Yemen is a least developed country. The negative consequences of the Gulf war of 1990/1991 in addition to domestic factors (civil war etc.) led to continuous and high increase in the deficit of the government budget, the balance of trade and the balance of payments. As a result, the country experienced slow economic growth, high rate of inflation, high level of unemployment and the reduction of government expenditures on public education and health services. This resulted in sharp deterioration in the standards of living. In Yemen as in other developing countries, climate change is crucial to the extent that it can affect the national objectives like protection of environment and sustainable development. Yemen's main national priorities are to improve its physical infrastructure, develop its human resources, increase economic growth and accelerate social development, education & public health and conserve and protect the environment from deterioration and pollution. Actions in the context of climate change hence are necessary for all kinds of development programs and they certainly require international assistance. Inclusion of issues related to climate change in future planning and strategies of energy development and measures to control the emission level of GHG are feasible and more beneficial in case of Yemen with only 38% of population electrified and total primary energy consumption in 1995 of 4.171 million TOE. Organization of climate change studies and UNFCCC activities in Yemen is the responsibility of Environmental Protection Council (EPC), established as the highest national authority promoting and coordinating all efforts related to environmental protection.

Greenhouse Gases (GHG) inventory

The year 1995 was used as a reference year for Yemen's GHG inventory due to the high uncertainty of 1994's information as a result of the April-July 1994 civil war. The greenhouse gas emissions for the three major GHGs, as required by Second Conference of Parties (COP2) guideline, carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) of the Republic of Yemen amounted to 11,358.1 Gg, 128.3 Gg and 15.0 Gg, respectively. Taking CO_2 removal into account, the total emission of CO_2 is sequestered from the amount of 10,513.7 Gg, resulting in 844 Gg net emission of CO_2. These figures are exclusive of the CO_2 emission from the international bunker (114.4 Gg) and from combustion of biomass (353.3 Gg). Table SE2, summarises national GHG source and Sink (Gg), 1995. Yemen's emission profile by gas type for 1995, indicates that CO_2 is the main GHG emitted in Yemen followed by CH_4 as the second major emitted GHG.

Observation, research & impacts

Data on hydro meteorological, crop productivity, sea level, environmental issues and hazards are scattered in various ministries and agencies and hence are not always easy to obtain. More exchange of information between ministries and/or agencies and the establishment of a database is urgently needed. Data requirements for IPCC methodology necessitate the existence of reliable databanks for many sectors.

Due to the variety of sectors targeted, the funds made available for studies conducted during the preparation of National Communication were not sufficient to undertake any new, medium or large scale scientific research. The study built on prior and ongoing studies, compiled the available information and undertook some small, well defined studies to fill the existing gaps for GHG inventory and abatement analysis. Nevertheless and despite the limitation of the data, financial resources, methodologies etc. an advanced level research project was carried out, using a number of models for sectoral analysis.

Yemen's natural systems and economy generally suffer from the mounting pressure of high population growth rate, limited natural resources and economic problems. All these contribute to make Yemen highly vulnerable to climate change. Impacts on key socio-economic sectors, water resources, agriculture and Coastal zone resources have been identified and assessed over representative area.

As in many Arab countries, water has a high social, economic and political value, yet the most vulnerable sector to climate change is water resources in terms of quantity and quality. The available runoff for spate irrigation indicates a deficit in the coverage of spate irrigation water demand as a result of fluctuation in the runoff. The spate irrigation water demand under maximum hot climate quantified as 595 MCM/year, while the available flow for spate irrigation under the same condition is only 105 MCM/year, which is less than a quarter of the demand. This shortage in available spate runoff would lead to rapid increase in groundwater abstraction for agriculture to supplement spate irrigation. Unfortunately, the groundwater aquifer in the study area would not be able to support that demand. Groundwater model predicted that the shortage in groundwater supply to irrigated agriculture would start from year 1997. Withdrawal of poor quality water out of the aquifer continues to increase with slight fluctuation due to recharge pulses. The gap between groundwater demand and supply in year 2050 is of about 162 MCM (66%) under UKHI scenario. Drying up and the abandonment of agriculture in Abyan Delta can be anticipated as it is running short of water. This implies that the whole rural economy is vulnerable to declining water availability.

All climate change scenarios resulted in simulated decreases in wheat and potatoes yields in the two main agroclimatic zones used. The degree of the expected reduction in the production, however, varies from one site to another. Although higher wheat and potato yields can be obtained by practicing supplemental irrigation, water resources scarcity puts a binding constraint on agriculture production. These imply that climate change may bring about substantial reduction in the agricultural production of wheat and potato. Moreover, it would be very difficult to replace Qat (cash, profitable crop) by other crops.

The impact on coastal zone done over a pilot area was assessed after delineation of "the risk zone" the region expected to be submerged in sea water. Total losses was estimated as US$ 1.3 billion. Beside the impact on the biological communities and the shoreline beaches, damage to the city of Hodeidah part alone was estimated at about 74 million US dollars.

Mitigation, adaptation and awareness

Two mitigation options to reduce GHG emission have been assessed, including both the demand and supply side of energy sector. The measures and assumption included in the demand side option are: switch to energy/equipment with lower GHG emissions (substituting electric for kerosene and LPG lamps, solar water heating for electric heating, LPG stoves for Fuelwood stoves) for household sector (urban and rural).

For transport sector: reduce taxes on new vehicles, raise taxes on old vehicles, switch to natural gas technology and solar technology. For industrial sector; fuel switching to natural gas and renewable energy, rational use of energy while for commercial sector, switch to energy/equipment with lower GHG emissions, energy-efficient equipment. For energy required for agriculture, switch to solar irrigation systems.
On the Supply-side mitigation option, is to switch over the use of fuel on a gradual basis for the electrical power sector (largest contributor to GHG emissions), and further from the use of fuel oil for power generation to the use of natural gas in high-efficiency combined-cycle gas turbine (CCGT) power plants. This gradual switching will reduce the quantity of burnt fuel from 80% to 5% by the year 2020, which in turn will drive a considerable reduction in emissions. Increasing the use of solar electricity for remote rural areas will also have the same effect. Considerations for both options are the same, expect for the capacity value of the new CCGT-power plant. The average emission reduction from baseline scenario for option (1), with a 100 MW CCGT power plant capacity, will be around 2935 million kg/year of CO_2. This gives per reduction a leveled cost of 21.27 US$/ton (real 1995 US$) and a leveled cost of 62.42 million US$/year. For option (2), with a 200 MW CCGT power plant capacity and a conversion efficiency of at least 52%, the average emission reduction will be around 3252 million kg/year of CO_2 which gives per reduction a leveled cost of 21.72 US$/ton (real 1995 US$) and a leveled annual cost of 70.64 million US$. The cost benefit analysis shows that there is a cost benefit ratio of 0.45 if option (1) is considered and 0.42 if option (2) is considered.

Besides listing proposed general measures that could be applicable to national level for water resources, agricultural production and coastal zone area, specific priority measures were assessed for pilot studied areas covered by the studies without attempting of extrapolate these adaptive measures to a National level. Moreover, for implementing the suggested measures, costs and/or feasibility study should be undertaken first.

Priority measures proposed for water resources in Abyan delta include: improvement in water use efficiency (irrigation) which has minimal costs, increase groundwater recharge through capturing the surplus runoff that goes to the Sea by structural means and desalination option as a source for Aden water supply instead of Abyan delta wellfield.

Lifting of wheat price subsidy in ***semi-humid areas***, will make rainfed wheat more attractive to farmers. Great attention should be paid to soil drainability in potato fields, when the wet scenario will prevail. Cost-effective drainage systems should be considered. In ***arid and semi-arid areas***, the need for both supplemental and conventional irrigation is more likely, due to water shortage for both potato and wheat. Additional investment will be needed for installing necessary irrigation management facilities. Increased attention must be paid to conserving scarce water supply as further deterioration of water resources related to climate change is predicted. Severe pressure on water will be posed by climate change, where the available water resources are insufficient. Consequent socio-economic measures should be given due consideration. The chemical plant protect will have to be increased carefully so that waters resources are not polluted. Thus, climate change would provide better conditions for the development of pests, and increase the cost of protection. Insufficient plant protection measures will reduce the profit of agricultural crops.

The losses associated with do nothing or abandoning about a quarter of the Hodeidah city amount to some US$ 1,3 billion. The protection required will vary along the coastline according to local requirements, and will comprise a number of elements: ***for southern part of the city,*** raising of the level of the rock revetment; ***for fishing port***, raising of area level, in the long term probably strengthening of the breakwaters; ***for north of fishing port***, raising of the level of the rock revetment; ***for Cornish area***, raising of the level of the wall, check on the stability of the foundations of the sea wall since it is expected that the beach will be eroded away; and ***Construction of a sea wall at the northern part of the city area.*** Summing up, considerable strengthening of the existing constructions will be required over a length of approximately 10 km. Assuming an average cost of US$ 2 million per km the total cost will amount to US$ 20 million for full protection provision.

The level of awareness of climate change phenomenon and its effect is very low in Yemen. The process of gathering appropriate literature on climate change and making it available to policy makers is actively on. However, more assistance (financial and technical) is required to support meaningful climate change research building capacity. Building national capacity in climate change is likely to create more interest in and ensure meaningful debate on the issue of climate change in Yemen.

RESEARCH NEEDS

Proper data organization is vital to address climate change issues. There is a need to centralize all climate change related data. The location of such an important data bank should rest with the Environmental Protection Council, the focal point of UNFCCC in Yemen.

There are significant financial constraints in conducting longitudinal or even medium-scale scientific research (e.g., gathering field data). Such constraints adversely affect the construction, validity and reliability of national studies. Although the findings of pilot

totally realistic. Only three studies were conducted over selected sites to assess the negative impact of climate change. There is a great need for further understanding of its likely impacts and adaptation at a national level for sectors covered during the preparation of the initial National Communication using a more integrated approach. More comprehensive research is required to complete work on impact and adaptation for sectors partially analyzed during the preparation of the initial National Communication as well as other specified sectors not covered yet, but likely to be effected by climate change, such as human health, desertification and land degradation. Impact assessment of climate change in these sectors should be done on a priority basis. Sufficient funding is needed to create an information pool and to make available the appropriate software programs for data analysis, documentation and dissemination, especially as climate change is a new subject in Yemen. Expertise in research related to climate change is important and Yemen requires developing research capacity in various related disciplines.

The few studies conducted for preparation of this initial National Communication provided indication of possible areas where further work ought to be done. Moreover. gaps in information for these sectors are reported.

Table SE.2 Summary of national GHG source and Sink(Gg), 1995

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	CO_2 Emissions	CO_2 Remova	CH_4	N_2O	NO_x	CO	NMVOC	SO_2
Total National Emissions and Removals	11358.09	-10513.7	128.3	15.02	89.06	451.95	92.94	7.69
1 Energy	**9968.28**		**6.02**	**0.12**	**88.13**	**433.93**	**85.36**	**7.36**
A Fuel Combustion (Sectoral Approach)	9968.28	0.00	2.48	0.12	87.85	433.50	79.92	2.92
1 Energy Industries	2402.62		0.10	0.02	6.37	0.48	0.16	
2 Manufacturing Industries and Const	577.19		0.02	0.005	1.55	0.08	0.04	
3 Transport	3808.45		1.12	0.06	64.10	403.20	76.27	2.92
4 Other Sectors	3180.03		1.25	0.04	15.83	29.75	3.46	
5 Other								
B Fugitive Emissions from Fuels	0.00	0.00	3.54	0.00	0.29	0.43	5.44	4.44
1 Solid Fuels								
2 Oil and Natural Gas	0.00		3.54	0.00	0.29	0.43	5.44	4.44
2 Industrial Processes	**546.67**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**7.57**	**0.33**
A Mineral Products	546.67					NE	5.91	0.33
B Chemical Industry								
C Metal Production								
D Other Production	0.00						1.66	
E Production of Halocarbons and Sulfur Hexafluoride								
F Consumption of Halocarbons and Sulfur Hexafluoride								
3 Solvent and Other Product Use								
4 Agriculture		**0.00**	**91.22**	**14.13**	**0.93**	**17.88**	**0.00**	**0.00**
A Enteric Fermentation			86.27					
B Manure Management			4.09	0.04				
C Rice Cultivation								
D Agricultural Soils				14.06				
E Prescribed Burning of Savannas								
F Field Burning of Agricultural Residues			0.85	0.03	0.93	17.88		
G Other								
5 Land-Use Change & Forestry	**843.14**	**-10513.7**	**0.02**	**0.0001**	**0.003**	**0.14**	**0.00**	**0.00**
A Changes in Forest and Other Woody Biomass Stocks	656.72	-10297.4						
B Forest and Grassland Conversion	186.42		0.02	0.0001	0.003	0.14		
C Abandonment of Managed Lands		-216.28						
D CO_2 Emissions and Removals from Soil								
E Other (please specify)								
6 Waste	**0.00**	**0.00**	**31.06**	**0.78**	**0.00**	**0.00**	**0.00**	**0.00**
A Solid Waste Disposal on Land			26.03					
B Wastewater Handling			5.03	0.78				
C Waste Incineration								
D Other (please specify)								
7 Other (please specify)								
Memo Items								
International Bunkers	**114.35**	**0.00**	**0.01**	**0.001**	**2.00**	**1.30**	**0.27**	**0.00**
Aviation	18.12		0.0001	0.001	0.08	0.03	0.01	
Marine	96.23		0.01	0.001	1.92	1.28	0.26	
CO_2 Emissions from Biomass	353.29							

Empty box: Not applicable
Shaded box: Not Estimated because unavailability of input data

Chapter One

INTRODUCTION

1. INTRODUCTION

The United Nations Framework Convention on Climate Change (UNFCCC) was signed in June 1992 in the Rio "Earth Summit". The ultimate objective of the convention is to stabilize greenhouse gas concentrations in the atmosphere at a level that would obstruct dangerous anthropogenic interference with the climate system.

Yemen ratified the United Nations Framework Convention on Climate Change on 21 February 1996, and it entered into force on 21 May 1996. By becoming a Party to the Convention, Yemen accepted a number of commitments like other developed and developing countries. These include:

- **develop, periodically update, publish and make available to the Conference of Parties (CoP) of the UNFCCC, national inventories of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol, using comparable methodologies;**
- **formulate, implement, publish and regularly update national programs containing measures to mitigate climate change**
- **measures to facilitate adequate adaptation to climate change; and**
- **communicate to the CoP information related to implementation of the convention, in accordance with article 12.**

As a Least Developed Country (LDC), Yemen may make its Initial National Communication at its discretion. Like other developing countries Yemen lacked financial resources to start the implementation of its commitments to theConventionandtoprepare its first national communication to the CoP. In accordance with Article 4.3 of the UNFCCC,the Government of Yemen had requested the GEF and the Netherlands to help the country financially to prepare its Initial National Communication to the CoP.

Under the project YEM/97/G31/A/1G/99 " Enabling Yemen to prepare its First National Communication in Response to its commitments to the UNFCCC", Yemen was provided with financial support by the Global Environment Facility (GEF) through the United Nations Development Program, its implementing agency, to complete:

- **GHG inventory**
- **The GHG abatement analysis**
- **Vulnerability assessment and adaptation analysis on the coastal zone (targeted site)**
- **Formulating programs and policy frameworks for effective response measures to climate change, especially with respect to the abatement of GHG emissions and enhancement of sinks.**

Under a project entitled "Climate Change Country Study inYemen"activitynumber:ww 094501-yem.1, The Netherlands Climate Change Studies Assistance Program (NCCSAP) provided funding for:

- **construction of future climate change scenarios,**
- **the vulnerability assessment and adaptation analysis on the agricultural production (selected crops).**
- **the vulnerability assessment and adaptation analysis on the water resource sector (targeted site)**
- **the Project Management Unit (PMU) and the preparation of the Initial National Communication of the Republic of Yemen.**

INTRODUCTION

The preparation of the national communication was the first step in the actual implementation of the UNFCCC in Yemen. A series of problems arose while conducting the climate change studies; including constraints on funding, human resources and technical assistance, and a lack of scientific research. Significant constraints to conduct longitudinal or even medium-scale scientific research (i.e. including gathering field data); adversely affect the construction, validity, and reliability of these studies. Although the findings of pilot studies that focus on a "representative" area can be generalized, the results may not be totally realistic. Sufficient funding is needed to create an information pool and to make available the appropriate software programs for data review, analysis, documentation, and dissemination. The technical assistance available for enabling activities was inadequate for a country that is just beginning climate change studies and that greatly needs scientific capacity building. Decrease in the uncertainty of study results was achieved through making the project timetable period more flexible to allow teams to verify their data collection and techniques more than once.

Despite the odds and limitations, the additional efforts of bilateral donor and national teams have accelerated the development of expertise in each sector involved in the preparation of the national communication, enhanced the institutional capacity in these fields, and increased the awareness of people and institutions concerning the UNFCCC and the Global Warming issue.

The study results obtained by various local teams of experts are the basis for this National Communication. An overview of the national circumstances that influence climate change response capacity is given in Chapter 2. Reports of the results of GHG national inventory for year 1995 are given in Chapter 3. The remaining sections outline the general description of steps, including; systematic observations, impact of climate change on selected economic sectors, abatement analysis, adaptation to anticipate climate change, and other information.

Chapter Two

NATIONAL CIRCUMSTANCES 1995

2. NATIONAL CIRCUMSTANCES 1995

Yemen is a least developed country and has high susceptibility to natural disasters which is exhibited in the tectonic processes that formed the mountains of Yemen and caused immense volcanic eruptions from the beginning of the Neozoic Age (some 70 million years ago) to the present. The Arabian plate, which separated from the African continent to form the Red Sea, still moves eastward a few centimeters each year. Today, there is no volcanic eruption, but there is high degree of seismicity. The severest earthquake of this century hit the Dhammar region in 1982, taking more than 2500 lives and affecting more than 265,000 people in 1072 villages and hamlets. The latest earthquake (tremor), measured 4.5 on the Richter Scale, occurred near Ibb in November 1991 and killed 26 people. The intensity of slope process contributes to landslide occurrence and development of erosion, desertification, rockiness, salinition of lands, water scarcity and flashy floods. In 1993, Aden suffered major floods, which killed 12 people and caused extensive damage to property and the city's aging drainage and sewerage systems. The high vulnerability of mountain ecosystem creates large difficulties in the economic use of territory and requires constant realization of complex protective measures, especially when it is augmented by possible global climate change. Table 2.1. presents information on the national circumstances of the Republic of Yemen in 1994.

Table 2.1 - National Circumstances

Criteria	Unit	1994
Area	000 Km^2	555
Population	000.000	14.9
Urban population as percent of total population	%	23.2
Land area used for agricultural purposes, (cultivable land)	000 Km^2	16.6
Population in absolute poverty	%	20-30
Life expectancy at birth	Years	57.5
Literacy rate	%	44
GDP	000.000 USD	5291.1
GDP per capita	USD $	355
Estimated share of informal sector in the economy in GDP	%	20-30*
Share of industry in GDP	%	20.66
Share of services in GDP	%	36.1**
Share of agriculture in GDP	%	21.7
Livestock population		
Cattle	000	1,151
Sheep and goats	000	6,940
Camels	000	171
Forest area	000 Km^2	24

Source: The Republic of Yemen Statistical Year- Book, 1996.

* Informal sector in Yemeni economy, Ministry of Planning, Sana'a, March 1996

**) Services sector includes: trade, restaurant, hotel, transport, storage, communication, supply, insurance, personal services and society services.

2.2. Geography

2.1.1. Location and size

The Republic of Yemen constitutes the southwestern portion of the Arabian Peninsula lying between latitude 12° - 20°N and longitude 41°-54°E. It covers an area of approximately 555,000 km^2 excluding Ar Rub Al Khali Desert, located towards the northeastern edge of the country. Apart from the mainland, the country includes many islands; the largest are Socotra in the Arabian Sea and Kamaran in the Red Sea. Coastal line of about 2500 kms faces the Arabian Sea and the Gulf of Aden in the south and the Red Sea in the West. To the North, the Country is bordered by Saudi Arabia and to the East by Oman.

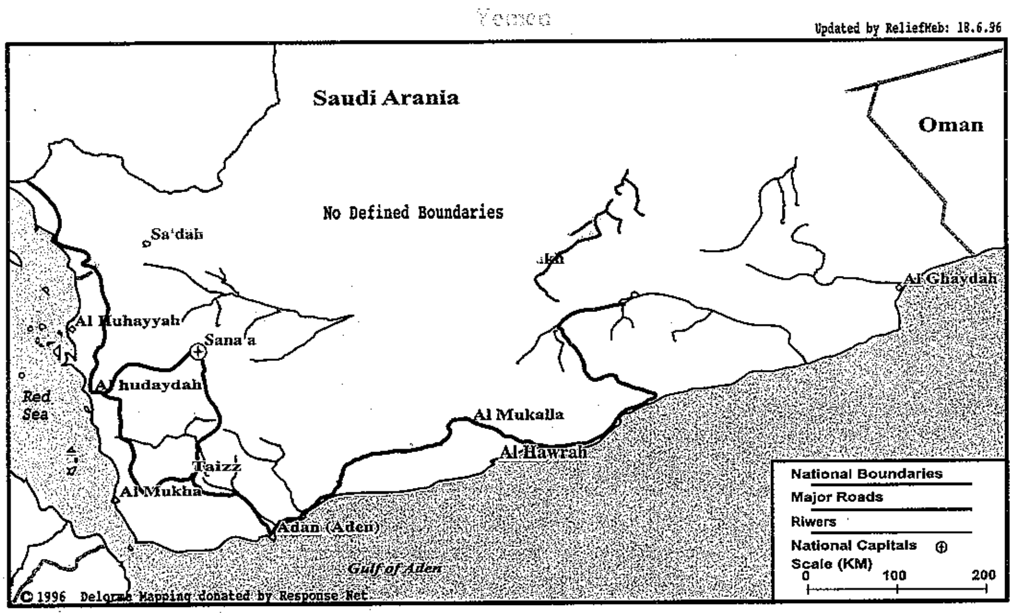

Figure 2.1a Location of Yemen

2.1.2. Population size and density

According to the 1994 census, the total population of the Republic of Yemen was 14,871,807, distributed over 2,162,847 households with an average of 6.74 persons per household. The annual average growth rate of population is 3.7%. The majority of people are rural with an estimated 76.53 % living in the countryside spanning widely scattered settlements in nearly 65,000 villages and hamlets. The population density over the country is 28 person per square kilometer. The uneven distribution of population between governorates has created difficulties maintaining essential services, such as electricity, water, health and education, in the majority of small settlements all over the country. Unbalanced and unsustainable socio-economic development has been the main cause of migration of population internally and abroad from rural areas. The migration from rural areas has adversely affected agricultural production on the one hand and has caused concentration of population in a few big cities on the other. This has fomented socio-economic troubles by exerting additional pressure on civic services, e.g. education, health, water, and electricity, in urbanized centers. A balanced strategy that focuses on the development of rural areas and encourages establishment of secondary cities is required in order to make population distribution effective to serve development processes.

2.1.3. Physical Features

The country comprises many different topographic features: mountains, plateaus, coastal plains, deserts, islands, etc. These can be grouped into three main geographical regions, shown in Figure (2.1b).

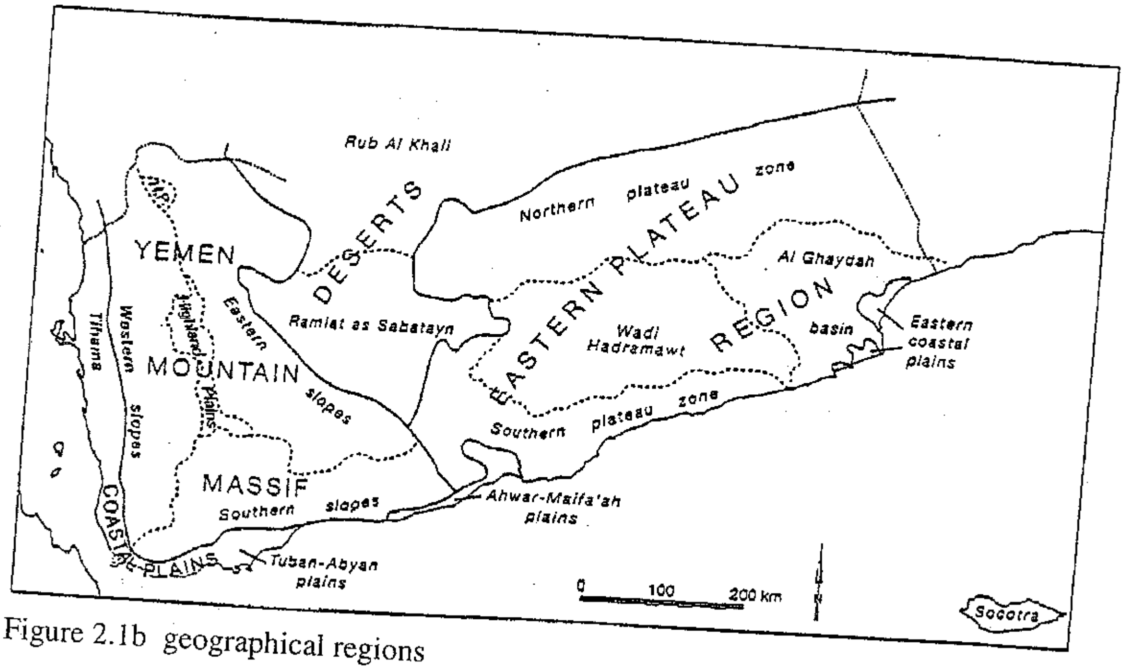

Figure 2.1b geographical regions

1. **The coastal plain** is broad (30-60km), flat to slightly sloping and undulating, with maximum elevation of only a few hundred meters above sea level. Alluvial and aeolian deposits typically characterize its surface. The coastal plains have a hot climate, with generally low to very low rainfall. Nevertheless, the plains contain important agricultural zones due to the numerous wadis (valleys) that drain the adjoining mountainous and hilly hinterlands. The wadis facilitate spate irrigation and provide recharge to the porous and permeable Quaternary sedimentary aquifers of the plains.
2. **The Yemen mountain massif** constitutes an uplifted zone of very irregular and dissected topography with elevations ranging from a few hundred meters (foothills) to 3766 m.a.s.l. (Jabal Nabi Shuayb near Sana'a). Accordingly, the climate varies from cool at the highest altitudes to warm at lower elevations. The Western and Southern Slopes of Yemen mountain massif are the steepest and enjoy moderate to rather high rainfall (300-500 mm/year, but locally more than 1000 mm/yr.), because they are favorably oriented in relation to the movement of moist air masses. As a result, rain-fed agriculture is practiced widely on numerous terraced mountain slopes, supporting rather high population densities. The Eastern Slopes show a comparatively smoother topography and the elevation range between 2000 to 1000 meter above sea level (m.a.s.l). As a result of greater distance between the sources of moisture and unfavorable topographic orientation, the average annual rainfall is low

and decreases rapidly from west to east. Population is sparse in the area of the Eastern Slopes. There are a number of important mountain plains within the Yemen Mountain Massif, the Highland Plains, where physical conditions are favorable for sustaining a relatively large population.

3. **The eastern plateau region** elevations decrease from 1800-1200 m at the main water divides to sea level at the coast and to approximately 900 m at the margins of the Ar Rub Al Khali desert. The Wadi Hadramout and its tributaries relatively dissect the plateau, in particular. The climate in general is hot and dry, with average rainfall typically below 100mm, except in the higher parts along the southern Hadramout arch. Nevertheless, floods after rare rainfall events are usually devastating. Population density is low, except in the Wadi Hadramout canyon where large areas of agricultural land are irrigated by groundwater pumped from aquifer rocks below the wadi bed.

2.1.4. Yemeni Islands:

There are more than 115 islands in Yemen with distinct climatic and natural characteristics. Among those located in the Red Sea, Kamaran is the biggest, and Mayoon Island in the Bab al Mandab strait, has strategic importance. Socotra is the largest Yemeni Island (3650 km^2) in the Arabian Sea and it has a more exuberant flora and fauna than any other region in the Arabia. There are more than 112 Yemeni islands scattered in the Red Sea.

2.1.5. Climate

Yemen has a predominantly semi-arid to arid climate, with rainy seasons during spring and summer, and with high temperatures prevailing throughout the year in low-altitude zones. This is primarily a consequence of the country's location with respect to the equator. It causes solar radiation to be of high intensity and during spring and summer it brings the area under the influence of the Inter-Tropical Convergence Zone (ITCZ) that is significantly effected by the Indian Ocean and causes the monsoon wind system, bringing about the main rainy season during summer (July-September). The Red Sea Convergence Zone (RSCZ) contributes to the spring rainy season (March-May). Light rains observed during the winter months are attributed to a similar convergence effect around the Mediterranean Sea.

The spatial pattern of ***annual rainfall*** varies from year to year. The controlling topographic factors, however, are strong enough to produce pronounced patterns that are fairly stable for long term averages of annual rainfall. The isohyet map shown in Figure 2.2 gives a clear and consistent picture of the spatial pattern of annual rainfall. Figures higher than 250 mm are only observed in the western and southern parts of the Yemen Mountain Massif, with a maximum near Ibb (1510 mm). Anywhere else the average annual rainfall is low. Comparison of rainfall averages during the eighties with longer term average (for stations with longer records) suggest that this period may have been 10 - 20% drier than average, although this may be variable for different regions in the country.

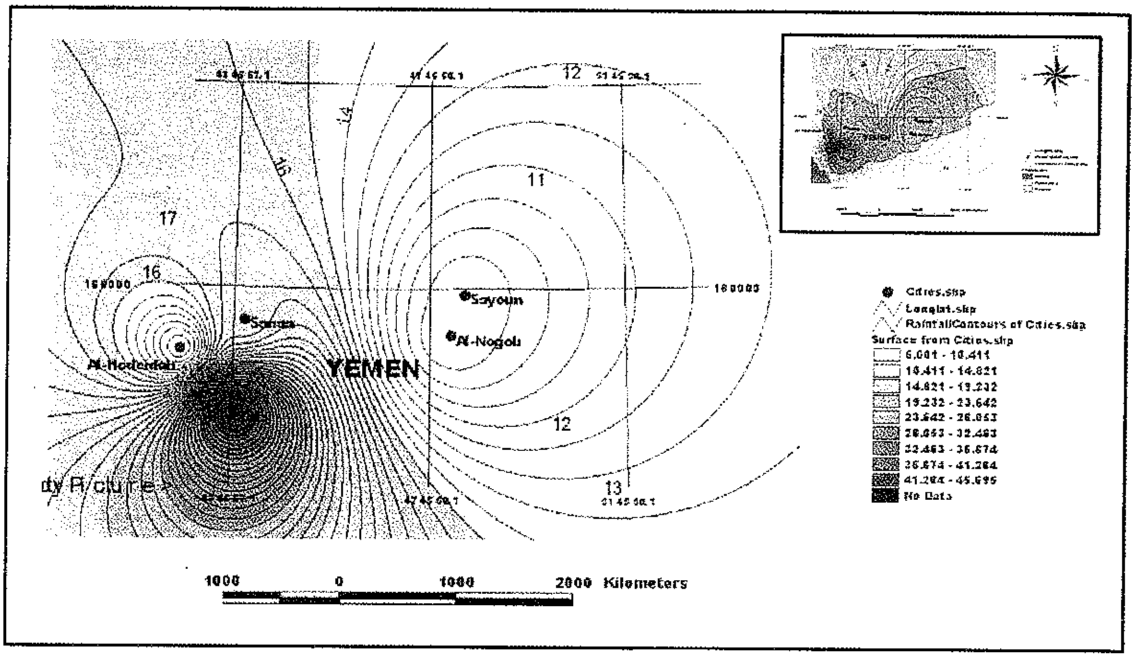

Figure 2.2. Distribution of annual rainfall (Isohyet map)

Table 2.2 presents a summary of meteorological parameters for selected meteorological stations. It merely gives an impression of spatial variability. Figure 2.3 depict average annual temperature distribution over Yemen together with average monthly values of ***temperature*** for a station at the coast (Hodeidah), two stations on Mountain Massif (one relatively dry, (Sana'a) and one relatively humid (Taiz), and a station in the hyper-arid interior zone (Seyun). Average temperatures are dominantly controlled by elevation with approximately linear relation with an average temperature gradient 0.6°C per 100-meter difference in elevation. Proximity to the sea and moisture content of the air are the controlling factors determining the value of annual range of temperature (difference between average temperature of warmest and coolest months of the year). This is also true of average daily temperature range, which is modest near the coast, 10 °C but does exceed 20 °C at higher elevations and in the arid interior (Seyun).

Table 2.2. Climatological averages.

[illegible]	[illegible]	[illegible]						
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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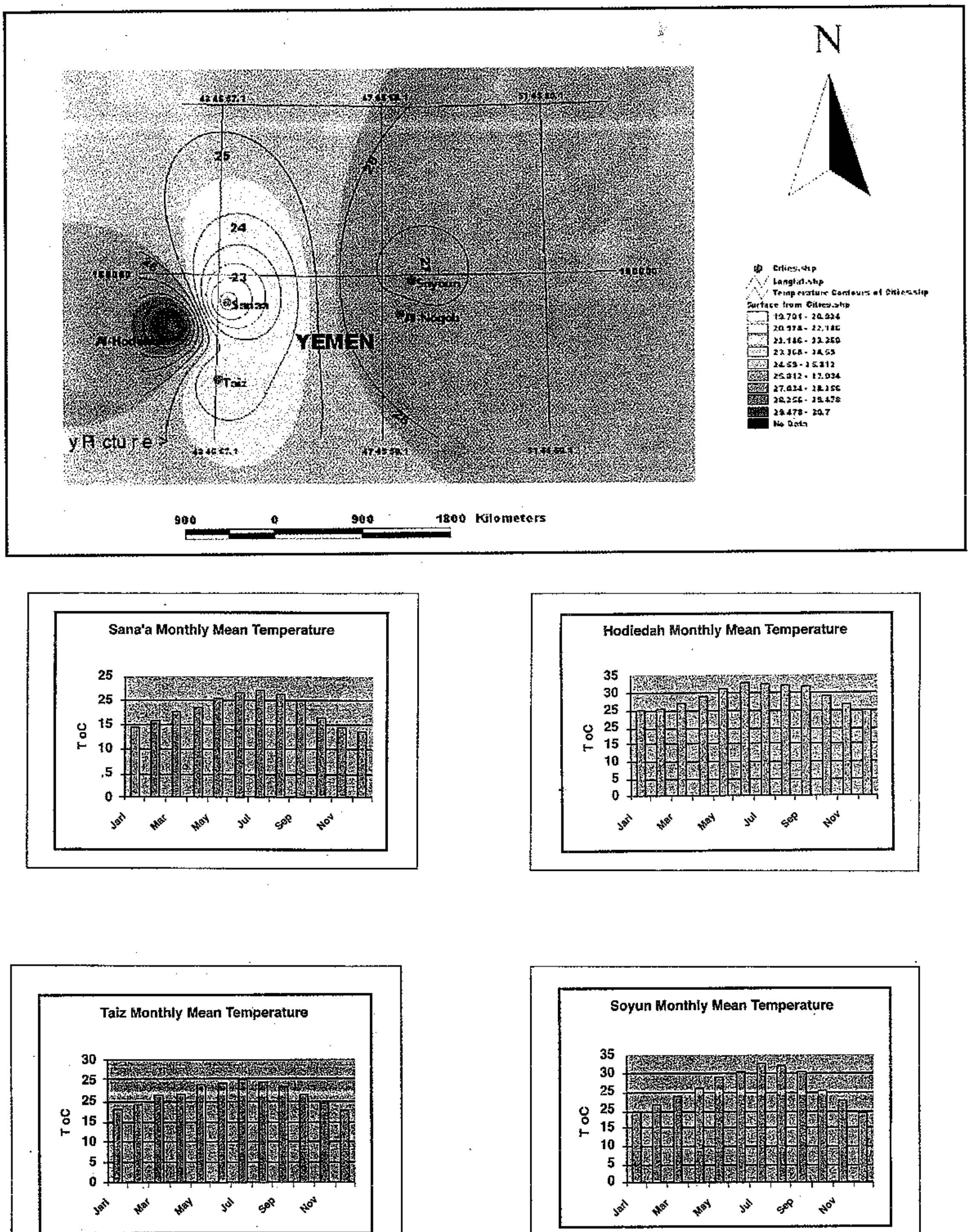


Figure 2.3. Distribution of annual Temperature °C - Average monthly for selected stations.

Clear skies are predominant during most of the year as is reflected in the records of sunshine duration. Recorded annual average values between 7-9 hours per day, which corresponds to 50 to 75% of the theoretical maximum. Solar radiation varies only slightly over the territory of Yemen, the pronounced difference in temperature regime is associated with other factors (e.g. elevation) as well.
Relative air humidity shows strong spatial variation. Values between 70-80% are typical for coastal locations and values of 50-70% for those parts of coastal plains and deltas that are more than 20kms from the sea. In the mountain regions they are usually between 30 and 60% and it reaches lowest values (20-45%) in the hyper arid interiors.
Average wind speed in a large part of Yemen is low to moderate (3-5 m/s) except on the coasts and at well-exposed locations in the mountain zones where it reaches 8 m/s..

In terms of ***aridity*** (rainfall (P)/evaporation (E_o)), the climate in Yemen is shown to vary from hyper-arid (deserts, most of the plateau, parts of the coastal plain) to subhumid (scattered wetter zones on the western and southern slopes), with even humid sites on a very small scale (Ibb).

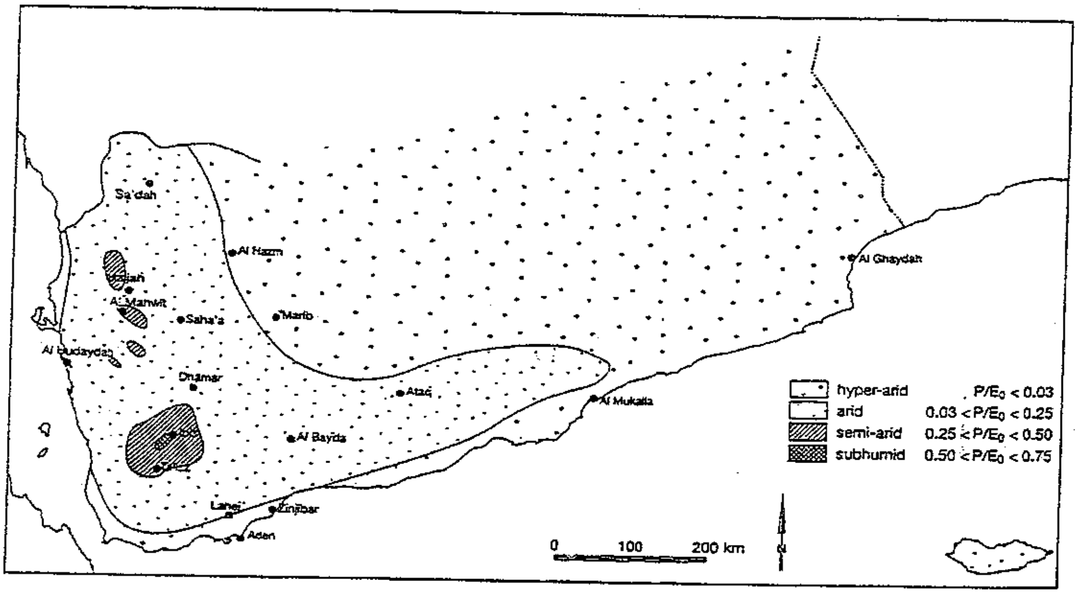


Figure 2.4. Climatic zones (aridity)

cereal declined from 62 percent in 1980 to less than 30 percent in 1995. This was mainly due to government subsidies to imported wheat and less rainfall to support rainfed crops. During this period, the production of oil seeds and pulses was also on the decline. The production of fruit and vegetables, however, has continued to be on the rise year after year and is almost close to achieving self-sufficiency.

According to the preliminary results of the household budget survey (CSO publication, 1998), the proportion of households below the food poverty line amounted to 16% of the population. But on looking at the upper poverty line, it appeared that almost 30% of the households throughout the country do not have enough income to meet their food and other basic requirements.

The government of Yemen has adopted a reform program of adjustment measures to revitalize the economy. These measures will have an impact on the agricultural sector, as it will squeeze farmer's margins. Prices for agricultural inputs and outputs are going to be affected by the removal of diesel subsidy and the replacement of the import ban on vegetables and fruit with a tariff system. The adjustment measures also cover the current system to subsidize wheat import. These are likely to increase the on-farm cost of irrigation and machinery, reduce the prices of vegetables and fruits and increase the prices of wheat. The scope of income effects will depend on how farmers can adjust their production to the new policy.

Generally speaking, agriculture in Yemen is mostly done on a small scale and is intended only for family subsistence. A recent agricultural economic policy reform program has led to significant positive aspects of agricultural sector performance and a tangible increase in agricultural production.

The present total area of forestland is estimated at about 24,000 square kilometer and mainly concentrated in zones of sufficient rainfall. Most of the forestland is privately owned.

2.2.3. Coastal zone & Marine resources

The coastal areas of Yemen are substantially developed and more development is expected in the decades to come, particularly in the field of free economic zones, industrial complexes, fisheries and trade. The ongoing accelerated sea level rise (ASLR) has already aggravated the existing erosion problem and future rise will pose new challenges to the management of the coastal zone. The coastline of Yemen stretches over a length of 2500kms. The nature has endowed it with numerous habitats of ecological and economic importance and natural harbours, such as Hodeidah, Mukha, Aden and Mukalla.

The fish fauna of the Yemen Red Sea and the Gulf of Aden/Arabian Sea is mainly of Indo-Pacific origin. Temperature increase would negatively affect reef fish through the increasing of coral reef bleaching where fish are found "live". A total of 65 families and 416 species of fish were identified in the Yemeni Red Sea. Fishes in the Socotra Archipelago have 35 families, which contain a total of 169 species. The exploitation of the sea to have fish for local consumption as well as for export is one of the most important national resources. Despite the fact that the level of utilisation of marine resources in Yemen is still limited, it is concentration on certain species and groups of organisms that could endanger these species and groups. The standing stocks of demersal fishes and shrimps in the Yemeni Red Sea are estimated roughly at about 27,000 m. tones. At present, local fishermen using sambuq (large boat) equipped with surface trawl nets do shrimping.

Utilisation of other resources includes the collection of the molluscan clam for fish bait, collection of gastropods for their opercula in Khor Omira and Ras Omran. In Socotra, fishing of the mother of pearl is done for pearl collection. Turtles are killed for their eggs and meat when they come ashore to breed by locals. Dolphins in Socotra are fished for bait material, for shark nets and lobster traps. Many species of fish are also fished and thrown away as by-product.

Marine and coastal flora are used and consumed by different sources. The dome palm *H. thebaica* is used as a source of fire wood for cooking, making ropes and mattresses in Tehama. Domesticated livestock in Tehama, Abyan and Al-Mahra coast heavily grazes Grass and Reed. Mangroves are used in the form of wood for fuel or construction. It is also grazed by camels and used as drug.

2.2.4. Other resources

Among the countries of the Arabian peninsula, Yemen is famous for its fertile soil, relatively high rainfall (in the northern part of the country), a great variety of fauna and flora and beautiful landscape. These resources, however, are threatened by climate change. The forecasted increase in average temperature and decrease in the amount of precipitation will significantly enhance the climate aridity and consequently intensify the process of desertification. This implies reduction of semi-arid areas. Also soil degradation will probably occur as a result of precipitation (downpour character) and thus cause the soil wash off. Finally, irrational use of water resources in irrigation will result in intensive soil salination and be intensified by increase in temperature and evaporation.

Both the IPCC and the World Health Organization (WHO) have raised concern about potential adverse effects of climate change on human health. Although no investigation has been carried out into possible implications of climate change on human health in Yemen, the appearance of Malaria incidences in cold highland areas is probably one of these adverse effects on human health.

Other natural resources include crude oil, natural gas, rock salt, marble, and small deposits of coal, gold, lead, nickel and copper. After years of exploration and drilling, both the former North and South Yemen became commercial oil producers in 1987. In 1995, the total crude oil production stood at around 360,000 b/d. Yemen has also identified remarkable natural gas reserves.

2.3. Socio-economic structure

2.3.1. Economy

By international standards, the Republic of Yemen is among the poorest of the world's nations. With an estimated GNP of $583 per capita in 1990, the United Nations has classified Yemen in the group of 40 lesser-developed countries. As a consequence of the economic difficulties the country was experiencing during 1990-1994, the estimated GDP in 1994 was 5291.1 Million US dollar and the per capita share was only US$ 355. The fragile and narrow base economy was affected by domestic political factors: realization of the Country's Unity in May 1990, struggle for establishing a new democratic system to ensure individual liberties and a multi-party system, mismanagement of the national economy and a brief civil war in mid 1994. These features have led to substantial increase in the current expenditure of the government and created unfavorable conditions for rapid socio-economic development. Coupled with the negative consequences of the Gulf war of 1990/1991, the domestic factors led to continuous and high increase in the deficit of the government budget, the balance of trade and the balance of payments. As a result, the country experienced slow economic growth, high rate of inflation, high level of unemployment and the reduction of government expenditures on public education and health services. This resulted in sharp deterioration in the standards of living.

The low growth rate reflects varying economic activity performance of various sectors contributing to the GDP. The degrees of performance for some economic sectors are summarized in Table (2.4). It is based on the degree of contribution of each sector to the GDP during 1990 and 2000. In general, the contribution shares from various sectors to the GDP were considerably varied. The two major contributors are agriculture and industry sectors with about 47% share in the total GDP. The contribution of electricity and water sector is almost constant with about one percent, while the Construction sector contribution remained constant 2.7% between 1990-1995. The contribution from the latter sectors reflects the degree of provision of basic services and indicates the limited availability of infrastructure projects, which are in turn indicators of instability and inconsistency in the production system of economy. There is little change range (1%) in the contribution of the commodities sectors to the GDP over the period 1990-2000 while for the services sector large decrease of the share ranged from 32.3% in 1990 to about 23.7% in 1995. The share of contribution of the government services sector increased from 15.5% in 1990 to 24.7 in 1995. During the period 1990-1995, the inflation rate (averaged to 36.1%) was very high, however, during the period 1995-1997 the annual inflation rates decreased to 28.5%. These rates led to the reduction of the living standards of people as well as the stagnant state of economy during both periods.

In an attempt to tackle acute economic problems, the government launched an Economic, Financial and Administrative Reform Program (EFARP) in November 1994. This Program introduced applying economic and financial policies and measures targeting the reduction of the government budget deficit and correction in the existing multi-system exchange of the Yemeni Rails. Also, it tried to activate monetary policies by manipulating the interest rates and bank credit ceilings and controlling money supply. Since then, the measures have succeeded in reducing gradually the subsidies granted to the public sector enterprises. In particular, subsidies for producing electricity and drinking water, fuel materials, communications and social services have been reduced.

Table 2.4. The degree of performance for various economic sectors over the period 1990-2000, given as share % to GDP.

Sectors	1990	1995	2000
Agriculture, Forestry, Fishing	24.2	22.1	22.7
Mining, Quarrying	13.6	14.9	16.1
Manufacturing	9.3	9.7	8.2
Water & electricity	1.2	1.1	1.1
Construction	2.7	2.7	3.7
Trade	8.1	7.2	7.7
Transport, storage & communication	14.8	8.5	7.8
Producers of Government services	15.5	24.7	24.0
Others	10.6	9.1	8.7

Source: national accounts for years 1990-1999, Central Planning Organization, Sana'a, 1999

liberalization policy, the government raised the price of the cement produced by the public sector enterprises. Steps were also taken to consider the state of foreign debt obligation. In addition, a privatization program has been prepared as part of government's new economic restructuring policies. However, the implementation of the program is still in progress. In general, the implementation of the economic reform policies caused a noticeable improvement in the economic situation and is expected to continue as long as the government is determined to exert its efforts to achieve the objectives of the EFARP. The prediction for the GDP growth rate in the next twenty-five years is around 5.5 percent.

2.3.2. Trade

The main exports of Yemen are crude oil, coffee, hides, skins, and fresh as well as dried and salted fish. Main imports are textiles and other manufactured goods, petroleum products, sugar, grain, flour, cement, machinery and chemicals. Despite oil discoveries in Yemen since 1988 and its dominating export earning (82% in 1994 with a contribution of 14.15% to GDP), the agriculture sector has continued to be a dominant sector in Yemen's economy, contributing 20.3% of the GDP and provides nearly two-third of employment. As the two major contributors to the country's economy are heavily dependent on natural resources for generating employment, food, income, and foreign exchange, the phenomenon of climate change is threatening to demolish Yemen's economy.
Income from the sale of oil amounts to approximately 40 % of Yemen's total revenue and is the country's main source of foreign currency, especially after reduction in expatriate remittances caused by the return of Yemeni families working abroad. Fluctuations in the world oil market therefore have significant impact on the economy of the country.

2.3.3. Welfare

The features that characterize the population of a society play an important role in determining the type and characteristic of economic, social and political activities. These features have affect not only the determination of development priority and its direction but also the speed of development. In Yemeni society today a little more than half the

population belong to the age group of newborn-14 years. This means that many people are falling out of work and consequently social, economic and total dependency is very high and living standards, saving ability, investment, and development are very low. Moreover, a large increase in social services, particularly in education and health services during the forthcoming decades, will exert more pressure on the state budget. In 1996, the country laid down a long-term population strategy and updated the action plan of 1991. The percentage of old age (65 and over) is 3.3 % of the total population. This implies that the average longevity of people is low (Table 2.1.), and that their living standards and health conditions are poor.
In 1990, the illiteracy was estimated at about 66.3%, which decreased to 55.8% by 1994 reflect an increase of people awareness.

Data of working power distribution between sectors indicated a decrease in the percentage of population working in agricultural sector from 62.3% in 1990 to 50% in 1997 as agriculture became less important, "less profitable" following water (rainfall) shortage. Consequently, the services and marginal sectors recorded more employment during 1990-1997. This relates to the fact that any change in climate has direct impact on population situation under the current production framework and current composition of working power.

2.4.Overview of the Energy Sector

2.4.1. Resources

The population growth and increasing population densities in Yemen and the parallel rise of living standard require the energy resources to expand enormously. The primary energy sector is dominated by fossil fuels and therefore it represents the main source of GHG emissions.

Crude Oil

Oil is the main source of energy in Yemen and the country's main source of income. In 1995, proven oil reserve was nearly 4 billion barrels.

Natural Gas

With natural gas reserve of 16.9 Trillion cubic feet, Yemen has considerable potential as a natural gas producer and exporter. The area in which this gas was found represents only 20-30% of the total area presently undergoing exploration. In early 1996, Yemen Liquefied Natural Gas Company (YLNG) was set up to operate a U$ 5 billion-LNG venture. A decision has now been taken to prepare for the project, pending the conclusion of a sales and purchase agreement for the LNG. YLNG project calls for the development of natural gas reserves in the Marib area where the bulk of Yemen's gas reserve is concentrated. Transportation of gas via a 320km 34-inch pipeline has the capacity of 830 million cubic feet/day with the LNG facility at the coastal town of Balhaf on the Gulf of Aden. The plant's base load capacity is 5.3 Million Tons per year over a 25-year period. Peak production is expected to reach 6.2 Million tons/year. A second 210km 14-inch pipeline from Marib to Sana'a with a capacity of 100 million cubic feet per day for Yemen's internal use is also included in the project (MOMR, 2000).

Fuelwood
Fuelwood constitutes a major source of energy, particularly for the rural household in Yemen. The shortage of electric supply and oil products has forced rural household to rely on Fuelwood. With increasing energy demand and limited supply of dead wood, the reliance on live wood has created a serious problem and posed a real danger of deforestation and the consequent negative impact on economy and environment. Of late, Fuelwood is being replaced gradually by LPG, which has become the major fuel for cooking.

There are no precise figures for the actual amount of Fuelwood consumed in Yemen. The present estimate is that Fuelwood provides 60% of the household energy, as a national average. The 1995 survey of consumption was estimated to be 2.03 million metric tons (771,294 TOE - Tons of Oil Equivalent).

Renewable Energy Resources
Yemen enjoys a very diverse natural environment and physical structure; mountainous, coastal, plateau, desert regions and islands, and consequently a very diverse climate. It belongs to the Sunbelt regions of earth. There is large potential for solar and wind energy use. Furthermore, there is a large quantity of agricultural waste that could be used for electricity production for domestic purposes. These renewable energy resources will be discussed in more detail below.

a) Solar energy potential

In Yemen, the average annual sunshine hours exceed 3000 hours/year and average annual global solar insolation is more than 2200 kWh per square meter per year.

The country has the capacity to make solar electricity generated directly from sunlight using solar cell modules (Photovoltaic modules) replace small applications of petroleum-fueled generators, grid power and even dry cell batteries. This can especially be an alternative for the power supply to rural and remote areas for solar home systems, small industries and institutions, telecommunications, health centers vaccine refrigeration and lighting, water pumping and other uses.
The potential for using solar thermal energy in Yemen is tremendous. The high solar insolation and sunshine hours make it possible for the country to exploit all possible solar thermal energy applications such as solar water heaters, solar crop dryers, solar cookers, salt production by evaporating ponds, sea water desalination, solar refrigerators and air conditioners and solar thermal power plants.

Solar thermal power plants are those plants in which solar radiation is converted into thermal energy by means of solar concentrators. This is carried out by a working fluid through a conventional process of electricity generation. Since such plants are based on the concentration of solar radiation to achieve high temperatures necessary for the thermo-dynamic power plant process, their application areas are restricted to earth regions with high solar radiation like Yemen. Unlike photovoltaic power plants, very large amounts of electricity (in the mega watt range) can be generated by means of solar thermal power plants. Three concepts of solar thermal power plants are now well known and established: parabolic trough power plants, solar tower power plants and dish/stirling systems (Al- Sakaf, 1998).

Sites with high insolation level, especially high direct solar radiation, reduce the amount of fossil fuel to be consumed for a given operation strategy of the plant. There are many potential sites for the application of solar thermal energy in Yemen, either for large-scale electricity generation or decentralized power supply (Al-Sakaf, 1999).

b) Wind energy potential

Yemen has a long coastal strip of more than 2500kms with a width of 30-60kms along the Red Sea, Gulf of Aden and Arabian Sea. Average annual wind speeds (measured at 10 m height) exceed 8 m/s at most of the coastal sites. There is a great potential for wind energy conversion at sites on the coastal strip, in addition to the offshore area. There is also great wind energy potential on Yemeni islands and inland hills and mountains.
Wind energy converters can efficiently meet the growing electricity demand in Yemen while providing a number of benefits: a free and widely available fuel source with no air, soil or water pollution and continually improving technology. Advancements in wind energy technology have led in recent years to economic feasibility and competitiveness of wind energy-based electricity generation in comparison with conventional power generation.

Stand-alone or hybrid wind energy systems (solar and wind) for rural electrification, water pumping, sea water desalination and wind power injection into isolated power supply systems as well as large-scale grid-connected electricity generation through wind farms could be the choice of the Yemeni power sector in future, given the appropriate framework conditions.

c) Biomass potential

Yemen is an agricultural country with a large amount of waste from agriculture and breeding products having a huge biomass potential, which can be utilized by gasification for electricity generation and/or cooking, especially in rural areas.

2.4.2 Primary Energy Production

Oil Sector

Oil production during the period 1994-97 was on an average 343000 barrels per day (B/D). The production at the end of 1998 had reached 430000 B/D. Yemen's oil production is expected to go further up in 2000 due to infrastructure investment in different fields. Yemen's oil ministry expects overall national production to increase to 500000 B/D by the end of 2000, through offering incentives for oil sector investment.
Currently, Yemen has a crude oil refining capacity of 120000 B/D from two small, old deteriorating refineries. Several companies have contacted Yemen's oil ministry for constructing a new refinery plant. The different petroleum products (gasoline, diesel, kerosene, fuel oil, LPG) marketed by the General Corporation for Oil in 1995 amounted to 3,170,352 metric tons [P& M, 2000].

Power Sector

The state-owned Public Electricity Corporation (PEC) is the body responsible for the generation, transmission and distribution of electricity. PEC operates three thermal power plants with heavy oil (mazot)-fired boilers and a number of diesel power stations, with the former being the major source of generation (about 70%), interconnected in a power system with around 1000 km 132 kV-transmission lines. The total installed capacity amounted in 1995 to 757.2 MW and 2422 GWh of total energy generated, Table (2.5).

Table 2.5: 1995-installed capacity, effective capacity, generated energy and fuel used

Plant	Capacity MW		GWh Generated	Fuel	Input Fuel MGJ
	Installed	Effective			
a) Interconnected Systems					
Steam turbines	435.0	295.0	1866.8	Mazot	25.523
Diesel units	187.0	68.0	280.3	Diesel	1.292
b) Isolated Systems					
Urban units	54.5	22.3	89.8	Mazot	0.913
Rural	80.7	38.7	184.7	Diesel	3.383
TOTAL	**757.2**	**424.0**	**2421.6**		**31.111**

In addition to the electricity generated by PEC, an appreciable amount of electricity is generated privately by small diesel units either for rural use or to cover the shortages in urban supply for commercial or industrial purposes (estimated at about 400 GWh annually).

The General Authority for Rural Electrification and Water (GAREW) was established in 1992. GAREW is responsible for the supply and erection of new electrical network in rural areas where PEC has no operating system. After completion of the construction of such networks they are handed over to Local Councils for operation and maintenance. In 1994 only about 19.2% of the rural population had access to electricity compared to 87.3% of urban population.

In addition to shortage in generation, the primitive interconnected system suffers from high power losses in transmission and distribution (about 25% in 1995) as well as generation (about 10% in 1995). The power sector is going to witness a significant restructuring process. The running project on 'Power Sector Reform" and the recently finished 'Power Generation Master Plan Project' will lead to new advancement and improvement in this sector.

2.4.3. Total Energy Consumption

The total primary energy consumption in Yemen in 1995 amounted to 4.171 million TOE. It comes to 3.40 million TOE from oil products and an estimated 771.294 TOE from Fuelwood consumed by rural community as mentioned earlier.

The major consumers are the household, commercial, industrial, transport and agriculture sectors. The relative energy consumption by different sectors in 1995 is depicted in Figure (2.5) About 47% of the total energy consumed is used for transport.

The electricity generated in 1995 amounted to 2422 GWh and the total sold energy to 1572 GWh. The consumption by sectors shown in Figure (2.6) indicates that the residential and commercial sectors are the largest consumers of electric energy.

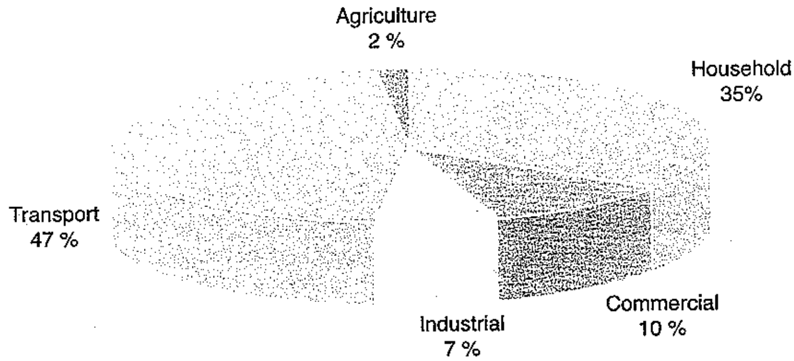


Figure 2.5: Relative energy consumption by sector for 1995

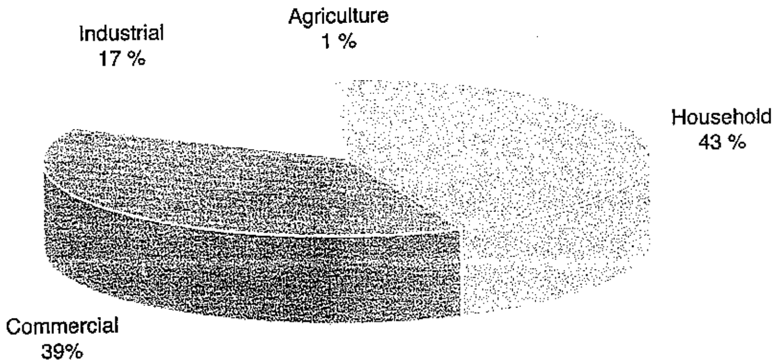


Figure 2.6 Relative electricity consumption by sector for 1995

2.4.4. Energy Policies

Responsible for the formulation and implementation of energy policies are the Ministry of Electricity and Water (MEW), the Ministry of Oil and Mineral Resources (MOMR) and recently, the Environmental Protection Council (EPC) has assumed the responsibility to promote environmental friendly renewable energy resources. The integration of their policy proposals is undertaken at three levels, namely, the Cabinet, the Ministry of Planning and Development (MPD), and the Supreme Council for Oil and Mineral Resources (SCOMR). The Cabinet by definition has the ultimate responsibility for energy policy. The MPD has both a coordinating and data collecting responsibility. Five-Year Plans prepared by the MPD define the sectoral objectives and establish comprehensive long-term energy plans.

For a sustainable development, a strict energy saving policy should be implemented. The proposals by Bin Ghadi & Mukbel (1996) can be adapted to improve energy efficiency and saving in different sectors:

- Establishing national legislation in the form of laws, codes and technical guides in the field of energy.
- Revising import policy and discouraging low-efficiency equipment.
- Establishing tax benefits for using energy conservation systems.
- Encouraging increased energy efficiency through appropriate measures.
- Promoting the use of renewable energy sources. As shown earlier, Yemen has huge renewable energy potential, especially, solar and wind. The use of renewable energy sources has the following advantages: reduced fuel consumption/imports, no emissions/ no environmental polluation, conservation of fossil fuel resources and employment in manufacturing, erection, installation and operation of emerging renewable energy facilities.

2.5. Decision making structure and Climate Change organization

Yemen is a unitary democratic republic with an elected parliament. The national legislature consists of House of Representatives (parliament) with 301 members, representing 301 regions of equal number of population. They are elected by universal adult suffrage every four years. The major functions of the Parliament are to enact laws and supervise the Government's administration. The Yemeni legal system is based on Islamic Sharia'a with origins in the Holy Quran and Sunnah of the Prophet Mohammed, and tribal customs, though there are government-administered civil courts as well. The country is administratively divided into 19 governorates and the Capital Sana'a, each headed by a governor who is appointed on political considerations by the President. Aden is the economic and commercial center with its free trade zone.

The Environmental Protection Council (EPC) was established in 1990 as a main body to formulate, coordinate and monitor the activities related to environment protection. In 1995, the Environmental Protection Law of Yemen was enacted. The law is designed to safeguard a sustainable use of natural resources and to provide a comprehensive framework for environmental management and establishment of sectoral legislation. Among other things, it stipulates the establishment of a specific Yemen Environmental Protection Fund. Priorities include regulatory framework, enforcement of law, the establishment of environmental assessment procedures and a system of permit for polluting activities. Despite the establishment of the EPC and its effort to coordinate environment related activities, significant problems remain in sharing the responsibilities and coordinating activities between different ministries and government agencies on specific topics.

For instance, several ministries claim responsibility over coastal zone management, but no one agency as yet has been designated to take the lead in addressing itself to this issue. Competing sectoral interests often undermine the goal to set overall objectives and to formulate sustainable policies and strategies to manage natural resources. Besides, the role of local administration in providing environmental services is limited, although the allocation of key natural resources, such as water, is mostly regulated at the local level.

EPC is the operational Focal Point for UNFCCC in Yemen, responsible for implementation of UNFCCC provisions and decision-making procedures relating to the matters of climate change. Since all the relevant ministries are already represented in the EPC, it acts as the policy level coordinating mechanism for preparation of the National Communication project which has been executed by the Environmental Protection council (EPC) on behalf of the Government of Yemen. Furthermore, EPC acted as a Climate Change Country Study Project Steering Committee consisting of senior officials from the relevant ministries qualified to provide assistance to the project manager and national experts. A PMU was installed within EPC's secretariat to manage the project on a day-to-day basis. The strategy of the General Project was to involve the best expert institutions in Yemen to implement the different activities of the project taking stock of and fully utilizing the resources and results of relevant prior or ongoing national or international activities. Experts in climatology, hydrology, agriculture, economics, ecology, coastal zone, water resources management, energy and industry from relevant ministries and institutions had participated in the country's climate change study-team. The Institute for Environmental Studies (IVM) of the Free University of Netherlands, which manages the NCCSAP on behalf of the Netherland's Ministry of Foreign affairs, had provided the necessary external technical backstopping to the local teams during execution of studies. In addition, an Advisory Committee to the project was established in May 1998, consisting of officials from relevant ministries, academic, non-governmental organizations and the private sector agencies. In May 2000, a National-expert technical-team was established, upon receiving additional limited fund from GEF for priority measures in capacity building and technology transfer. This fund has allowed establishment of a mechanism to update the inventory and other studies so that once new information becomes available, the results and conclusions can be easily updated to reflect the latest available information.

The 1998 National Workshop held in Sana'a for Consultative Council on environment, strongly recommended that Yemen should make a comprehensive review of its environmental legislation with emphasis on conducting a review of all International Conventions by the EPC. The legislative aspect (Yemen context), the UNFCCC and the Biodiversity Convention are to be reviewed under this process. Preparations for a National Legislative Review Programme started recently.

Chapter Three

NATIONAL GREENHOUSE INVENTORY

3. NATIONAL GREENHOUSE GAS INVENTORY

3.1 Introduction

Natural greenhouse gases in the atmosphere absorb or "trap" part of the outgoing radiation from the earth and re-radiate it, thus keeping the planet earth warmer than it should be and thus uninhabitable. The massive injection of man-induced GHG into the atmosphere increases its concentration and is expected to disturb the natural radiative balance. This can have severe impact on climate system resulting in global warming and sea level rise.

As part of the global efforts being made to stabilise atmospheric concentration of greenhouse gases, Articles (4) and (12) of the United Nations Framework Convention on Climate Change, require each Party to include into the National Communication, inventories of anthropogenic emissions by sources and removal by sinks of all greenhouse gases not controlled by the Montreal protocol "to the extent its capacities permit, using comparable methodologies"

The year 1995 was used as a reference year for Yemen's GHG inventory due to the high uncertainty of 1994's information as a result of the April-July 1994 civil war. The total greenhouse gas emissions (CO_2, CH_4, N_2O) of the Republic of Yemen, in 1995, amounted to 18,709 Gg CO_2.eq, (CO_2=11,359, CH_4=128.31 and NO_2=15.02). Taking CO_2 removal into account, the total net emission of CO2 is 845 Gg. These figures are exclusive of the emission from the international bunker (114.35 Gg CO_2) and from combustion of biomass (353.29 Gg CO_2).

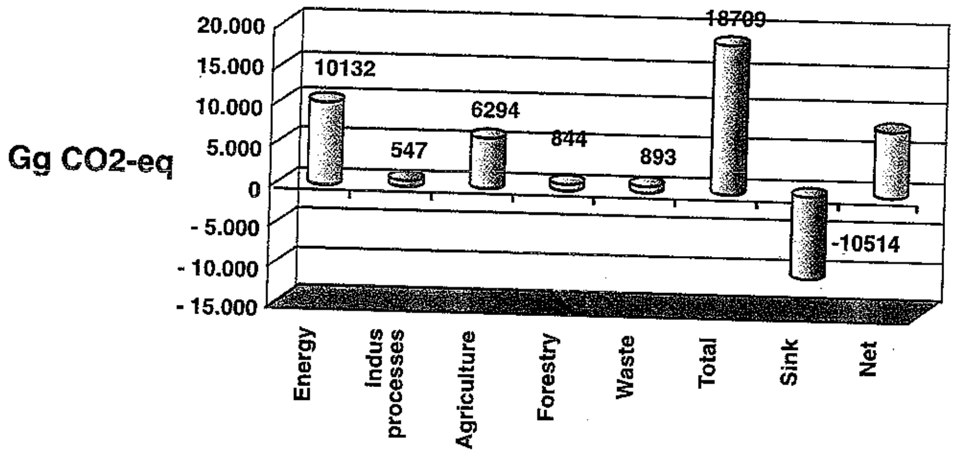


Figure 3.1. Total Yemen's GHG emission in Gg CO_2.eq by sector, 1995

Yemen's emission profile by gas type for 1995, as illustrated in Figure (3.2) shows the CO_2 accounts for 61% of total national GHG emission (11358 Gg CO_2), N_2O 25% (4657 Gg CO_2.eq) and CH_4 14% (2694 Gg CO_2.eq). Table (3.1) shows details of emission by gas over various sectors.

Table 3.1. Sectoral Breakdown of GHG emission, 1995

	Source	Emission Gg	Emission Gg CO_2 eq
[illegible]	Energy	9968	9968
	Industrial processes	547	547
	Forestry	843	843
	Subtotal	11358	11358
[illegible]	Energy	6.02	126
	Agriculture	91.22	1916
	Land use change & forestry	0.02	0.34
	Waste	31.06	652
	Subtotal	128.34	2694
[illegible]	Energy	0.12	37
	Agriculture	14.13	4379
	Land use change & forestry	.0001	0.03
	Waste	0.78	240
	Subtotal	15.02	4657
Total National Emission		11501	18709

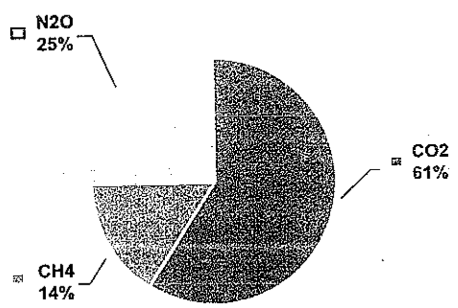


Figure 3.2 Yemen's GHG emissions by gas type (%), 1995

3.2 Methodology and Data

To ensure that emission inventory is consistent and comparable across sectors and between Parties, the emission estimates of 1995 were calculated according to Revised IPCC Guidelines for national GHG emission inventories (IPCC, 1996). This includes the use of the IPCC methodology and default values as well as reporting formats. A copy of each the IPCC guideline worksheets and reporting tables is appended to the annexes together with information on activity data and computations. Although the national study adopted the IPCC methods for certain processes, the default emission factors seem unrealistic in the case of Yemen. Other uncertainties and limitations, as per IPCC guidelines, are given in the relevant sections.

Both the top-down and bottom-up approaches have been used for the preparation of this national inventory of greenhouse gases. Under the IPCC guidelines, each of greenhouse gases has different contribution to the greenhouse effect, which can be expressed as the global warming potential (GWP) and allows GHG to be expressed as CO_2 equivalent. GWPs used values for three gases with direct greenhouse effect are:

Carbon dioxide (CO_2) = 1
Methane (CH_4) = 21
Nitrous oxide (N_2O) = 310

The data required for IPCC method application was obtained from various local official statistical institutions, including research centers, Ministry of Planning and Development, Ministry of Oil and Mineral Resources, Ministry of Agriculture and other specialized agencies. In a few cases, where the data was unavailable from local sources, internationally recognized agencies were approached. Local experts from concerned parties in order to arrive at the most viable and reliable data scrutinized, evaluated and verified the whole corpus of the available data. Information on solvent use, however, has not been made available up to now. Data requirements for IPCC methodology necessitate the existence of reliable databanks for many sectors.

Yemen's inventory provides emission estimates for six greenhouse gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), carbon monoxide (CO), and oxides of nitrogen (NO_x), non-methane volatile organic compounds (NMVOC) and sulphur dioxide (SO_2). The inventory of these gases has been divided into five broad categories:

- Energy
- Industrial processes
- Agriculture
- Land-use Change and Forestry
- Waste

Emission for each sector is discussed below.

3.3 Energy

Energy related activities are the most significant contributors to the total GHG emissions in Yemen accounting for 10132 Gg CO_2-eq, out of which 9968 Gg is CO_2 (Figure, 3.3). The energy related GHG emissions originated from fossil fuel combustion in various sectors (energy industry, manufacturing industry, transport, residential, commercial and agriculture) and from fugitive sources. The sector-wise amount of emission is summarised in Table (3.2).

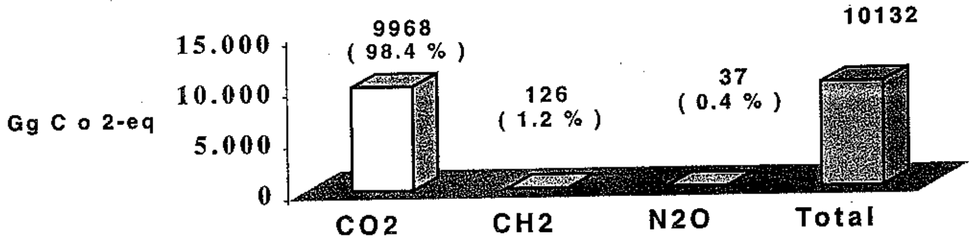


Figure 3.3 Energy related GHG emissions by gas type, 1995

Table 3.2. Energy related GHG emission by sector

Sector	Emission Gg $CO_{2 eq}$	Percent
Transport	3,851	38.0
Residential, commercial and agriculture	3,218	31.8
Energy industry (electricity)	2,411	23.8
Manufacturing	579	5.7
Fugitives	74	0.7
Total	10,132	100.0

Table (3.2) shows that transport, other sectors (residential, commercial and agriculture) and energy industries were the major contributors, while manufacturing industry and fugitive sources were minor contributors to the total energy related GHG emission. Despite the fact that transport sector was known to be the largest emitter, it was difficult to identify the vehicle types causing maximum amount of emission.

Table (3.3) presents an account of CO_2 emissions obtained from bottom up versus top down approach recommended by IPCC. The emission estimate for CO_2 from the reference approach was 10244 Gg of CO_2 and the emissions estimated by the bottom-up approach were 9968 Gg CO_2, implying that the result obtained from reference approach is 3% higher than that obtained from bottom-up approach. The Table also shows that fuel consumption quantities were higher by 2% in the IPCC reference approach implying that apparent consumption term in reference approach is higher by about 2% than actual consumption term in the bottom-up approach. This difference is partly due to rounding errors and partly due to oil smuggling across national boarders. However, the results obtained by the two approaches are highly comparable with only a small degree of uncertainty.

Table 3.3 Energy consumption and emission, 1995: Bottom up versus top down

	Fuel consumption (TJ)		CO_2 Emissions (Gg)	
	Reference	Tier 1	Reference	Tier 1
Total	143483	140880	10244	9968
Difference	2%		3%	

GHG emission in the energy sector is resulted from the use of various petroleum. products. These products are shown in Table (3.4) with the relative contribution of each fuel type compared with the total national energy consumption in 1995. The total fuel consumption of Yemen amounted to 140,879 T Joules from various fuel types in 1995.

Table 3.4. Fuels consumption (in T Joules) and the relative shares of each fuel products, 1995

Fuel	Energy consumption (T joule)	Percent
Gasoline	46,896	33.3
Gas/Diesel oil	37,291	26.5
Residual fuel	30,845	21.9
LPG	14,945	10.6
Kerosene	6,054	4.3
Jet Kerosene	3,312	2.4
Lubricants	1,536	1.1
Totals	140,879	100

3.4 Industrial Processes

There are many industrial processes by which greenhouse gases are produced as a by-product of the process itself and not as a result of energy consumption during the process. In Yemen, among the industrial processes, cement production generated the maximum amount of emission (99.3%). Other production processes with minor emissions are lime production, limestone use and soda use (food & beverages). (Table 3.5).

The total GHG generated by the above mentioned processes was estimated as 546.67 Gg CO_2-eq which accounted for 2.92% of the total GHGs emission of the country. The production of cement in Yemen in 1995 was 1089,000 tons that resulted in CO_2 emission of 542.867 Gg CO_2-eq representing 4.8% of the country's total CO_2 emissions, while it represents around 2.9% of the total GHGs.

The CO_2 emission from cement production was calculated by multiplying 1995-cement production (1,089,000 tons) by the emission factor (0.4985 Ton of CO_2 per ton of cement produced). The SO_2 emitted from cement production was obtained by using emission factor of 0.3 Kg SO_2/ton cement, thus leading to 0.330 Gg SO_2 in 1995.

Table 3.5 Amount of GHG emission from Industrial processes

Production process	Amount Gg CO_2-eq	Percent
Cement production	542.867	99.3
Lime production	1.260	0.2
Limestone use	0.010	0.0
Soda ash use	2.54	0.5

Other gases emitted by this sector amounted to 7.57 Gg NMVOC, of which 5.91 Gg resulted from road paving with asphalt, and the rest 1.66 Gg NMVOC from food manufacturing process

3.5 Agriculture

In 1995, agricultural activities emitted 6294 Gg CO_2-eq which was 33.64 % of Yemen's total GHGs emission. Out of this emission, 70% (or 4379 Gg-CO_2-eq) was emitted as N_2O and the rest (1916 Gg-CO_2-eq) as CH_4, Figure (3.4).

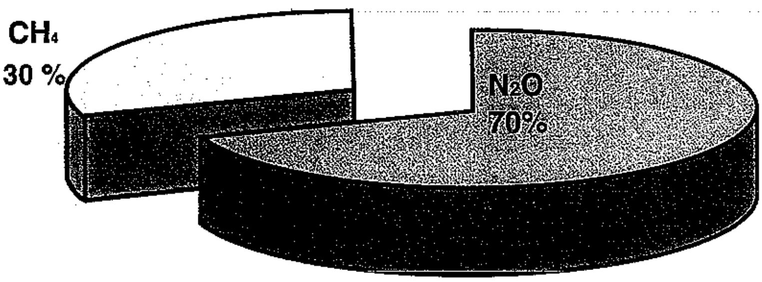


Figure 3.4. N_2O & CH_4 emission from Agricultural sector , 1995

In 1995, the nitrogen input to soil from crop residue, nitrogen-fixing crops and grazing animals along with the application of synthetic and animal fertilisers accounted for 69.2% (14.06 Gg N_2O equivalent to 4359 Gg CO_2) of the total GHG in agriculture. Enteric fermentation was the second significant source in the sector, accounting for 28.8% (86.27 Gg CH_4 equivalent to 1812 Gg CO_2). Other sources are manure management and burning of crop residues, collectively responsible for the balance of 2%, Table (3.6).

Table 3.6 GHGs emission from agricultural processes

Sub-sector	GHG emission Gg CO_2-eq	Relative share %
Agricultural Soil	4359	69.2
Enteric fermentation	1812	28.8
Manure management	98	1.6
Agricultural Burning	26	0.4
Total	6294	100.0

The majority of 1995 CH_4 emissions (94.6%) arose from enteric fermentation in livestock, while animal waste management was responsible for about 4.4% and crop residue burning contributed less than 1% (Table 3.7).

Table 3.7. CH_4 emission from agriculture, 1995

Processes	Gg CH_4	Gg CO_2-eq	Relative share %
Enteric Fermentation	86.27	1812	94.6
Manure Management	4.09	86	4.4
Agricultural Burning	0.85	18	0.9
Total	91.22	1916	100

99.5% of Nitrous oxide emission came from agricultural soil and the remaining was emitted by manure management systems and the burning of agricultural residue, (Table 3.8).

Table3.8. N_2O Emission from agriculture, 1995

Processes	Gg N_2O	Gg CO_2-eq	Relative share %
Agricultural Soil	14.06	4359	99.5
Manure Management	0.04	12	0.3
Agricultural Burning	0.03	8	0.2
Total	14.13	4379	100

The only source of carbon monoxide and nitrous oxide emission from the agricultural sector is the crop waste burning process with 0.93 Gg NO_x and 17.88 Gg CO_2 emission. Due to unavailability of specific data as weight, age, intake and production of each animal type, only the tier 1 approach could be used. It is believed that a high degree of uncertainty is associated with the 1995 emission estimates as a result of using the tier1 instead of tier2 approach. The use of tier2 needs to conduct a study with the purpose of developing Yemen's specific figures required for the application of tier2 as stipulated in the IPCC guidelines.

The total biomass burned on site represents 22.5% of the dry residue resulting from crop harvest in 1995. According to household energy strategy study (Griffin, 1987), only 5% of the residue is burned for energy purposes, while the largest portion is used as fodder for animals. Emission estimate for the energy purpose is reported here and is calculated in the energy sector. However, there is a degree of uncertainty regarding the above percentages, as they were based on a study covering only part of the country. Therefore, in order to reduce uncertainty, extension of the scope of that study to cover the whole country is recommended.

3.6 Land use change and Forestry

Table (3.9) shows that land-use changes and forestry are sources and/or sinks for all major GHGs (CO_2, CH_4, N_2O). Emissions from this source category are associated with: Changes in forest stocks, abandonment of managed lands, and forest and grassland conversion.

Table 3.9 GHGs Source and sink in Gg, 1995

Processes	CO_2 Uptake	CO_2 Emissions	Net CO_2 Removal	CH_4 Emissions	N_2O Emissions
Forest stocks	-10297	657	-9641		
Abandonment	-216		-216		
Forest and grassland conversion		186.42	186	0.34	0.03
Total	-10514	843	-9671	0.34	0.03

The forests of Yemen are important sinks of carbon dioxide. In 1995, the total annual CO_2 uptake by the forests in the country was calculated as 10514 Gg. This uptake build up from the accumulation of total growth increment of managed forest was 10297 Gg, and the accumulation of abandonment of managed lands over the past 20 years come to 216 Gg. The total CO_2 emission from forest ecosystem of Yemen in 1995, due to reduction of 843 Gg in forest uptake, thus resulted in net CO2 uptake of only 9671Gg. The emissions from forest ecosystem were the emission resultant from forest harvest (657 Gg) and grassland conversion (186.42 Gg).

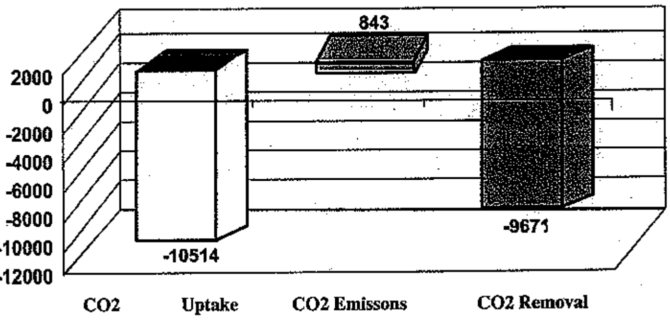


Figure 3.5 Carbon dioxide emission and removal Gg, 1995

Forest management activities also resulted in fluxes of other greenhouse gasses, but their emissions were relatively minor when compared with CO_2 in 1995. CO_2 was the most dominant gas emitted by agriculture sector having the largest contribution across all subcategories. Other gases had very minor emissions from forest/grassland conversion processes and zero shares in the other subcategories. The table indicates that the total GHG emission from grassland conversion was 186.79 Gg, the vast majority of which (186.42 Gg) was emitted as carbon dioxide and the remaining 0.37 Gg CO_2-eq as a combination of CH_4 and N_2O.

As for NO_x and CO emission, forest/grassland conversion in 1995 was reported as a single source of the gases, releasing 0.003 Gg NO_x and 0. 14 Gg CO.

CO_2 sequestration in Yemen is as high as 55% of the total GHG emission (10,514 Gg CO_2-eq), and nearly 4% higher than energy related CO_2 emissions. This result could change substantially if a well-documented inventory on forestation, afforestation, tree plantation and removal is made available for the next GHG inventory update.

The availability of such an inventory would help in developing GHG inventory of a wider temporal coverage by including sub-sources and regions uncovered in this inventory into the upcoming inventory update. Specifically, the proposed inventory will help in realistically addressing CO_2 offsetting by re-growing biomass through securing the necessary information on dispersed trees and date palms in order to be included in biomass stock calculation. The same applies to missing information on forestland and grassland converted all over Yemen to cropland over the last 20 years.

3.7 Waste management

The two emission sources responsible for the release of CH_4 and N_2O in waste management sector are landfills and wastewater treatment. The emission of the two gases in 1995 totalled to 893 Gg CO_2-eq, representing a small share (4.9%) of national total GHG emission. As seen in Figure 3.6, the largest share (73%) (652 Gg CO_2-eq) of emission of the sector was emitted as CH_4 (31.06 Gg CH_4) and the remaining 27% (240 Gg CO_2-eq) released as N_2O (0.78 Gg N_2O). An overview of GHG emission by sub-sector in 1995 is shown in Figure 3.7. Out of the 893 Gg CO_2-eq emitted by waste sector, landfills accounted for 61% and wastewater treatment accounted for 39%.

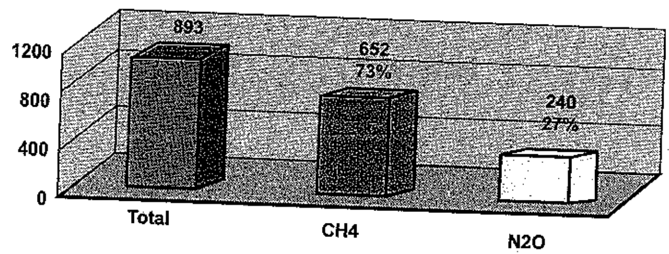


Figure 3.6 GHG emission by gas type in waste management sector

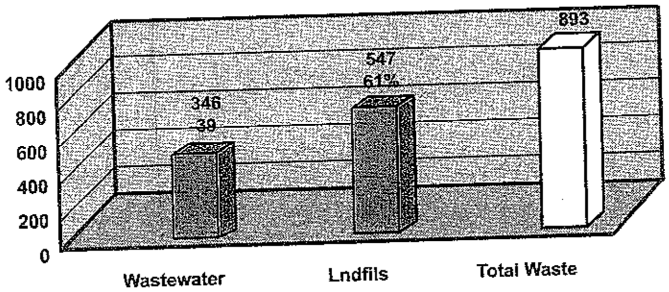


Figure 3.7 GHG emission from waste management, 1995

3.8 International bunkers and biomass

Emissions from international bunkers are excluded from the total according to the IPCC methodology. In 1995, bunker fuel supplied locally to international transport (international aviation and marine bunkers) generated 114 Gg, the largest portion of which 96 Gg (84%) was emitted from marine bunkers and the remaining (16%) from international aviation.

In 1995, the biomass related emissions were estimated at 353.29 Gg and mainly attributed to Fuelwood consumption. (Total biomass consumption in the Republic of Yemen in 1995 was estimated to be around 322.28 KT dried matter).

3.9 Summary

The summary report for national greenhouse gas Source and Sink for the reference year 1995 as required by the IPCC guideline is shown in Table 3.10 and 3.11.

Electricity production and transportation have been found to be the major emitters in Yemen. Several follow-up studies and research are required to improve and update the national GHG inventory (chapter 6).

Table 3.10 Summary of national GHG source and Sink(Gg), 1995 (absolute values)

GREENHOUSE GAS SOURCE AND SI CATEGORIES	CO_2 Emissions	CO_2 Removals	CH_4	N_2O	NO_x	CO	NMVOC	SO_2
Total National Emissions and Removals	11358.09	-10513.77	128.31	15.02	89.06	451.95	92.94	7.69
1 Energy	**9968.28**		**6.02**	**0.12**	**88.13**	**433.93**	**85.36**	**7.36**
A Fuel Combustion (Sectoral Approach	9968.28	0.00	2.48	0.12	87.85	433.50	79.92	2.92
1 Energy Industries	2402.62		0.10	0.02	6.37	0.48	0.16	
2 Manufacturing Industries and Construction	577.19		0.02	0.005	1.55	0.08	0.04	
3 Transport	3808.45		1.12	0.06	64.10	403.20	76.27	2.92
4 Other Sectors	3180.03		1.25	0.04	15.83	29.75	3.46	
5 Other								
B Fugitive Emissions from Fuels	0.00	0.00	3.54	0.00	0.29	0.43	5.44	4.44
1 Solid Fuels								
2 Oil and Natural Gas	0.00		3.54	0.00	0.29	0.43	5.44	4.44
2 Industrial Processes	**546.67**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**7.57**	**0.33**
A Mineral Products	546.67					NE	5.91	0.33
B Chemical Industry								
C Metal Production								
D Other Production	0.00						1.66	
E Production of Halocarbons and Sulfur Hexafluoride								
F Consumption of Halocarbons and Sulfur Hexafluoride								
3 Solvent and Other Product Use								
4 Agriculture		**0.00**	**91.22**	**14.13**	**0.93**	**17.88**	**0.00**	**0.00**
A Enteric Fermentation			86.27					
B Manure Management			4.09	0.04				
C Rice Cultivation								
D Agricultural Soils				14.06				
E Prescribed Burning of Savannas								
F Field Burning of Agricultural Res			0.85	0.03	0.93	17.88		
G Other								
5 Land-Use Change & Forestry	**843.14**	**-10513.77**	**0.02**	**0.0001**	**0.003**	**0.14**	**0.00**	**0.00**
A Changes in Forest and Other Woody Biomass Stocks	656.72	-10297.49						
B Forest and Grassland Conversion	186.42		0.02	0.0001	0.003	0.14		
C Abandonment of Managed Lands		-216.28						
D CO_2 Emissions and Removals from S								
E Other (please specify)								
6 Waste	**0.00**	**0.00**	**31.06**	**0.78**	**0.00**	**0.00**	**0.00**	**0.00**
A Solid Waste Disposal on Land			26.03					
B Wastewater Handling			5.03	0.78				
C Waste Incineration								
D Other (please specify)								
7 Other (please specify)								
Memo Items								
International Bunkers	**114.35**	**0.00**	**0.01**	**0.001**	**2.00**	**1.30**	**0.27**	**0.00**
Aviation	18.12		0.0001	0.001	0.08	0.03	0.01	
Marine	96.23		0.01	0.001	1.92	1.28	0.26	
CO_2 Emissions from Biomass	353.29							

Empty box: Not applicable
Shaded box: Not Estimated because unavailability of input data

Table 3.11 Summary Report For major GHG Source and Sink, 1995

Greenhouse gas source and sink categories	(Gg) of CO_2 Equivalent				Relative Share %
	CO_2	CH_4	N_2O	Subtotal	
1 Energy	**9968**	**126**	**37**	**10132**	**54.16**
A Fuel Combustion (Sectoral Approach)	9968	52	37	10058	53.76
1 Energy Industries	2403	2	6	2411	12.88
2 Manufacturing Industries and Construction	577	0	1	579	3.09
3 Transport	3808	24	19	3851	20.58
4 Other Sectors	3180	26	11	3218	17.20
B Fugitive Emissions from Fuels	0	74	0	74	0.40
1 Solid Fuels					
2 Oil and Natural Gas		74		74	
2 Industrial Processes	**547**	**0**	**0**	**547**	**2.92**
A Mineral Products	547			547	2.92
B Chemical Industry					
C Metal Production					
D Other Production					
E Production of Halocarbons and Sulfur Hexaflouride					
F Consumption of Halocarbons and Sulfur Hexaflouride					
3 Solvent and Other Product Use					
4 Agriculture	**0**	**1916**	**4379**	**6294**	**33.64**
A Enteric Fermentation		1812		1812	9.68
B Manure Management		86	12	98	0.52
C Rice Cultivation					
D Agricultural Soils			4359	4359	23.30
E Prescribed Burning of Savannas					
F Field Burning of Agricultural Residues		18	8	26	0.14
5 Land-Use Change & Forestry	**843**	**0.34**	**0.03**	**843.52**	**4.51**
A Changes in Forest and Other Woody Biomass	657			657	3.51
B Forest and Grassland Conversion	186	0.34	0.03	187	1.00
C Abandonment of Managed Lands					
D CO_2 Emissions and Removals from soil					
6 Waste	**0**	**652**	**240**	**893**	**4.77**
A Solid Waste Disposal on Land		547		547	2.92
B Wastewater Handling		106	240	346	1.85
C Waste Incineration					
7 Other					
Total National Emissions and Removals	**11358**	**2694**	**4657**	**18709**	**100.00**
International Bunkers	**114**	**0**	**0**	**115**	
Aviation	18.12	0.003	0.16	18	15.91
Marine	96.23	0.13	0.24	97	84.09
CO_2 Emissions from Biomass	353.29				

Chapter Four

OBSERVATION, RESEARCH AND VULNERABILITY TO CLIMATE CHANGE

4. OBSERVATION, RESEARCH AND VULNERABILITY TO CLIMATE CHANGE

4.1. Observation and Research on Climate Change

4.1.1. Monitoring network

The general aim of monitoring networks for hydro-meteorological, crop productivity, sea level rise etc. are to observe relevant variables over a period of time at a number of selected locations. Such variables may include temperature, rainfall, relative humidity, surface water level, stream flow, groundwater level, agricultural production, water use, water quality, sea level, etc. Well designed monitoring networks reveal the dynamics of the systems (meteorological, hydro, etc) concerned: they characterize the circumstantial and natural variations within these systems, and show how and to what extent are systems modified by external change, especially by human activities. Monitoring data are indispensable for proper planning of natural resources development and management.

Clusters of stations in certain zones reflect the fact that most of the stations were designed as part of project networks in project areas of limited size, rather than as stations of a national monitoring network. Also the type of equipment used is related to these project networks. Networks in Yemen hence are not operated centrally, rather local or regional networks are run by a large number of organizations. Most of the stations started as project stations and were after a couple of years taken over by government agencies under which the project resumed work. As a result, there is no national standardization of equipment and monitoring practices. Moreover, difficult physical conditions, large distances, shortage of operational personnel and funds, safety problems, etc. impose heavy constraints on network operation.

Despite the fact that monitoring networks do not have a long tradition in Yemen, climatic variables have been systematically observed for more than a century, even though with the help of only a few stations and with considerable gaps between the periods of observation. Several meteorological stations were installed during the late 1970s and early 1980s. Automation, especially the introduction of Eprom recorders, has improved the operational conditions and consequently the records as well.

Stream gauging over different flow ranges is extremely difficult in the capricious wadis in Yemen, thus the rating curves and resulting stream flow records are never very accurate. It should be realized that the older stream flow records and some of the current ones as well are based on staff gauge readings, and thus are not suitable for reconstructing instantaneous reconstructed flows.

A well-established system to collect and record data related to agroclimatic is found at the Agricultural Research and Extension Authority (AREA). Data since early 1980s has been collected systematically. Though the research in the area is limited due to budget constraint. Harbor Authorities at Hodeidah and Aden are monitoring variations in the sea level. Seawater quality and the state of the reefs are monitored intermittently following the duration of project or research.

Beach monitoring is one of the requisites for the purpose. It will be prudent to gather more data to monitor the development of the coast in the pilot area. In this manner accurate rates of erosion will be defined enabling proper management to be done. The monitoring of beach profiles should be carried out monthly for the first year to study the trends of erosion within all sandy shores and then monitoring should be carried out at intervals of three months. It will be necessary to link the monitoring of offshore profiles with that of the beaches. On account of the expensive nature of determining offshore topography, it is proposed that the offshore profiles be determined at intervals of 6 months.

4.1.2. Data banks

Given the fact that many organizations and projects are running monitoring networks and conducting field studies in Yemen, obtaining original data from the various operating agencies could be tedious and time consuming and sometimes even difficult. A national database recently established at NWRA within the framework of the UNDP assistance is intended to act as a centralized publicly accessible national water resources database. Data exchange and cooperation with other partners (organizations) and their database have been useful for the newly established central database. The most important partner in this respect is the Civil Aviation and Meteorological Authority (CAMA), a body responsible for climatic parameter observation. Time series data and other basic numerical information on the climate, hydrology and hydrogeology of Yemen are stored in the database of NWRA, in the form of digital files. In spite of shortcomings, it has already fulfilled part of this task for a number of years and was extensively consulted for the preparation of climate change studies.

A soil database which includes field description of about 800 soil profile over different potential areas has been established at AREA together with crop management data and the potential yield for some main crops.

Other information and data on environmental issues and hazards like, crop productivity, sea level, etc. are scattered in various ministries and agencies and hence are not always easy to obtain. More exchange of information between ministries and/or agencies and the establishment of a data base is urgently needed. Data requirements for IPCC methodology necessitate the existence of reliable databanks for many sectors.

4.1.3. Research on climate change

Due to the variety of sectors targeted, the funds made available for studies conducted during the preparation of National Communication were not sufficient to undertake any new, medium or large scale scientific research. The study built on prior and ongoing studies, compiled the available information and undertook some small, well defined studies to fill the existing gaps for GHG inventory and abatement analysis. Nevertheless, few local research assistants, involved in the preparation of the national studies, undertook partial research, despite the limitation of the data, financial resources, methodologies etc.

An advanced level research project was carried out, using a number of models for sectoral assessment. In the water resources impact & adaptation study, researchers used four models to calculate the demand and supply sides of water resources and in this a new methodology was designed for assessing the vulnerability of water resources in Yemen (Alderwish & Al-Eryani, 1999).

> *The strategy used four interacting models; a Rainfall-Runoff Model, an Irrigation Simulation Model, a Groundwater Simulation Model, and an Economic Policy Model. The outputs were used to create a wadi basin water resources simulation model. Linking the models was found to yield predictions that were more meaningful in the formulation of water management policies. The approach was developed because of the difficulties in assessing the sensitivity of water systems to climate change in arid and semi-arid regions. For example, runoffs in wadis are characterised by flood peaks and flash floods and hourly or daily time step models are needed to capture these effects. The results of the study are considered preliminary, especially in relation to predicting future availability of water resources. This is because the minimum time interval that can be calculated using GCM scenarios is one month. In arid and semi-arid regions, shorter time intervals (e.g. one day) are needed to produce more reliable results, because of the variability of hydrological events. However, results show that water use conflicts will emerge or become worse.*

A semi-quantitative approach, capable of quantifying various processes and factors influencing production level of agriculture was used to assess the vulnerability and adaptation of two main crops, wheat and potatoes, to different climate change scenarios. The steps involved in the assessment of yield reductions, besides climate change effect include; yield reduction as a result of water stress, lack of nutrients, weed competition, diseases, pest incidence and socio-economic constraints (farm management).

The levels are in fact nested crop production systems starting with the highest or potential level related to optimal conditions working down to production levels at sub-optimal conditions. The steps followed in the analysis to estimate the impact of climate change on crop production are:

1. Calculate potential production
2. Define water related yield to reduction levels
3. Define nutrient related to yield reduction
4. Define weed related to yield reduction
5. Define diseases related to yield reduction
6. Define pests related to yield reduction
7. Analyse and rework collected data
8. Define socio-economic scenario for Yemni agriculture
9. Define yield reduction related to socio-economic constraints
10. Identify adaptation measures

For coastal zone, the procedure used involved a description of the environmental characteristics of Yemen's coastal zone, the selection of a high risk area as pilot area, and the collection of data on infrastructure, land, buildings and population along the coastline that would potentially be vulnerable to sea-level rise. The most likely scenario of a rise of one meter by the year 2100 has been examined in some detail. An analysis of the cost involved in adopting measures to adapt to the risk is being carried out. Using the geographical information system (GIS) over the studied area facilitated the preparation of a topographic map of suitable scale for the coastal area and consequently delineation of the risk zone, (contour line Of 2 meter from the coastal line) i.e. the region expected to be submerged in sea water and finally the estimation damage caused to life around the sea shore. Using civil engineering plans and comparing the built-up regions with other regions, some information has been collected through a field survey about the case study regions which will be threatened by water overflow and about an estimated damage likely to be caused in eco-social fields.

The beach profile is expected to move horizontally by shoreline recession and vertically upward. Bruun's Rule has been used for determining the movement of shorelines due to increase in water levels.

Sharp interface approach was employed to locate the fresh/saline water interface. This approach presents the changes in the position of the interface in both directions, vertically and horizontally. The vertical changes, according to Ghyben-Herzberg relation, were supposed to be 40 times of the change in the aquifer water table relating to the original sea level, while the horizontal changes were estimated using trigonometry relationships.

In Yemen, there are a number of existing research institutes which carry out research on the interface between climate change and the respective economic sector. Academic institutions like Sana'a University and Aden University have done some research and conducted training programs in the environmental field, and both universities also have research groups dealing with alternative energy sources. More recently, the University of Science & Technology has started to involve itself in research in solar energy. Other institutions working in this field include Environmental Protection Council, National Water Resources Authority; Water and Environment Center and Marine Research Institute in Aden and Hodeidah.

4.2. Vulnerability to climate change

Vulnerability in the present context refers to the extent to which climate change may damage or harm a system (IPCC, 1996). Yemen's natural systems and economy generally suffer from the mounting pressure of high population growth rate, limited natural resources and economic problems. All these contribute to make Yemen highly vulnerable to climate change. Some of the key socio-economic sectors, most likely to be affected by climate change and for which financial support was made available include Water resources, Agricultural production, and Coastal zone resources. The impact of climate change on each of these sectors can be identified and assessed.

4.2.1. Climate change Scenarios

Climate change scenarios were used to identify sectoral sensitivity to climate change. Out of the 14 runs (experiments) of General Circulation Model (GCMs), under doubling of carbon dioxide content (2 x CO_2), three models were selected to cover a wider range of possible future change in climate and were used for vulnerability analyses. These are OSU, Oregon State University, representing average climate conditions, UKHI United Kingdom meteorological office, High Resolution for a dry climate conditions and ECHAM3TR (MAX Plank institute (Geostrophic Ocean) for very wet conditions.

In addition, assumed incremental changes were combined with observed climate data of rainfall and temperature to construct additional climate change scenarios. These are:
Incremental 1 = + 20% Rainfall & + 2° C,
Incremental 2 = - 20% Rainfall & + 2° C,
Incremental 3 = + 20% Rainfall & + 3° C, and
Incremental 4 = - 20% Rainfall & + 3° C

4.2.2. Socio-economic scenarios

As part of the climate change vulnerability and adaptation assessment socio-economic scenarios were constructed. General quantitative country-level scenarios comprise a range of issues related to population and economic activities were developed and used as basis for sector/site specific scenarios. Additional parameters include crop-specific agricultural production, main water using sectors over specific (study) area, and economic activities for coastal zone management over study area. After assessing the impact of climate change in agricultural production, water resources and coastal zone under the used socio-economic scenarios, the results were then incorporated to the overall socio-economic situation of the country. Although the results obtained of limited accuracy, the exercise was beneficial to the local expertise.

In brief the following has been drawn from the future projection:

- Most of economic sectors and associated activities would achieve high growth rate during the first quarter (2001-2025) of the century, followed by gradual decline in the growth rates for the second quarter (2026-2050). The first high annual growth rates may be attributed to availability of many opportunities to extensively develop natural resources of the country, while the following declining trend of annual growth rates would result from:
    1. Less opportunities to develop new/additional resources after heavy exploitation of these resources during the first 25 years.
    2. Increase of competition for local commodities as market economy becomes open.
    3. The values upon which the growth rate is based would lead to the limitation of the growth rate itself.

- Several promising activities such as fishing, mining and tourism would become more important and would positively affect other related sectors.

- There would be a tangible change in production structure of the system that would lead to more benefit to appropriate sectors like fishing, industry, manufacturing and many other production services' sectors, especially financial services. Also the improved structure would allow avoiding unwanted existing activities in the system like Qat production or those associated with external (international) factors as crude oil production. Special consideration should be given to keep agricultural sector as an important strategic sector to provide sufficient food for a rapidly growing population.

For water resources study, multiple future baseline socio-economic scenarios were constructed over Abyan Delta, using low middle and high values of population growth, agricultural land and industrial development. Future water demands under climate change scenarios were assessed assuming business as a usual scenario based on a projection of observed trends, corrected in the light of recent reforms and expected future government policies. Consequently, main characterization of future study area emerges, allowing analysis of effects of socio-economic development on the impacts. The results were used in evaluating spontaneous and planned adaptation.

4.2.3. Water Resources

In Yemen, as in many Arab countries, water has a high social, economic and political value, yet the most vulnerable sector to climate change is water resources in terms of quantity and quality. Under the circumstances of scarce availability of water resources and the anticipated anthropogenically induced climate change, assessment of impact on water resources becomes crucial and the results obtained require to be of, at least, reasonable accuracy.

As most of the water resource systems in Yemen exploit combination of surface and subsurface storage, the study has involved aspects of water resource system simulation and performance assessment. The selected modeling strategy that is used for the first time in climate change assessment studies comprised 4 interacting models: rainfall-runoff model, irrigation simulation model, groundwater simulation model and an economic model capable of adequate indication of the water system's sensitivity to climate change in arid and semi-arid regions. This has been achieved through a distributed representation of the physical setting with sufficient resolution to effectively evaluate the impact of water management measures and the evaluation of economic and other policies used in adaptation analysis. The vulnerability assessment of water resources was conducted on the example area of Abyan Delta with its contributing catchments. The area selected has special social and economic importance not only because it encompasses the main well field that supplies water to Great Aden, but also because it includes major agricultural activity. The extent, however, has been delineated to include the three main hydro-climatic zones in Yemen, namely: the Highland, the Middle highland (escarpment) and the plains (Abyan Delta).

THE SUPPLY

Table 4.1 lists the values of surface water resources in the study area under current conditions and under climate change scenarios using GCMs and incremental scenarios.

With intermediate CO_2 concentration levels, the OSU predict an increase of 12% in the runoff volume by year 2050, and a shift in the temporal distribution of monthly runoff toward the second half of years. UKHI predicts 5% decrease in surface runoff while ECHAM3TR predicts an increase of 111%. UKHI and ECHAM3TR were selected to be included because they represent the driest and wettest conditions between the 14 GCMs experiments.

Table 4.1: Average surface water resources in Abyan delta under various climate conditions (MCM).

Climate Conditions	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Normal climate	5	4	21	27	17	11	40	52	17	5	3	4	205
UKHI	5	4	20	23	13	10	46	49	14	5	3	4	196
OSU	5	7	21	33	24	10	42	59	18	5	3	4	230
ECHAM3TR	5	4	26	27	15	10	97	202	29	7	3	9	434
Inc2 +20% rainfall	7	7	26	28	30	13	55	70	18	5	3	5	269
Inc4 -20% rainfall	6	6	15	15	13	10	31	37	11	4	2	4	152

Note: For the GCM models and the four incremental climates, the reported runoff are the average values for the study horizon (1991-2050).

The total average annual renewable resources at Abyan Delta have been calculated under various climate scenarios. Like other coastal plains in Yemen, direct precipitation is insignificant (50 mm/year) and their resources depend on runoff generated at mountainous areas. WEAP allows allocation of these resources between spate irrigation, wadi recharge, irrigation return, and the sea.

Table 4.2 The available water resources (MCM/year) in Abyan delta over the next 50 years

Water sources/ climate conditions	Normal	UKHI	OSU	Increm. 1 & 3	Increm. 2& 4
Runoff generated	205	196	230	269	152
Renewable resources	192	183	214	249	142
Runoff available to spate irrigation	127	122	133	146	105
Irrigation return	41	40	44	48	35
Wadi recharge	38	35	46	57	22
To the sea	27	26	35	46	15

THE DEMAND

Under each climate change scenario, the water demand and the groundwater resources were evaluated under Business As Usual (BAU) scenario. The BAU scenario assumes continuation of rated historical water demand trends together with current exploitation practices and water use efficiency in irrigation under the existing institutional set-up. No government intervention is foreseen in this case, except for the public water supply and maintaining the spate irrigation infrastructures to its current situation. The water demand within the study area can be aggregated into three major water-use sectors. These are:

Municipal; comprising domestic supply,

Agricultural; serving irrigation and livestock uses, and

Industrial; including mining.

For each sector future water demand was calculated. The total water demand for all sectors under various climate conditions is given in Table 4.3.

Table 4.3: Total water demand (MCM/Year) for all sectors under various climate scenarios in Abyan Delta (BAU, medium growth rate)

Year	Normal	UKHI	OSU	Incr.1	Incr.2	Incr.3	Incr.4
1991	439	440	440	440	440	440	440
2000	454	457	458	458	460	458	461
2010	475	481	481	482	485	484	488
2020	501	511	512	513	517	515	521
2030	531	544	545	546	553	549	557
2040	561	579	580	582	591	586	597
2050	593	615	615	618	630	624	637

Agriculture was the major water consumer in the study area representing 97% of total water demand in 1990; the percentage will decrease to 93% by year 2050. The increase of temperature has the major effect on the agricultural water demand in the study area, as rainfall over the area is little. Under the maximum hot scenario (incremental 4), the agricultural water demand is usually more than under normal climate by about 8%.

SUPPLY-DEMAND RELATION

In future supply, priority would be given to domestic water supply followed by industry and agriculture. The groundwater simulation model predicts that domestic and industrial water demand would be secured over the time horizon. However, that would be possible only under higher costs as a result of the decline in the level of groundwater.

The available runoff for spate irrigation indicates a deficit in the coverage of spate irrigation water demand as a result of fluctuation in the run of the runoff. The spate irrigation water demand varies between 551 MCM/year under normal climate condition to 595 MCM/year under maximum hot climate, while the available flow for spate irrigation under the same conditions are 127MCM /year (normal climate) and 105 MCM/year (incremental 4), which is less than half of the demand. This shortage in available spate runoff would lead to rapid increase in groundwater abstraction for agriculture to supplement spate irrigation.

Unfortunately, the groundwater simulation model shows that groundwater aquifer in the study area would not be able to support even normal demand (without taking effect of runoff shortage) as several wells start to withdraw salt water (below 0 level) and that started as early as 1997. Withdrawal of poor quality water out of the aquifer continues to increase with slight fluctuation due to recharge pulses. The gap between demand and supply in the year 2050 is of about 162 MCM (66%) and 154 MCM (65%) under UKHI and normal climates respectively. Drying up and the abandonment of agriculture in Abyan Delta can be anticipated as it is running short of water. This implies that the whole rural economy is vulnerable to declining water availability. Figure 4.1 shows demand-supply gap in the groundwater resources For UKHI scenario. Table 4.4 reports the differences in five year interval.

Table 4.4: Water demand and supply in Abyan delta, MCM/year (BAU & UKHI)

Year	Water demand	Water supply	Deficit in supply
1991	84	84	0
1995	91	91	0
2000	100	78	-21
2005	109	70	-39
2010	120	70	-51
2015	134	75	-59
2020	148	60	-88
2025	163	61	-102
2030	178	67	-112
2035	194	71	-123
2040	210	77	-133
2045	227	78	-148
2050	244	85	-159

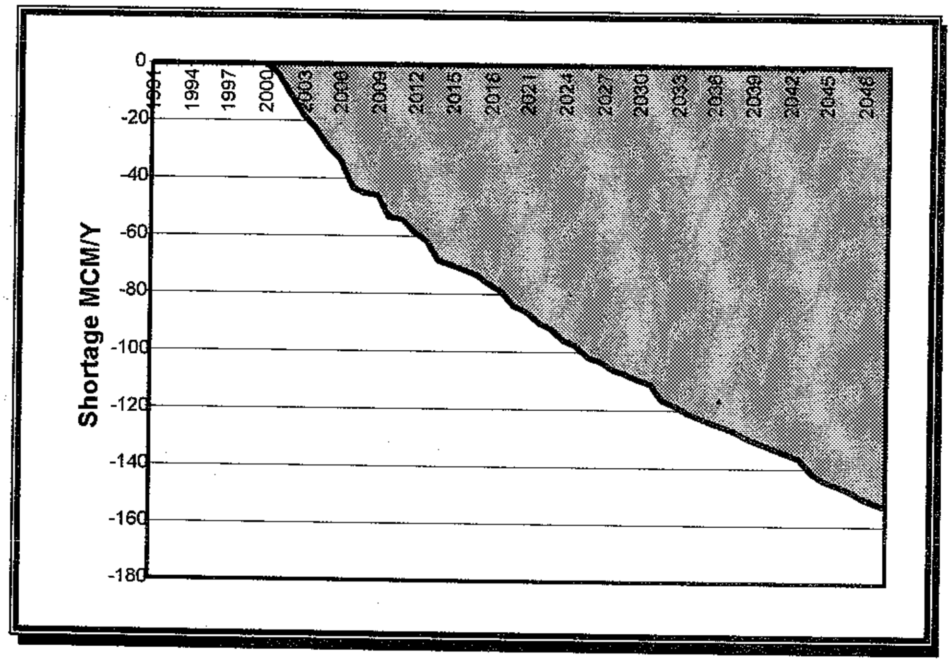


Figure 4.1. Groundwater supply/demand deficit in Abyan delta (under BAU & UKHI)

These results should be considered preliminary, especially in application to predict the available water resources at the national level under future climate change. Further investigations are required.

4.2.3. Agricultural production

Agricultural activity is a key element in Yemen's economy and is expected to continue to be so for the forthcoming decades. It has a strong socio-economic bearing and needs to be assessed for its vulnerability. The agricultural development priorities, as reflected in the five-year plans, placed greater emphasis on increasing crop and livestock production to meet the domestic food demand and expand exports. At the same time, it called for increasing food security levels. With only 3 percent of the country's total area used as cultivable land, Yemen will have to rely on imports amounting to about 35 percent of the national food supply.

Cereals form the bulk of the diet of the world population and cereal products rank highest among agriculture imports of Yemen. Wheat is mainly grown in the highlands and the plateau zones. In the highlands wheat is grown twice a year: in summer under rainfed conditions and in winter under irrigation. In the plateau zone wheat is grown in winter under irrigated conditions. It occupied, in 1995, about 14% of the total area of cereals grown and 21 % of the total cereal production, ranking second among cereal crops after sorghum. Potato is gaining ever-increasing comparative advantage as potential export commodity; thus, compensating for wheat import and a potential alternative to Qat. Thus the two crops selected for quantitative analysis were Wheat and Potatoes and Qat was analyzed only qualitatively.

Four sites were chosen, representing the two main agroclimatic zones where both wheat and potato are grown. These zones are: the Mountain Highland Zone located in Dhammar and Ibb and the Desert Plateau Zone located in Marib and Seyun.

The impact of climate change on wheat and potato is quantified using a semi-quantitative approach using basic agronomic rules combined with rating factors for yield reducing factors. Temperature is the major factor influencing crop growth. Potential production is directly related to cumulative heat (degree-days (^{o}Cd)). Temperature changes directly influence the maximum or potential production level. Water is essential for crop development. Yield reduction as a result of water stress, in most cases related to water shortage, is a function of climatic, soil and crop characteristics. Pest and disease may harm the crop physically or compete for resources. Weed competition in low input agriculture is an important yield reducing factor.

Precipitation in terms of total quantity as well as spatial and temporal distribution will modify the magnitude of the yield reduction due to soil water availability, especially in rainfed farming systems. Likewise, changes in temperature will affect crop production levels. Specifically, temperature change influences the rate of crop development, consequently affecting the length of the growing season. It should be noted that not only the length but also the start of the growing season might change. In this study the changes in grain filling period for wheat and tuber formation period are used to quantify the potential production level length of phonological stages. According to field observations during 1997/1998 in Marib and Seyun, high temperatures in the first stages of wheat production led to low tillering and thus reduced the number of days from sowing to harvesting by 10-15 days. Consequent wheat yield reductions were in the range of 2.4 ton/ha (in Marib). Other results were found for potato at other sites. (Tables 4.5 & 4.6).

Using the FAO model, CROPWAT (Smith, 1992), wheat and potato yield reductions (YR) in rainfed areas and net irrigation requirements (NIR) in irrigated areas were predicted for the year 2050, under the three proposed climate change scenarios: OSU, UKHI, and ECHAM3TR. These results (with combined effect of changes in temperature and precipitation) were then compared with YR and NIR results using the mean of the observed climatic data.

In the semi-humid areas (Ibb) of the mountain highlands agroecological zone, the changes in temperature and precipitation given by all three scenarios will introduce lesser potato yield reductions than the observed YR, which may indicate favorable climatic conditions for potato growth in this high-rainfall region. It should be noted that potato YR for the wet scenario (ECHAM3TR) is expected to be more than twice as much under the other two scenarios. This could be due to potentially poor soil drainage induced by wetter climatic conditions. On the other hand, wheat yield showed no response to climatic changes; as both the observed and predicted YR were zero. This result could not indicate the vulnerability of wheat farming systems to expected climate change scenarios. In general, crops like wheat and potato may not show vulnerability, in terms of heat and water requirements under prevailing climatic conditions of the semi-humid highlands in Yemen.

In the semi-arid highlands (Dhammar), wheat and potato, on the contrary, are expected to experience higher future crop yield reductions than the present (except under the wet scenario). Spring Potato (15 Feb-1 June) yield reductions will be considerably high (50%) under rainfed conditions which may necessitate supplemental irrigation. Meanwhile, autumn potato (20 Jun-13 Oct) is expected to have slightly higher (10%) irrigation requirements and more water demand than that at the present. Summer wheat grown in this semi-arid region, however, will maintain its present or slightly higher YR (25%) rate except under the wet scenario (ECHAM3TR). YR sustains only a third of the present level of YR. It may be concluded that higher wheat yields can be obtained by practicing supplemental irrigation in the absence of wetter climatic conditions.

Table 4.5 Potatoes' potential production under normal and climate change (ton/ha).

Sites	Pot. production Normal climate	Pot. Production OSU (+1.7°C)	Pot. production UKHI (+1.85°C)	Pot. Production ECHM3TR (+2°C)
Semi-humid Ibb	48.8	42.8	42.5	42.2
Semi-arid Dhammar	43.8	41.9	41.6	41
Arid Marib	52.4	48.5	48.2	47.9
Hyper-arid Seyun	62.8	56.7	56.3	56.0

Table 4.6 Wheat's potential production under normal and climate change (ton/ha).

Sites	Pot. production Normal climate	Pot. production OSU (+1.7°C)	Pot. production UKHI (+1.85°C)	Pot. production ECHM3TR (+2°C)
Semi-humid Ibb	[illegible]	6.2	6.1	6.1
Semi-arid Dhammar	7.2	5.8	5.8	[illegible]
Arid Marib	[illegible]	10.1	10	9.9
Hyper-arid Seyun	10.9	11.2	11.1	11

In the arid areas (Seyun and Marib) of the desert plateau zone, generally, potato will have higher demand for water than under normal climate; whereas, wheat would demand less water. Regional differences are evident of vulnerability of both crops to expected changes in temperature and precipitation. In Seyun, the net irrigation requirements for potato will increase slightly (a range of 2-10%) over the present NIR levels, depending on the scenario used. In contrast, potato growing in Marib is expected to demand around 25% higher NIR in all scenarios used. The difference in potato irrigation water demand between the two regions might be partially related to the usual lack of rainfall in Marib, during the potato growing season. According to CROPWAT estimates for present situation the actual water use for potato growing is approximately 10% more in Marib than in Seyun. This result is mainly associated with higher radiation load, higher wind speed and relatively drier air prevailing in Marib. These climatic conditions are well pronounced because of the difference in annual potential evapotranspiration (PET) between Marib (1811 mm) and Seyun (1640 mm). Basically, spring wheat growing in the desert plateau will require about 10% less irrigation than it does under normal climate; the increased NIR in Marib, as given by the OSU and ECHAM3TR scenarios, is up to 2%. Wheat would show almost no vulnerability to climate change. This conclusion may support the idea that wheat production in Marib area will have substantial potential. This matter remains to be further investigated along with predictions of CO_2 concentration.

Other signs of vulnerability in crop production under expected changes in temperature and precipitation could be related to the incidence of pests and soil conditions. Increased temperatures coupled with the same or higher precipitation generally provide better conditions for the development of diseases and pests including weeds. Due consideration should be given to diseases and insects endangering agricultural crops, especially when some crops become particularly susceptible to transmission of diseases via insect-damaged tissues.

The physical condition of soil is sensitive to the potential climatic change. If precipitation increases and temperature either remains constant or increase, drainability of soil in the semi-humid region (Ibb) would change and thus expand the area of land vulnerable to flood hazard and poor drainage. In fact, not only the amount of rainfall but also its intensity will play an important role, which is however difficult to assess.

3.3.4. Coastal zone

A. rich diversity of ecosystems and a great number of socio-economic activities characterise the coastal zone of Yemen. The procedure followed in the assessment of impacts of Accelerated Sea Level Rise (ASLR) involved a description of the environmental characteristics of the Yemen coastal zones, a selection of the high risk area as pilot area, the collection of data on infrastructure, land, buildings and population along the coastline that is potentially vulnerable to sea-level rise.

Hodeidah city and its surrounding areas were selected for a detailed impact assessment. The city is the largest on the Red Sea coast with a considerable economic and trade activity, and it's the second largest port in Yemen. The selected area also includes the low lying sandy spit extending about 12kms north-west of the city, and the coast south of the city to a distance of 10 km, where two wadis abound on the shore and where a few fishery settlements exist close to the beach. The level of the area is low and the city has suffered a considerable rate of erosion of the coastline.

The Risk Zone area of impact has been delineated as the area within the coastal zone and below the 2-m contour line, Figures (4.2). High water line over the last 35 years is shown in Figure (4.3).

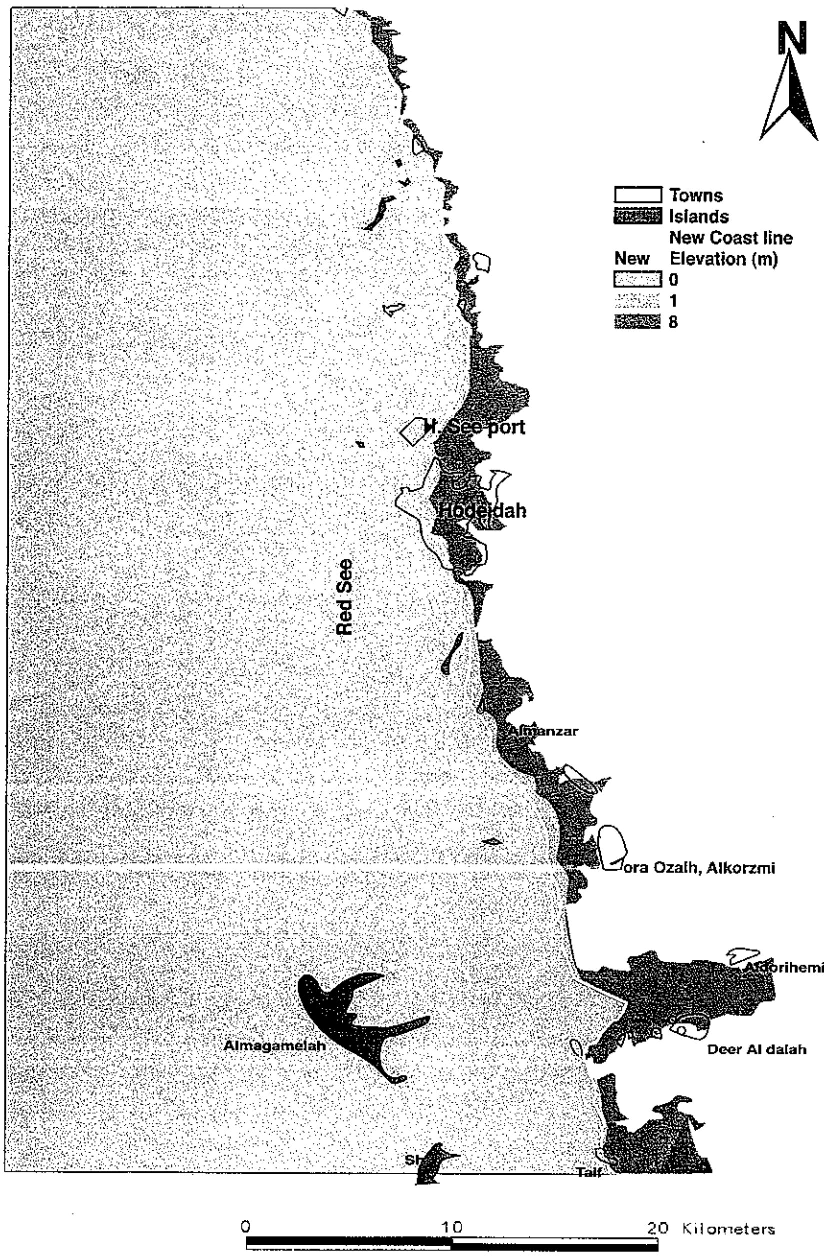
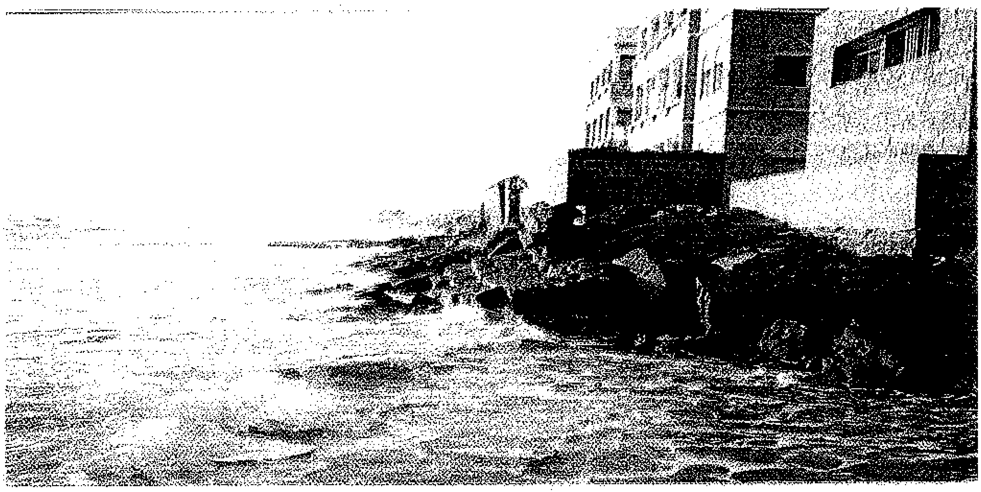


Figure 4.2 Simplified map showing the expect shoreline after 50 years.



1985 2000

Figure 4.3 (Plate) Building in Hodeidah retreated for about 30m during the last 35 Years. Arrows show the old location of high water line as indicated by the area inhabitants.

Various kind of impacts are grouped under the following:

Impact on biological communities

The Yemen coastline wetlands are found associated only with sheltered bays. Mangrove swamps provide the basis for many important marine food chains and they also provide nesting sites for a wide range of sea and shore birds. The wetlands and mangroves found in the pilot area are located in the bay to the east of the sand spit. A sea level rise of 1 m in 100 years would destroy the existing vegetation. On the other hand the shoreline would move inland creating new opportunities for the wetland and mangrove development. The balance between accretion and submergence (survival) of the wetlands due to sea level rise is complex and depends upon coastal types as well as coastal settings (muddy, tide-dominated systems, or organic systems, areas of high or low tide range, and in areas of high or low sediment and freshwater input). Other crucial factors for that balance are the rate of sea-level rise and coastal topography and sediment supply.

Impact on the shoreline beaches

The loss of land attributable to sea-level rise occurs from the erosion of sandy shores and erodible cliffs "shoreline recession". Loss of land on low-lying coasts sheltered from wave attack is usually caused by inundation.

Bruun method (1962) has been used for determining the movement of shorelines due to increases in water levels. For the pilot area, the recession due to a sea level rise of 1 m is estimated at about 100 m. This happens because of a potential land loss along the shoreline of the pilot area (length 20-km) of about 200 ha. It should be mentioned that silty soils found in the bay (Port of Hodeidah) would erode even faster than the Bruun

Rule suggests for sandy shores. Luckily, the sand spit safeguards the shoreline from wave attack protecting the area from erosion.

Impact on Coastal structures

With rising sea-levels coastal structures are expected to become more vulnerable to failure. Increases in water levels would sustain the higher amounts of wave energy coming closer to the shore. While water level increases would permit larger waves to come closer to the shore, increases in the intensity and duration of storms generating the waves would further increase the vulnerability of coastal structures. The changes in the intensity and duration of storms would result into changes in the wave climate. Building is most likely to be collapsed under the effect of such strong wave action (Figure 4.4). The possibility of the occurrence of more intense storms along the shores of Yemen is not much known at the present. However, the structures in the pilot area likely to be affected in this manner are the breakwaters of the fishing port, the revetments and sea walls of the city and the shoreline defence along the road leading to the naval base. The maintenance of these structures or their performing under ASLR would demand the re-assessment of their structural integrity in the light of new evidence of water level increases. Note in Figure 4.5. (plate), the wave is starting to break through the existence defence structure. This line is most likely to be demolished in the very near future.

Figure 4.4 (Plate) Shows another building and coast line pounded by high energy wave action.

Impacts on the pilot area

The ongoing erosion of the coastline will be aggravated by the onset of the accelerated sea-level rise. This may affect the power station which exists along the coastal line as well as the sand spit with a road leading to the naval base which is at the moment under attack in high water conditions. It is also foreseen that if in the event of a major breach a part of the spit is washed away, there could be significant changes in the tidal regime in the bay area. Such changes could increase siltation of the access channel to the port. Maintaining or not maintaining the spit will have a number of financial consequences, however, If a decision is taken not to maintain the spit, the consequences for the access channel to the port would have to be investigated by carrying out a computer modelling study.

Figure 4.5 (plate) Newly built defense structure (1999) in the pilot area.

Impacts on the city of Hodeidah

The shores in Hodeidah are sandy, with slanting character. This plays a great role in the water overflow in the residential and commercial regions and in the coastal region especially near the old city of Hodeidah. In Figure 4.6 note the absence of the beach while in Figure 4.7 the main road is approximately 40cm lower than the shoreline.

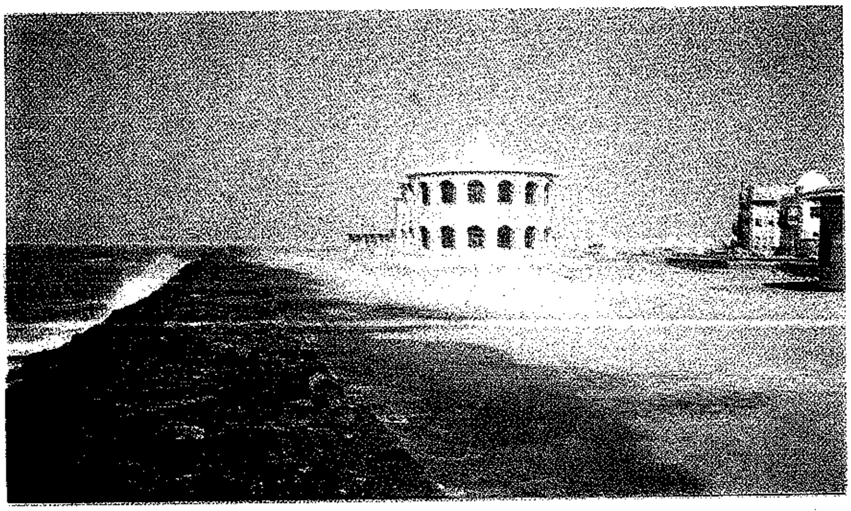


Figure 4.6 (plate) Shows a stone built sea-wall structure of Hodeidah front.

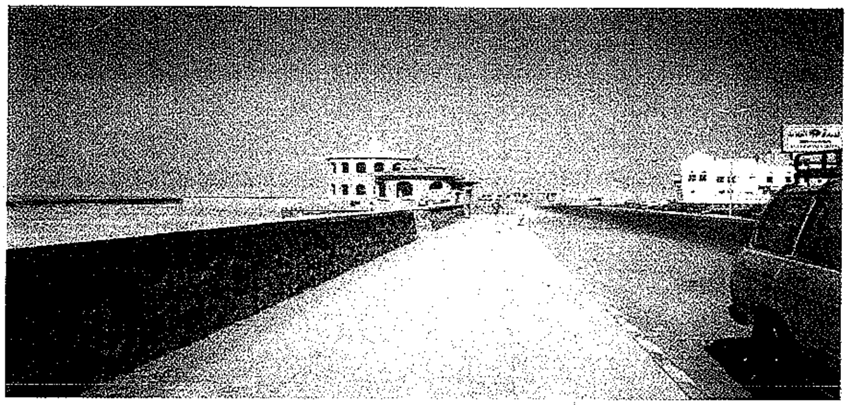


Figure 4.7 (plate) Shows the other side of the coastline shown in Figure (4.6)

The losses along the coastal area caused by expected overflow of seawater and their cost in US dollars are summarised in Table (4.7).

Table (4.7) Losses and costs due to ASLR

Description	Cost in $ US
15,070 Houses	759,075,900
15 km asphalt roads	8,888,900
35 km paved roads	555,555
2 agricultural facility	444,444
22 primary schools (12 classes each)	6,528,812
9 secondary schools (9 classes each)	1,777,778
2 High education faculties	25,925,926
1 Marine College	29,629,630
Health 3 (2 hospitals & 1 health centre)	6,518,520
Tourism One 4* hotel, 8 medium size hotel	16,296,292
26 governmental buildings and Presidential house	72,592,587
20 Mosques	14,814,800
15 Parks	3,333,330
Electricity Ras Kateib power station	8,148,148
Sewage system	2,962,963
Water supply	5,703,704
Communication facility	2,222,225
Industry 4 large and 20 medium size 150 small size	11,825,855
The Port 7 platforms, 2 floating platforms for oil, area of marketing goods and containers, etc.	239,185,185
Others	74,074,075

Saline water intrusion

The fresh-sea water interface is diagonal and has a maximum depth of 300m within the inland distance of less than 10Kms from the coast. Under the sea level rise, using sharp interface approach, the interface has been relocated, vertically according to Ghyben-Herzberg relation (40 times the change in the aquifer water table relating to the original sea level), and horizontally using trigonometrical relationships. This distance in the study area is estimated to be 400 times of the changes in the seal level. An area of 20 km^2 would be affected by the saline intrusion. This implies that wells or boreholes located in this zone would start withdrawing saline water causing losses in cultivable areas. Fortunately, no wells exist in this zone at the moment and, hence, in future any development in this area should be discouraged.

4.4 Concluding Remarks

Negative/positive impact assessment for the three sectors, namely water, agriculture and coastal zone, clearly indicates the vulnerability of these sectors. Water resources, however, are most vulnerable and the situation could be disastrous to the country if no immediate action is taken.

Chapter Five

MEASURES TO REDUCE GHG EMISSION AND ADAPTATION TO CLIMATE CHANGE

5. MEASURES TO REDUCE GHG EMISSION AND ADAPTATION TO CLIMATE CHANGE

5.1. Introduction

Yemen as a developing country, not included in the Annex I countries of the UNFCCC, has no commitment to greenhouse gas emission reduction. However, it could undertake voluntary obligation to limit it with the assistance of the developed countries within the frame of the corresponding mechanisms for implementation of the Convention, which unfortunately has not been agreed clearly by the CoP. Therefore, greenhouse gas abatement as evaluated and developed in accordance with Yemen's national priorities was intended to improve its people's living standards, develop its improvement of infrastructure and increase its economic growth, based on sustained development and preservation of environment.

Adaptability can be defined as the degree to which adjustments are possible in practices process and structure of systems to projected or actual change of climate. Adaptation can be spontaneous or planned and can be carried out in response to or in anticipation of changes in conditions (IPCC, 1996). In the context of vulnerability and assessment studies for initial national communication of non-Annex I, this definition of adaptation is too broad and does not distinguish between adaptation at the individual, institutional and government levels. Mitigation & Adaptation measures were considered assuming the national scope, which would require coordinated actions of ministries and government agencies, non government organizations and general public.

5.2. Mitigation measures

To project future energy demand for each energy sector, National Statistical Office's annual growth rate were adopted for required sectors. These are 3.5% annual growth for household and for commercial sector, 4% and 6% where adopted for general services and the use of LPG, respectively. Annual growth rates over the time horizon for industrial, transport and agriculture sectors are assumed to be 7.75%, 6.75% and 5.6%, respectively.

Table (5.1) depicts the projection of the total inland energy requirement up to the year 2020, while Figure (5.1) shows projected energy requirement by sectors for the base year 1995 and the year 2020. In 1995 the transport sector and household sector dominated the total energy requirement. By the year 2020, they would remain the dominating sectors. However, the energy requirement for transport sector would be far much than that of the household sector and would remain a major source of pollution.

Table 5.1: Projections of total inland energy requirement by fuel type in million GJ (Baseline scenario)

Fuel	1995	2000	2005	2010	2020
Petroleum products	113.38	159.71	209.24	261.72	377.19
Electricity	5.66	7.61	10.44	14.07	24.82
Fuelwood	32.31	34.68	33.54	31.17	21.28
Charcoal	0.09	0.14	0.15	0.17	0.20
Total	**151.45**	**202.13**	**253.38**	**307.13**	**423.48**

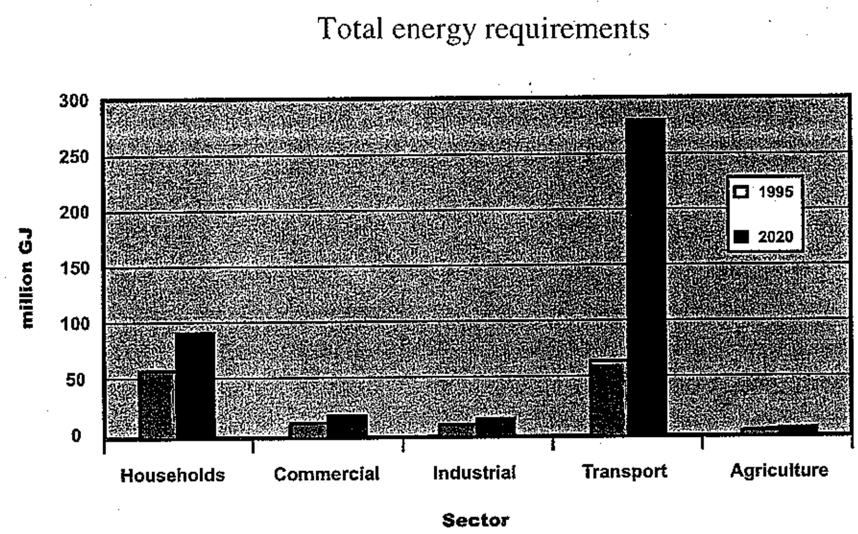


Figure 5.1: Projections by sector for the base year and the year 2020

The electrical power supply required to cover the electrical energy consumption and the expected losses caused thereby would rise from 424 MW effective generation (2422GWh) in 1995 to 3819 MW total capacity generation (10,606 GWh) by the year 2020.

The GHG emissions result mainly from fuels, such as petroleum products, Fuelwood or charcoals and natural gas. The total amount of GHG emissions for the energy sector in 1995 was 10.94 million tons CO_2 equivalent. This value is projected to increase to 36.15 million tones CO_2 equivalent by the year 2020 based on the baseline scenario. This increase is considered to be around 3.3 times higher over a period of 25 years. The GHG emissions estimated as a result of the baseline scenario are illustrated in Figure 5.2.

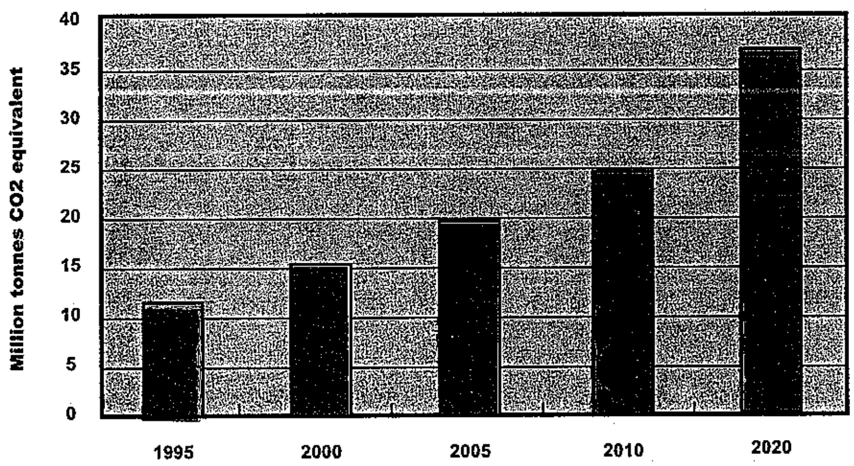


Figure 5.2: Projected GHG emissions under the baseline scenario

5.2.1. Scenarios of GHG Emissions

An assessment study of mitigation options in Yemen over a period of 25 years was conducted using 1995 as the base year. Based on the assumptions of existing situations and changes in the future governed by the available indicators and socio-economic projections, a baseline scenario of GHG emission till the year 2020 was developed. With this baseline scenario of GHG emission, the CO_2 and Methane emissions appeared to be the major contributors to the National GHG emissions. With this in mind, two out of several scenarios developed were chosen to fulfil the objective of reducing emissions gradually by 5%, 12.5% and 20% by the year 2005, 2010 and 2020 respectively.

The two mitigation scenarios considering both the demand and supply side of the energy sectors are described below.

Scenario 1

On the Demand-Side mitigation options certain measures and assumption were taken into account in different demand sectors. These measures and assumption are as follows:

a. Household sector (urban and rural)
   - Switch to energy/equipment with lower GHG emissions (substituting electric for kerosene and LPG lamps, solar water heating for electric heating, LPG stoves for Fuelwood stoves)

b. Transport sector
   - Reduce taxes on new vehicles
   - Raise taxes on old vehicles
   - Switch to natural gas technology and solar technology

c. Industrial sector
   - Fuel switching to natural gas and renewable energy
   - Rational use of energy

d. Commercial sector
   - Switch to energy/equipment with lower GHG emissions
   - Energy-efficient equipment

e. Agriculture
   - Switch to solar irrigation systems

On the Supply-side mitigation option, the electrical power sector is the largest contributor to GHG emissions and therefore the best option is to switch over to the use of fuel on a gradual basis, and further from the use of fuel oil for power generation to the use of natural gas in high-efficiency combined-cycle gas turbine (CCGT) power plants. This gradual switching will reduce the quantity of burnt fuel from 80% to 5% by the year 2020, which in turn will drive a considerable reduction in emissions. Increasing the use of solar electricity for remote rural areas will also have the same effect.

The option considered in scenario 1 comprises a gradual replacement of existing plants by new CCGT-power plants with a capacity of 100 MW and a conversion efficiency of at least 44%.

Scenario 2

In this scenario, considerations are similar to those of scenario 1 except a gradual replacement of existing plants with new CCGT-power plants with a capacity of 200 MW and a conversion efficiency of at least 52%, instead of that used in scenario1 with lower capacity value of 100 MW.

The achievement of both scenarios shows that the Global warming potential will increase from 10.94 million tons CO_2 equivalent in 1995 to 28.88 million ton equivalent CO_2 and 28.17 million tons equivalent CO_2 for scenario 1 and 2 respectively. It will be an increase of approximately 2.6 fold of GHG emission over a period of 25 years compared to that of 3.3 fold increase of the baseline scenario. Thus a good reduction was achieved by both scenarios. Figure 5.3.shows the reduction achievement compared to the targeted values. Obviously scenario 2 meets very closely the set target percentage reduction. On the other hand, scenario 1 did not deviate much either.

The average emission reduction from baseline scenario for scenario 1 will be around 2935 million kg/year of CO_2. This gives per reduction a leveled cost of 21.27 US$/ton (real 1995 US$/ton) and a leveled cost of 62.42 million US$/year. For scenario 2 the average emission reduction will be around 3252 million kg/year of CO_2 which gives per reduction a leveled cost of 21.72 US$/ton (real 1995 US$/ton) and a leveled annual cost of 70.64 million US$/year.

The cost benefit analysis shows that there is a cost benefit ratio of 0.4501 if scenario 1 is considered and 0.4198 if scenario 2 is considered.

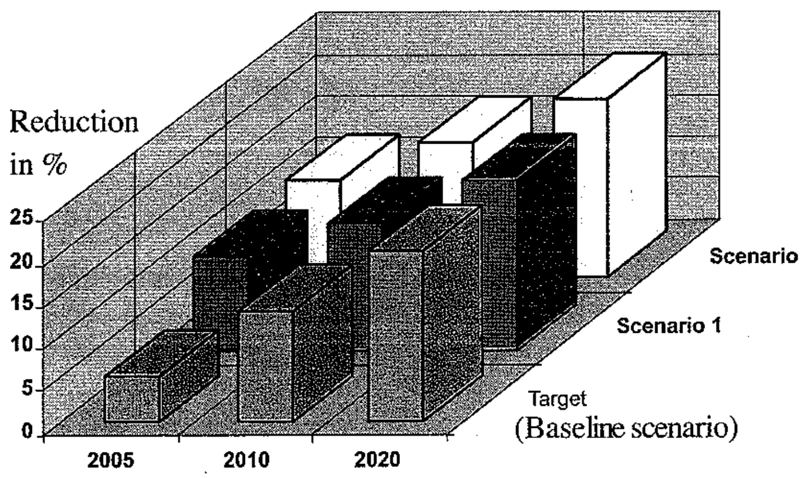


Figure 5.3 Expected CO_2 reduction for the two scenarios

5.2.2. An Overview of Measures (Options)

A sustained development of Yemen makes it necessary for the country to develop a comprehensive national action plan to identify and implement different possible mitigation and adaptation options to reduce GHG emissions and to cope with climate change. Such a plan would unify and guide the efforts of different institutions involved to a fruitful coordination and cooperation and to implementation.
In addition to those options included in the mitigation scenario, a number of other mitigation measures can be introduced:

5.2.2.1. SUPPLY SIDE MEASURES

Power generation

a) *Efficient power generation, transmission and distribution*
This implies the improvement of the efficiency of the existing power plants, reduction of transmission and distribution losses, integration, where feasible of renewable energy sources for electricity generation to cover the auxiliary power supply of power plants and substations and hence increasing the overall efficiency, and supplementing conventional power plants gradually with solar thermal plants to save fuel.

b) *Switch to efficient power generation for new generation capacities that are to be installed.* CCGT plants use two stages of energy extraction from the fuel (gas and steam turbines), allowing overall efficiencies to approach 60%. They are best suited for central (interconnected) power supply. CHP-systems (Combined Heat and Power) with overall efficiencies of more than 80% are appropriate for decentralized power supply and can be used for rural electrification, and in industrial, commercial and residential sectors. CHP-systems generate electricity and thermal energy in a single, integrated system.
The thermal energy recovered in a CHP system can be used for heating or cooling in industries or buildings. The significant increase in efficiency with CHP results in lower fuel consumption reduced emissions compared with separate generation of heat and power.

c) *Promote the use of renewable energy sources for electricity generation.*
For many rural areas in Yemen, especially where population is dispersed in scattered dwellings, grid connection is economically not feasible. Power supply using diesel units is technically non-feasible. Therefore, renewable energy-based decentralized power supply using PV-systems (Solar Home Systems), wind energy converters, where feasible, and biomass, in stand-alone and hybrid schemes will be the best alternative.
Yemen can also generate electricity on a large scale from renewable energy sources because of its location and climate diversity. Solar thermal power plants and wind farms can directly make grid-connected operations and substitute huge amounts of fossil fuels fired in conventional power plants.

Fuel switching to natural gas

Natural gas is environmental friendly and is considered as the fuel of the future. Due to the enhanced fiscal incentives offered by the government, more international investment in the gas sector is expected. It is planned that natural gas should be widely used for power generation and industry, in addition to the residential and commercial sectors in rural and urban parts of the country.

5.2.2.2. DEMAND SIDE MEASURES

As identified earlier, the household and transport sectors are the most energy-intensive sectors in Yemen and therefore the main sources of GHG emissions. Strict energy saving policy should be especially implemented for these sectors. In the following paragraphs, measures are briefly presented for application in the main sectors.

Residential and Commercial Sectors

a) *Launching energy-efficiency programs through establishing energy efficiency standards and labeling.* With efficient appliances, Yemen can enhance the overall efficiency of its national economy and meet climate change goals and avert urban/regional pollution. The substantial savings obtained by countries that have implemented energy efficiency programs demonstrate the enormous potential waiting to be tapped.

b) Appropriate energy use regulations should be introduced.

c) Public awareness campaigns should be implemented. The integration of energy saving and environment awareness concepts in education and curricula (schools, vocational and technical institutes, universities) is of major significance. All communication media can be exploited for this purpose. The NGO's can play an important role in this respect.

d) Regulations for energy-efficient buildings should be issued. No energy-related codes and/or regulations and standards exist till now in Yemen. While traditional Yemeni buildings that were built in harmony with local environment by means of local construction materials are considered energy efficient and most of them energy-sufficient, a huge amount of (heating/cooling) energy is lost in modern concrete buildings and constructions due to inappropriate thermal insulation of construction materials.

e) Passive use of solar energy. It comprises the use of appropriate structural measures to heat buildings, provide lighting or air-conditioning. Passive solar measures extend beyond the simple approaches to thermal insulation. They should explicitly take account of the diurnal and annual variation in the solar radiation to create pleasant living conditions and also save energy. No negative aspects are observed for the passive use of solar energy.
It is important to choose the right direction now in the formulation of building regulations, and building contractors and architects should be made aware of these aspects, so that the application of new technologies and designs can be encouraged at least in the new building sector.

f) Active use of solar energy. The promotion of the use of solar water heaters to meet the demand of hot water for residential and commercial sectors will have huge energy savings. Electric water heaters consume about 60% of the electrical energy in northern regions in Yemen in winter and nearly the same rate is consumed by cooling loads (air-conditioning, ventilation, refrigeration) in southern and eastern regions. Efforts to promote the use of solar-driven air-conditioning and solar refrigeration should be encouraged for the same reason.

Transport sector

The use of energy in this sector should be rationalized through the following measures:

a) *Improve fuel efficiency.*
b) *Establish an efficient traffic management system*
c) *Encourage import of fuel-efficient vehicles.*
d) *Increase efficiency of freight transport*
e) *Shift from gasoline and diesel to LPG*
f) *Launch awareness raising programs*

Industrial sector

a) *Fuel switching to natural gas as discussed above.*

b) *Rational use of energy.* Energy saving, waste heat recovery, optimization of existing energy conservation and production processes, use of energy-efficient equipment, CPH-(co-generation) systems are very promising.

c) *Integration of renewable energy sources in the industrial energy supplies concepts.* Solar water heaters and solar collector systems can replace electric ones; process heat or steam can be supplied by solar concentrator systems (e.g. parabolic troughs). Where feasible, electricity generation from solar energy (PV) and/or wind can contribute partially to cover the industrial electrical demand.

5.3. Adaptation measures

The proposed adaptation measures are generally applicable to national level, however, as the studies were area-specific or crop-specific, specific adaptations were also assessed for the study areas.

5.3.1. Water resources:

National water strategy

Study results indicate high vulnerability of water resources to potential climate change impacts and the serious dimensions of the water crisis in Yemen which is primarily manifested by decrease and shift in rainfall distribution, scarcity of water resources, depletion of groundwater, low efficiency of water use, and by low coverage of water and sanitation services. The need for rational use of water resources in Yemen becomes even more urgent in view of the potential anthropogenic climate change, and such a strategy should be accepted as the water management policy in the country, as several adverse effects (e.g. desertification) may take place.

In an attempt to avoid future catastrophes, water crisis has been addressed at the official and public levels, within a comprehensive national water strategy, which set for the long-term objectives and principles of the water sector. The government has adopted the following water strategy, and will supplement it with a set of policies and action plans to help achieve its objectives, such as irrigation policy, water utility policy, and wastewater policy. Incorporating climate change impact assessment results into Yemen's national development plans has not yet been worked out. This is mainly because the results obtained are considered preliminary as it covers only part of the country. Further research will be required for application of the results to the whole country.

The proposed National Strategy of water resources sector adaptation of Yemen comprises several measures that can be grouped under:

1. Measures to support development and management of water resources
2. Measures for private sector participation
3. Measures for investment and water pricing
4. Legislation and institutional set-up measures
5. Capacity building and performance measures

Full practical implementation of adaptation measures will require significant investment and a long period of time.

Priority adaptive measures for Abyan delta

Priority of measures allowing conservation and increase of water resources available for economic activity on the Abyan Delta was assessed through the water resources management model, which can be dealt with as follows:

(i) It is estimated that agriculture currently uses about 90% of the water resources in Abyan Delta. Irrigation efficiency varies from 40-60% (averaged 55%). The improvement in water use efficiency is one form of adaptation that has minimal costs. To increase irrigation efficiency in Abyan delta from 58% in 1995 to 75% in 2025 and then to 80% in the year 2050 would cost about 15.7 Million US dollars and would save a cumulative total of 1300 Million cubic meter of groundwater allowing for the cropping pattern to be changed toward cash crops.

(ii) The amount of water stored as groundwater in Abyan Delta is estimated as 5670 MCM. The annual recharge rate to groundwater aquifer is 18 MCM/year while annual abstraction rate in 1995 was 68 MCM/year and is expected to increase to 187 MCM/year by year 2050 due to fluctuation of rainfall and runoff under climate change. One feasible adaptation to increase groundwater recharge is through capturing the surplus runoff that goes to the Sea, averaged as 27 MCM/year by structural means. The cost of construction of two medium size dams in Abyan delta is about 2.5 Million US dollars.

(iii) Abyan Delta supplied Aden City 11 MCM/year in 1995 from its groundwater aquifer and it is expected to become 18 MCM/year by the year 2050. As the aquifers in Abyan delta would start to be depleted partially starting year 2002, other sources for supply to Aden city should be located as people in Abyan would not accept their water to be taken away to Aden while their agriculture drying up and abandoned. Aden City is located near the Gulf of Aden and hence desalination option represents a feasible measure compensating Abyan Delta source. The construction of a desalination plan capable of producing 15 MCM/year is about 45million US dollars.

5.3.2. Agriculture

Simulated adjustments included a change in planting dates, i.e. altered varieties and changed tillage practices. In addition, technological advances assumed irrigation efficiency and crop drought resistance as well as improvement in a number of crop specific characteristics, including water use efficiency, photosynthetic efficiency, harvest index, earliness, yield stability, and disease and pest resistance.
A number of management options would be thought of, such as water harvesting, weed control, use of machinery in planting and harvesting, improved seeds, better storage conditions, etc.. Several management options are given below:

(i) Improved irrigation practices such as optimal scheduling of high frequency and low-volume water delivery, adequate drainage and salinity control in Agricultural land already irrigated, and extension of appropriate irrigation techniques to rainfed areas will be the key element in expanding food production to meet increased demands in the future.

ii) Traditional technologies, such as multiple cropping and terracing may serve to buffer the small holder farming system against climate variability by conserving soil moisture and fertility and by increasing yield.

(iii) Climate change alters the amount and distribution of rain and thus the growing season for crop also changes, and crop performance might be improved by shifting the sowing date. However, farmers wait for the first rain in the season to plant wheat. If the rain delays, they plant other crop, such as barley, lentils or fenugreek. And in this case adaptation measures can be taken as producing varieties which can finish the production cycle before the frost of weather sets in.

(iv) Less rainfall in the semi-arid highlands of Yemen may persuade farmers to cultivate drought resistant crop such as barley, sorghum, lentils, etc., to alter crop management, to change varieties, and to adopt better tillage practices. In addition, technological advances will be expected in irrigation efficiency and crop drought resistance as well as improvements in a number of crop specific characteristics, such as harvesting index and photosynthetic efficiency.

Policy Options for Adaptations in Agriculture:

1. *Develop new crop types and enhance seed banks:* Seed banks having a variety of seed types provide farmers with an opportunity to both counter the threat of climate change and develop a profitable categorization.
2. *Develop of more and better heat and drought resistant crops:* It will help fulfil current and future demand of food grains by enabling their production in marginal areas to expand. This kind of improvement will be crucial because Yemen's population will continue to increase, regardless of climate change.
3- *Avoid mono-culture and encourage farmers to plant a variety of heat and drought resistant crops:* Growing of single crops, such as sorghum, increases farmers' vulnerability to climate variability. If the probability of drought and heat waves increases with climate change, such vulnerability can further increase. One adaptation option for farmers will be to plant a wide range of crops to reduce the risk of crop failure. Through its agricultural extension service, the Yemen Government should advise farmers to grow drought resistant food crops.

4- *Avoid tying subsides or taxes to the types of crop and acreage:* Commodity support programs or tax policies may discourage switching from one cropping system to the other that is better suited to a changed climate. Therefore efforts to stabilize farm supply and maintain farm income should avoid disincentive for farmers to switch and rotate crops and use the full acreage normally planted. This policy approach will increase the efficiency of current farming practices and will also increase the ability of the system to quickly recover from climate change.
5- *Increase efficiency of irrigation:* Many farming technologies, such as efficient irrigation systems, provide opportunities to reduce direct dependence on natural factors such as rainfall and runoff. In evaluating improvement to irrigation systems, the additional benefit of reducing vulnerability to climatic variations and natural disasters should be considered. Utilizing highly efficient irrigation systems provides for sustainable agriculture by reducing water consumption with minimal yield reductions as well as releasing pressures on scarce water resources.
6- *Disperse information on conservation management practices:* Many practices such as conservation, tillage, furrow, terracing, contouring and planting vegetation to act as windbreak will protect fields from water and wind erosion and can help retain moisture by reducing evaporation and increasing water infiltration. Using management practices that reduce dependence on irrigation will reduce water consumption without reducing crop yield.
7- *Liberalize agriculture trade: Lowering* trade barriers will result in higher levels of global agricultural production both under the current climate and under climate change scenarios. Farmers will receive information on changes of global market conditions faster than if trade barriers were not lowered.
8- *Promote agriculture drought management:* Encourage Management practices that recognize drought as part of highly variable climate and not treat it as a natural disaster should be encouraged. Farmers should be given information on climatic conditions, incentives should be offered to them to adopt sound practices for drought management. They should also be discouraged from relying on drought relief aid.
9- *Establish flexible mechanisms for intervention especially for dealing with Qat:* In order to limit Qat cultivation area expansion, new alternative cropping should be encouraged and thus the eventual goal of phasing out Qat can be achieved.
10- *Promote awareness of climatic variability and the potential risk of climate change:* This phenomenon is not well understood by people or by decision markers. Because climatic adaptation will affect the individual, organizational and policy levels, communication about the human significance of climatic variability is important at all levels in a community. Increasing sensitivity to climate issues will facilitate adaptation of measures to prepare for climatic variability and change.
11- *Maintain options to develop new dam sites:* In order to enhance water resources through increasing run-off utilization and reducing water demand from the already depleted groundwater aquifers to increase water supply, new dam sites should be developed. Hence, creating better chances for protection against future drought, and adopting early-warning planning for drought risk management should be promoted.

Additional adjustments for crops studied

The impact of climate change on crop yields reduction and net irrigation requirement exhibits significant temporal and spatial variability. The social and economic cost/benefits of such variability is described below.

In the semi-humid areas, where wheat will show invulnerability to climate change and less yield reduction in potato, expansion in the production of these crops will be more likely. Provided that farm gate prices for wheat are going to increase as a result of the lifting of wheat price subsidy rainfed wheat will be more attractive to farmers. On the other hand, great attention should be paid to soil drainability in potato fields, when the wet scenario will prevail. Cost-effective drainage systems should be considered.

In the semi-arid areas, the need for both supplemental and conventional irrigation is more likely, due to water shortage for both potato and wheat. Additional investment will be needed for installing necessary irrigation management facilities. Increased attention must be paid to conserving scarce water supply. Further deterioration of water resources related to climate change is predicted.

In the arid areas, further deterioration in water resources related to climate change is predicted, particularly in the Marib area, where the irrigation water demand is higher than that of other regions of the country. It is anticipated that even mild climate change (OSU-scenario) could cause severe pressure on water, where the available water resources are insufficient. Consequent socio-economic measures should be given due consideration.

For the sake of plant protection, a careful chemical treatment will have to be increased so that waters resources are not polluted. Thus, climate change would provide better conditions for the development of pests, and increase the cost of protection. Otherwise, insufficient plant protection measures will reduce the profit of agricultural crops.

5.4.3. Coastal zone

Policy adaptation options:

Managing shorelines in the environment of global sea level rising has been a great challenge. Historically, the primary choice of measure for managing coastal erosion has been the protection of shorelines with hard-engineered structures. The high cost of protection, in the order of US$2,000 per meter of protected shoreline for sandy shores, should be borne in mind when making decisions about the construction of hard defences. Besides, the high cost associated with coastal protection, protecting one segment of shoreline often translates the problem to the downdrift shores. The case of protection on sandy beaches with the bedrock not shallow enough to provide a good foundation for coastal structures has rendered such structures under these environments to serve only as a temporary measure. Either the beach will have to be replenished periodically at great cost or armour rock will have to be added to maintain the structure with time. The long-term cost can be prohibitive.

In response to lessons learnt on managing shorelines and the high cost associated with shoreline hardening, it has become prudent to manage shoreline considering all options available. Retreating inland from the existing line of flood defence may be necessary for coastal protection, while monitoring and maintaining an awareness of the consequences of retreat. The concept requires an understanding of the entire process influencing shoreline dynamics to enable appropriate intervention when necessary. It includes:

• *Set back*, which means allowing space between the shoreline and associated coastal hazard and property to act as buffer, is most suited for coastal areas that are not yet developed. Knowledge of historical rates of erosion for the particular coastal segment is required. With the assumption that this rate will remain the same in the future, a line (set back) is determined where the shoreline position will not reach during the life of proposed structures within the area. The usual trend is to fix the set back using the projected shoreline position after 60 years. So if the rate of erosion is 2 m per year, the set back will

• be set at 120 m from the shoreline.

The advantages for such a measure is that it enables nature to take its own course and avoids the need to put up expensive protection with resources, which are often not available. Even when resources are available they should be used for other developmental purposes.

• *Controlled abandonment:* Requires abandoning the existing line of defence and allowing nature to redefine the shoreline position. Monitoring would be required regularly and possible intervention in the form of protection applied when necessary would also be required to achieve objectives in respect of environmental enhancement.

• *Full protection:* Deliberate actions are needed to maintain the shoreline position at a particular location often through the design and construction of artificial structures. The structures include revetments, sea walls, groynes, artificial headlands and beach nourishment. These are some suggested criteria to determine the areas for full protection. Various reports have suggested the protection of all areas with a population density of 10 persons per square kilometre.

• *Do nothing:* Refers to the option that involves the abandoning of the existing line of defence without any future monitoring or intervention of any kind.

The various options of managed retreat will be considered for each of the shoreline segments. For the shores that have remained undeveloped, more detailed assessment of the situation is possible to come up with a rational response.

Adaptation measures for pilot area

CITY AREA

The losses associated with do nothing or abandoning about a quarter of the city amount to some US$ 1,3 billion. It is clear that this option is not acceptable and that full protection should be provided. This protection will vary along the coastline according to local requirements, and will comprise a number of elements:

- southern part of the city: raising of the level of the rock revetment;
- fishing port: raising of area level; in the long term probably strengthening of the breakwaters;
- north of fishing port: raising of the level of the rock revetment;
- Cornish area: raising of the level of the wall; check on the stability of the foundations of the sea wall since it is expected that the beach will be eroded away;
- Construction of a sea wall at the northern part of the city area.

Summing up, considerable strengthening of the existing constructions will be required over a length of approximately 10 km. Assuming an average cost of US$ 2 million per km the total cost will amount to US$ 20 million.

SAND SPIT

There is a risk that in the coming years an increasingly longer length of road will be provided with stone protection to prevent the road from being washed away. Before this happens the relevant authorities should decide whether to indefinitely maintain this road to the naval base at large costs in the future or to abandon the sand spit and move the naval base. As described before, abandoning will probably mean a breaching of the spit and a changed current regime in the access channel to the port, leading to increased siltation. The decision to be taken must also weigh these consequences.

5.4. Education, Training, and Public awareness

The Environmental Protection Law of Yemen enacted in 1995 paved the way for most environmental programs in Yemen, including signing and ratification of the UNFCCC by Yemen. Article 6 of the UNFCCC requires Parties to the convention to promote and facilitate the development and implementation of education and public awareness programs on climate change and its impact.

Education and awareness on climate change, its implications and ramifications on nation's natural resources, economy etc. are of utmost importance in the formation of environmentally aware and enlightened citizens.

The preparation of the national communication in early 1998 was the first step in the actual implementation of the UNFCCC in Yemen. During that process, special emphasis was put on strengthening the dialogue, information exchange and cooperation among all the relevant stakeholders including governmental, non-governmental, academic and private sector representatives at technical as well as political level. By doing so, it is believed that a process of educating and taking increasingly climate change related issues into account in the general planning and strategy formulation process in the country has been facilitated- not only as an obligation but also as an opportunity to introduce new strategies and technologies on a "win-win" basis. Involvement and cooperation of all relevant stakeholders have been achieved through organizing a number of national workshops funded by NCCSAP by the PMU. In addition, national experts, hired to implement the activities, have liaised and conducted their studies in close consultation with the relevant ministries and other stakeholders and they incorporated a summary of official inputs and comments of these institutions into their final report.

A general strategy regarding the target audience for the workshops was to make the "policy oriented" workshops accessible to a broader audience, including both policy makers and technical experts from the governmental as well as from the private sector. Technical training/coordination workshops were meant more for the people actually conducting studies so that their capacity could be built. The latter has benefited from the

NCSSAP/GEF funding in building capacity for the preparation of the national communication, where several training workshops were held on how to conduct national studies (greenhouse gas inventory, mitigation, vulnerability and adaptation on water, agriculture and coastal zone).

Several seminars, meetings and local workshops were organized at some universities in Yemen to further encourage and stimulate interest in climate change and its environmental impacts among the researchers, professionals and students. Coverage of these events by the popular and easy means of communication, TV, Radio, and Newspapers and separate talks given by local and foreign experts further facilitated reaching to the largest audience.

Climate change per se has not yet been included in the curricula of the formal education system in Yemen as it is a new, developing science. However, climate change and related issues have been included in various courses offered by the university of Sana'a and Aden, especially in earth and environmental sciences, agriculture, geography and Engineering.

"Environmental clubs" have been created in primary and secondary schools and some information and training on climate change and its impact with other environmental issues has been given to the active members.

Awareness-promoting materials such as, posters, pamphlets, on climate change also can help to promote climate change understanding and raise the level of public awareness in concrete everyday terms.

A few recently established environmental NGOs, such as the Yemen Society for Environmental Conservation, contribute to the raising of public awareness and education on environmental issues. It also serves as an informal forum to exchange information and views on environmental issues between its members from different ministries, universities, etc. Climate change has been taken into the main stream of their environmental discussions.

People also become aware of climate change from their own observation of some rapid changes taking place, such as increasingly warmer seasons, erratic rainfall, drought followed by exceptionally heavy rains, coastal erosion and reduced yield in agriculture, presence of Malaria in the cold highland areas, and public inquest. *People do not necessarily understand the scientific principle of climate change as the underlying cause of the observed effects of rapid changes in climate. Still it formed a resource base for non-formal education, which is being encouraged.* EPC took the initiative to inform many journalists about climate change, many of whom put up lengthy reportage, included opinions of several officials from relevant institutions and published an interesting series of articles on the effects of climate change which directly affect people in their everyday life.

The observations and views of many researchers and scientists working in the area of water, agriculture and coastal climate related aspects in Yemen, expressed in personal discussions, symposia or professional meetings were broadcast and televised.

Chapter Six

RESEARCH NEEDS

6. CLIMATE CHANGE RESEACH NEEDS

The Republic of Yemen, being vulnerable to impacts of climate change, is interested in conducting systematic observation of all relevant variables to climate change phenomenon. Also local experts and researchers are keen to participate in international activities and programs related to the Global Climate Change to fulfil the commitments of the country towards the implementation of the climate change convention.

The level of awareness of climate change phenomenon and its effect is very low in Yemen, mainly due to the relatively short time since the start of the actual implementation of the UNFCCC. The process of gathering appropriate literature on climate change and making it available to policy makers is actively on. However, more assistance (financial and technical) is required to support meaningful climate change research building capacity. Building national capacity in climate change is likely to create more interest in and ensure meaningful debate on the issue of climate change in Yemen.

Proper data organization is vital to address climate change issues. There is a need to centralize all climate change related data. The location of such an important data bank should rest with the Environmental Protection Council, the focal point of UNFCCC in Yemen.

There are significant financial constraints in conducting longitudinal or even medium-scale scientific research (e.g., gathering field data). Such constraints adversely affect the construction, validity and reliability of national studies. Although the findings of pilot studies that focus on a "representative" area can be generalised, the results may not be totally realistic. Only three studies were conducted over selected sites to assess the negative impact of climate change. There is a great need for further understanding of its likely impacts and adaptation at a national level for sectors covered during the preparation of the initial National Communication using a more integrated approach. More comprehensive research is required to complete work on impact and adaptation for sectors partially analyzed during the preparation of the initial National Communication as well as other specified sectors not covered yet, but likely to be effected by climate change, such as human health, desertification and land degradation. Impact assessment of climate change in these sectors should be done on a priority basis. Sufficient funding is needed to create an information pool and to make available the appropriate software programs for data analysis, documentation and dissemination, especially as climate change is a new subject in Yemen. Expertise in research related to climate change is important and Yemen requires developing research capacity in various related disciplines.

The few studies conducted for preparation of this initial National Communication provided indication of possible areas where further work ought to be done. Gaps in information for these sectors are reported below.

Water resources

- Conducting impact assessment on other sites that will enable regionalization of results for the whole country. Areas that experience high stresses of water resources at the moment and hence are more vulnerable.
- Identification of potential adjustments and adaptation measures to climate change, as it will vary greatly from one region to another.

Van der Gun J. M., & Abdul Aziz Ahmed. 1995, The water resources of Yemen. A summary and digest of available information. WRAY Report 35. TNO/Netherlands, GDH/Yemen.

World Bank, 1997; The world Bank and Climate change : Middle East and North Africa, information sheet (http/www.worldbank.org/html/extdr/climchng/mnaclim.htm)