IMPACT OF CLIMATE CHANGE ON HUMAN HEALTH IN THE COASTAL GULF REGION USING DATA FROM GLOBAL CLIMATE MODELS

JUNAID RAFI CHAUDHARY

Impact of Climate Change on Human Health in the Coastal Gulf Region using Data from Global Climate Models

by

©Junaid Rafi Chaudhary

A thesis submitted to the School of Graduate Studies in partial fulfillment of the requirements for the degree of Master of Engineering

Faculty of Engineering and Applied Science

Memorial University of Newfoundland

October, 2006

St. John's **Newfoundland** **Canada**

Your file Votre référence
ISBN: 978-0-494-31240-7
Our file Notre référence
ISBN: 978-0-494-31240-7

Abstract

The study was conducted to assess long-term impacts of the anticipated changes in temperature, precipitation and humidity in the five Arabian Gulf countries over the next hundred years. The impact of the anticipated climatic changes on human health was estimated based on the Intergovernmental Panel on Climate Change (IPCC) database. Long-term simulated records for A2 and B2 scenarios were retrieved for longitude 41.25°E to 61.875°E and latitude 9.278°N to 27.833°N for Bahrain, Oman, Qatar, United Arab Emirates (UAE) and Yemen using the following three global climate models (GCMs).

1. Hadley Centre Global Model (U. K)
2. Canadian Centre for Climatic Modeling and Analysis (CCCMA)
3. National Centre for Atmospheric Research (NCAR) Model (USA)

Using average of 1970 to 2000 values as baseline values, the changes in the humidity, temperature and precipitation were estimated for the period 2020 to 2050 and 2070 to 2099. The study showed inconsistency in the prediction of temperature, precipitation and humidity by the above three GCMs, probably due to lack of validation and poorly defined boundary conditions for the region. The predicted temperature increase by NCAR was conservative in 100 years as compared to the other two models. While CCCMA and NCAR predicted higher precipitation fluctuations as compared to Hadley model. The higher uncertainty and inconsistent trends in data prediction as observed by these GCMs require further investigation by validating an appropriate regional climatic model.

The climatic variations play a critical role in increased morbidity and mortality due to spatial and temporal spread, timing and severity of infectious diseases. The summarized impacts of climatic changes on the human health based on the empirical approaches project significant increases in disability adjusted life years (DALY) and mortality rates. Amongst the five Gulf coastal countries Yemen and Oman are found more adversely affected with higher anticipated mortality and DALY rates than Bahrain, Qatar, and UAE.

Acknowledgments

I dedicate this thesis to my late father Chaudhary Jahan Dad Khan who apart from being a teacher was a visionary person blessed with courage and determination. He died in Pakistan during the course of my studies and kept on advising till the very end to remain focused on my studies and did even permit me to plan a visit to see him. My special thanks to my mother Ghulam Zainab for her unflinching support, love and prayers.

I am grateful for the support, love and care extended by my wife Shaheen, daughter Mashal and son Zeerak during my studies. I am also indebted to my brothers Dr. Sohail Safi, Nadeem Zaki and Sarmad Waqas for their tremendous support during my graduate work.

I would like to extend my heartfelt gratitude to my supervisor Dr. Tahir Husain who always extended maximum help in my research, and provided me his expert guidance at Memorial University of Newfoundland. He was a source of tremendous strength and knowledge.

It was indeed a source of utmost pleasure that I was able to work with and learn from such a distinguished Professor. Acquaintance with him during the course of my studies will indeed remain a part of my cherishable memories in the years ahead.

I am also thankful to Dr. Anver Rahimtula, Dr. Norm Catto and Dr. Leonard Lye for the valuable knowledge they imparted to me through their respective courses during my studies.

Finally I would also like to thank all of my friends in the University for providing me with a wonderful and pleasant working environment during my stay at Memorial University of Newfoundland.

Table of Contents

List of Tables

List of Figures

List of Symbols

GCM	Global Climate Model
IPCC	Intergovernmental Panel on Climate Change
IPCC(TAR)	Intergovernmental Panel on Climate Change's Third Assessment Report
IDDC	Data Distribution Centre
CO	Carbon monoxide
CO_2	Carbon dioxide
N_2	Nitrogen
NO_2	Nitrogen dioxide
NO_X	Nitrous oxide
O_2	Oxygen
O_3	Ozone
SO_2	Sulphur dioxide
CH_4	Methane
PM	Particulate Matter
TSP	Total Suspended Particles
Ar	Argon
IR	Infrared radiations
UV	Ultra Violet
HC	Halocarbons
GHG	Green House Gases
UNEP	United Nations Environment Programme

UNDP	United Nations Development Programme
WHO	World Health Organization
WMO	World Metrological Organization
ICSU	International Council of Scientific Unions
AGGG	Advisory Group on Greenhouse Gases
FAO	Food and Agricultural Organization
IAEA	International Atomic Energy Agency
WEC	World Environment Centre
US EPA	United States Environment Protection Agency
VBD	Vector Borne Diseases
CDC	Centre of Disease Control and Prevention
DALY	Disability adjusted life years
YLL	Years of life lost
YLD	Years of life lost to disability
CFC	Chloro Flouro Carbons
SRES	Special Report on Emissions Scenarios
A-2	Fragmented World Scenario
B-2	Local sustainability Scenario
IPAT	Impact Population Affluence Technology
GDP	Gross Domestic Product
AGCM	Atmosphere General Circulation Model
OGCM	Ocean General Circulation Models

AOGCM	Coupled Atmosphere-Ocean General Circulation Model
TGICA	Task Group for Impact and Climate Analysis
MDG	Millennium Development Goals
LNG	liquefied natural gas
CIA	Central Intelligence Agency
RHUM	Relative Humidity
SPHM	Specific Humidity
EMRO	Eastern Mediterranean Region
NKr	Norwegian Krone
EWS	Early Warning Systems
RCM	Regional Climate Model

Chapter 1

Introduction

1.1 Background

Among all the different planets of our solar system, only the Earth is livable planet for mankind because of its position as compared to the sun and the natural greenhouse effect of its atmosphere. The earth's atmosphere constitutes approximately 60% of water vapor, 25% of CO_2, 8% of ozone and about 7% of other trace gases like methane, etc. *(Karl and Trenberth, 2003)*. These constituents, combined with the clouds, determine the overall natural greenhouse effect. The natural greenhouse effect is amplified because of the altered atmospheric composition due to rapidly increasing population and elevated levels of emissions caused by the human influences (industrialization, transportation increased energy consumption and land use etc). According to the Intergovernmental Panel on Climate Change (IPCC), developed countries are consuming higher quantities of fossil fuels as evident from the 31% increase in the CO_2 since 1750 (*IPCC, 2001a*).

Though the earth's climate has always been changing due to the natural greenhouse effects, but the sharp increase in the rate of change at regional and global levels due to the human induced greenhouse gas emissions is a source of concern for mankind and necessitates proper ramification at national and international levels. This assertion has been verified by the Third Assessment Report (TAR) of IPCC which clearly attributes the increased global warming over the last 50 years to human activities (*IPCC, 2001a*).

1.2 Weather and Climate

Weather describes the physical state of the air at any particular time and location and the subsequent changes in them over time encompassing the daily changes in temperature, precipitation, humidity, pressure, and wind conditions, whereas climate encompasses the statistical description of different atmospheric conditions.

The term "climate change" refers to the changes in the average weather (temperature, wind patterns and precipitation), experienced by a particular region over a certain period of time that can range from months to decades and to thousands of years. However the metrological organizations describes the period spreading beyond three decades as a classical period.

Climate is linked to almost all the aspects of our economy and daily life. Resources such as agriculture, energy, forests and fisheries are particularly sensitive to meteorological changes and climate variations. Human health depends on factors like availability of sufficient quantities of food, safe drinking water, proper living conditions, and effective mitigative steps required to control infectious diseases. Since these health determinants are affected by the variations in the climate, the subsequent climatic changes are bound to have wide-ranging impact upon human health.

1.3 Climate System Components

The climate system constitutes five major components namely, the atmosphere, the hydrosphere, the cryosphere, the land surface, and the biosphere. All of these constituents are influenced by various forcing mechanisms, with 'sun' being the most vital, apart from the human influences which are generally referred to as external forcing. (*IPCC TAR-01*)

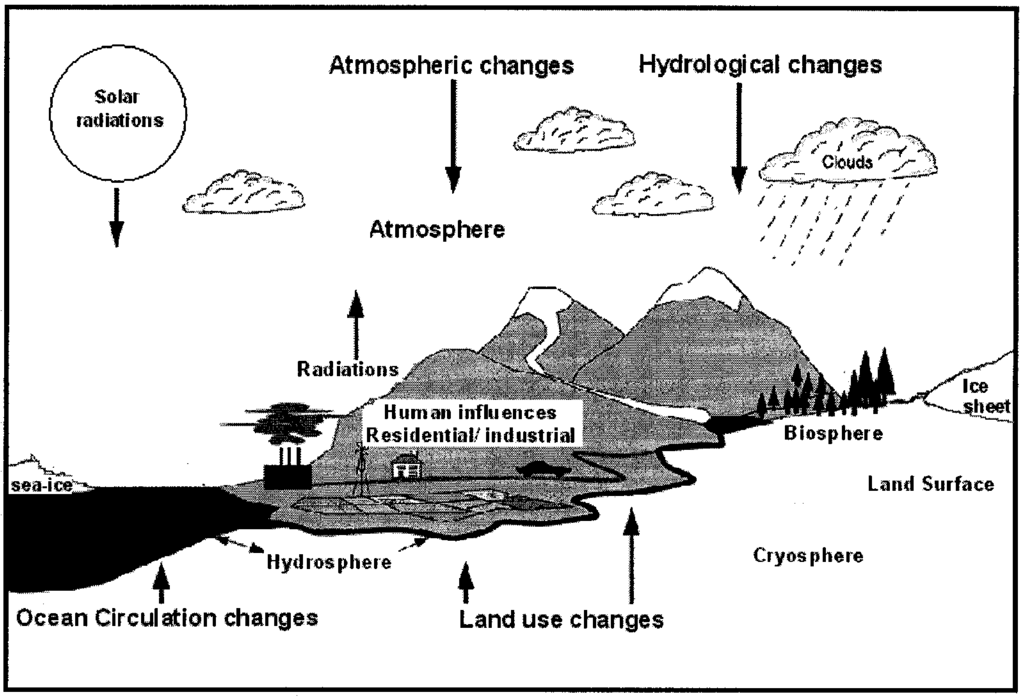


Fig 1.1: Different interacting components of the global climate system (Modified from *IPCC, 2001*)

The atmosphere is extremely unstable, its composition has been rapidly changing since the Earth's evolution but it occupies the central role. Dry atmosphere consists of nitrogen (N_2), oxygen (O_2), and argon (Ar). They have limited interaction with the incoming solar radiation and they do not interact with the IR radiations emitted by the earth. But there are other gases referred to as greenhouse gases, including CO_2, CH_4, N_2O and O_3, which not only absorb but also emit infrared radiation. Greenhouse gases and water vapors play a central role in the Earth's energy budget, as they absorb the IR emitted by earth, and then re-emit it in both upward and downward directions hence raising the earth's temperature near its surface.

The hydrosphere consists of fresh water (rivers, lakes and aquifers) and saline water (oceans and seas). Fresh water runoff influences the ocean's composition and circulation as they store and transport large quantities of energy and CO_2. Ocean circulation regulates the Earth's climate, on extended time-scales.

The cryosphere consisting of the ice sheets (e.g. glaciers) is important for the climate system because of its properties like albedo (high reflectivity), etc, and their role in the ocean water circulation. As ice sheets store large amount of water, variations in their volume results can have considerable variations of sea level.

Land surface consisting of soil and vegetation patterns determines the amount of solar energy returned to the atmosphere. Some of the energy is returned back as IR radiation, heating the atmosphere while the other is utilized for evaporating water, from the soil and plants thus bringing water back into the atmosphere.

Biospheres (marine and terrestrial) play a major role in the atmospheric composition. As plants store huge amounts of carbon from carbon dioxide (CO_2) by virtue of the photosynthesis process, they influence uptake and release of greenhouse gases. They regulate carbon cycle as well as the budgets of gases like methane and nitrous oxide. The storage of carbon and interaction of trace gases is strongly influenced by climate and can be observed from fossils and tree rings, to assess the past climate.

1.4 Interactions among components

Numerous physical and chemical reactions are constantly taking place between various components of the climate system on a broader spatial and temporal scale. The components of the climate system are unique in nature but their physical and chemical properties like structure and behavior are all linked by fluxes of mass, heat and momentum. For instance, the biosphere affects the input of water in the atmosphere by evapotranspiration (because of albedo), atmosphere and oceans exchange CO_2, among other gases, and maintains a balance by dissolving it in colder waters releasing it at relatively warmer temperatures.

Changes in the components of the climate system or their interactions either natural or anthropogenic, or in the external forcing, can result in considerable climate changes.

The cyclic variations in earth's orbital and planetary motion are also responsible for the world's changing climate, along with the variations in solar radiations and volcanic activity (short-term). Various studies of warming trends show inconsistent rise in nighttime and winter temperatures, causing increased frequency and severity of extreme weather events resulting in significant biological implications, by adversely affecting hydrological system, fresh water resources, agricultural productivity and bio-diversity (*Epstein et al., 1997*).

1.5 Effects

These anthropogenic climate changes are not only an environmental issue rather they are a question of long-term sustainable development, as they are capable of endangering our survival with regards to the fundamental requirements like clean water, enough food and a healthy and safe environment to live in. Climatic changes alter the frequency and severity of extreme weather events, as is evident from the changes observed at regional levels. The increased frequency of these extreme weather events (flooding, hurricanes and tornados etc.) results in increased risk to human health because of increased number of injuries, infectious diseases, stress-related disorders, social disruption, forced migration and deaths associated with these events.

Hence climate can be considered to be one of the basic driving forces behind epidemic spread, as its effects are widespread and pronounced, if the necessary adaptive measures are inadequate, or uneven among the population. Health effects of climatic changes can be broadly sub divided into two categories (*Woodward et. al., 1998*):

Direct

- Illness and deaths due to temperature extremes
- Injuries because of floods and storms

Indirect

- Increased vector borne infections
- Increase in the number of other infectious diseases
- Respiratory problems/diseases
- Disrupted agricultural activity causing malnutrition
- Poor health due to migration and social dislocation

The Synopsis of these direct and indirect adverse impacts due to climate change can still further be distinguished on the basis of direct health impacts and ecosystem mediated health impacts. These are unequivocally laid out in detailed format in the following table:

Table 1.1: Synopsis of projected direct and ecosystem-mediated effects of climate change (*Balbus, 1998*).

Climate Change	Direct Health Effects	Ecosystem mediated Health Effects
Increased temperatures and diverse precipitation patterns	Heat related excess morbidity and mortality Increased photochemical smog, with other air pollutants causing more respiratory problems More frequent and severe extreme weather events (floods, storms, cyclones etc.)	Altered spatial and temporal spread of vector borne diseases Increased water borne diseases Malnutrition
Sea level rise	Decreased agricultural productivity, polluted fresh water resources Saddled health infrastructures	Reduced fish stocks

The US EPA established National Ambient Air Quality Standards for six criteria pollutants (CO, NO_2, SO_2, O_3, PM, & Pb) to protect human health, and monitors their concentrations in the ambient air and at the actual emission sites. Apart from these criteria pollutants, marked increase in the atmospheric levels of aerosols and persistent organic pollutants have been recorded. Ozone depletion in the stratospheric zone (10 to

30 miles above the Earth's surface) has also been observed which protects us from the sun's harmful UV radiations,

According to *WHO (1996)*, 30 new diseases have surfaced in the last two decades apart from the resurgence and redistribution of the vector borne diseases like malaria and dengue fever. As the effects of climatic changes pose major threat to human health, understanding the nature of the climatic system and gathering of accurate and reliable data for assessing the climatic effects will be the first step towards well-planned adaptation strategy. It will enable us to better equip ourselves against the adverse consequences of apprehended climatic changes. This should be our top priority in the rapidly changing industrialized world.

1.6 Outcome

On the basis of natural climate variations as well as the changes in the solar radiations, the scientific community agrees that the anthropogenic emissions of greenhouse gases are responsible for 0.6°C rise in the temperature of the earth during the last century (*WHO, Climate Change and Human Health ~ Risk and Responses SUMMARY*). The earth's average surface temperature is at the highest level when compared with the last 100,000 years.

The observed climate changes in atmospheric composition, primarily because of the increased energy consumption and urbanization, are exceeding all natural variations boundaries. In-depth understanding of the changes in the climate and improved forecasting by the precise modeling tools indicate a sharp increase in the frequency and intensity of heat-waves, cyclones, floods, and El Niño cycles. (*Watson, 2001 and European Climate Forum, 2004*)

Our failure to curtail greenhouse gas emissions rapidly will not only result in the continuously changing climate and rising oceans levels, but would further amplify the risks to human health and endanger their survival. The irreversible negative impacts on the ecological environment are evident from the receding glaciers, coral reefs, forests along with the ecosystems in polar and alpine regions. Some of the threatened and more sensitive species can face extinction.

1.7 Objectives

Considerable research work has been done for the American and European regions with regards to possible climate changes and their adverse impacts on the human and ecological health in future. However, the Middle Eastern region consisting of the Gulf coastal countries such as United Arab Emirates, Oman, Qatar and Yemen Arab republic have not been studied so far. As the region particularly has very harsh and arid climate, even a minor change in the temperature, precipitation and humidity levels are bound to cause a significant impact on the human and ecological health. As some parts of the region experience extremely low rainfall, certain plant species rely upon the humidity levels for their survival and existence in the prevailing climate. With the increasing greenhouse gas emissions and the resulting global warming trends the possibility of the existence of these plant species appear to be bleak and their extinction cannot be ruled out.

An effort is being made here to assess possible climatic conditions over the next 50 - 100 years under the various plausible scenarios of population growth, and socio-economic and technological developments in the region. Climatic changes based on these scenarios will be determined with respect to the baseline period over the next fifty and hundred year period and the possible health impacts for human population in the region will be investigated. The study is expected to help in better understanding of the climatic changes and its impact on human population, thus enabling the scientific community to reduce vulnerabilities and advise on necessary adaptative measures.

1.8 Layout of Chapters

This thesis is organized as follows:

- Chapter 2 contains extensive literature review of the causes of the global warming, health effects of changing climate with particular reference to particulate matters and the resulting respiratory problems; vector borne diseases due to the spatial and temporal spread of vectors, thermal stresses, and increased incidences of cancer due to depletion of stratospheric ozone layer.
- Chapter 3 refers to the background information regarding formation of Intergovernmental Panel on Climate Change (IPCC); review of various global climate models for data resources under different plausible scenarios; IPCC's achievements and conclusions with reference to the possible effects and available remedial options.

- Chapter 4 contains climatology and geography of the region with particular reference to the environmental and natural hazards faced by the Gulf coastal countries, such as Oman, Qatar, the United Arab Emirates, and Yemen.
- Chapter 5 covers detailed methodology adopted for the data collection; contour mapping of the region for the anticipated changes in the temperature, precipitation and humidity. The specific detailed results on the predictive changes over the next 50 years and 100 years and uncertainties in the predictive strengths of the various models with possible explanations are presented in this chapter.
- Chapter 6 discusses the health impacts in the region and the shortcomings due to non-availability of authenticated hospital records for emergency room visits as well as morbidity and mortality data for various illnesses due to climatic changes.
- Chapter 7 highlights detailed discussions on the investigative results.
- Chapter 8 lists conclusions and possible recommendations for the region based on the anticipated changes.

Chapter 2

Literature Review

2.1 Introduction

Individuals quality of life in any region is assessed on the basis certain key indicators like physical, mental and social well being. Annually, billions of dollars are spent on the improvement of health care infrastructures by various governments worldwide. Apart from a number of socio-economical factors, climatic conditions are also an important determinant of human health and obvious seasonal trends have been observed in various diseases.

There is a need for considerable improvement in the knowledge regarding the relationship between the climate and health. As the health impacts of climate change vary amongst different regions of the world, there is a requirement of precise regional health indicator based on the reliable monitoring.

The impacts of the climate change on health require monitoring on the basis of well-documented, precise, and reliable data. The quantification of the adverse health impacts due to the climate changes is critical for a well planned adaptation strategy for the warmer world in the next century.

Epidemiologists have been using mathematical models with scenario-based risk assessments for determining health impacts due to anticipated climate changes in the past, and still the typical epidemiological data can be used to determine the initial health impacts based on the climate-attributable changes in the physical systems and biological processes. There are undeniable indicators that variations in the temperature, precipitation and humidity affect the biological processes in a complex but significant manner.

2.2 Greenhouse effect and Global warming

The ever-increasing population with large-scale industrial growth is resulting in the increased concentration of the gases like carbon dioxide (CO_2), methane (CH_4), nitrous oxide (NOx) and halocarbons (HCs) etc. in the environment. These gases trap the energy in the environment, resulting in enhanced greenhouse effect, and alter world climate. According to the United Nation's Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report (TAR) *(2001): **"There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities"** (IPCC - Climate Change 2001: TAR (Vol-1).*

According to the above IPCC report climatic data indicates 0.6 °C increase in the global temperature during the twentieth century, in which the major increase was witnessed after 1975 because of the extensive industrial activities (i.e. human impact).

Forecasts based on the advanced mathematical modeling techniques predict the global temperature increase in the range of 1.4°C to 5.8°C by the end of 2100 A.D *(IPCC).* These predictions are based on plausible future scenarios depicting social, economical, technological advancement under reasonable assumptions of population growth rates. The forecasts indicate considerable climatic variability's (i.e., changes in the precipitation levels, the atmospheric and oceanic circulation, cloud cover, flooding, drought, increased frequency and intensity storms, tornados, tropical cyclones and hurricanes) apart from other biological and ecological changes like glacial retreat. The net impact of all of these factors is the increased episodes of heat stress, spatial and temporal spread of infectious vector-borne (VBD) and water-borne diseases.

2.3 Climate Change and Health Effects

The climate change, apart from causing ecological suffering and social disruption, has the capability to cause significant adverse impact on human health through a variety of pathways. These impacts have different intervening processes and health outcomes. The various health outcomes due to the physical, chemical, biological, social and geographical impacts result in the increased morbidity and mortality due to different diseases. The impacts, processes, their health outcomes in terms of diseases for human population are outlined in the table below:

Table 2.1: Effects of climate change on human health (Modified from *Last and Chioti, 2001*).

Impacts	Intervening process	Health Outcomes	Common Diseases
physical	heat waves	heat stress	heat stroke, heat stress
Physical /chemical	air-pollution	respiratory illnesses	Obstructive lung disease, asthma, cancer
	floods & release of toxic chemicals	acute and/or chronic poisoning	

Physical /biological	disease agents, vectors & habitats	water-borne diseases	cryptosporidiosis, E. Coli, cholera, malaria, dengue
	reduced food production & nutrient value	Lesser access to food	nutritional deficiencies
	aeroallergens	respiratory allergies	asthma
Social & geographical	forced migration in low lying areas	infectious diseases, mental health	diarrhea, malnutrition, overcrowding, depression, etc.

Tables (*2.1 & 2.2*) are being reproduced with some modifications from the report titled "*Monitoring Health Impacts of Climate Change in Europe*". They cover the following fundamental aspects for facilitating future research and investigations to determine appropriate solutions and mitigative measures for adaptations.

- Criteria for selecting potential diseases for climate change surveillance,
- High priority infections due to the climatic changes

Table 2.2: Selection criteria of potential diseases for climate change surveillance (Modified from *WHO-ECEH, 1998*).

Criteria	Significance	Observations
Appropriate for continuous monitoring	Requires time series analysis for comparison with climatic factors	Low frequency infections, appropriate for detailed outbreak surveillance
Recognized Aetiology	Distinguish direct climate effects from other known factors	Aetiology established for most common infections
Environmental sources	Infections associated with environment are likely to be affected by climate	Waterborne diseases and those sensitive to temperature variations
Minimal transmission	Strengthens link with environmental exposure	e.g. Malaria, Tick borne encephalitis etc.
Sustainable	Surveillance not considered cost-effective for infections not regularly monitored or with lesser clinical value	Examine feasibility of using existence surveillance methods and agree on surveillance priorities
Existence of public-health & preventive steps	Effort justified	Steps for improved sanitation, flood prevention and vaccination etc.

Some of the common communicable diseases along with their transmission modes, global distribution status, climate-epidemic link and climate sensitivity as listed in *WHO's 2004* document titled "Using climate to predict infectious disease outbreaks: a review" published in preparation for accessing the potential of early warning systems is to enhance the global surveillance and response to epidemic-prone diseases due to climate change are listed in *Table-2.3* below:

Table 2.3: List of communicable diseases their transmission modes, distribution and association with climate change (*WHO/SDEOEH/04.01, 2002*).

Disease	Transmission	Distribution	Inter-annual variability	Climate-epidemic link	Strength of climate sensitivity
Diarrhea	Food and water borne	Worldwide		Linked to temperature increases and reduced precipitation.	Moderate
Cholera	Food and water borne	Africa, Asia, S. America, Russia	Very Strong	Linked to sea and air as well as El Nino events.	Well documented. Climate primary determining factor in some epidemics
Malaria	Biting of female *Anophes* mosquitoes	Endemic situation for >100 countries in tropics and subtropics	Very Strong	Epidemics linked to altered temperature and precipitation levels. Vector characteristics, drug resistance, immunity levels and population movement	Well documented. Climate primary determining factor in some epidemics
Meningoco-ccal meningitis	Air borne transmission	Worldwide	Strong	Linked to temperature increases and reduced humidity.	Significant
African traypanoso-miasis	Biting of male & female *tsetse* flies	Africa	Moderate	Vegetation patterns, cattle density and changes in temperatures and rainfall may be linked to epidemics	Moderate
Dengue	Biting of female *Aedes* mosquitoes	Africa, Europe, S. America, SE Asia & West Pacific	Strong	Epidemics linked elevated temperatures and higher precipitation levels. Non climate factors can have more pronounced effect	Significant

St. Louis encephalitis	Biting of female *Culex* and *Aedes* mosquitoes	North and South America	Moderate	Epidemics linked to elevated temp. and higher precipitation Reservoir animal factors also important	Significant
Rift Valley Fever	Biting of female *Culex* and *Aedes* mosquitoes	Africa	Moderate	Heavy rains associated with the start of epidemic and ending with cold weather. Heavy rains associated with the start of epidemic and ending with cold weather.	Significant
Ross River virus	Biting of female *Culex* and *Aedes* mosquitoes	Australia and Pacific Islands	Some	Elevated temperatures and heavier precipitation associated with epidemic onset. Reservoir animal factors also important	Significant
Murray Valley fever	Biting of female *Culex* mosquitoes	Australia	Some	Higher precipitation and below average atmospheric pressure associated with epidemic	Significant

Based on the available literature *Table2.4* below highlights the types of surveillance, sensitive regions of three highly infectious diseases, having established aetiology and diagnostic criteria's and with significant association towards climatic variations.

Table 2.4: Climate change surveillance: High Priority Infections (Adapted from *Monitoring Health Impacts of Climate Change in Europe, EUR/01/502 6360*).

Disease	Continuous surveillance	Active surveillance	Significant association with environment	Sensitive areas
Malaria	Yes	Info on local & imported cases	Yes, Water breeding sites, association with rainfall & temp. Parasite develop in vectors, Strong temperature dependence	Central Asia, SE Europe & Mediterranean
Cryptospori-dium	In some countries	No except U.K	Yes water + zoonotic sources, individual child transmission	Northern Europe but can increase due to flooding
Tick borne encephalitis	In some countries	In some countries	Yes, behavioral factors, changing vector patterns	Endemic areas & regions with higher vector population

2.4 Thermal Stresses

Human populations can face direct impact due to the regional/local climatic conditions. Higher mortality rates have been observed during the heat-wave periods. In countries with more prevalent cold climate, winter seasonal death rates are observed to be higher than summer mortality because in winter thermal stresses occur over a wider temperature range as compared to summer.

Severity of the heat wave is generally defined as state when the daily ambient temperature continuously exceeds the normal body temperature of 37 °C (98.6 °F). It is also referred to as a state in which body temperature rises to such a level that it becomes noxious agent and damages body tissues of multiple organs causing clinical and pathological syndrome. The observed effects of heat stress i.e. continuous exposure to elevated temperatures appear in form of dizziness, weakness and fatigue and the severity of illness depends upon the exposure duration, prevalent temperatures in the region and degree of hyperthermia. However acute heat strokes with body temperatures 41 °C (106 °F) can result in unconsciousness and even death.

Excess cases of mortality have been reported in densely populated areas due the "heat island effect", apart form the regions with improper ventilation and/or lack of air conditioning facility. Reduced winter mortality has been observed in these regions but the excess summer mortality being much higher. *(O'Neill, et. al., 2001)*

Increased temperatures will result in the increased incidence of photochemical smog in the urban areas, along with increased frequency of food poisoning. The consequences of disturbances like changes in population distribution structure, rising sea levels and economic effects on human health, will not be visible for number of decades unlike those observed in the natural and man made food-producing zones which can become evident immediately (*Watson et al., 2001*).

Ando et al., (1998) investigated the effects of the heat wave of July 1998 in Nanjing China, when the mean and maximum daily temperatures exceeded 30ºC and 36ºC respectively for continuous 17 days. During the same period marked increase in the heatstroke cases along with the mortality rates was observed. The results of epidemiological investigation of the Nanjing-heat wave are being reproduced below in Fig-2.1.

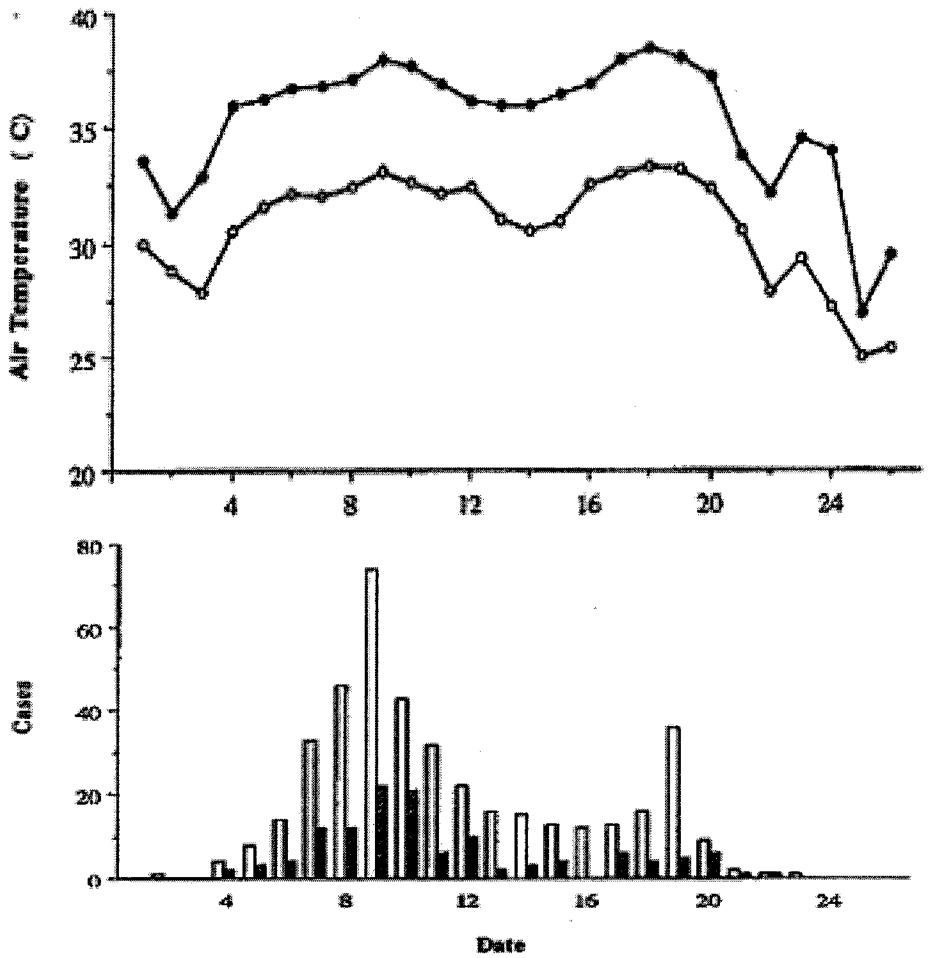


Fig 2.1: Relationship between daily maximum (●), mean (○) temperature change and the incidence of heat stroke (□) and death (■) during the heat wave in Nanjing, China, in July 1988 (*Ando et al., 1998).*

Ando et al., (1998) conducted an experimental study on Fischer rats; they were divided into four groups for temperature ranges: 25 ± 0.5 °C, 30 ± 0.5 °C, 32 ± 0.5 °C and 35 ± 0.5 °C respectively, with humidity levels of 40 ± 10% for 7 days to 42 days. After sacrificing the animal when their organs were analyzed it was observed that their thermoregulatory function was intact with clear signs of hyperthermia and their core body temperatures increased immediately after exposure to the elevated temperatures.

Agricultural yields are also predicted to decrease at all latitudes (except high) with a temperature rise of 2 - 3 °C, especially in South Asia, Central America and certain regions of Africa. This will result in increased number of malnourished population estimated to be 830 million increasing by a considerable margin, especially in the Sub-Saharan Africa. (*Houghton et al., 1996*) Figure 2.2 on the following page shows the effects of severe heat stress on thermoregulatory systems, core temperature increase and the incidences of heat-related disease:

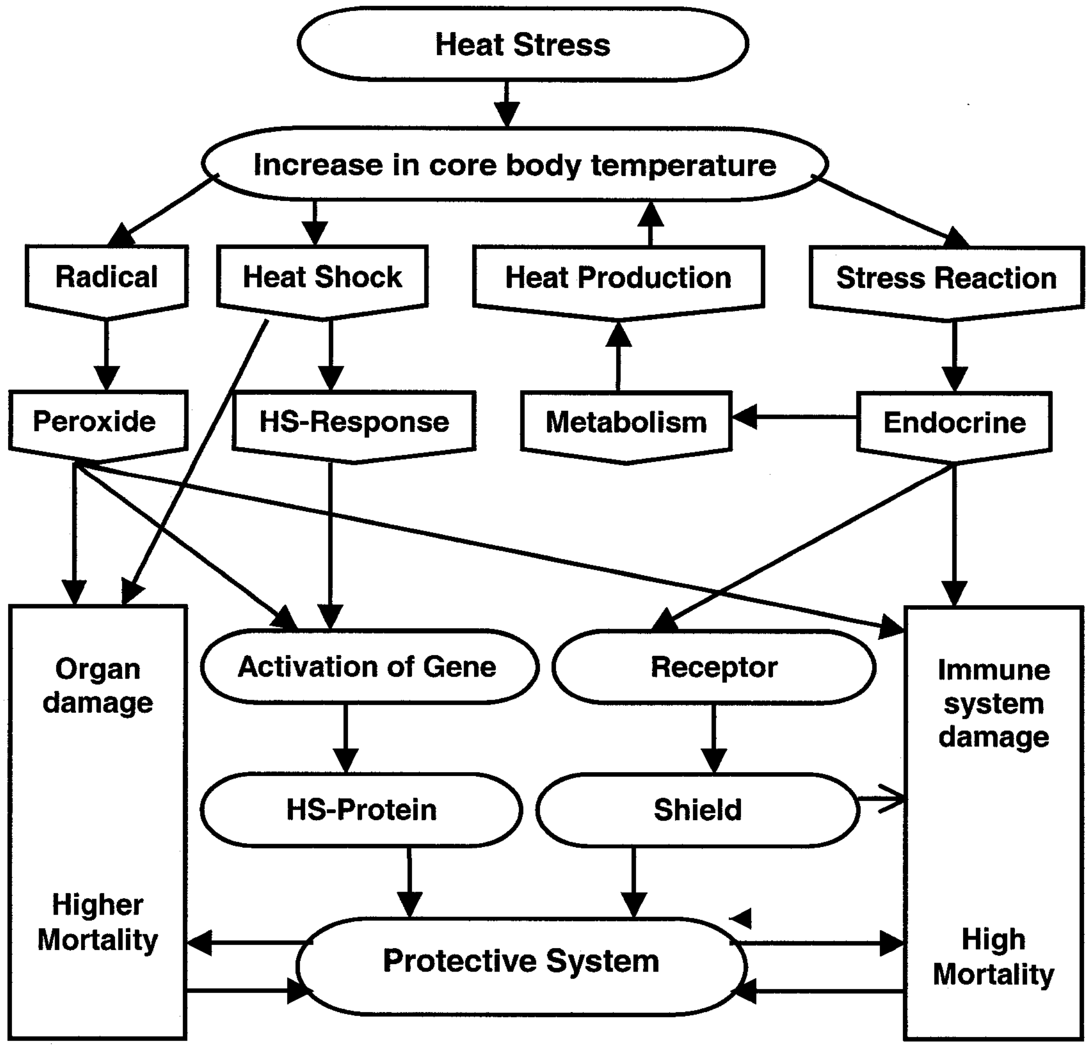


Fig 2.2: Layout indicating the effects of the heat stress on human body (Modified from *Ando, 1998*).

Based on the literature survey, Table 2.8 shown below indicates the impacts of altered temperatures on the human health with particular reference to the cardiovascular diseases in different countries around the globe.

Table 2.5: Studies conducted to access temperature–mortality relationship.

1968-1994 Heat related deaths in Japan	Elevated temperatures	Mortality	Mortality beyond 101°F with exponential dependence on no. of hot days; 50% of deaths for children<4yr old and elderly ≥70yr.	Nakai et al., 1999.
1970-1974 Greater London adults >45 yr	Weakly mean temperatures	Ischemic heart disease	Linearity between IHD mortality for all ages with temperature with identical proportional changes for all age groups	Bainton et al., 1977
1962-1966 32 cities of USA	Daily temperature and snowfall	Coronary heart disease	Increased mortality at temp>60-70°F and <10°F	Rogot et al., 1976
1980-1996 Toronto, Ontario Canada	Humidex	Mortality	Higher mortality with humidex 86-95°F. Increased mortality at high humidex and apparent temp for people ≥65yr of age.	Smoyer et al., 2001
1988-1993 Christchurch New Zealand	Daily temperatures	Daily mortality	Temp increase of 1.8°F associated with a 1% (95% CI*: 0.4, 2.1%) increase in all-cause mortality and a 3% (95% CI: 0.1, 6%) increase in	Hales et al., 2000

			respiratory mortality	
1973-1994 11 cities of USA	Daily temperatures	Daily mortality	Temperatures indicated strong U-shaped relationship with mortality	Curriero et al., 2002
1976-1996 London U.K	Daily temperatures	Daily mortality	Av. temp above the 97th centile (70°F) caused increased mortality by 3.34% (95% CI: 2.47, 4.23%) for every 1° increase in av. temp; longest duration highest temp had greatest mortality effect	Nakai et al., 1999
1962-1966 St. Louis and Kansas, USA	Total heat stroke	Daily Mortality	July 1980 heat wave associated with increased episodes of heatstroke especially for elderly and poor	Jones et al., 1970
1981-1987 Athens, Greece	Daily temperatures	Mortality	July 1987 heat wave resulted in increase mortality as compared to the last 6 years with statistically significant interaction between temp and SO_2	Katsouyanni et al., 1993

2.5 Infectious Diseases

The ecology and transmission of the various infectious diseases depend on the demographic as well as other socio-economic factors. The diseases spread by various means i.e. through vectors (mosquito, ticks and fleas etc), other species and from one individual to other. Majority of the vector borne diseases are found in developing countries of the tropical region.

As the vectors are not capable of regulating their own body temperatures they depend on environmental factors i.e. temperature and humidity for their survival.

Thus variations in temperature, humidity, sea level, and altered rainfall affect the growth and spread of the vector borne diseases.

The socio-economic living conditions of population (density, availability of clean water, housing conditions, human behaviors, handling of wastes and proper sewage etc.) with demographic factors and climatic changes have direct influence on the distribution of the vectors. Temperature is important as it affects the survival, reproduction and maturation of the vector population, along with necessary vegetation and stagnant water for their breeding sites. The combined effect of these factors is responsible for spatial and temporal spread.

2.5.1 Malaria

Malaria is a global problem capable of causing intricate issues for human health. It is a vector borne disease (VBD) and is transmitted by *metaxenicas* and *P. falciparum* mosquitoes. Climatic variability plays important role in the transmission and incidence of this parasitic disease, as its transmission vector is mosquito, which is sensitive to weather conditions.

On wider scales, climate conditions determine the geographic distribution of the vectors and spreading of this disease. Any changes in temperature, precipitation and humidity levels along with the wind patterns can have considerable effect on the development and longevity of these mosquitoes. Altered temperatures also affect the parasite development within the mosquito.

The incidence of malaria transmission has been escalating at an alarming rate emphasizing the need for mapping and predictive modeling of distribution, intensity and seasonality of its transmission. Existence of malarial diseases (spread) with altered geographical ranges and seasonality have been reported in the following countries by Centre of Disease Control as of 2003.

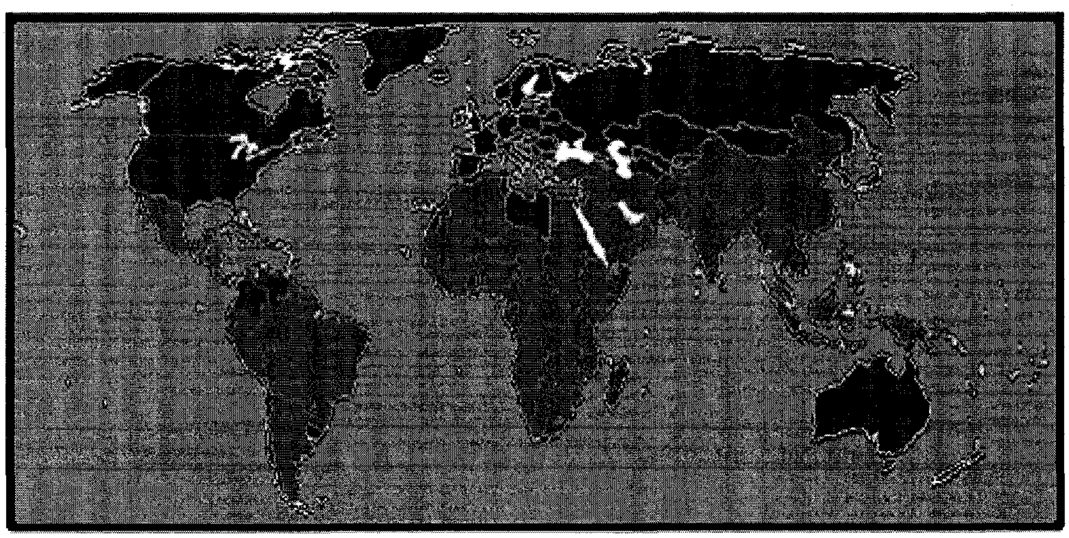


Figure 2.3: Malaria-prone regions of the world highlighted in red (Modified from *Centre of Disease Control and Prevention, 2003*).

Malarial outbreak is reported to have occurred in USA in the beginning of this century, but there is no documented evidence of the changes at higher elevations in plants and glaciers. The decade of 90's saw the outbreaks of locally transmitted malaria in USA e.g. in New Jersey in 1991, and in Queens in New York in 1993 (*Zucker, 1996*). These outbreaks of malaria at localized places are consistent with the model projections that warm and wet conditions favor rapid transmission potential at higher latitudes. *(Epstein, 1998)*

World Health Organization's statistical data indicates that almost 2400 million people live in malaria prone areas *(WHO, 2004)*. Almost 300-500 million people get infected annually and more than a million children die of it on yearly basis *(RBM, 2004)*.

According to an epidemiological model, with a global increase of 3°C in temperature by year 2100 with constant population size and anthropogenic contributions, the malarial transmission is predicted to double in the tropical regions and increase ten times in the temperate regions (*Martens, 1994, 1995*). Malaria has been found at higher elevations i.e. in the regions of Nairobi-Kenya, Central Africa and Latin America. *P. falciparum* is becoming a threat for the elevated regions like Rwanda *(Loevinsohn, 1994)* in the eastern, southern, western and Chimbu highlands of Papa New Guinea (*Rozendaal, 1996*), and in Irian Jaya at the altitude of 2100m. (*ProMED, 1997*)

The increasing episodes of the malarial transmission in Usamabara Mountains in Tanzania when investigated by *Matola et al., (1987)*, was found to be closely associated with the constant rise in the annual temperatures.

Harasawa et al (1995)., based on the malarial Asian-Pacific Integrated Model (AIM) / Impact model predicts that with 2 °C increase in the temperature there will be a considerable increase in the population living under endemic malaria conditions. He reports that entire population of the UAE and Oman and < 50% of Yemen's population are living in malarious regions. Though there will be no increase in the "High Risk" category of malarial disease, but

- Low malarial risk will remain unchanged for UAE (1.07 million affected population)
- Low malarial risk will reduce from 0.92 to 0.48 million affected people from Oman.
- Low malarial risk will rise markedly for Yemen by affecting larger population group i.e. from 1.08 to 2.38 million

Malaria is a complex disease that can be affected by a number of factors other than the climatic changes like drug resistance, breakdown of control programs, and land-use changes (*Tanser, 2003*)

Lindsay and Birley (1996) attributed the re-emergence of drug resistance form of malaria to increased human population, frequent movement, land-use change, and deteriorating public health infrastructure. He further argued that the variations in the malarial transmission ranges could also be attributed to variations in the temperature, rainfall, humidity and immunity levels. These factors, as shown in Table 2.6, interact to affect adult mosquito density and subsequent growth of the parasite within the mosquito.

Lindsay and Martens, (1998) and Cox, (1999) agree that the future climate change can increase transmission in the elevated regions.

2.5.2 Dengue

Dengue is one of the major vector borne diseases (VBD) in the world, with no available vaccine for its prevention affecting millions annually. It is spread mainly by mosquito species *"Aedes aegypi"* which live closer to the human populations. Mosquitoes need stagnant waters for breeding while warmer temperatures are critical for the development of larvae, feeding and mortality.

Simon Hales, (2002) while trying to determine future geographical limits of dengue transmission ranges on the basis of climatic changes and present ranges concluded that vapor pressure was the most important individual predictor of the dengue fever distribution. He predicted that while 1.5 billion people (approx 30%) were at risk in 1990 with almost 40% of the entire world population (approx 2 billion in 1990) living in areas that reported at least one outbreak between 1975~1996. Assuming baseline humidity and projected population growth rates the estimated vulnerable population to dengue was calculated to be 3.2 billion (34%) in year 2055 and 3.5 billion (35%) in year 2085. Incorporating changes in the humidity levels as projected by HADCM2 the calculated forecast showed 4.1 billion (44%) and 5.2 billion (52%) people at risk in years 2055 and 2085 respectively.

Koopman, 1991 reported that Dengue fever, previously found at the elevation of approx 1000m, in the tropics with 10°C winter isotherm, is now appearing at 1700m in Mexico.

While *Suarez, & Nelson, (1981)* reported dengue at elevations of 2200m in Colombia. Latin America has been warned of the increased risk of resurgence of urban yellow fever. Although the findings of the authors emphasize the fact that geographical limits of the dengue fever transmission are definitely determined by the climatic conditions, still the future spread of the dengue fever will also depend on the socio-economic and other environmental factors.

2.5.3 Water Borne Diseases

Increased temperatures coupled with higher precipitation levels due to climate change can result in higher risk of waterborne diseases, e.g. cryptosporidiosis, and giardiasis. These waterborne diseases are generally not life threatening except for the children and elderly population. Excessive rainfalls by flushing sewage, fertilizers and other organic wastes can contaminate our fresh water resources. As increased temperatures encourage growth of algae, bacteria and other micro-organisms, they aggravate the problem of water contamination.

Lack of sanitation, coastal sewage discharge, contamination of drinking water because of the agricultural fertilizers and waste contribute towards the increase in the likelihood of water-borne diseases. The populations are exposed to the water borne diseases through any of the following mechanisms:

- Drinking contaminated or cooking food in contaminated water
- Consumption of seafood from polluted waters,
- Fishing and bathing in contaminated waters, etc.

Water quality is strongly influenced by the factors like temperature, humidity, wind, rainfall and precipitation, and any changes in these will have significant effect on water quality. Some of the pathogens of concern to the human health include viruses and bacteria like *Vibro vulnificus,* (estuarine bacteria, temperature sensitive capable of causing death) and *Cryptosporidium.* E.g. Wisconsin water supply system in USA got contaminated by *Cryptosporidium,* in 1993 resulting in almost 400,000 illnesses. US EPA in 1994 laid out a framework for avoiding mixing of the combined sewer waters with surface waters.

2.5.4 Other Infectious Diseases

Third Assessment Report of the IPCC states that Malaria is undergoing a global resurgence because of the influencing factors like reduced funding and policy changes, which were instrumental in malarial control programs in 1970's and 1980's. *Table-2.9* below which has been reproduced from the above report highlights different vector borne diseases, the populations at risk, number of prevailing infected people and their areas of distribution:

Table 2.6: VBD, populations at risk, number of prevailing infected people and areas of distribution (*IPCC, 2001, Pim Martens*).

Disease	Vector	Population at Risk (million)	Currently infected people or new cases /year (million)	DALY's Lost* (million)	Present Distribution	Likelihood of Altered distribution with climate change
Malaria	mosquito	2400	27.3	3.93	Tropics/ subtropics	Highly likely
Schistosomiasis	snail	500 to 600	120	1.7	Tropics/ subtropics	Very Likely
Lymphatic filariasis	mosquito	1000	120	4.7	Tropics/ subtropics	Likely
Dengue	mosquito	3000	Tens of millions of cases/year	1.8	All tropical countries	Very Likely
Yellow Fever	mosquito	468	0.2 million cases/year	NA	Tropical S America & Africa	Likely
Leishmaniasis	sandfly	350	1.5 to 2million cases/year	1.7	Asia, Africa, S. Europe & Americas	Likely

**Disability-adjusted life Years (DALY): Population health deficit due to chronic illness or disability or premature death. Data from Gubler and Metzer (1999). Numbers rounded to nearest 100,000.*

Table 2.10 has been reproduced with slight changes from Inter-governmental Panel on Climate Change-Climate Change 2001: Third Assessment Report (TAR) Vol-1 and it shows the relationship between various climate factors, vectors, pathogens and vertebrate hosts and rodents.

Table 2.7: Climatic Factors effecting transmission of vector and rodent borne diseases (*IPCC-TAR, 2001*).

Climate Factor	Vector	Pathogen	Vertebrate Host and Rodents
Increased Temperature	Spatial and Temporal spread Reduced survival (*Reeves, 1994*) Increased population growth (*Reisen, 1995*) Vulnerability changes of certain pathogens (*Reisen,1995*))	Prolonged transmission seasons (Reisen, *1993, 1995*) Spatial spread (*Hess, 1963)* Increased rate of vector extrinsic incubation	Warm winter support rodent survival
Decreases in Precipitation	Water inadequacy can increase container breeding sites; Higher mosquitoes breeding in dried river beds (Wijesunder, 1993) Extended droughts can reduce/eliminate snails	No Effect	Food shortage to effect population sizes
Increases in Precipitation	Higher precipitation levels cause increased larval habitat and	Trivial indication of direct effects with some	

	population size Higher humidity level favor vector endurance Excessive rainfall can wash away vector habitat and increase downstream snail habitats	available data showing humidity effects on development of malarial parasites	
Increase in precipitation extremes	Heavy rainfall can wash away breeding sites, and harmonize vector host-search and virus transmission (Day and Curtis, 1989)	No Effect	Contamination risk of flood water runoffs with rodent pathogens
Sea level rise	Coastal flooding effects vector abundance for mosquitoes breeding in salty waters e.g. malarial vectors in Asia	No Effect	No Effect

2.6 Decreased Stratospheric Ozone

Ozone depletion adversely impacts human health in concurrence with other ecological and demographic changes at spatial and temporal scales (*McMichael et al., 1996*). The decrease in stratospheric ozone due to increased concentrations of some greenhouse gases and cloud formation at higher altitudes is causing more incidences of harmful solar ultra-violet (UV) radiations having adverse impact on human health (*WHO, Third Ministerial Conference, London 1999*). Human life style i.e. longer summer recreational seasons because of global warming also contribute towards increased population exposure to harmful ultra-violet radiations. The impacts are evident in some of the following forms: *(WHO Climate change & Human Health-Risks and Responses, 2003).*

- **Skin**: Sunburn, malignant melanoma, non-melanocytic skin cancer, basal cell carcinoma etc. (UV induced immunosuppression is a major risk factor for skin carcinomas (*Pim Martens, 1998*). *Fig-2.4* below co-relates the evidence of the incidents of Skin Cancer and estimation of stratospheric ozone depletion with reference to Montreal Protocol, Copenhagen amendments and the scenario of *"NO restriction on CFC release"*.
- **Eyes**: Stratospheric ozone depletion has severe impact on the eye e.g. cataract, acute solar retinopathy, macular degeneration, cancer of cornea and conjuntiva, acute photoconjuntivitis and uveal melanoma etc.
- **Immunity and infection**: UV radiations have shown to suppress immune systems in animal models (*Pim Martens, 1998*). Higher exposure to infection, inhibition of cell mediated immunity and activation of suppressed virus infection etc. are some of the results of stratospheric ozone depletion.
- **Indirect effects**: It includes effects on vectors of infectious diseases and air pollution etc.
- **General effects**: Disturbed mood and sleep cycles can be observed; lower risk of schizophrenia, breast and prostate cancers; The potential benefits may include probable prevention of Type-1 diabetes and possibility of

some benefits for patients suffering from ischemic heart diseases and tuberculosis.

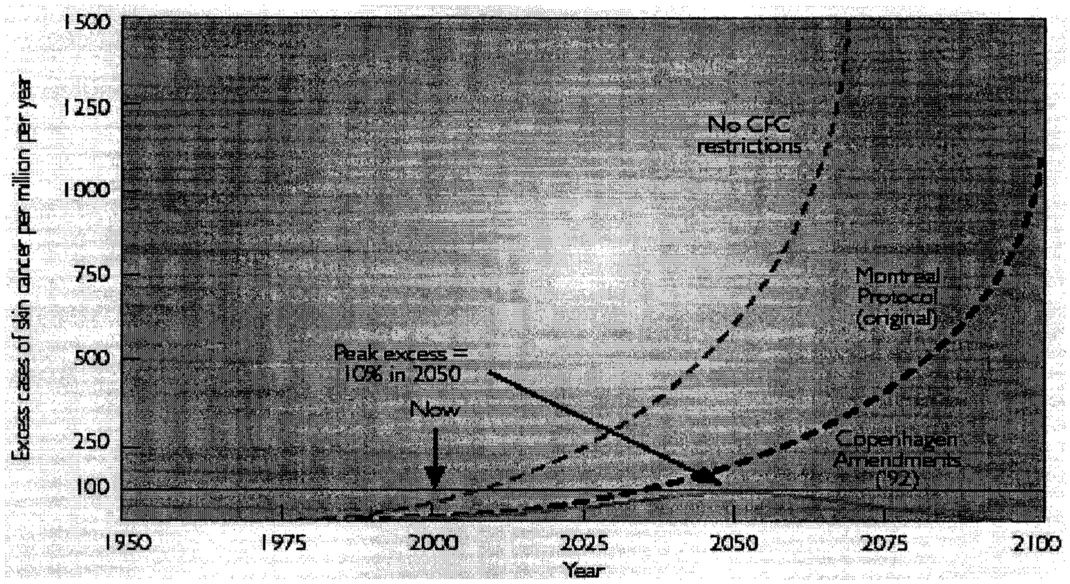


Fig 2.4: Estimation of Ozone depletion and the incidence of skin cancer for Montreal Protocol achievement (Reproduced with Permission)

2.7 Summary of Various Contributing Factors

Some of the major contributing factors that play an important role in determination of future climatic changes, their impact on human health as well as marine and terrestrial ecosystems are being summarized below:

- The change in the seasonal weather patterns due to global warming is more important than increase in the mean temperature
- Increase in the temperature with decrease in precipitation is anticipated to have major negative impact on agriculture yields and fresh water resources

- Human health will be more adversely affected by higher temperature and humidity levels than from increases in the average temperature
- Increased morbidity and mortality amongst the elderly population
- Increased effects of heat stress
- Increased risk of infectious diseases in the developing world who have limited resources and in the developed countries due to rapid migration and transportation

Chapter 3

IPCC - Background, Models and Scenarios

3.1 Background

World Metrological Organization (WMO) in 1979, while organizing "World Climate Conference", expressed concern about the impact of the human activities on climatic changes at regional as well as global level. It was the first forum to introduce the idea of "global collaboration among the nations to evaluate probable climatic changes and take suitable actions for societal development strategy.

A joint conference of WMO, United Nations Environment Programme (UNEP) and International Council of Scientific Unions (ICSU), held in 1985 to assess the role of CHG in climatic changes and their impacts, concluded that in the first half of the 21st century the increase in the GHG due to man made causes would result in considerable climatic changes and significant rise in the global mean temperatures (*IPCC, 2004*).

As a result of the findings and deliberations at the conference an "*Advisory Group on Greenhouse Gases (AGGG)*" was established for constantly reviewing technological knowledge, climatic changes and the resulting implications.

During the 10th WMO Congress an urgent need was felt for an unbiased and well-synchronized scientific assessment for better understanding of the effects of the increased concentrations of GHG in the atmosphere at globally and the methods in which they can affect various social and economical aspects. The executive council of the WMO then proposed for the constitution of an ad-hoc intergovernmental body to provide the details of the scientific assessments of climatic changes. This ultimately led to the establishment of the Intergovernmental Panel on Climate Change (IPCC) in 1988 at the 40^{th} session of WMO with the approval of the UNEP. IPCC Secretariat was thus established in WMO headquarters in Geneva in 1988. IPCC has since collaborated with various Intergovernmental and Non-Governmental agencies like Food and Agricultural Organization (FAO), International Atomic Energy Agency (IAEA) and World Environment Centre (WEC) etc. for achievement of its goal.

The main purpose of the establishment of this prestigious world body was the provision of authenticated advice on the extremely delicate and complex scientific issue of emerging climatic changes in the world. The first task assigned to IPCC was to prepare a report on the climate changes based on the most recent and authenticated scientific data and to develop necessary strategies for minimizing the adverse impacts of the change. For this purpose IPCC constituted three independent working groups for the preparation of three assessment reports: -

- **Working Group - I:** This group was assigned the task of collecting reliable scientific data on climate change.
- **Working Group - II:** This group was assigned the task of accessing environmental, social and economical impacts of climate change.
- **Working Group - III:** This group was assigned the task of devising necessary response strategies

The tasks of the IPCC included broad based assessment of the human influences on climatic changes due to various social, economical and scientific factors responsible for changing climate, resultant potential impact and necessary adaptative and mitigative steps required. Experts as well as the member States scrutinized panel's findings. The responsibilities of the panel did not include new research and data monitoring, rather it was the responsibility of member States of UNEP and WMO. The assigned tasks to the IPCC's as quoted in its brochure (*IPCC, 2004*) are:

(a) To ascertain disparities and uncertainties with reference to our knowledge about climate change and its possible impacts, with a short term plan to cope with the situation.

(b) To highlight necessary information required for assessing policy implications and response strategies of climate change.

(c) To evaluate prevailing and future national and international strategies in relation to greenhouse gas emissions.

(d) To evaluate scientific and environmental data regarding greenhouse gases and disseminating the information on the findings to all governmental and intergovernmental organizations, so that it can be incorporated in their future policies on socio- economic development and environmental programs.

3.2 IPCC Achievements

IPCC have been instrumental in developing in-depth understanding of the causes and impacts of future climatic changes, and is credited for the publication of various assessment reports. Its work is extensively recognized and quoted as standard references by the scientific communities.

Research work on the climatic changes became more extensive as a result of well-devised strategy of the IPCC to attract scientists and engineers from around the globe, resulting in widening of the scope of research. IPCC earned reputation of an organization which has done tremendous work of exceptional quality, and generated keen interest in research and motivated collaboration in this sensitive field worldwide.

The three IPCC reports that have been published so far are a perfect demonstration of organizational and technical/scientific expertise that the IPCC was able to generate, by bringing together thousands of researchers from all geographical regions. To realize the exact extent of the climatic changes comprehensive interpretation of its biophysical characteristics is extremely important for socio-economic and environmental health around the globe.

3.3 SRES Scenarios

In 2000, IPCC published Special Report on Emissions Scenarios (SRES) highlighting the set of emissions scenarios used in the Third Assessment Report (TAR). It defines set of future emission scenarios based on energy consumption, economic activity and population growth rates of the world and used the scenario's to investigate future developments in the global environment on the basis of greenhouse gas and aerosol emissions. Scenarios have been developed on plausible and uniform assumptions ignoring any possibility of emission reduction. Future climatic projections were made on the basis of these scenarios.

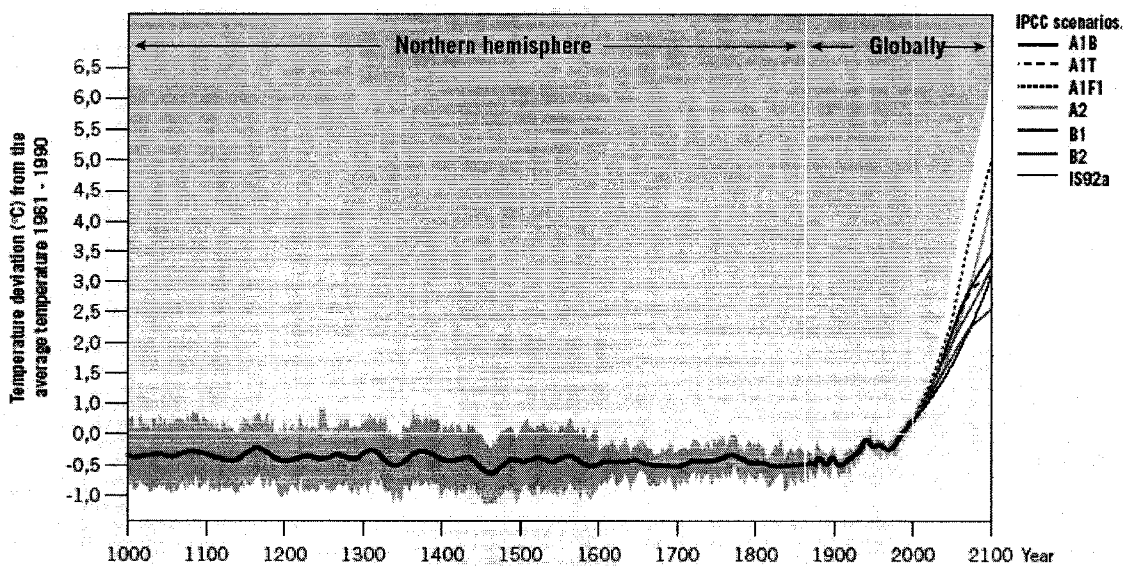


Fig 3.1: Anticipated temperature increases during the 21st century compared with temperature changes over the last 1,000 years (*Maria Kvarnbäck, 2001*)

The above figure reflects the anticipated increase in temperature by the end of the present century. The observed temperature increase since the beginning of nineteenth century does not have any comparison over the last 1,000 years. In the above graph the temperature data for the years 1000-1861 is based upon tree rings, corals as well as historical data for the northern hemisphere while that from 1861-2000 is the recorded data. The temperatures projections from 2000-2100 are based upon various socio-economic development scenarios (*Maria Kvarnbäck, 2001*).

Some of the major scenarios, their driving forces and the resulting climatic impacts, are outlined below:

3.3.1 Rapid Growth Scenario (A-1)

It highlights an era of sharp economic growth with technological and scientific developments, and world population that is anticipated to reach its peak around the middle of the century before starting to decline over the next 50 years (*Met Office, 2000*). Increased social and cultural contact with lesser disparity in per capita income amongst various regions of the globe is envisioned for this scenario.

- **A1FI Scenario:** This scenario anticipates a future where coal, oil, and gas will remain a dominant source of energy supply
- **A1B Scenario:** This scenario projects a balance between fossil fuels and other energy sources
- **A1T Scenario:** This scenario relies upon the use of latest technologies like renewable energy instead of fossil fuels

3.3.2 Fragmented World Scenario (A-2)

The scenario projects continuous population growth with considerable per capita income variations amongst regions, highlighting self-dependence and local identities, i.e. relying upon lesser regional based technological advancement in a diverse world.

3.3.3 Sustained Development Scenario (B-1)

The scenario highlights converging world based on the population estimates peaking around the middle of the century before starting to decline like A-1 Scenario, but in a different economical setting with more emphasis on the service industry. A sophisticated and environmental friendly technological advancement is also assumed in this case. Universal solution to socio-economical and environmental problems is anticipated in this scenario with no significant efforts towards climate improvement.

3.3.4 Local sustainability Scenario (B-2)

The scenario projects persistent increase in the population rate (lower than A-2 scenario), moderate economical development, slower but diverse technological development and regional solutions of socio-economical issues. The scenario adopts balanced approach towards the environmental and ecological issues. (*IPCC Data Distribution Centre*)

3.4 Scenario Driving Forces

There are different scenario driving forces which determine present and future rate of emission of anthropogenic greenhouse gas emissions. They include local topography, geographical location and social, economical, scientific and technological advancement. The social, economical and technological forces/systems mutually interact amongst themselves in a complex manner. According to the IPCC Special report on Emission Scenarios the most commonly used approach is based on the following Impact Population Affluence Technology (*IPAT*) identity equation *IPCC Special Report on Emission Scenarios*):

$$\textbf{\textit{Impact}} = Population \times Affluence \times Technology \qquad (3.1)$$

The equation states that impacts (*i.e. emissions*) are dependent on population size; their affluence levels (*per capita income i.e. GDP/population*); and technological advancement (*emissions per unit income*). Thus the above equation can be reproduced in a much simpler form as follows:

$$\boldsymbol{CO_2\ Emissions\ (impact)} = Population \times (per\ capita\ income\ /population) \times (Energy/GDP) \times (CO_2\ /Energy) \qquad (3.2)$$

This IPAT equation has been extensively used in the analyses of CO_2 emissions. (*IPCC SRES*).

3.5 Global Climate Models

Global Climate Models (GCMs) represent climate on the basis of three dimensional grid. GCMs usually have a coarser horizontal resolution ranging from 250 and 600 km; 10 to 20 vertical layers in atmosphere and even up to 30 layers in oceans. The physical processes involved in the GCMs are quite complicated e.g. the process of regulating the cloud cover transpires at smaller scales, resulting in considerable difficulty to model their influences properly over larger scales. This problem is overcome by a process called "parameterization", which involves the averaging of known properties over smaller magnitude over wider ranges but the process imparts uncertainty in future prediction of climatic changes based on GCM run simulations.

The other important contributing factors include proper modeling with regards to factor like water vapor and warming, ocean circulation and ice albedo. As all the GCMs estimate various feedbacks in distinct way; the GCMs can simulate quite different responses to the same "forcings".

IPCC Data distribution Centre has provided data from seven research facilities around the world and is based on seven models as detailed below:

1. Max Planck Institute for Metrology's model - ***ECHAM4/OPYC3:*** It is a coupled atmosphere-ocean general circulation model.
2. Hadley Centre for Climate Prediction and Research model - ***HADCM3:*** It is explained in detail in the following section.
3. Australia's Commonwealth Scientific and Industrial Research Organization's model – ***CSIRO-Mk2***: It is a coupled ocean-atmosphere-sea-ice model, incorporating global atmospheric, oceanic, sea-ice and biospheric sub-models
4. National Centre for Atmospheric Research - ***NCAR-PCM*** & ***NCAR-CSM***: The model NCAR-PCM has been explicitly explained in the following section.
5. Geophysical Fluid Dynamics Laboratory's model – ***R30***: It is a coupled atmosphere general circulation model (AGCM) and Ocean Mixed Layer model (MLM).
6. Canadian Center for Climate Modeling and Analysis – ***CGCM2***: It is explained in detail in the following section.
7. Center for Climate System Research National Institute for Environmental Studies model - ***CCSR/NIES AGCM + CCSR OGCM***: The model is a

coupled atmosphere general circulation model (AGCM) and ocean general circulation model.

Out of the above seven Global Climate Models (GCM), the three most frequently used models for research purposes were selected for our investigative study. The salient features of the three chosen models are listed below:

3.5.1 HADLEY Centre for Climate Prediction and Research Model - HadCM3

The model used for predictions at the Hadley Centre is a coupled atmosphere-ocean general circulation model (AOGCM) as described by *Gordon and Pope, 2000.* It is the most complex model in use, consisting of

- **Atmosphere General Circulation Models (AGCMs):** They represent the atmosphere in a three-dimensional way coupling atmosphere with the land and cryosphere. These models resemble the models used for predicting weather but have a coarser resolution as it encompasses wider time frame. Though the models require input like sea surface temperatures and sea-ice coverage, still they cannot predict climate changes because the ocean component is lacking.
- **Ocean General Circulation Models (OGCMs):** In these models the ocean and sea-ice is represented in a three-dimensional way, and are used for studying ocean circulation, and inconsistencies of the internal processes. Model input data includes sea surface temperatures along with atmospheric properties.

- **Coupled Atmosphere-Ocean General Circulation Models (AOGCMs):** They are the most intricate models presently and involve the coupling of AGCMs and OGCMs.

It does not require flux adjustment (more "artificial" heat and freshwater fluxes at the ocean surface) for improved simulation due to its higher ocean resolution. (Note: In fluid dynamics / transport phenomena heat flux is referred to as heat transferred rate per unit area) HadCM3 model has been run for more than thousand years and has shown minimal drift in its surface climate.

3.5.2 Model of Canadian Center for Climate Modeling and Analysis - CGCM2

CGCM2 is the improved version of earlier Coupled Global Climate Model (CGCM1), and it lays particular emphasis on improvement of the ocean mixing parameterization that was changed from horizontal / vertical diffusion scheme to the isopycnal / eddy stirring parameterization, which has been explained in detail by *Gent and McWilliams (1990).* (Note: In the stably stratified interior of the ocean, eddies transport material by advection and isopycnal stirring. Isopycnal is the surface where water density is constant and eddies are defined as the drift/tendency that acts in the direction opposite to the main current, especially in a circular motion)

In this GCM modification was made for ocean spin-up and flux adjustment procedures apart from inclusion of sea-ice dynamics as mentioned by *Flato and Hibler (1992).* This model has been used for projecting climate changes based on IPCC SRES A2 and B2 scenario runs.

3.5.3 National Commission of Atmospheric Research Model - NCAR-PCM

It is a Parallel Climate model (Ocean circulation model in which depth is used as the vertical coordinate) by National Commission of Atmospheric Research USA incorporates high-tech atmospheric component and latest version of radiation, boundary physics, soil physics and vegetation patterns etc. The ocean component of the model includes carefully modified bottom topography for achieving accurate flow around the globe.

The sea-ice component includes complete thermodynamic treatment having energy and mass conserving one dimensional thermodynamics as described by *Bitz and Lipscomb (1999)*; four vertical layers for resolving vertical temperature gradients in the ice, and temperature and salinity-dependent thermal properties for sea ice.

It calculates ice thickness distribution using 5 thickness categories with individual thermodynamic calculations for each category to determine average albedo, ice growth or melt rates, vertical heat exchange at surface and solar radiation transmission to the ocean. (*NCAR Parallel Climate Model*)

3.6 Resource Data

Data Distribution Centre (DDC) as desired by the 13th IPCC Plenary is a joint venture of Deutsches Klimarechenzentrum (DKRZ/MPI) Germany and Climatic Research Unit (CRU) at the University of East Anglia, Norwich, UK and the data is managed by three offices located in USA, Germany and U.K. The Data Distribution Centre provides data in accordance with the laid down criteria of IPCC Task Group on Data and Scenario Support for Impact and Climate Analysis (TGICA).

3.7 Important Conclusions of IPCC Report

According to the third assessment report of the IPCC earth's climate has indeed changed in the 20th century, with certain changes that can only be attributed to human influences. IPCC anticipates considerable reduction in the aerosols concentrations in future by anticipating lesser emissions from industrial activities. (Note: The aerosol particles are capable of exerting negative radiative forcing of the same magnitude as that of the GHG, they can cause cooling effect.)

Scientists are of the view that actual temperature increase can be higher than what has been previously reported. Based upon the latest emission scenarios the IPCC expects the earth's temperature to rise in the range of 1.4 °C - 5.8 °C during the 21st century. The predictions of Global Climate models regarding the rise in the earth's average temperature by 1.4 °C - 5.8 °C from year 1990 to 2100 is based primarily on the different development scenario assumptions. Higher temperature rise is expected over land than at sea due to the ocean effect/conductivity. (*2001*)

3.7.1 Temperature

The IPCC anticipates the variations in temperature to be as per following:

- Increase in average temperature of the earth is by 0.6 °C (± 0.2 °C) since 1860, with the last two decades being the warmest in the 20th century.
- Human influence has been a major contributor towards the global warming over the last 50 years.

3.7.2 Carbon Dioxide (CO_2)

The IPCC anticipates the increases in CO2 levels to be as follows:

- IPCC anticipates that the CO_2 levels in the atmosphere are bound to rise significantly during the 21^{st} century, under all the socio-economic development scenarios with an anticipated increase of 50 % - 160 % in its concentration levels by the end of the century as compared with the present concentration levels.

3.7.3 Precipitation

The IPCC anticipates the variations in precipitation to follow the following pattern:

- Precipitation trends have changed with observations of increased incidence of heavy rainfall in certain regions. In general average precipitation levels are anticipated to rise but regional precipitation levels can vary either way.

3.7.4 Sea Level

The IPCC anticipates the sea-level variations to be as listed below:

- 10-20 cm rise in sea levels during the 20th century was observed as a result of receding glaciers. Arctic ice-cover is rapidly diminishing.
- Frequency of extreme weather events like heat-waves, heavy rainstorms, flooding and droughts etc. is expected to increase.

3.8 Resultant Effects

The resultant effects due to the climate change are summarized below:

- Both positive and negative impacts on human and ecological health are being anticipated due to climate change. E.g. for slight increase in temperature increased agricultural yield at medium-high and high latitudes regions will be noticed. There is however consensus among the scientific community that more negative impact will be observed with climate change especially for the elderly and child population. Food shortages and water scarcity will be more pronounced in certain areas.
- Heat related mortality is anticipated to increase because of the sharp increase in diseases like malaria, dengue and cholera.
- Significant increase in the risk of flooding is anticipated because of the higher precipitation level which is bound to affect millions around the globe.
- Acute water shortages can be anticipated for peripheral tropical regions which are already faced with water scarcity. More dryness is expected in the Mediterranean region. Increasing temperatures can further reduce the agricultural productivity in these affected regions.

Chapter 4

Climatology and Geography of the Gulf Region

4.1 Introduction

Five coastal Gulf countries have been included in this research study. These are Bahrain, Oman, Qatar, United Arab Emirates and Yemen. The geographical location of these countries, their relevant socio-economic status including agricultural and industrial development along with the challenges regarding natural hazards and environmental issues are briefly outlined in the following sections. (*Michigan State University Global Access Resource*)

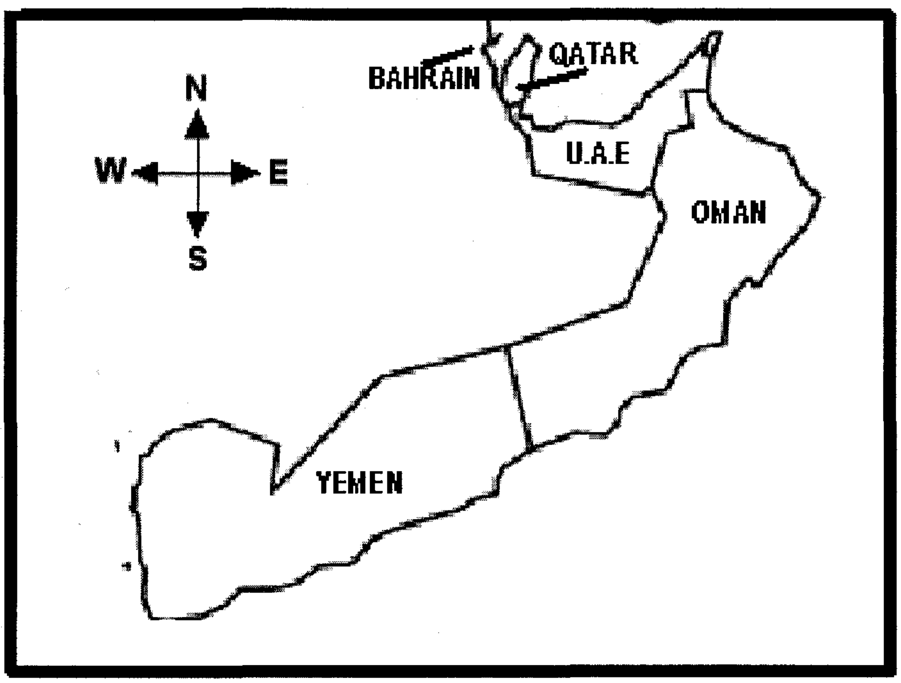


Fig 4.1: Outline map of the region

4.2 Regional Vulnerability

The entire region is extremely vulnerable to variations in climatic conditions. Due to the smaller amounts of annual scattered rainfall even small changes in the annual precipitation and humidity levels can have significant impact on the biodiversity because there are number of plant species whose very survival and existence depend upon the moisture contents in the atmosphere.

There are large human settlements residing closer to the coastal areas, which are already facing issues like coastal degradation and are very vulnerable to sea level rise. Sea-level rise can be a major threat for the region as it can pose major problems like physical displacement, psychological and adaptation issues etc. and will certainly require high priority from all the governmental authorities. Because of these reasons proper forecasting/ monitoring and data collection for anticipated climatic changes under plausible scenarios of socio-economical and technological development should be a priority for the governments of the Gulf region. By keeping the focus on vulnerability even wide-spread problems can be resolved in an amicable way. Proper information and community participation can result in better planning with improved adaptive measures to minimize the possible adverse impacts. Considerable advantages can be achieved if positive steps are taken to minimize possible future impacts of climate change.

4.3 Bahrain

Bahrain consisting of more than 30 islands is situated in the Gulf, closer to the shores of the Arabian Peninsula and has a total area of 716 sq km. These islands are approximately

24 km from the east coast of Saudi Arabia and 28 km from Qatar. The largest island, forming 83 % of Bahrain is spread over 572 sq km. From north to south, Bahrain is 48 km long; at its widest point in the north, it is sixteen kilometers from east to west. It elevation extremes range from 0m at the Persian Gulf to about 103 m at Jabal ad Dukhan. Bahrain has the geographical coordinates of 26 00 N, 50 33 E with highest population density along the 161 km coastline and spreading along 8000 sq km of marine area (*UNDP*).

Bahrain's with Manama as its capital city has an estimated total population of 698,585 including 235,108 expatriates as of July 2006 estimates (*CIA World Factbook, 2006*). Its annual Gross Domestic Product (GDP) is US $13.01 billion with services sector being major contributor with a share of 58.4 %, followed by 41 % share of the industrial sector (*2004 est.*). Smallest contribution of 0.7 % comes from the agriculture sector because only 2.28 % of Bahrain's total area is arable with permanent crops over only 5.63 % of the total area. It has only approximately 40 sq km of irrigated land as of 2003. Most of the agricultural yield is from of fruits and vegetables however poultry, dairy products and fisheries also contribute to some extent.

As Bahrain has considerable natural resources like oil, natural gas, pearls and fisheries, its industrial activities are mainly dependent on processing and refining of the petroleum products, aluminum smelting, fertilizers, ship repairing apart from offshore banking & tourism sectors. It has been connected to Saudi Arabia through a causeway.

It has a hot and humid climate with little annual precipitation. It mainly consists of the flat expanses of sand and rock. It is an arid region with milder and pleasant winters but extremely hot and humid summers. Bahrain's imports crude oil for the refining purposes along with machinery, transport equipment and chemicals for its everyday requirements (*CIA World Factbook, 2006*).

Frequent dust storms and sporadic droughts are considered to be the natural hazards in Bahrain. Inadequate fresh water resources, high population growth rates and unplanned urbanization and industrialization activities are its major challenges (*UNDP Energy and Environment Bureau for Development Policy*).

Ground water and sea water (costly desalination processes) are the only two sources available for use for all agricultural and domestic utilities. Around 6 % increase domestic water demand per annum has been noted since 1986 with average per capita water consumption being around 500 L/day (*MDG, 2003*).

Shortage in the fresh water resources is not only causing rapid degradation of arable land and desertification but coupled with the high population growth, rapid urbanization and industrialization, it is causing significant adverse impacts in form of depleting natural resources and shrinking biodiversity (*UNDP*). Only 30 % of the total sewage effluent is being currently treated to tertiary stages for watering crops and landscapes, however there are plans to fully utilize recycled wastewater by 2010, which is expected to save another 20 % of the present annual requirement (*MDG, 2003*).

One of the other major environmental challenges faced by Bahrain is the continuous coastal degradation due to the oil spills and discharges from tankers, oil refineries, etc.

According to the Millennium Development Goals-First report 2003, Bahrain's energy sector is responsible for discharging maximum CO_2 emissions of 75.8 % in the atmosphere followed by 10.1 % by waste and more than 8 % by industrial processes/ effluents. According to the estimates of initial vulnerability assessment due to higher CO_2 emissions Bahrain's total land area will have an inundation level of 5 % if the sea-level rises by 20 cm. Government of Bahrain recognizes that adequate steps are required for proper assessment of the situation and following appropriate steps are required:

- Pursue environmentally sustainable policies with proper resource utilization
- Formulate and execute national strategies for coastal zone management
- Carry out environmental impact assessment on the basis of valid database

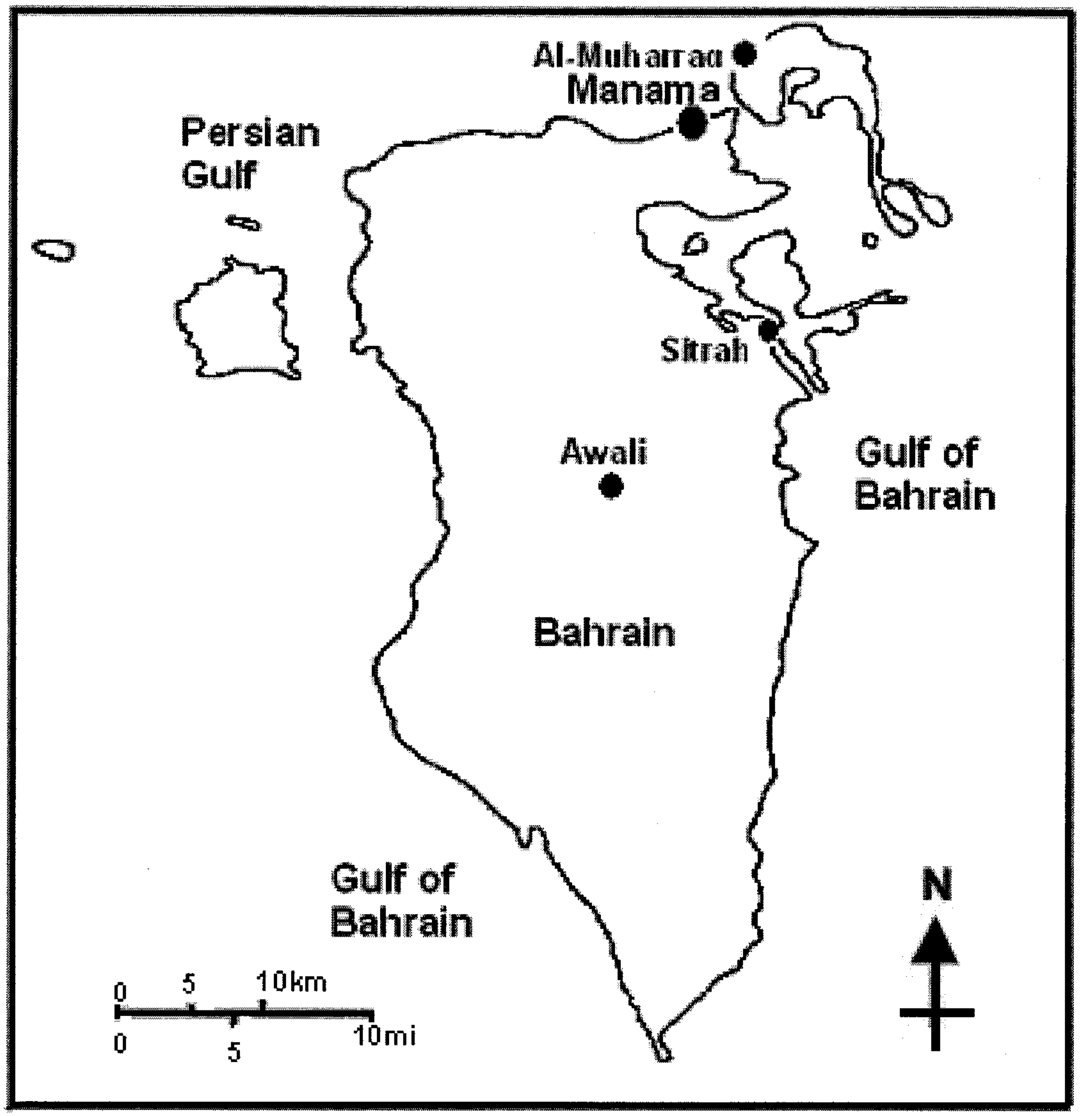


Fig 4.2: Country map of Bahrain (outline)

4.4 Oman

Oman with Muscat being its capital, is a 1,000-mile-long (1,667-km) coastal plain bearing co-ordinates 21 00 N, 57 00 E at the southeastern tip of the Arabian peninsula along the Arabian Sea. It lies between Yemen in the south, and Saudi Arabia and United Arab Emirates in the west. The total population of Oman is expected to be more than

3,100,000 with more than half million non-nationals as of July 2006 estimates. (*CIA World Factbook, 2006*) Oman has a total area of 212,460 sq km with elevation extremes ranging from 0m at the Arabian Sea to 2,980 m at Jabal Shams. Its coastal line is spread over 2,092 km.

Vast desert plain covers most parts of central Oman, with mountainous ranges along the northern and southeast coast, where the country's main cities are located. It is strategically located on Musandam Peninsula adjoining Strait of Hormuz, which is a vital transit point for world crude oil transportation.

The GDP of Oman is approximately $38.09 billion (*2004 est.*) with maximum contribution of 55.8 % from the services sector followed by 41.1 % from industrial sector. The lowest contribution 3.1 % is from the agricultural sector because according to 2005 estimates it has only 0.12 % arable land with permanent crops occupying only 0.14 % of the total land area. The agricultural productivity is limited to dates, limes, bananas, alfalfa, vegetables; camels, cattle apart from fisheries.

Oman natural resources include petroleum, natural gas, copper, asbestos, marble, limestone, chromium and gypsum. The industrial activity in Oman is mainly dependent on crude oil production and refining, production of natural and liquefied natural gas (LNG). However other sectors such as cement production, construction, copper, steel, optic fiber and chemical industry also have considerable contribution.

The 2005 Millennium Development Goal (*MDG*) Report anticipated the annual per capita CO_2 emission increase from 1.7 metric tons in 1990 to 3.8 metric tons per capita by 2020, thus showing the annual increase rate of 2.59 %.

Oman is a dry desert which is hot, and humid along the coast, while hot and dry conditions persist in the interior experiencing strong southwest summer monsoon in far south during the months of May to September. It annual rainfall is less than 100 mm. Hajar range experiences more but periodic rainfall and has more vegetation (which is limited due to its rocky terrain). Vegetation in the central plains benefits significantly from the fog moisture especially during the spring and autumn seasons (*Environmental Society of Oman, 2006*).

Summer sandstorms and dust storms in interior regions along with sporadic droughts are among the major natural hazards faced by Oman. Shortage of the fresh water resources is resulting in rapid degradation of arable land and desertification along with higher levels of salinity in soil. Continuous coastal degradation is yet another major environmental challenge for Oman because of the polluted beaches caused by the spillage of oil and discharges from tankers, etc.

Oman has to rely on imports for food, livestock, manufactured goods, lubricants, machinery and transport equipment (*CIA World Factbook, 2006*). Oman is faced with a tremendous challenge of water scarcity (*MDG 2005*) coupled with unreasonably high consumption rates. Not only is the demand of water very high but even the water available for irrigation is not of appropriate economic value.

Gathering and proper utilization of environmental statistical data is of utmost importance, to devise suitable adaptative strategies and to ensure implementation of future development programs.

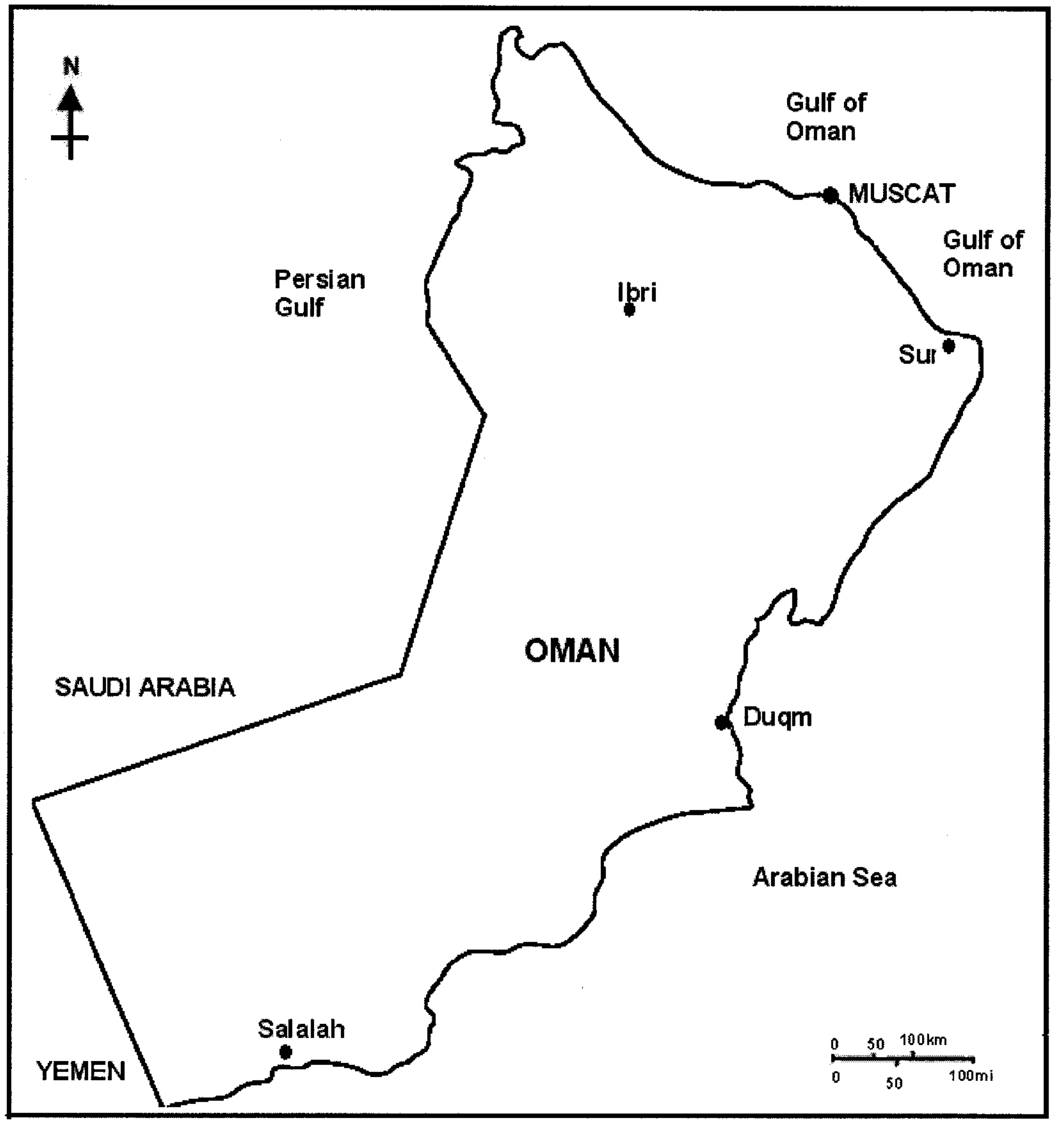


Fig-4.3: Country map of Oman (outline)

4.5 Qatar

Qatar with Doha as its capital consists of mainly a flat and barren country lying between the geographical latitude co-ordinates of 24 27 N and 26 10 N, and longitudinal coordinates of 50 45 E and 51 40 E (*MDG, 2005*). Qatar has a total area of 11,437 sq km spreading along 563 km of coastline and lying on small peninsula along the Persian Gulf on the east and sharing its western border with Saudi Arabia and the south-eastern border with United Arab Emirates. Qatar extends approximately 160 km to the north into the Persian Gulf and its elevation extremes range from 0m at Persian Gulf to approximately 103 m at Qurayn Abu al Bawl. Its width varies from 55 km to 90 km while the land is mainly flat and rocky.

With population estimates of 885,359 as of July 2006 (*CIA World Factbook, 2006)* its GDP is $19.49 billion (*2004 est.*) relying mainly upon the industrial (58.2 %) and services sectors (41.5 %) with the minimal contribution of 0.3 % from agricultural sector. The reason behind lesser contribution from the agricultural sector is that only 1.64 % of its total area is arable land and permanent crops are grown over only 0.27 % of the area. Its agricultural yield is mainly in forms of fruits, vegetables; poultry, dairy products apart from fisheries.

According to the US, EPA in 1996 total per capita CO_2 emissions were 32 metric tons/year. According to another statistical data reported by World Resource Institute CH_4 emissions (equivalent to CO_2) in Qatar increased from $2.23x10^6$ metric tons in 1990 to $4.2 \text{ x}10^6$ metric tons in 2000.

Qatar's climate has minimal variations in temperature and humidity throughout the country but it experiences hot and humid summers with pleasant and partially dry winters and sporadic rains. Extremely low annual precipitation and limited underground waters mostly with high mineral contents makes it unsuitable for drinking or irrigation purposes. Although water from underground sources is being utilized yet the desalinated seawater is fulfilling all the major requirements.

Qatar's major natural resources are petroleum deposits along with fisheries. Its industrial activity includes oil production and refining along with production of petrochemicals, ammonia, fertilizers, cement, and manufacturing of reinforced steel bars along with service industry like commercial ship-repairing.

The usual natural hazards faced by Qatar include frequent sandstorms and dust storms along with haze, but its major environment issue / challenge is the inadequate fresh water resource and its significantly increased dependence on desalination facilities which are extremely costly when carried out for broader national scale. Qatar's fulfils its basic requirements like food, chemicals, machinery and transport equipment through imports (*CIA World Factbook, 2006*).

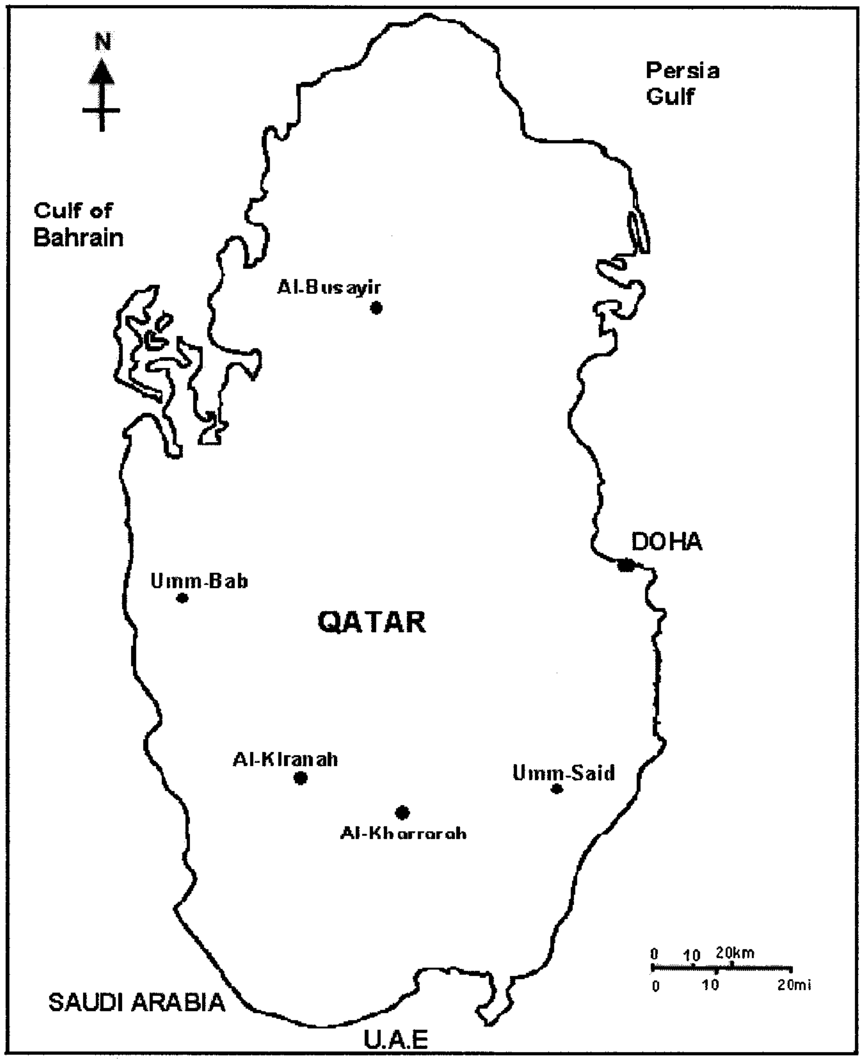


Fig-4.4: Country map of Qatar (outline)

4.6 United Arab Emirates

United Arab Emirates (UAE) lying across the geographical coordinates of 24 00 N and 54 00 E is located in the northeastern part of the Arabian Peninsula, extending along Gulf of Oman and the southern coast of the Persian Gulf. UAE with Abu Dhabi as it capital has most of its inhabitants/ settlements along the coast of Persian Gulf with some along the coastal regions of Gulf of Oman. UAE has total coast line of 1,318 km and its elevation extremes vary from 0 meters at Persian Gulf to about 1,527 m at Jabal Yibir. Its neighbors include Saudi Arabia to the west and south, Qatar to the north, and Oman to the east.

The expected total population of United Arab Emirates is estimated to be 2,602,713 by July 2006 (*CIA World Factbook, 2006*) its GDP is \$63.67 billion (*2002 est.*) relying mainly on the industrial (58.5 %) and services sectors (37.5 %) with the minimal contribution of 4 % is from agricultural sector as well.

Although the total area of UAE is 82,880 sq km but only 0.77 % of it is the arable land and has permanent crops over 2.25 % of the total area. According to 2003 estimates only 760 sq km of UAE land was being irrigated with its main agricultural yield being dates, vegetables, watermelons, poultry, dairy products and fisheries.

Emirates industrial activities are related to oil production and refining, production of aluminum, fertilizers, cement, petrochemicals, construction material and textile. Services sector involving commercial ship-repairing is also an important contributor apart from fisheries.

In terms of energy consumption and emissions, the per capita CO_2 emissions increased from 29.32 metric tons in 1990 to 33.56 metric tons in 2003 according to MDG (*2006*) report indicating a significant overall increase of more than 12.5 % in this period.

United Arab Emirates encounters natural hazards like frequent sandstorms and dust storms because most of the land is flat, barren and sandy with mountainous region in east which covers only a small percentage of the total area. But the major environment issue/challenge for the Emirates is the scarcity of fresh water resources that necessitates higher dependence on desalination facilities. The water shortage is causing degradation of arable land resulting in desertification. Petroleum and natural gas are the main natural resources and involve considerably high volumes of oil exports. As UAE is situated along the southern approaches to Strait of Hormuz which is a central transit point for world crude oil it also encounters issues of polluted beaches due to oil spillage.

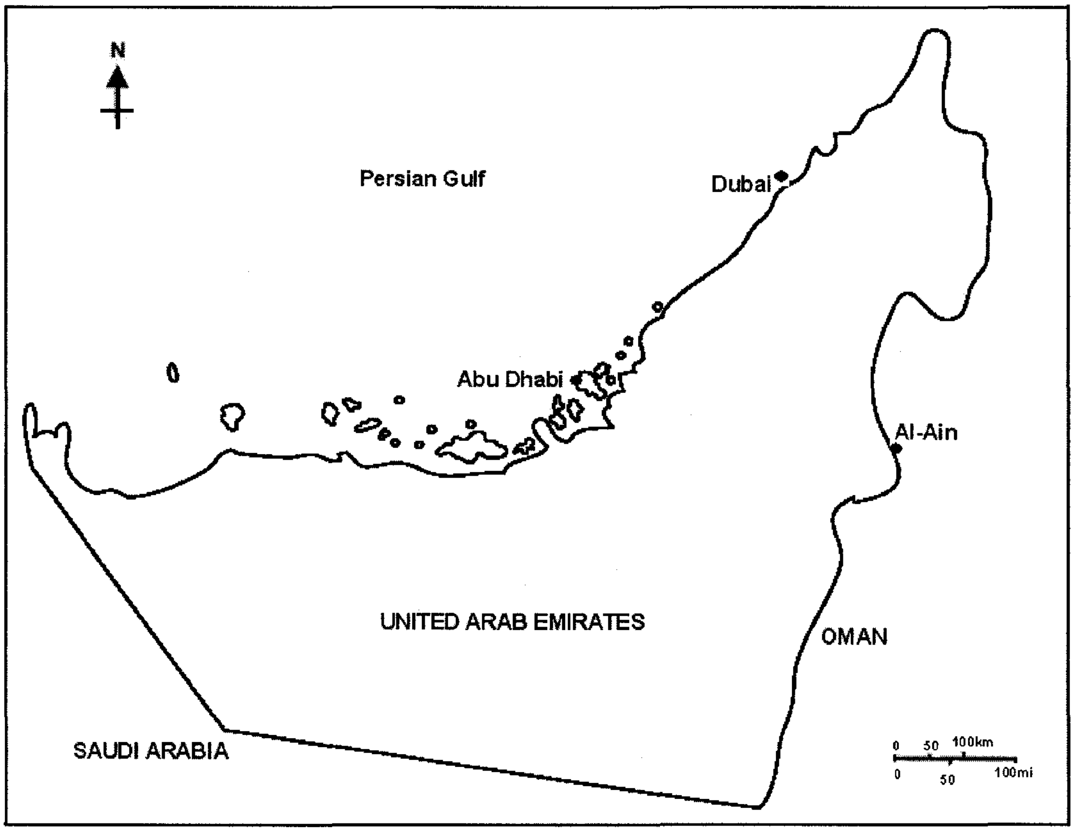


Fig-4.5: Country map of U.A.E (outline)

4.7 Yemen

Yemen with its capital city Sanaa bears geographical co-ordinates of 15 00 N and 48 00 E and is strategically located along one of the world's most active shipping lanes. It lies along the southwestern edge of Arabian Peninsula on Red Sea extending along the southern part of the Arabian Peninsula on the Gulf of Aden and Indian Ocean. Yemen's has a coast line of 1,906 km with its elevation extreme ranging from 0m at Arabian Sea to 3,760 m at Jabal an Nabi Shu'ayb.

Yemen's neighbors include Saudi Arabia on the north and Oman on the east. It consists of 700-mile (1,130 km) narrow coastal plain in the south followed by the mountainous and plateau regions. It constitutes mostly desert, with hot and humid climatic conditions along the western coast and temperate along the western mountains because they are influenced by the seasonal monsoon.

The population of Yemen is estimated to be 21,456,188 as of July 2006 (*CIA World Factbook, 2006*), with national GDP of $16.25 billion (2004 est.) primarily relying on the contributions from industrial sector (44.7 %), services sector (39.7 %) and from agricultural sector15.5 %.

According to the 2003 MDG report, as majority of the people still use wood as a source of fuel, the forest cover is rapidly diminishing and threatening wildlife as well biodiversity apart from increasing the GHG emissions. As numbers of colonies are situated along the coast areas, their sanitation/sewerage and ship discharges have accelerated the process of coastal degradation.

Yemen has a total area of 527,970 sq km, out of which only 2.91 % is arable land and has permanent crops over 0.25 % as of 2005. Water scarcity and high salinity coupled with hot and dry atmospheric conditions pose a greater environmental risk for desertification, already causing 3 % - 5 % annual reduction in arable land. Its agricultural productivity consists of grain, fruits, vegetables, pulses, coffee, cotton, dairy products apart from livestock (sheep, goats, cattle, and camels), poultry and fisheries.

Yemen's natural resources include petroleum products, rock salt, marble, small coal deposits; metals like gold, lead, nickel, copper, along with fertile soil in west and the fisheries.

The industrial activity of Yemen revolves around sectors like crude oil production, petroleum refining, small-scale production of cotton textiles and leather goods, food processing, handicrafts, small aluminum products factory, cement and ship repairing at commercial levels.

The natural hazards of Yemen like other Gulf countries include frequent summer sandstorms and dust storms. Like other gulf countries major environment issue/ challenge for the Yemen is the extreme scarcity of fresh water resources. Higher evaporation rates due to the hot and dry climatic conditions prevalent over 90 % of the total Yemen area further aggravates the problem apart from the issue of over-pumping of the ground water (*MDG, 2003*). Water drop of 1~8m has been recorded inmost of the areas. MDG report further predicts complete depletion of most of the ground water reservoirs in 15-50 yrs time period.

In terms of health issues malaria which is a disease whose association with climate is proven. In Yemen malaria is widespread and considered to be one of the leading killers. Though precise statistical data is not available for evaluation yet according to estimates its incidence increased from 23 % in 1990 to 35 % in 2000. The government is committed to take all possible steps to combat malaria through various national health agencies.

The Government of Yemen recognizes the environmental challenges faced by their nation with regards to monitoring, data collection and evaluation, capacity to carry out statistical analysis. In the 2003 MDG report the seventh Goal "Ensure Environmental Sustainability" considerable emphasis has been laid on issues like:

- Proper implementation of regulations concerning environment protection
- Participation of local communities in resource management and for fighting pollution with governmental and non-governmental organizations
- Promoting awareness, data management and research.

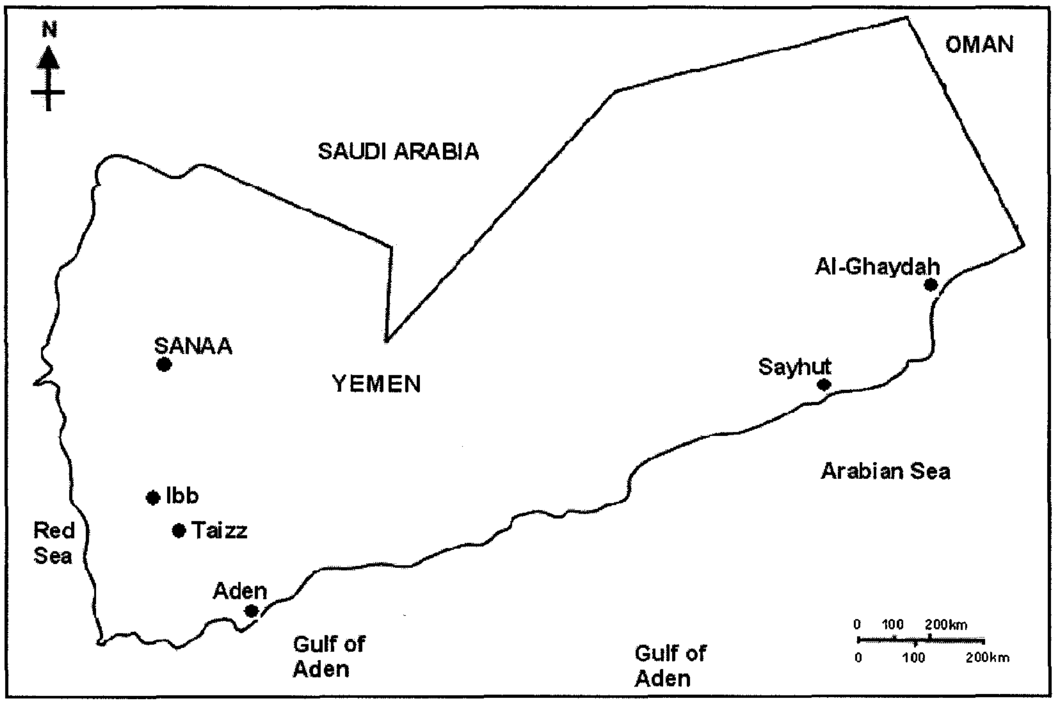


Fig-4.6: Country map of Yemen (outline)

Chapter 5

Methodology

5.1 Introduction

The process of assessing vulnerability in agriculture, water resources, marine and terrestrial ecosystems, and coastal zone management due to climate change requires the construction of a predicted vision of climate scenarios under physically reasonable assumptions of levels of greenhouse gases. The estimation of future rate of emissions of greenhouse gases (GHG) depends upon future energy consumption, economy and population growth rates and it can be assessed on the basis of intricate system of various determinant factors which include demographic situation, socio-economic and technological developments.

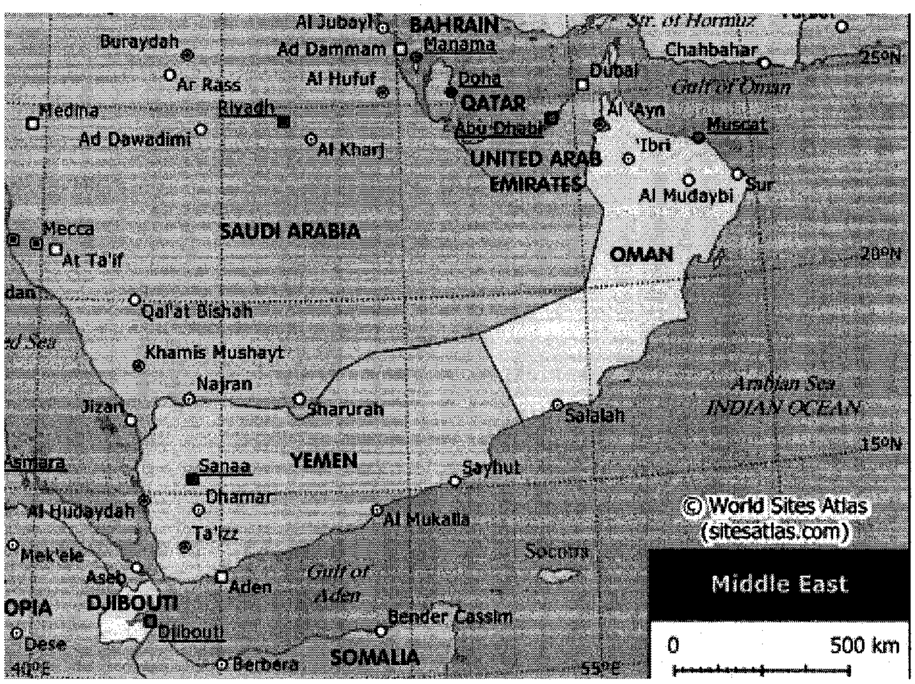


Fig- 5.1: Study area consisting of five Gulf countries with geographical co-ordinates *(Modified from http://www.sitesatlas.com/Maps/Maps/MEast.htm)*

In arid and hot climatic conditions witnessed in the Gulf coastal region countries consisting of Bahrain, Oman, Qatar, United Arab Emirates and Yemen *(Fig 5.1)* even minor climatic changes will not only have significant impact on human health but also on the existence/survival of certain plant species, wild animals, and other desert ecosystems. This research is focused on future changes in temperature, precipitation and humidity in the above Gulf countries on the basis of long-term simulated records of temperature, precipitation and humidity using Intergovernmental Panel on Climatic Change (IPCC) database. All seven models presented at the IPCC website have been validated before their data was made available in public domain for research activities. The three Global Climate Models (GCMs) selected for study from amongst the seven GCMs were the ones which are widely used for the research work and whose data is also available at the IPCC data distribution centre's website.

1. Hadley Centre Global Model --- (HadCM3)
2. Canadian Centre for Modeling and Analysis (CCCma) model ---(CGCM2)
3. National Center for Atmospheric Research (NCAR) model --- (NCAR-PCM)

5.2 Data Retrieval

For this research study the concentration was on SRES scenarios as they incorporated the recent global population projections having a span of greater range of potential economic futures. After reviewing various climate change SRES scenarios as developed by IPCC, the two plausible and extensively used climate scenarios were chosen for the study. These two chosen are the A2 and B2 family of climate scenarios which anticipates continuous increase (no reduction or curtailment) in CO_2 emissions in future. These two most likely and widely used scenarios have the following representative characteristics:

- Fragmented world scenario (A-2): Highlights continuous population growth with considerable per capita income variations amongst the regions in the world, self-dependence and local identities along with the region-based technological advancement in a diverse world.
- Local sustainability scenario (B-2): Depicts persistent increase in the population growth rate with moderate economical development, slower but diverse technological development and regional solutions of anticipated socio-economical issues.

Long-term simulated records of different climatic parameters from variety of different atmospheric research centers based on their monthly mean data are available at the IPCC database in the public domain. The IPCC database stores data at global level for different climatic scenarios up to the year 2099 for IS92a emission data and SRES scenarios. The selected SRES scenarios (A-2 and B-2) had core data as well as optional data available for different parameters. The core data is available for the following parameters:

Table 5.1: Parameters for which 'Monthly Mean Core Data' is available for **A-2** SRES scenario

Parameter	unit
2m mean surface air temperature -> 1.5m	°K
2m mean maximum air temperature -> 1.5m	°K
2m mean minimum air temperature -> 1.5m	°K
Total precipitation	mm/d
Total incident solar radiation	W/m^2
Mean Scalar wind speed	m/s
Relative Humidity (for Hadley's model)	%
Specific Humidity (for NCAR and CCCma model)	kg/kg
Man sea level pressure	hPa
Global mean sea level change (thermal expansion)	mm/y

Table 5.2: Parameters for which 'Monthly Mean Core Data' is available for **B-2** SRES scenario

Parameter	unit
2m mean surface air temperature -> 1.5m	°K
2m mean maximum air temperature -> 1.5m	°K
2m mean minimum air temperature -> 1.5m	°K
Total precipitation	mm/d
Total incident solar radiation	W/m^2
Man scalar wind speed	m/s
Relative Humidity (for Hadley's model)	%
Specific Humidity (for NCAR and CCCma model)	kg/kg
Mean sea level pressure	hPa
Global mean sea level change (thermal expansion)	mm/y

The predicted climatic data for temperature, precipitation and humidity based on the selected scenarios is downloaded from Intergovernmental Panel on Climate Change (IPCC) website for data distribution centre for the three Global Climate Models and for each of the three individual parameters based on "SRES" scenario runs for Third Assessment Report (TAR) for the tree models (*Ref: IPCC Data Distribution Centre*).

The available data is in grib format (representing forecast and analysis products in self descriptive binary format). The specific data for the Gulf region is retrieved from the database in the following manner:

- GRIB converter software is available at the IPCC's (IPCC, 2006) website for downloading. It converts the already downloaded binary data of the entire world to numeral format for further processing.
- The data so obtained is for the entire world, and there is a need for extraction of the data for our specific regions from the individual GCMs database.
- The entire region lies in geographical co-ordinates of longitude 41.25 °E to 60.0 °E and latitude 12.5 °N to 27.5 °N. The specific data for an individual parameter based on any one of the above three selected GCMs is obtained by exclusively using the grid definitions of that particular model with the help of three different computer programs (for each model) which were coded in 'MS Visual C++'. The grid definitions of the three models are listed in *Table-5.3*:

Table 5.3: Grid definitions of 'Global Climate Models" used for data collection

Centre	Model	Grid Pts (lat x long)	Longitude	Latitude
Hadley	*HadCM3*	73 x 96	221.25 - 240.00	12.50 - 27.50
CCCma	*CGCM2*	48 x 96	221.25 - 240.00	9.2779 - 27.8334
NCAR	*NCAR-PCM*	64 x 128	222.1875 - 241.875	12.55776 - 26.51077

All the Global Climate Models have distinct model resolutions (defining particular region with reference to the latitude-longitude coordinates). This resolution is characterized by Grid definitions. This is the reason that the models have different latitude longitude coordinates as seen in the above table.

The data gathered for the purpose of analysis indicated that the three models with data in daily mean values when taken in Excel sheets involved considerable matrix sizes for each of the individual parameter i.e.

- For Hadley model for each of the three parameters the data matrix size was 373 vertical columns x 45 horizontal columns for 1970-2000 and 2020-2050 period, where as it involved 361 vertical columns x 45 horizontal columns for 2070-2099.
- For Canadian model the matrix sizes were 373 vertical columns x 39 horizontal columns for 1970-2000 and 2020-2050 period, and 361 vertical columns x 39 horizontal columns for 2070-2099.
- For National Commission for Atmospheric Research model the matrix sizes were 253 vertical columns x 51 horizontal columns for 1970-2000, 373 vertical columns x 51 horizontal columns for 2020-2050 period, and finally 361 vertical columns x 51 horizontal columns for 2070-2099. There was lesser data volume for this model for the baseline period because the model provides data from 1980 onwards and hence ten year data was not available which reduced the matrix size.

Total number of the matrixes was 18 each for both Hadley and CCCma model but those for NCAR model was 15 due to the non-availability of baseline period data for "Local sustainability scenario (B2)" scenario.

5.3 Assessment of Health Impacts

Climate change is bound to cause adverse health impacts for the human population in the region through variety of pathways. The net impacts are assessed on the basis of the altered spatial and temporal ranges of specific infectious diseases: "Disability Adjusted Life Years" and increased mortality, etc.

DALYS is the life years lost due to premature death and/or years lived with disability along with variations in morbidity and mortality rates with the burden of disease being calculated on the basis of available quantitative data and its co-relation with specific disease incidence within population-group/region based on the dose-response health impacts.

Climate changes due to human influences and natural variations cause significant variations in regional weather patterns due to altered temperature, precipitation and humidity levels. These regional changes play extremely critical role in disease transmission dynamics by influencing factors such as vector longevity and development, pathogen development, distribution and abundance of natural vertebrate hosts, and vector and rodent habitat. Due to the non availability of the hospital records empirical approach was adopted to access the possible changes in these two vital parameters over time.

Chapter 6

Climate Change Prediction and Result Analysis

6.1 Result Outline

The study region consisting of five Gulf coastal region countries indicate considerable inconsistencies regarding predicted variations in temperature, precipitation and humidity data over the next fifty (referred to as Step-1 i.e. *S-1*) and hundred years (referred to as Step-2 i.e. *S-2*) i.e. during the period 2020-2050 and 2070-2099 compared with the baseline period of 1970-2000 by the three models under the Fragmented world (A-2) and Local sustainability (B-2) as shown in tabular form below: The detailed explanation of the anticipated changes in temperature, precipitation and humidity as highlighted in tables 6.1, 6.2 and 6.3 are mentioned in sections 6.2, 6.3 and 6.4 *(Chaudhary and Husain, 2006a).*

It is important to mention over here that the humidity data obtained as shown and explained in the following tables and subsequent sections is in two forms i.e. in (%) and (kg/kg). This is because of the data availability by the three models. Hadley Centre's model provide data for relative humidity which defined as the amount of water vapor in air at any given instant which is generally less than that required to saturate the air, i.e. it is the percentage of the saturation humidity and is measured in percentage.

$$\mathrm{Re}\,lateive\ Humidity(RHUM) = \left(\frac{actual\ vapor\ density}{saturation\ vapor\ density}\right) \times 100\%$$

Whereas the models by the other two centres namely Canadian Centre for Climatic Modeling and Analysis and National Centre for Atmospheric Research provide specific humidity data and is defined as the mass of water vapor present in the air divided by the total mass of air and is expressed in terms of "mass of water vapor in grams to the mass of air in kilograms (g/kg)" or "mass of water vapor in kilograms to the mass of air in kilograms (kg/kg)" i.e.

$$Specific\ Humidity(Sp.Humidity) = \left(\frac{mass\ of\ watervapor}{total\ mass\ of\ air}\right)$$

The data by the three GCMs show the anticipated temperature variations to be uniform and all the models predict increase in temperature over the next century. The anticipated precipitation changes does not seem to be realistic through these models because of the huge variation in the range, as Hadley anticipates an increase in precipitation from 3 mm to 486 mm whereas CCCma predicts variation range from -147 mm to +174 mm with NCAR predicting the same range to be from -157 mm to 458 mm for the A-2 scenario. It is pertinent to note that in these Gulf countries even the annual rainfall is below 100 mm in most of the areas so the anticipated changes are not realistic.

The possible reasons for this marked variation in predicted results by the GCMs can be attributed to their poorly defined boundary conditions and lack of model validation. The GCMs have much coarser horizontal resolution i.e. typically around 250-600 km as compared to RCMs horizontal resolution of around 50 km. RCMs because of their finer horizontal resolution are also capable of incorporating topographic features in a much better way when the focus is on a smaller area.

Table 6.1: Predicted data by models with selected scenarios

Para-meter	Hadley (A-2)	Hadley (B-2)	CCCma (A-2)	CCCma (B-2)	NCAR (A-2)	NCAR (B-2)
Temp.	*°C*	*°C*	*°C*	*°C*	*°C*	*°C*
S-1	0.94 to 1.23	0.78 to 1.05	0.79 to 1.09	0.67 to 0.94	0.40 to 0.66	0.31 to 0.55
S-2	2.58 to 2.93	1.93 to 2.47	2.47 to 3.37	1.55 to 2.16	1.33 to 1.80	NA
Ppt.	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*
S-1	-44.6 to +108.39	-12.7 to +144.3	-152.7 to +103.8	-197.2 to +61.2	-102.5 to +138.5	-0.12 to +145.07
S-2	+3.0 to +485.90	+16.9 to +530.4	-147.4 to +174.1	-126.0 to +113.6	-157.4 to +458.1	NA
Hum	*%*	*%*	*g/kg*	*g/kg*	*g/kg*	*g/kg*
S-1	-0.12 to 0.44	-0.16to 0.71	0.74 to 1.13	0.68 to 0.95	0.43 to 0.69	0.26 to 0.58
S-2	0.08 to 1.39	0.25 to 1.76	3.08 to 3.72	1.85 to 2.25	1.09 to 1.92	NA

Table 6.2: Statistical data analysis of 50 year variations under two scenarios

Parameter	Model	Scenario	Min	Max	Mean	Std Dev
Temperature (°C)	Hadley	A-2	0.9414	1.2298	1.1262	0.0844
		B-2	0.7836	1.0518	0.9232	0.0785
	CCCma	A-2	0.7950	1.0828	0.8978	0.0748
		B-2	0.6656	0.9363	0.7617	0.0771
	NCAR	A-2	0.4003	0.6603	0.5224	0.0761
		B-2 Single Step	0.3134	0.5493	0.4508	0.05134

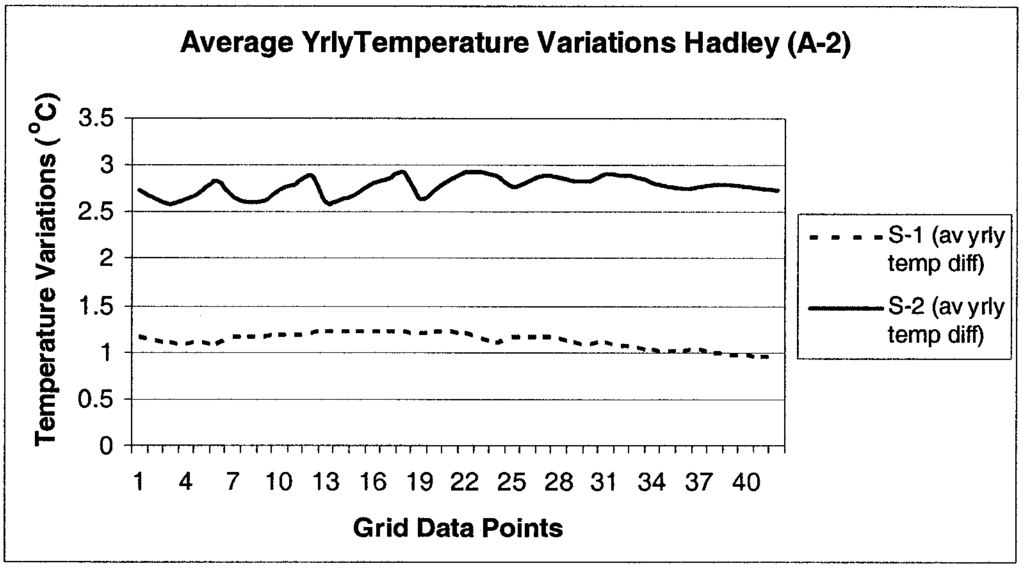
Precipitation (mm)	Hadley	A-2	-44.666	108.40	24.075	35.786
		B-2	-12.732	144.28	45.253	45.192
	CCCma	A-2	-152.74	103.78	-11.945	50.011
		B-2	-197.22	61.230	-35.265	59.868
	NCAR	A-2	-102.51	138.49	22.388	48.752
		B-2 Single Step	-80.121	145.07	-1.4539	48.310
Humidity	Hadley (%)	A-2	-0.1169	0.4392	0.1108	0.1492
		B-2	-0.1565	0.7078	0.2724	0.2763
	CCCma (g/kg)	A-2	0.7440	1.1317	1.0147	0.1009
		B-2	0.6828	0.9539	0.8448	0.0674
	NCAR (g/kg)	A-2	0.4307	0.6942	0.5941	0.0774
		B-2 Single Step	0.2604	0.5834	0.4287	0.1028

Table 6.3: Statistical data analysis of 100 year variations under two scenarios

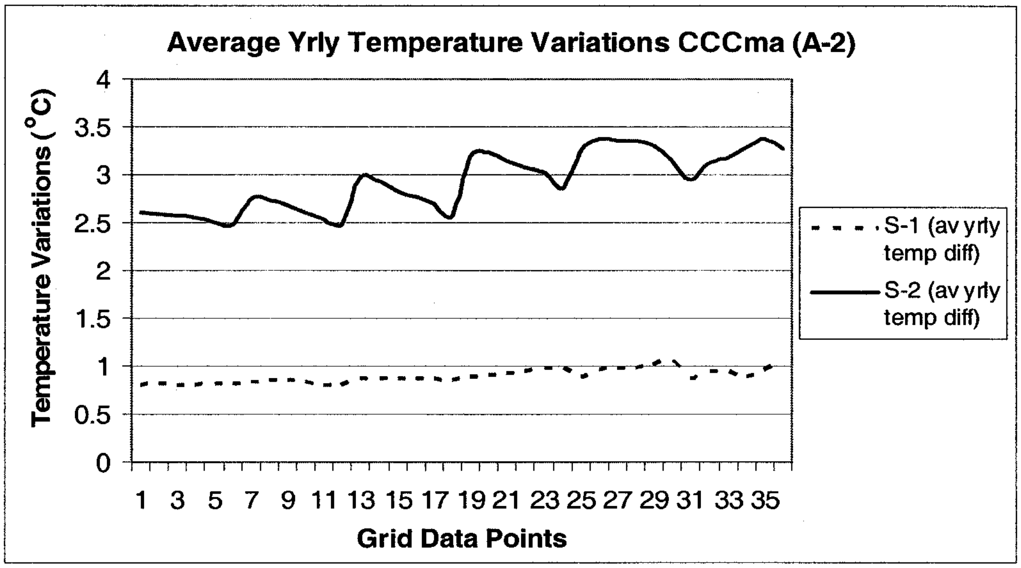
Parameter	Model	Scenario	Min	Max	Mean	Std Dev
Temperature (°C)	Hadley	A-2	2.5767	2.9268	2.7753	0.0984
		B-2	1.9295	2.4716	2.2223	0.1531
	CCCma	A-2	2.4743	3.3747	2.9248	0.3079
		B-2	1.5546	2.1647	1.8471	0.2006
	NCAR	A-2	1.3294	1.8039	1.6188	0.1364
		B-2	N/A	N/A	N/A	N/A
Precipitation (mm)	Hadley	A-2	3.0743	485.90	137.62	153.20
		B-2	16.893	530.44	180.62	171.79
	CCCma	A-2	-147.44	174.11	28.534	84.006
		B-2	-126.02	113.57	22.981	48.294
	NCAR	A-2	-157.36	458.14	57.353	104.32
		B-2	N/A	N/A	N/A	N/A
Humidity	Hadley (%)	A-2	0.0843	1.3896	0.8177	0.3566
		B-2	0.2459	1.7643	0.9714	0.4477
	CCCma (g/kg)	A-2	3.0844	3.7226	3.5034	0.1765
		B-2	1.8476	2.2463	2.1298	0.1173
	NCAR (g/kg)	A-2	1.0948	1.9214	1.6067	0.2193
		B-2	N/A	N/A	N/A	N/A

The graphical representation of the anticipated 50 yr and 100 yr changes are shown in the following figures for the two scenarios with brown line representing the anticipated changes after 100 yr i.e. for 2070 to 2099 and the blue line indicating the expectations after 50 yr period i.e. for 2020 to 2050.

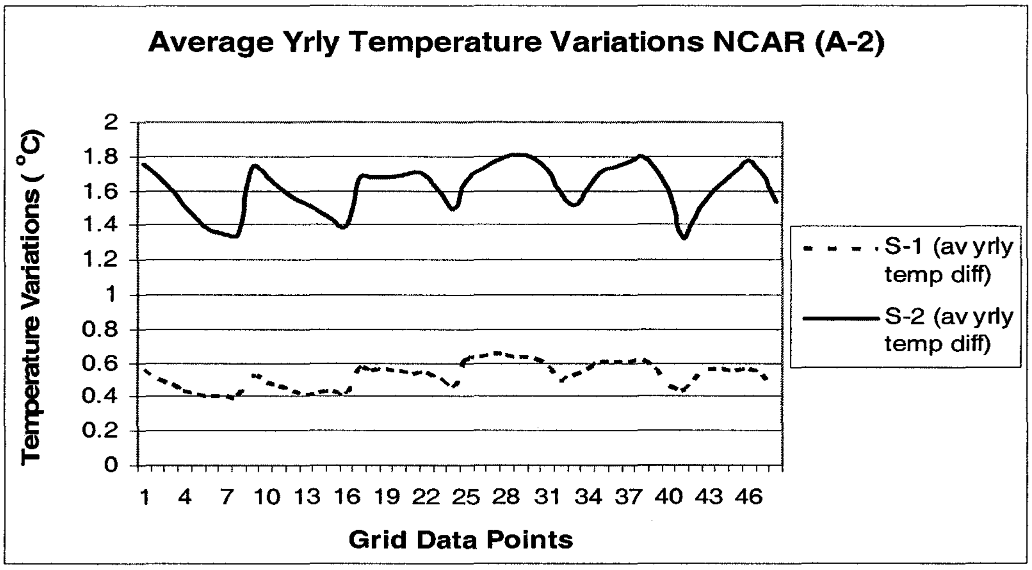
Temperature Comparison of A-2 Scenarios



(a)



(b)

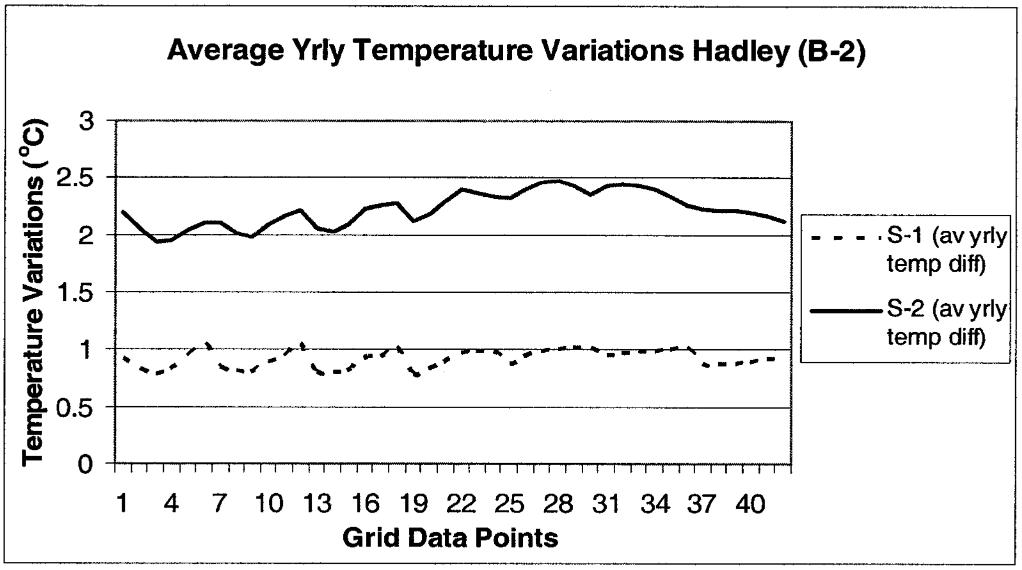


(c)

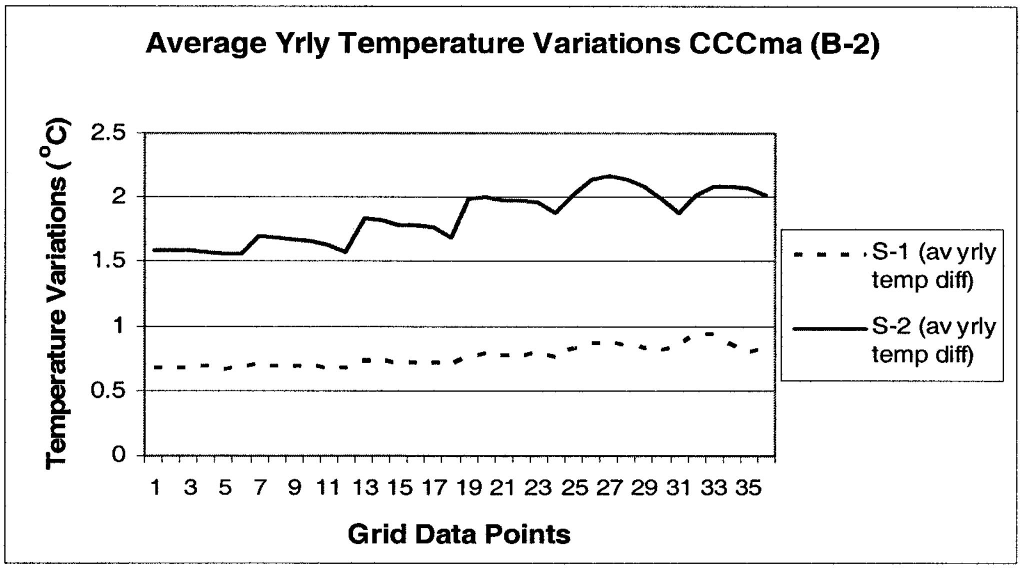
Fig 6.1: Anticipated (50 yr and 100 yr) temperature changes for A-2 scenario (a) Hadley model, (b) CCCma model and (c) NCAR model

The anticipated temperature changes observed for A-2 scenario over the short term and long term range indicate that Hadley model predicts almost constant rate of increase throughout the next 100 yr the CCCma and NCAR model while predicting more fluctuations with in the area indicate a much sharper increase for the second fifty year term.

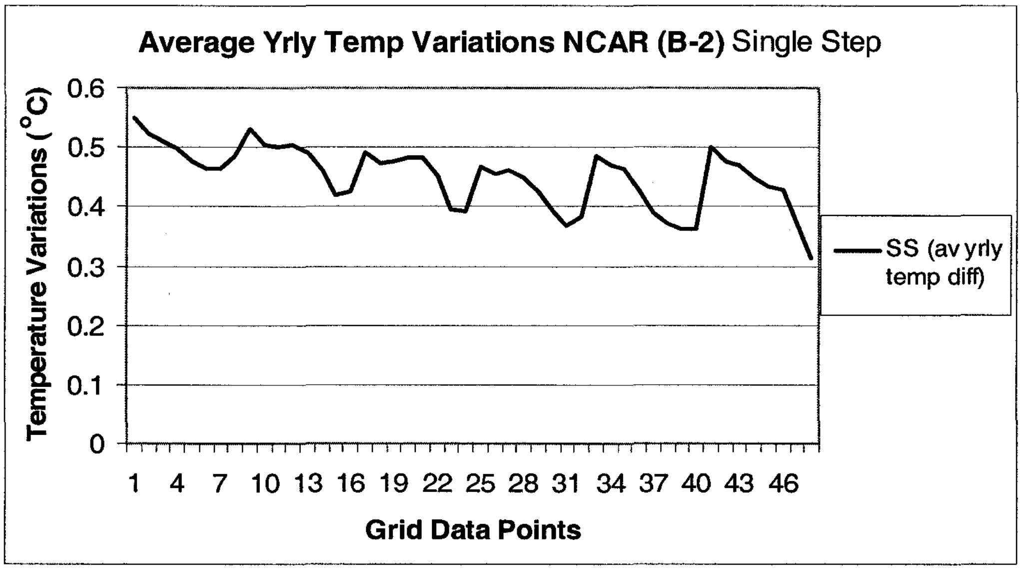
<u>**Temperature Comparison of B-2 Scenarios**</u>



(a)



(b)

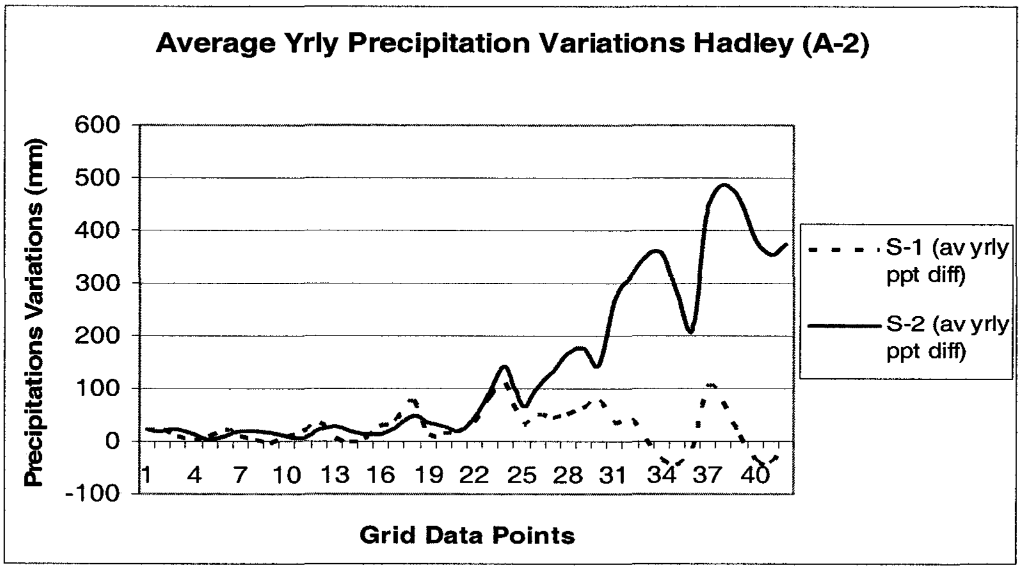


(c)

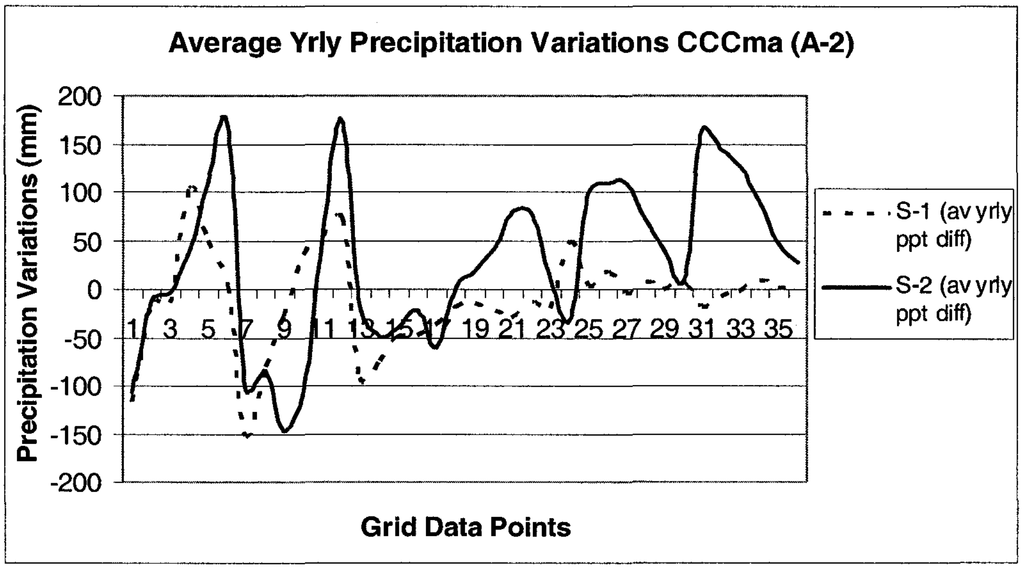
Fig 6.2: Anticipated (50 yr and 100 yr) temperature changes for B-2 scenario (a) Hadley model, (b) CCCma model and (c) NCAR model

The predicted temperature changes for B-2 scenario over the short term and long term ranges indicate similar trends by Hadley and CCCma models as noticed for the A-2 scenario. NCAR model does not provide data for the baseline period however there seems to be considerable temperature fluctuations with in the area over the fifty year period.

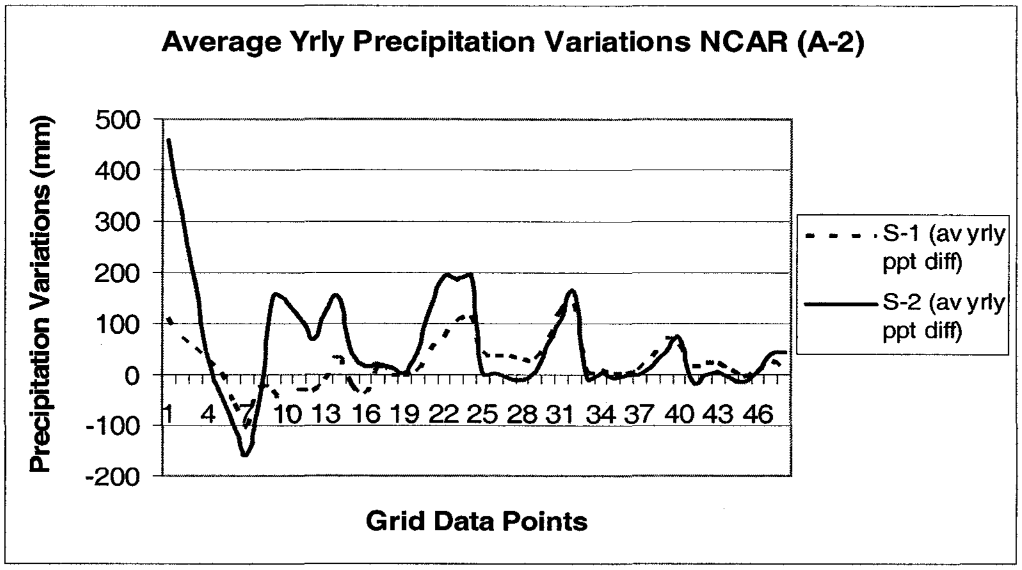
Precipitation Comparison of A-2 Scenarios



(a)



(b)

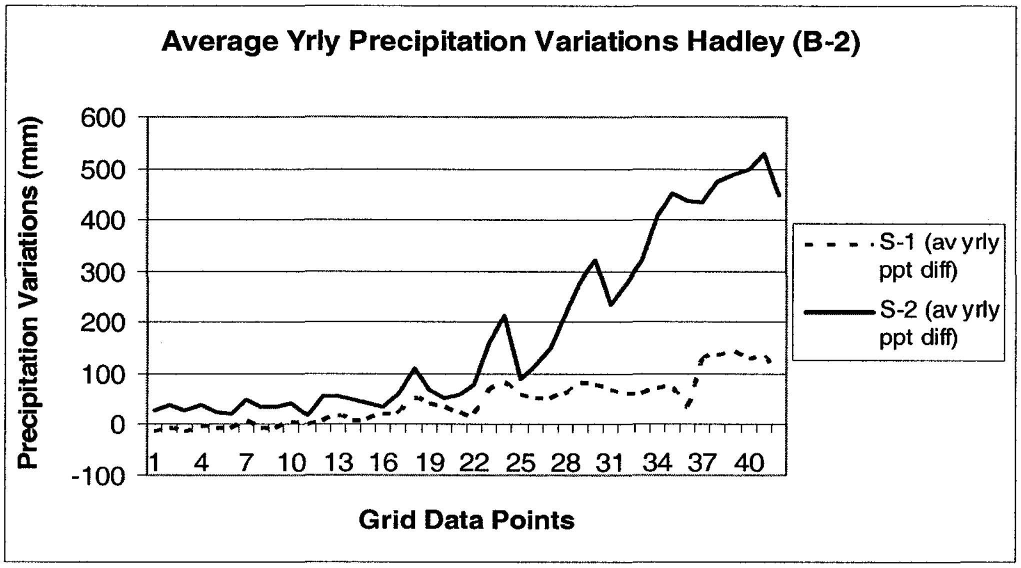


(c)

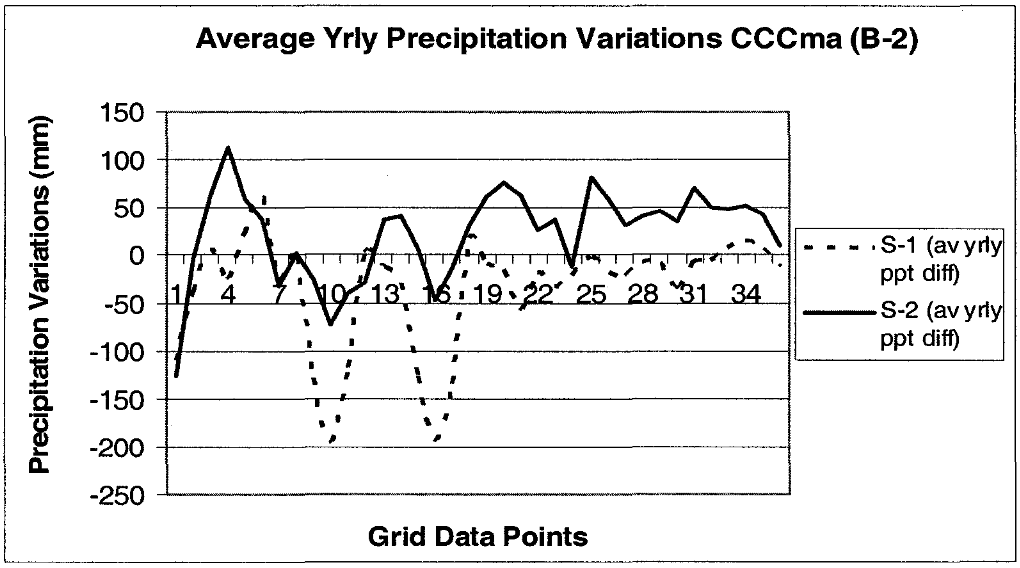
Fig 6.3: Anticipated (50 yr and 100 yr) precipitation changes for A-2 scenario (a) Hadley model, (b) CCCma model and (c) NCAR model

The anticipated precipitation variations for A-2 scenario by the three models over the fifty and hundred year periods show completely diverse patterns, with Hadley model predicting overall precipitation increases in the area in the long term. While CCCma and NCAR models predict higher fluctuations with certain areas facing precipitation shortfall both in the short term and long term ranges.

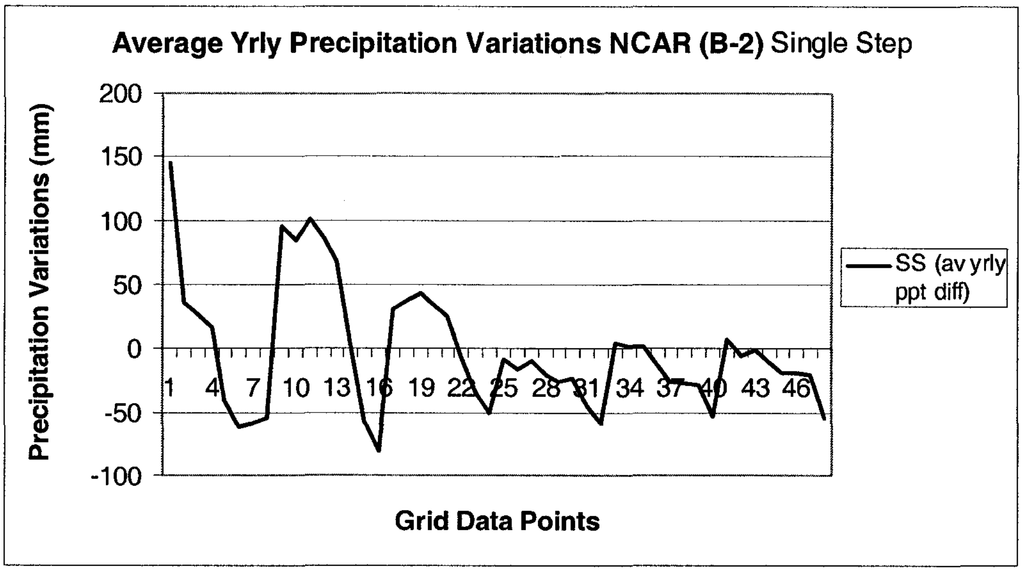
Precipitation Comparison of B-2 Scenarios



(a)



(b)



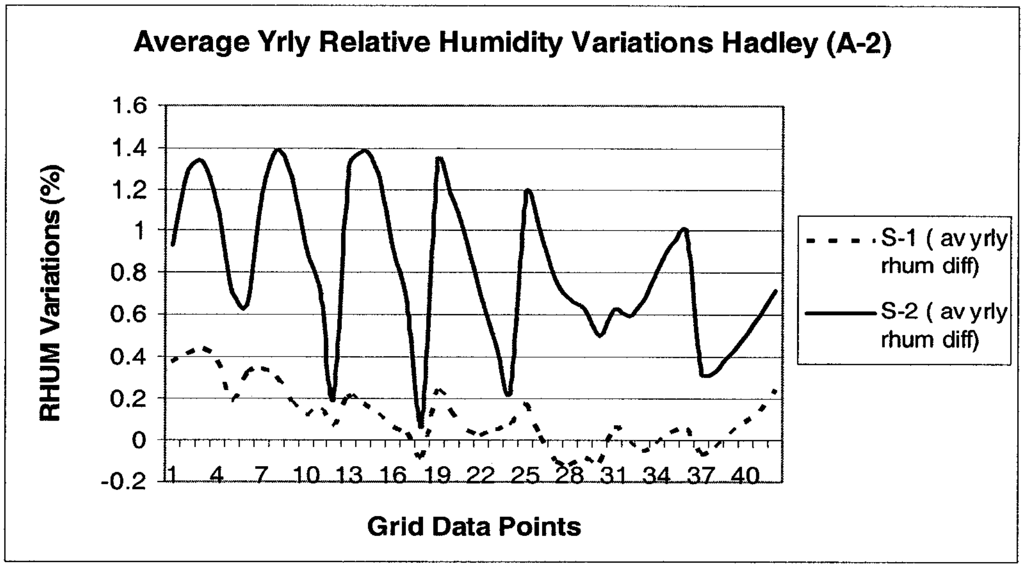
(c)

Fig 6.4: Anticipated (50 yr and 100 yr) precipitation changes for B-2 scenario (a) Hadley model, (b) CCCma model and (c) NCAR model

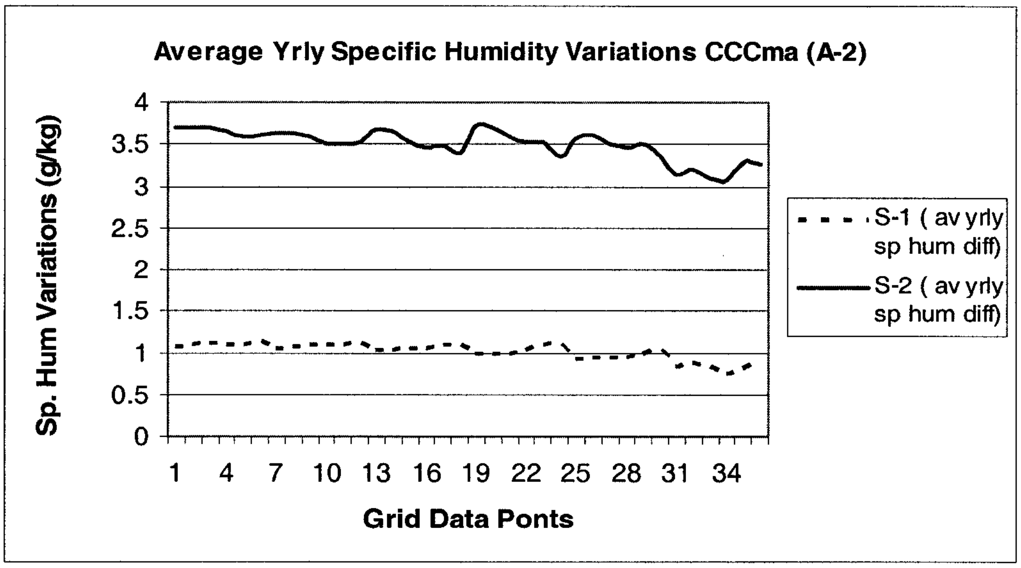
B-2 scenario projected precipitation variations by Hadley and CCCma models indicate identical trends but with much lesser amounts of precipitation.

NCAR models single step fifty year predicted data precipitation shortfall for most of the region.

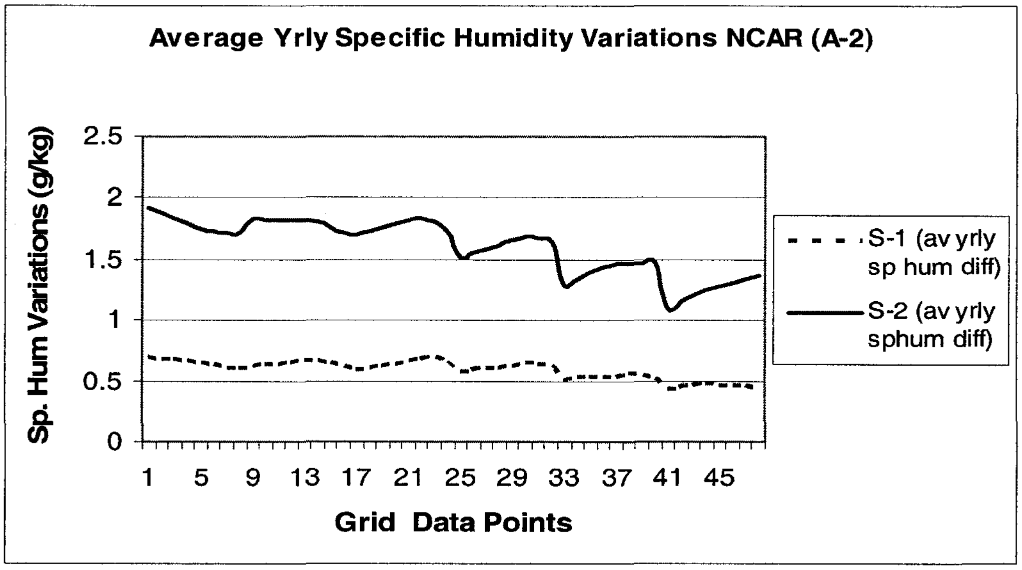
Humidity Comparison of A-2 Scenario



(a)



(b)

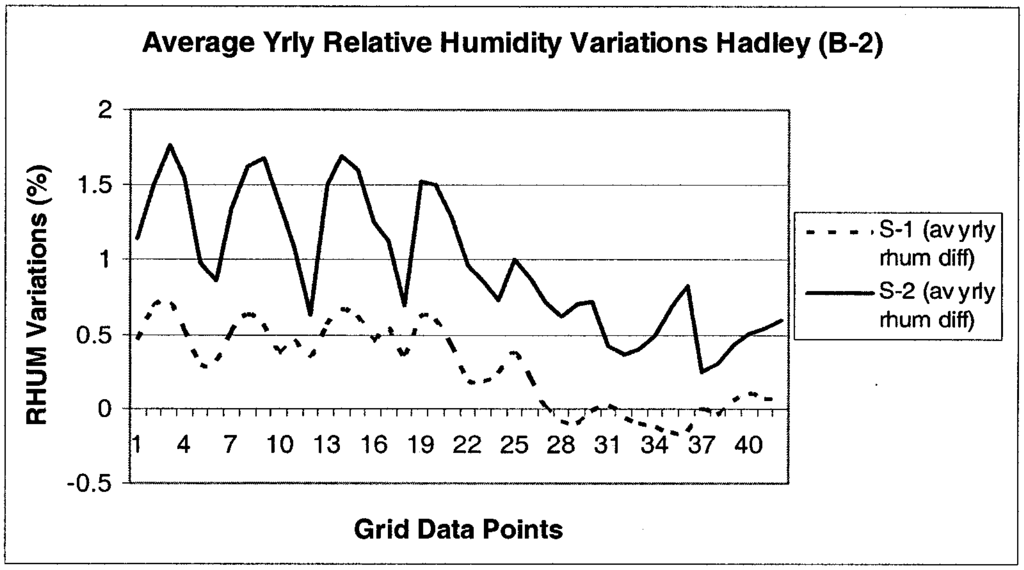


(c)

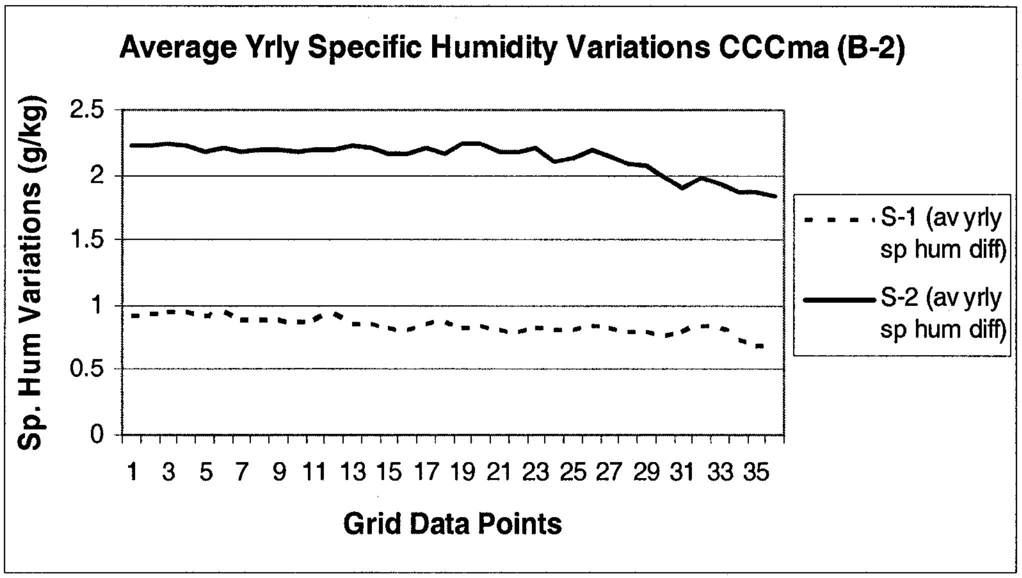
Fig 6.5: Anticipated (50 yr and 100 yr) humidity changes for A-2 scenario (a) Hadley model, (b) CCCma model and (c) NCAR model

Hadley model's predicted relative humidity variations for A-2 scenario indicate considerable fluctuations in the region especially more pronounced in the long term range. CCCma and NCAR model's predicted specific humidity variations follow the uniform pattern of accelerated levels for the long range after the first fifty years, with lesser degree of fluctuations with in the region.

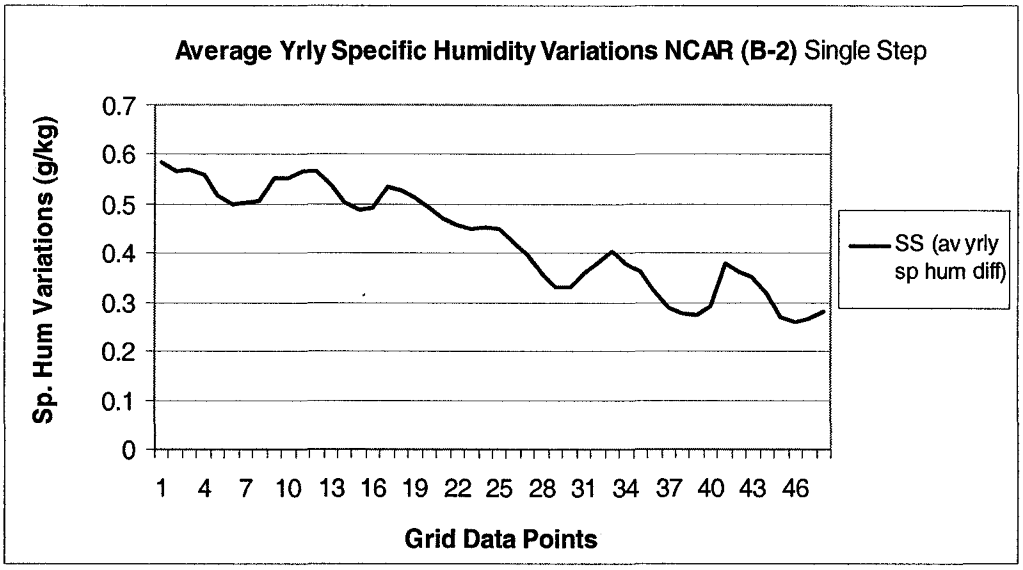
Humidity Comparison of B-2 Scenario



(a)



(b)



(c)

Fig 6.6: Anticipated (50 yr and 100 yr) humidity changes for B-2 scenario (a) Hadley model, (b) CCCma model and (c) NCAR model

Hadley model's anticipated relative humidity variations for B-2 scenario indicate considerable fluctuations in the region following the trend of A-2 scenario by being more pronounced in the longer range. CCCma model's predicted specific humidity levels also follow the trend of A-2 scenario but have lesser magnitude. NCAR model's single step specific humidity variation pattern indicates higher fluctuation degree.

The predicted results based on individual longitude-latitude coordinate points obtained by the models were used to draw contour maps for individual parameters by using the "Surfer32" software. The inconsistencies as indicated by the data through the three global climate models over the next 50 yrs and 100 yrs are discussed in detail below:

6.2 Temperature

6.2.1 50 year Predicted Results under A-2 Scenario

Hadley model predicts 0.94 to 1.23 °C increase in average temperatures with a mean of 1.13 °C and standard deviation (S_D) of 0.084, as compared to CCCma model which predicts 0.79 to 1.08 °C average temperature increase and with 0.89 °C mean and S_D of 0.075, while NCAR model predicts the temperature range to vary from 0.40 to 0.66 °C with a mean of 0.52 °C and S_D of 0.076.

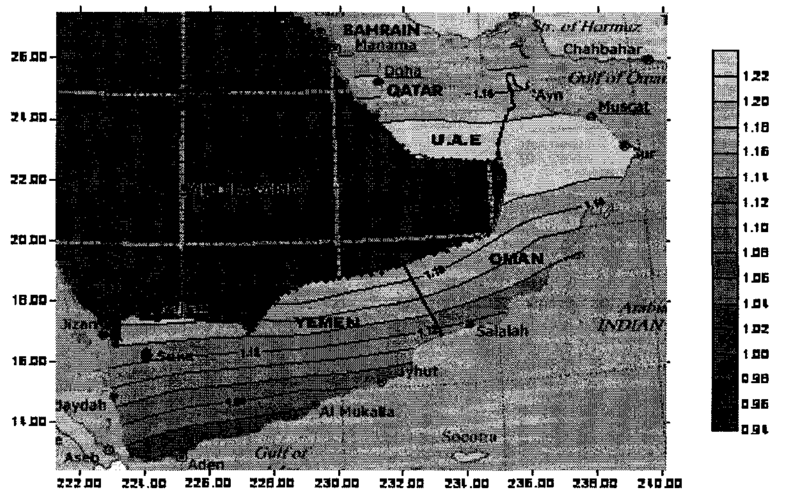
1. Hadley predicts maximum increase of >1.2 °C for UAE and parts of Oman (around Muscat and Sur) followed by Bahrain, Qatar and the remaining regions of Oman. <1.0 °C temperature rise is expected for regions like Aden, Ta'izz, and Al Mukalla in Yemen.
2. CCCma model anticipates highest temperature increase around Muscat and Sur (Oman) followed by other areas of Oman, U.A.E, Bahrain and Qatar. Anticipated lowest increase is for Aden, Ta'izz, and Al Mukalla in Yemen.
3. NCAR model predicts maximum increase in Al Khuwayr and Al Huwaysah (Oman) followed by regions like Muscat and Sur (Oman), U.A.E, Bahrain and Qatar. Minimum increase is anticipated for areas between Ra's Mijdahah and Sayhut in Yemen.

6.2.2 50 year Predicted Results under B-2 Scenario

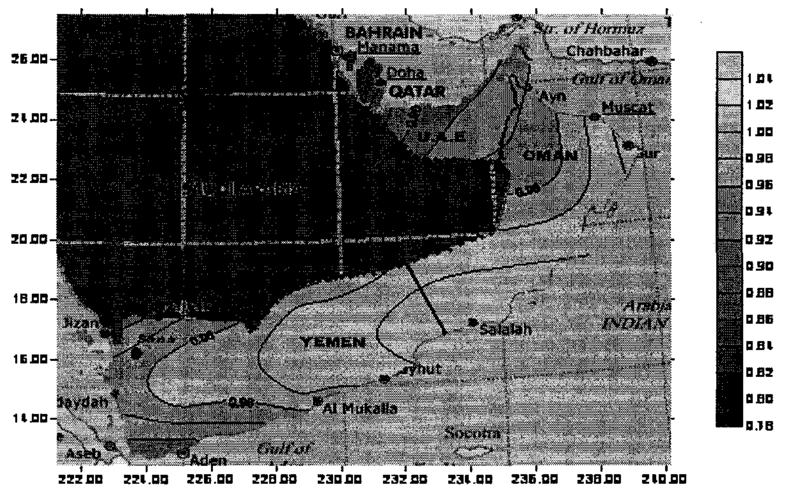
Hadley model predicts 0.78 to 1.05 °C increase in average temperatures with mean of 0.92 °C and standard deviation (S_D) of 0.785, as compared to CCCma model which predicts 0.67 to 0.94 °C average temperature increase having 0.76 °C mean and 0.077 S_D. Due to the non-availability of NCAR model's baseline data for B-2 scenario, 50yr temperature variations were determined on the basis of average difference in 2070-2099 and 2020-2050 indicating temperature increase of 0.31 to 0.55 °C with a mean value of 0.45 °C and S_D of 0.051.

1, Hadley predicts increase of around 1.0 °C for most parts of Yemen and Oman while lesser increase is anticipated for U.A.E, followed by Bahrain and Qatar.
2. CCCma model predicts lesser increase (0.72 °C) for areas like Sanaa, Aden, Al Mukalla and Salalah (Yemen), while predicted increase for Oman is from 0.72 to 0.84 °C, U.A.E is expected to face 0.84 °C to 0.86 °C temperature increase; 0.9 °C increase is anticipated for Bahrain and Qatar.
3. NCAR model predicting modest increase as compared to the other two model anticipates increase of <0.38 °C for areas like Muscat and Sur (Oman). U.A.E, Bahrain and Qatar are expected to be slightly warmer with highest anticipated increases for regions like Sayhut, Al Mukalla, Aden, and Ta'izz (Yemen).

Temperature comparison of A-2 & B-2 Scenarios (50 yr)

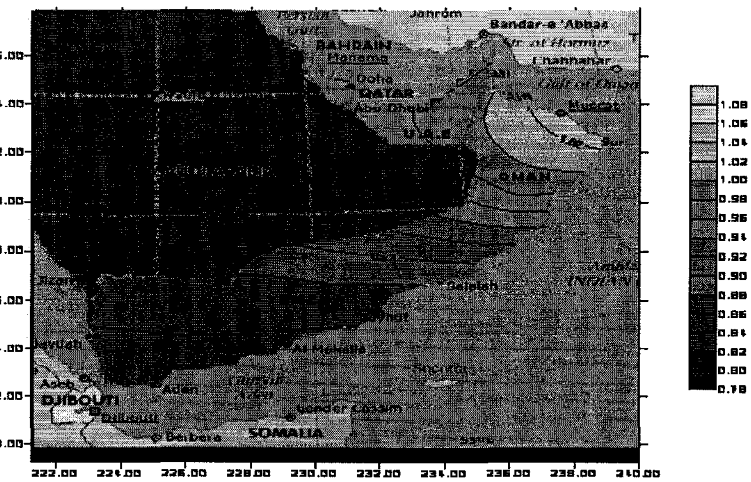


(i)

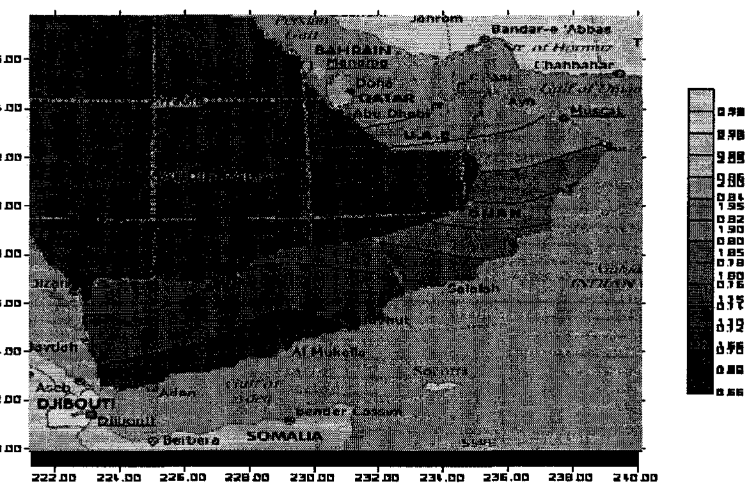


(ii)

Fig 6.7: Contour maps of Hadley model's 50 yr projected temperature variations for (i) A-2 and (ii) B-2 scenarios

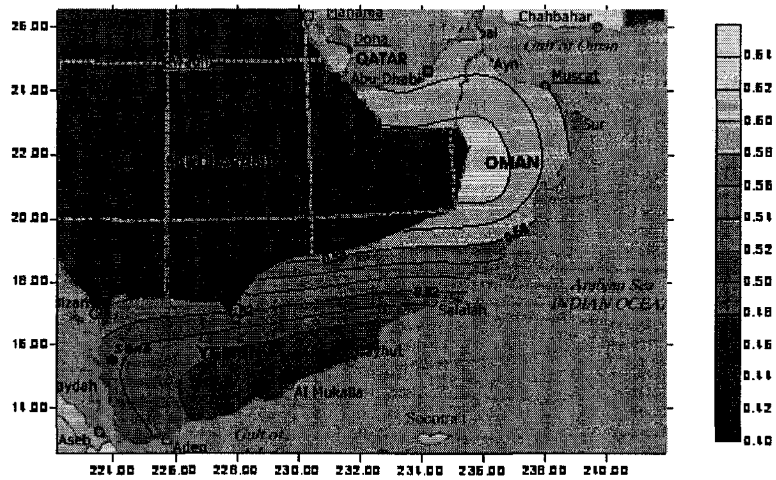


(i)

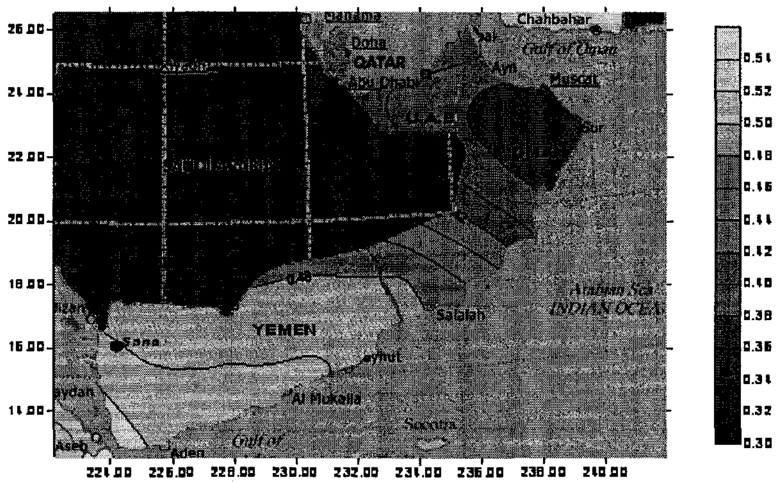


(ii)

Fig 6.8: Contour maps of CCCma model's 50 yr projected temperature variations for (i) A-2 and (ii) B-2 scenarios



(i)



(ii)

Fig 6.9: Contour maps of NCAR model's 50 yr *(2070-2099 vs. 2020-2050)* projected temperature variations for (i) A-2 and (ii) B-2 scenarios

6.2.3 100 year Predicted Results under A-2 Scenario

Hadley model predicts temperature increase of 2.58 to 2.93 ºC with a mean of 2.78 ºC and standard deviation (S_D) of 0.098, while CCCma model which predicts 2.47 to 3.37 ºC increase with mean of 2.92 °C and S_D of 0.308. NCAR model suggests 1.33 °C to 1.80 °C temperature increase with a mean of 1.62 °C and S_D of 0.136. The predicted results highlight following significant factors:

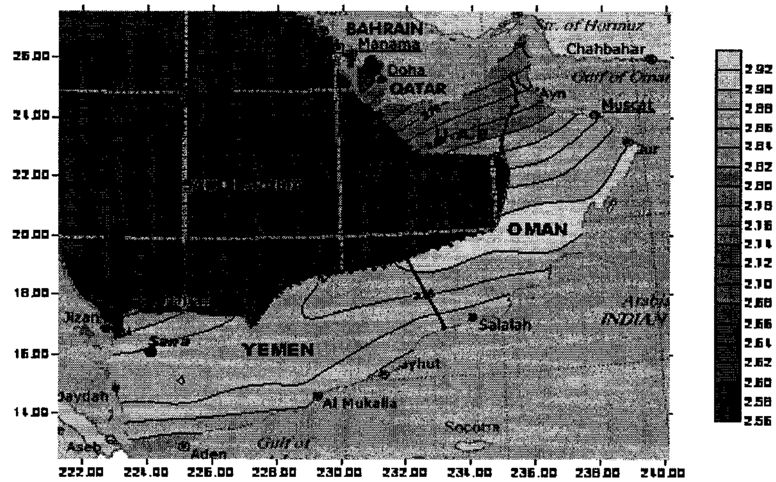
1. Hadley predicts highest increase for Oman followed by Yemen then U.A.E, with minimum increase anticipated for Bahrain and Qatar.
2. CCCma anticipates highest temperature increase of >3.2 °C for Bahrain, Qatar and U.A.E and lesser increase (<3.0 °C) for Oman and Yemen.
3. NCAR model predicts modest temperature increase with highest increase expected for Oman and U.A.E as compared to other areas.

6.2.4 100 year Predicted Results under B-2 Scenario

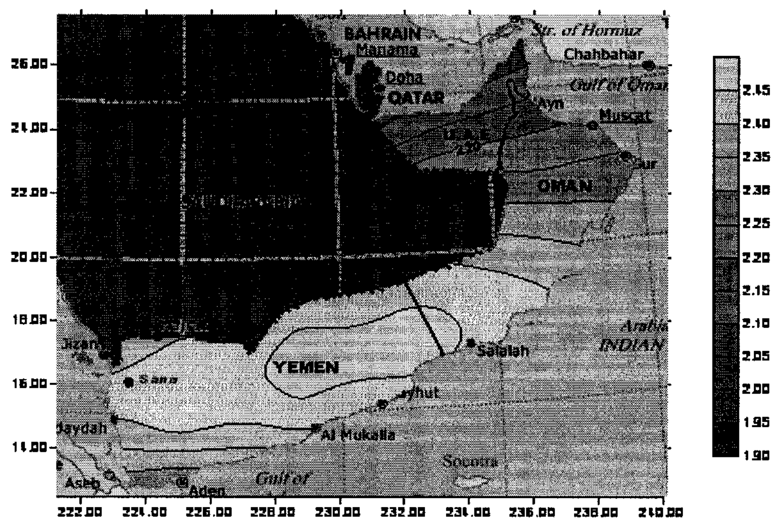
Hadley model predicts average temperatures increase of 1.93 to 2.47 °C with mean and standard deviation (S_D) of 2.22 °C and 0.153 respectively, while CCCma model anticipates 1.55 to 2.16 °C increase with 1.85 °C mean and S_D of 0.201. According to *Chaudhary and Husain, (2006b):*

1. Hadley model projects highest increase of >2.4 °C from Hadramawt and Al Mahrah (Yemen) to Habarut and Mudayy (Oman) while lowest increase of around 2.0 °C is anticipated for Bahrain followed by Qatar and U.A.E.
2. CCCma model anticipates highest rise of around 2.05 °C for Bahrain, Qatar and parts of U.A.E, while less then 1.85 °C rise is expected for Yemen and temperature increase of 1.75 to 2.05 °C is predicted for Oman.
3. NCAR model does not provide data for the baseline period.

<u>**Temperature comparison of A-2 & B-2 Scenarios (100 yr)**</u>

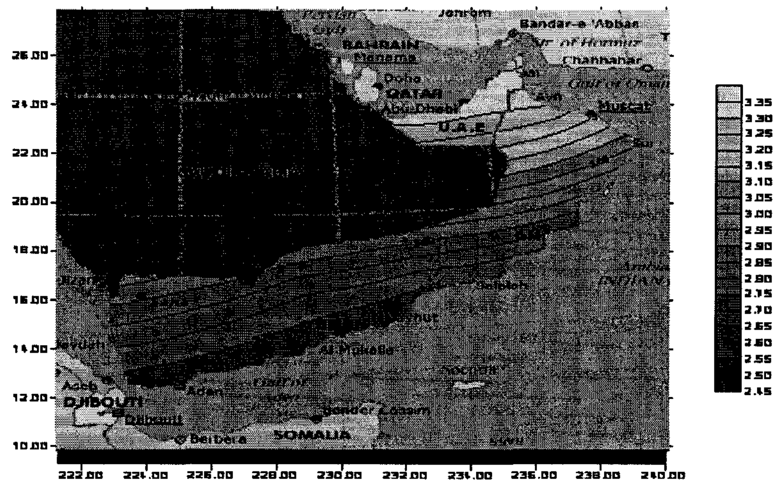


(i)

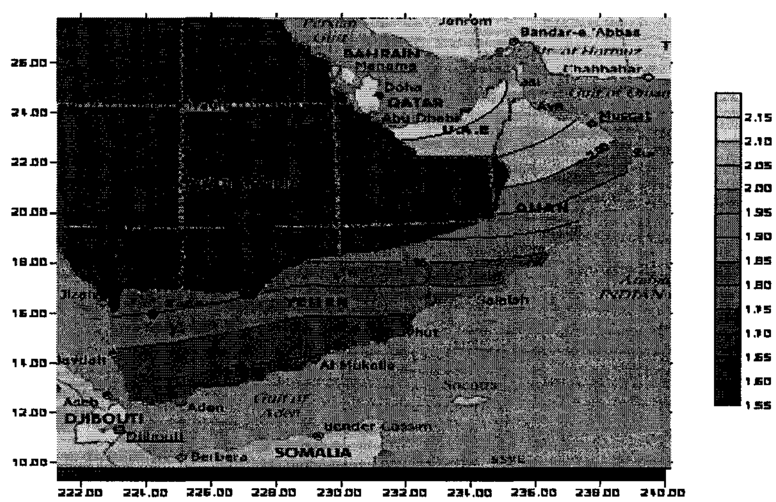


(ii)

Fig 6.10: Contour maps of Hadley model's 100 yr projected temperature variations for (i) A-2 and (ii) B-2 scenarios *(Chaudhary and Husain, 2006a)*



(i)



(ii)

Fig 6.11: Contour map of CCCma model's 100 yr projected temperature variations for (i) A-2 and (ii) B-2 scenarios *(Chaudhary and Husain, 2006a)*

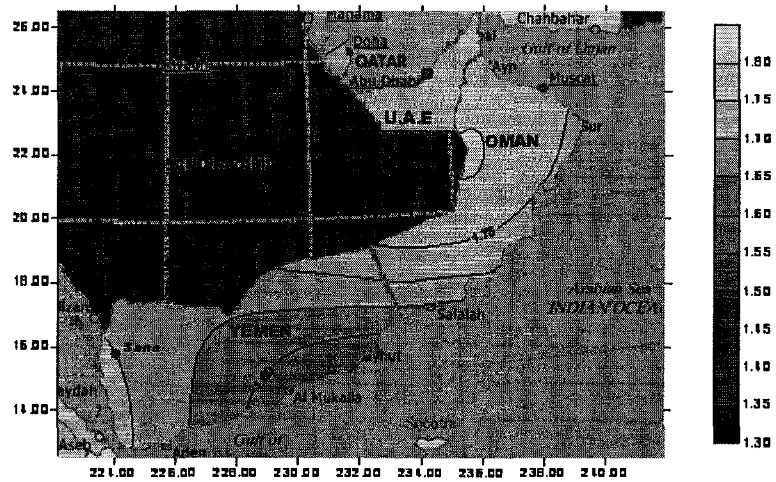


Fig 6.12: Contour map of NCAR model's 100 yr projected temperature variations for A-2 scenario *(Chaudhary and Husain, 2006a)*

6.3 Precipitation

6.3.1 50 year Predicted Results under A-2 Scenario

Hadley predicts average annual precipitation variation range to be from -44.7 to +108.4 mm having a mean of +24.07 mm with S_D of 35.79, as compared with the predicted average annual precipitation variation of -152.7 to +103.7 mm by CCCma model with mean of -11.95 mm and S_D of 50.011 and NCAR predicts the precipitation range to vary from -102.5 mm to +138.5 mm having mean of 22.4 mm and S_D of 48.752.

1. Hadley model predicts increased average precipitation levels by >60 mm for areas like Aden, Ta'izz (Yemen) and for regions like Al Khahil to Sur in Oman. Lesser increase of upto 30 mm is expected for U.A.E, Bahrain Qatar and other parts of

Yemen. Anticipations are that the coastal belt extending from Al Mukalla to Sayhut will experience precipitation shortfall.

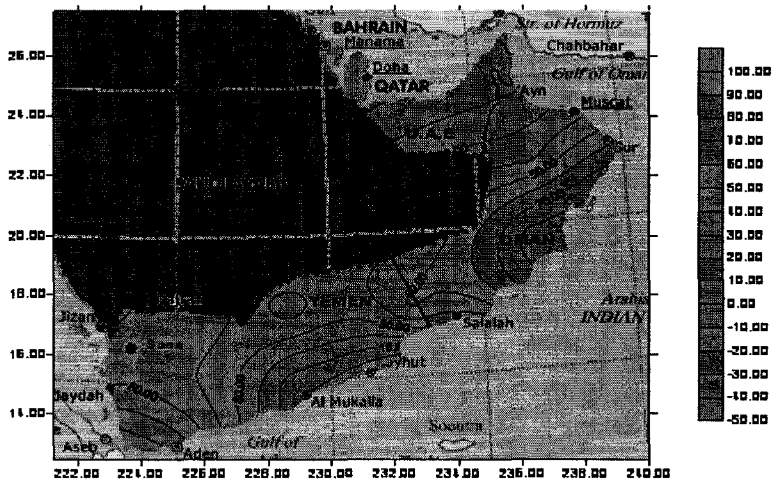
2. CCCma model predicts considerable precipitation shortfall throughout Yemen with worst hit areas like Aden, Ta'izz, and Al Makha facing >100 mm shortfall. Oman's bordering regions with Yemen up to Khaluf, will face 20 to 40 mm shortfall. Bahrain, Qatar along with areas like Muscat and Sur (Oman), Dubai, Abu Dhabi and Al-Ain (U.A.E) will encounter negligible or very small precipitation increase.
3. NCAR model predicts that areas around Sanaa will experience maximum shortfall of 60mm, with some increased precipitation around Aden (>20 mm) and Yemen's bordering regions with Oman. Bahrain, Qatar and U.A.E will encounter minor increases while Oman will experience much higher precipitation levels especially around Filim, Kalban and Ra'sar Ru'ays.

6.3.2 50 year Predicted Results under B-2 Scenario

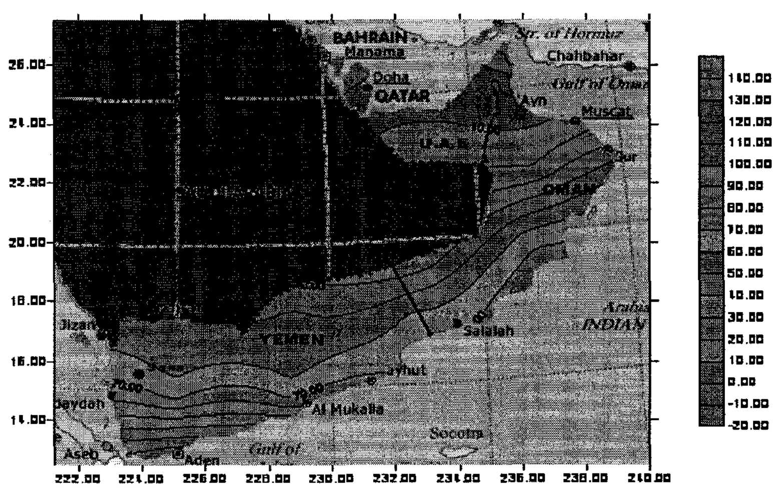
Hadley predicts average annual precipitation variation range to be from -12.7 to +144.3 mm having a mean of +45.3 mm with S_D of 45.2, as compared with the predicted average annual precipitation variation of -197.2 to +61.2 mm by CCCma model with mean of -5.3 mm and S_D of 59.87. Due to the non-availability of baseline precipitation data for B-2 scenario the 50 yr variations were determined on the basis of average difference in 2070-2099 as compared to 2020-2050. The overall precipitation variation predicted by NCAR models ranges from -80.1 to+145.1 mm with a mean of -1.45 and S_D of 48.31.

1. Hadley model predicts negligible to minor precipitation increase for Bahrain, Qatar and U.A.E. However Oman is expected to face increased precipitation levels from throughout with maximum anticipated rise of more than 60 mm for the coastal belt extending from Salalah to Duqm. Yemen is expected to face maximum increase with >65 mm for Sanaa; >100 mm for areas like Aden and Ta'izz.
2. CCCma model predicts minimal precipitation changes for Bahrain, Qatar and UA.E. Precipitation throughout Oman and Yemen is expected to decrease with worst hit areas being in Yemen that extend from Sahyut and Al Ghaydah to Salalah (Oman) facing >180 mm shortfall. Areas like Aden and Sanaa (Yemen) and Muscat and Sur (Oman) are expected to face shortfall of about 20 mm.
3. NCAR model predicts 50 yr variations (2070-2099 to 2020-2050) in the region to have precipitation shortfall of about 20 mm for Bahrain, Qatar and U.A.E along with most areas of Oman except around Salalah which is expected to receive minor increases. Yemen is anticipated to have increased precipitation levels with the maximum of about 80mm being around Ta`izz and At Turbah.

<u>**Precipitation Comparison of A-2 & B-2 Scenarios (50 yr)**</u>

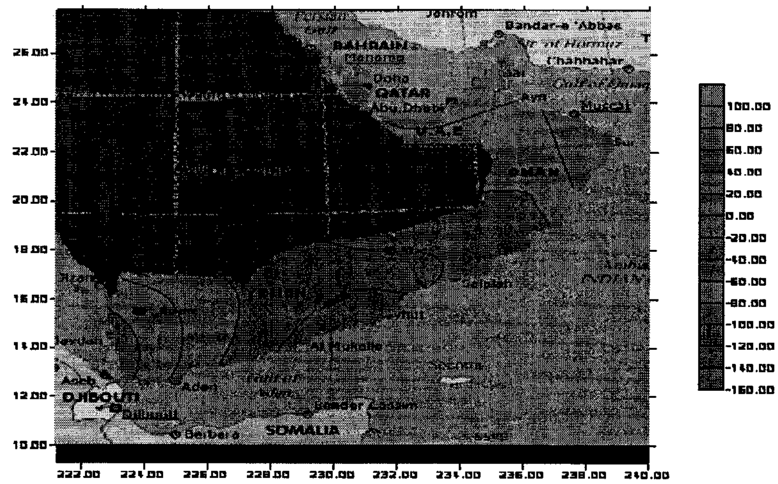


(i)

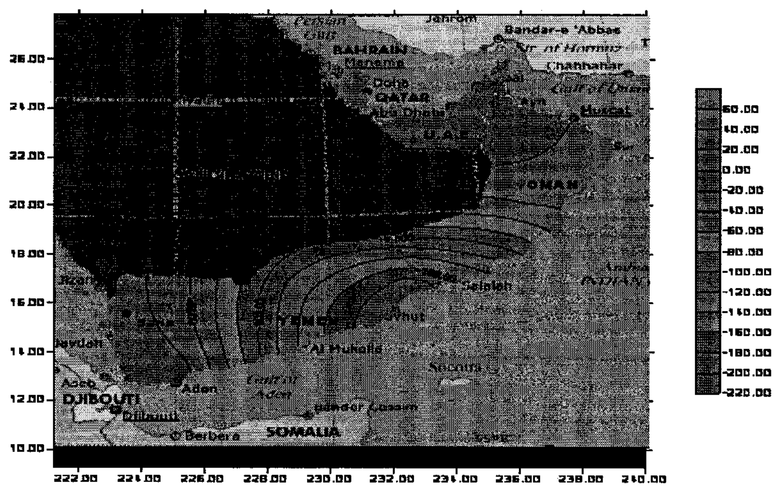


(ii)

Fig 6.13: Hadley model's 50 yr projected precipitation variations for (i) A-2 and (ii) B-2 scenarios

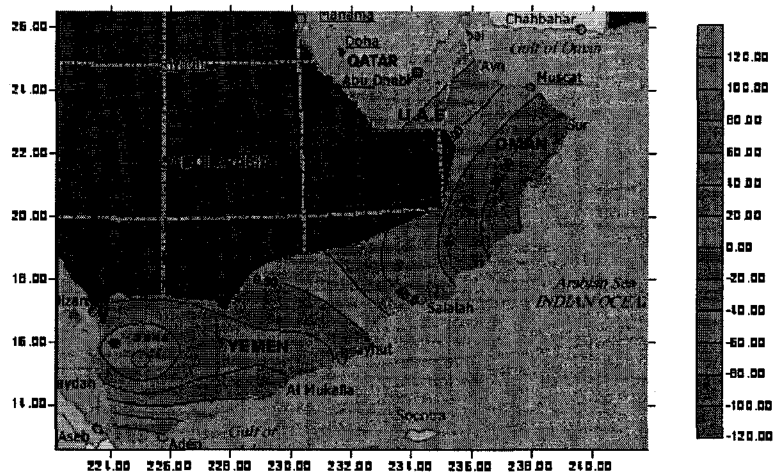


(i)

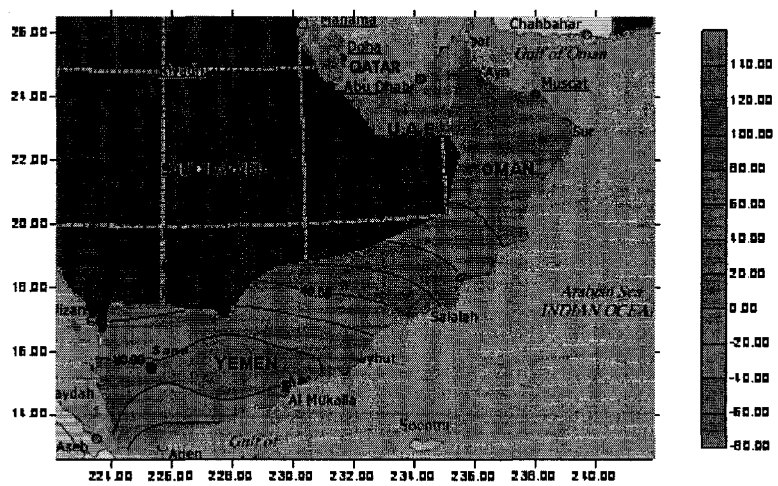


(ii)

Fig 6.14: CCCma model's 50 yr projected precipitation variations for (i) A-2 and (ii) B-2 scenarios



(i)



(ii)

Fig 6.15: NCAR model's 50 yr projected precipitation variations for (i) A-2 and (ii) B-2 scenarios

6.3.3 100 year Predicted Results under A-2 Scenario

Hadley predicts precipitation variations from +3.1 to +485.9 mm with mean of +137.6 mm and S_D=153.20, where as CCCma model predicts precipitation to vary from -147.4 to +174.1 mm with 28.5 mm mean and S_D of 84.0. Similarly NCAR predicts -157.4 mm to 458.1 mm variations with 57.35 mm mean and S_D of 104.32. The diverse precipitation patterns further indicate that:

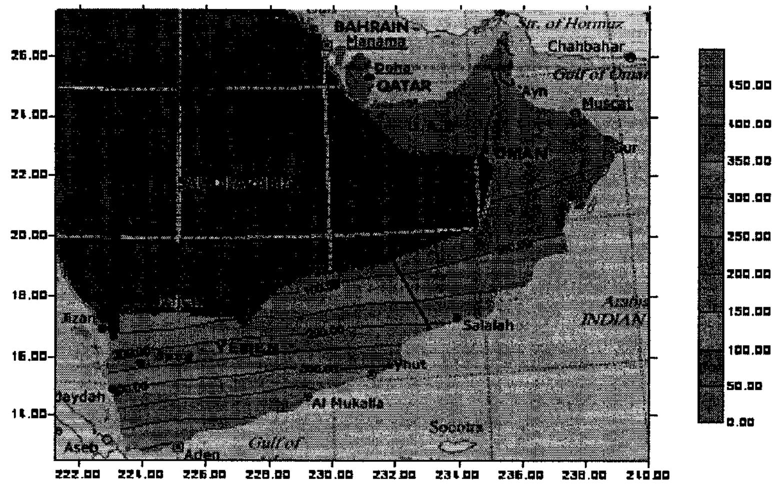
1. Hadley model predicts average precipitation levels to increase in the entire region with considerable variations. Least increase (<50 mm) is anticipated for Bahrain, Qatar, U.A.E and areas around Sur in Oman, while highest increase is anticipated for Yemen with maximum levels of >400 mm projected for areas like Aden, and Zinjibar. *(Chaudhary and Husain, 2006b)*
2. In contrast CCCma model predicts precipitation shortfall in Yemen with the worst hit areas facing shortfall of >100 mm being around As Sufal and Al Mukalla. Oman's coastal regions from Salalah to Ra'sal are expected to face a shortfall of >20 mm; However Bahrain, Qatar, UA.E and areas like Ibri in Oman are expected to receive more rainfall. *(Chaudhary and Husain, 2006b)*
3. Considerable precipitation variations i.e. from -157.4 to 458.1 mm are predicted by NCAR model over the region, with areas like Aden, Ta`izz, Sanna (Yemen) and Salalah (Oman) expecting higher precipitations (>200 mm) while Bahrain Qatar and U.A.E along with Ibri, Muscat and Al Mudaybi in Oman are predicted to face negligible variations, however increased precipitation is anticipated over other parts of Oman. *(Chaudhary and Husain, 2006b)*

6.3.4 100 year Predicted Results under B-2 Scenario

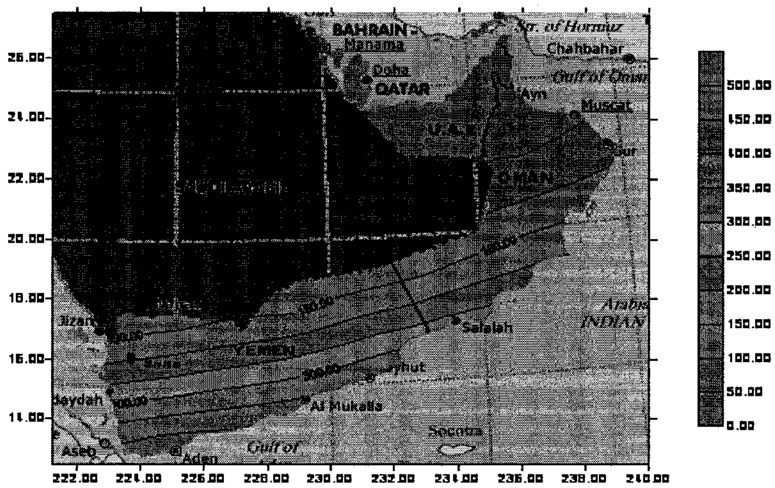
Hadley predicts average annual precipitation variation range to be from +16.9 to +530.4 mm having a mean of +180.6 mm with S_D of 171.8, as compared with the predicted average annual precipitation variation of -126.0 to +113.6 mm by CCCma model with mean of 22.9 mm and S_D of 48.3. However no data from NCAR model is available as it does not provide data for the baseline period. Both Hadley and CCCma models show distinct variation patterns indicating *(Chaudhary and Husain, 2006b)*:

1. Hadley model anticipates average annual precipitation levels to increase throughout the region with >300 mm increase predicted for areas around Aden, Ta'izz and Al Mukalla in Yemen, and lesser increases anticipated for Bahrain, Qatar and UAE.
2. According to CCCma model annual precipitation variations with >20 mm precipitation anticipated shortfall expected for areas like Al Mukalla, Sayhut (Yemen) and Salalah (Oman), while increased precipitation of >40mm is anticipated for Bahrain, Qatar and U.A.E.

Precipitation Comparison of A-2 & B-2 Scenarios (100 yr)

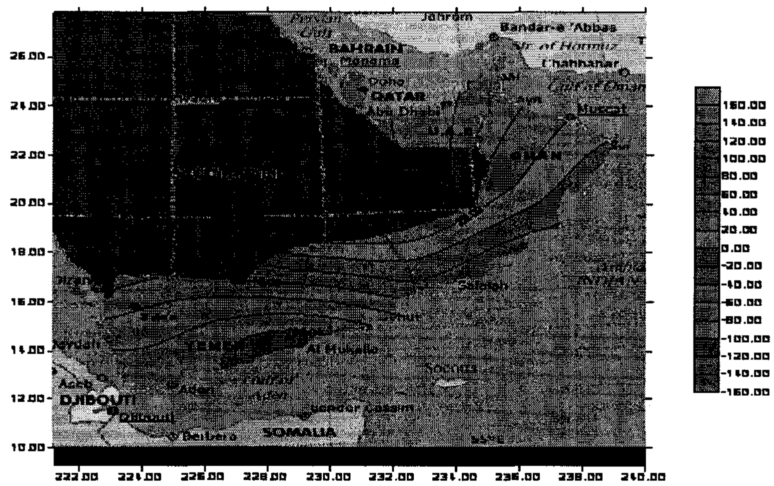


(i)

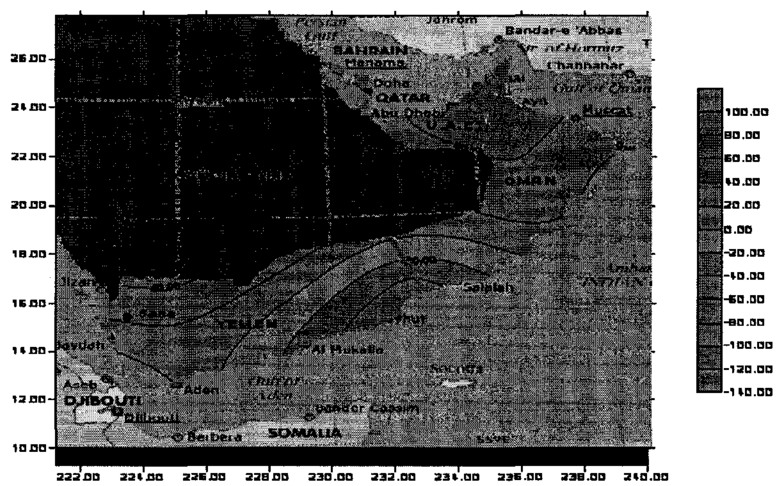


(ii)

Fig 6.16: Hadley model's 100 yr projected precipitation variations for (i) A-2 and (ii) B-2 scenarios *(Chaudhary and Husain, 2006a)*



(i)



(ii)

Fig 6.17: CCCma model's 100 yr projected precipitation variations for (i) A-2 and (ii) B-2 scenarios *(Chaudhary and Husain, 2006a)*

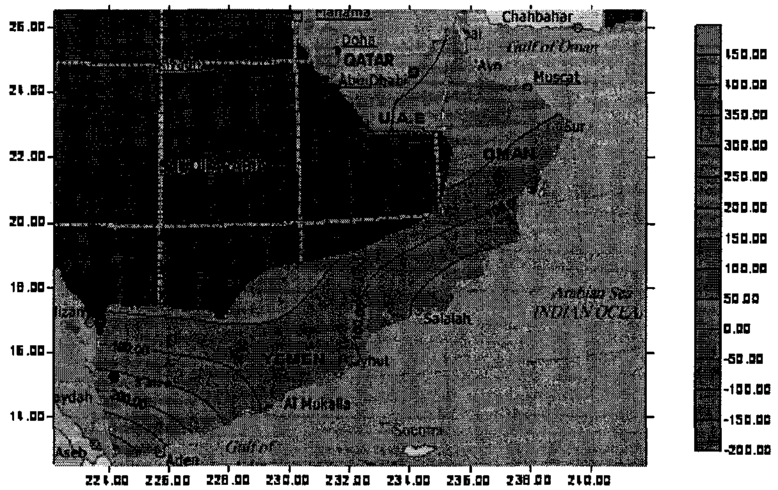


Fig 6.18: NCAR model's 100 yr projected precipitation variations for A-2 scenario *(Chaudhary and Husain, 2006a)*

6.4 Humidity

6.4.1 50 year Predicted Results under A-2 Scenario

The average predicted variations in relative humidity levels by Hadley model show variation range from a minimum of -0.12 % to a maximum of +0.44 % with 0.11 % mean value and S_D of 0.149. Whereas predicted specific humidity variation range by CCCma model lies between 0.74 to 1.13 g/kg with mean and S_D being 1.01 g/kg and 0.101 respectively along with the NCAR models predicted average specific humidity variation ranging from 0.43 to 0.69 g/kg with mean of 0.59 g/kg and S_D 0.0774.

1. Hadley model anticipate maximum increase in relative humidity level for Bahrain followed by Qatar and U.A.E; reduction is predicted for most of Yemen, and Oman while faces slightly increased humidity levels.

2. CCCma model projects highest increase in specific humidity in the entire region with highest increase (>1 g/kg) anticipated for Yemen and Oman while less increase (>0.9 g/kg) is anticipated for U.A.E, Qatar and Bahrain.
3. NCAR model project moderate increase in specific humidity with highest increase of >0.68 g/kg expected for areas like Aden, Sayhut (Yemen) and Salalah (Oman). Areas like Muscat and Sur will face >0.5 g/kg increase. The lowest increase of >0.4 g/kg is anticipated for Bahrain, Qatar and U.A.E.

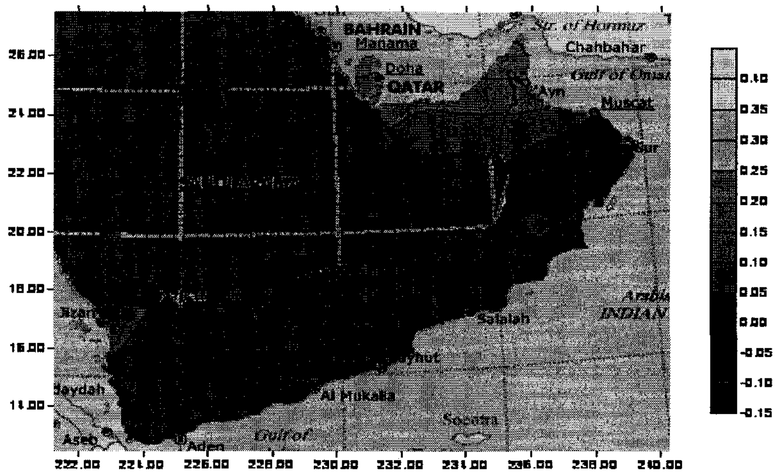
6.4.2 50 year Predicted Results under B-2 Scenario

The average predicted variations in relative humidity levels by Hadley model show variation range from a minimum of -0.16 % to a maximum of 0.71 %, with mean 0.27 % and S_D of .276. The predicted specific humidity variation range by the CCCma model lies between 0.68 to 0.95 g/kg with mean and S_D being 0.84 g/kg and 0.067 respectively. As baseline specific humidity data by NCAR model for B-2 scenario was not available; the single step 50 yr (2070-2099 compared with 2020-2050) predicted variation range was from 0.26 to 0.58 g/kg with mean of 0.43 g/kg and S_D 0.103.

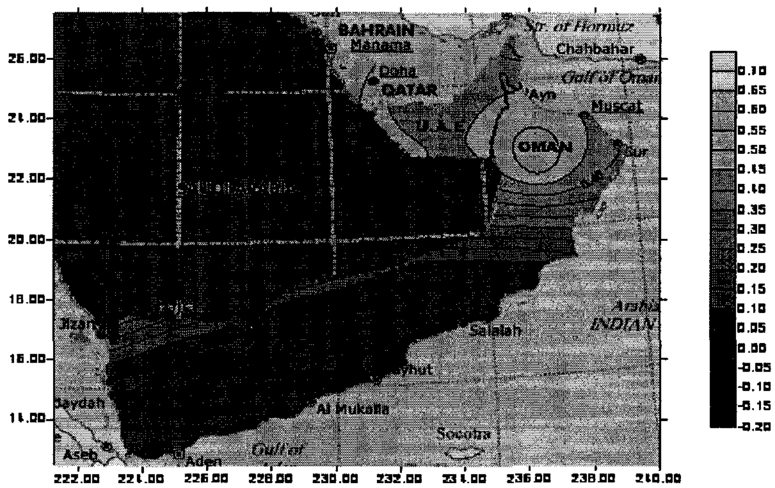
1. Hadley model predicts increased relative humidity (>0.4 g/kg) for Bahrain, Qatar and U.A.E. Oman is expected to experience reduced humidity levels around Salalah while increases around Muscat and Salalah. Decreased humidity is anticipated for most of Yemen except for regions like Sa'dah.
2. CCCma projects increases >0.78 g/kg in specific humidity levels for Bahrain, Qatar, U.A.E and Oman while areas like Aden are anticipated to face >0.9 g/kg.

3. NCAR model's predicted 50 yr variations (2070-2099 and 2020-2050) indicate moderate increase in specific humidity levels with highest anticipated rise of >0.58 g/kg being for Aden, Ta'izz (Yemen) followed by Oman while minimal increase of >0.25 g/kg is expected for Bahrain Qatar and U.A.E.

Humidity Comparison of A-2 & B-2 Scenario (50 yr)

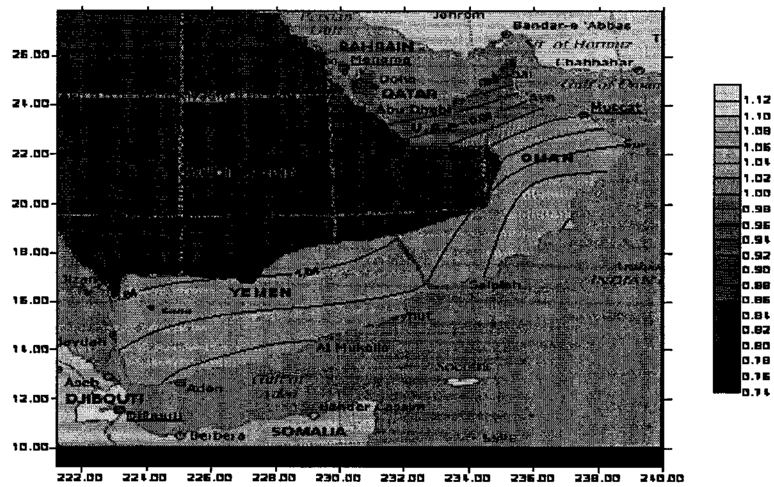


(i)

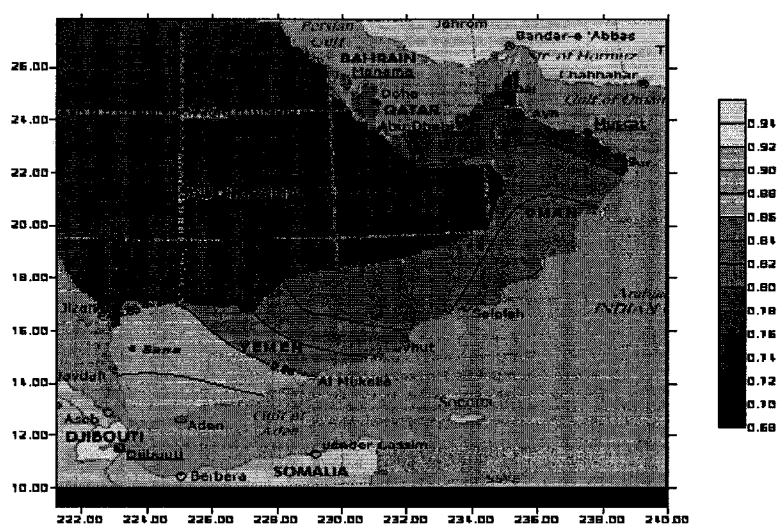


(ii)

Fig 6.19: Hadley model's 50 yr projected relative humidity variations for (i) A-2 and (ii) B-2 scenarios

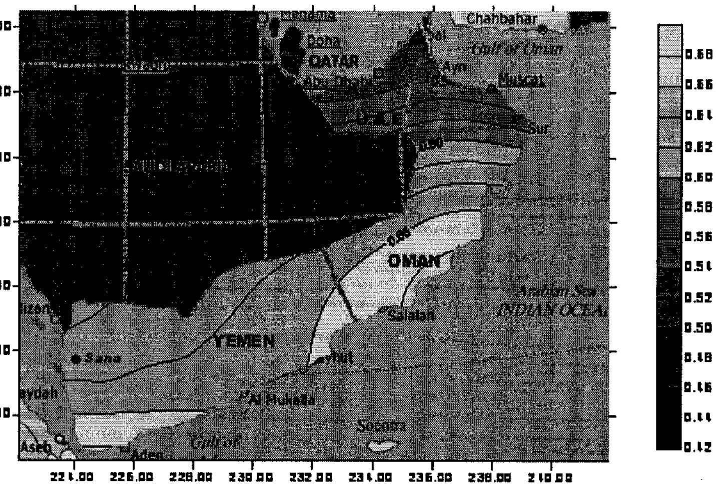


(i)

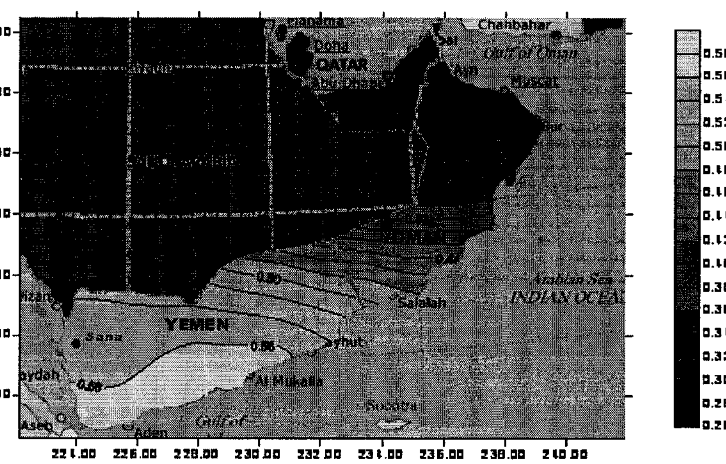


(ii)

Fig 6.20: CCCma model's 50 yr projected specific humidity variations for (i) A-2 and (ii) B-2 scenarios



(i)



(ii)

Fig 6.21: NCAR model's 50 yr projected specific humidity variations for (i) A-2 and (ii) B-2 scenarios

6.4.3 100 year Predicted Results under A-2 Scenario

The variations in relative humidity as predicted by Hadley model show variation range of 0.08 to 1.4 %, with a mean of 0.82 % and S_D of .0357.

CCCma predicts specific humidity variations ranging from 3.08 to 3.72 g/kg with mean of 3.50 g/kg and S_D of 0.176 as compared to NCAR which predicts variations of 1.09 to 1.92 g/kg with mean of 1.61 g/kg and S_D 0.219. Distinct humidity variation patterns projected by three models indicate *(Chaudhary and Husain, 2006b)*:

1. Hadley model predicts increased relative humidity of 0.3 % over Sur (Oman) and Aden (Yemen), whereas higher increases (>0.9 %) for Bahrain, Qatar and parts of U.A.E are anticipated.
2. CCCma model projects highest increase in specific humidity variations with entire region anticipated to experience >3.35 g/kg increase in specific humidity level.
3. NCAR model projected moderate increase in specific humidity range with highest anticipated rise of >1.8 g/kg being in Yemen followed by Oman while minimal increase of about 1.35 g/kg is expected for Bahrain.

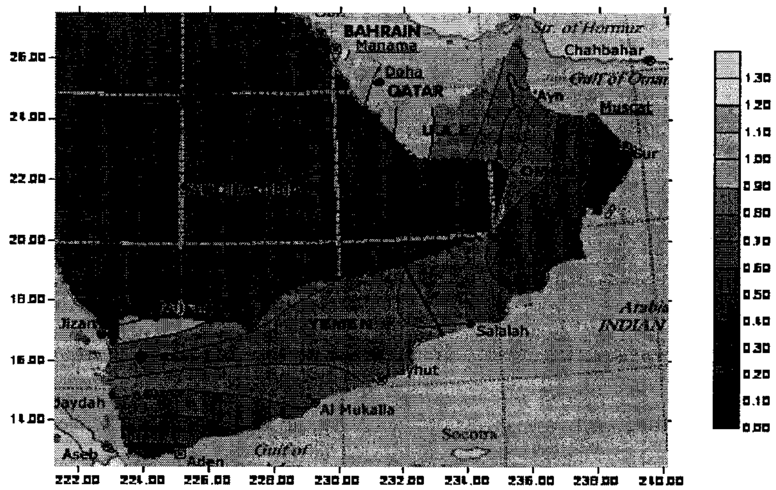
6.4.4 100 year Predicted Results under B-2 Scenario

7 The average predicted variations in relative humidity levels by Hadley model show variation range from a minimum of 0.25 % to a maximum of 1.76 %, with mean 0.97 % and S_D of .0448.The predicted specific humidity variation range for CCCma model lies between 1.85 to 2.25 g/kg with a mean of 2.13 g/kg and S_D of 0.117.

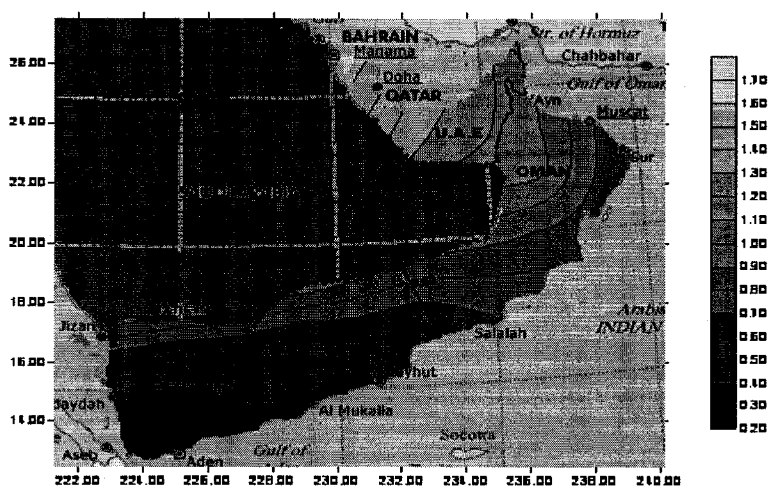
With non availability of data for baseline humidity variations for NCAR model, the distinct humidity patterns for Hadley and CCCma indicate *(Chaudhary and Husain, 2006b)*:

1. Hadley model anticipates lesser increase of around 0.3 % for Aden and Tai'zz (Yemen), while higher increase of >1.5 % is anticipated for Bahrain followed by Qatar and U.A.E.
2. CCCma model expects higher specific humidity levels for Yemen and Oman with maximum around Sanna and Sawqirah respectively, while lowest increase is predicted around Khasab and Ash Sha'm.

Humidity Comparison of A-2 & B-2 Scenario (100 yr)

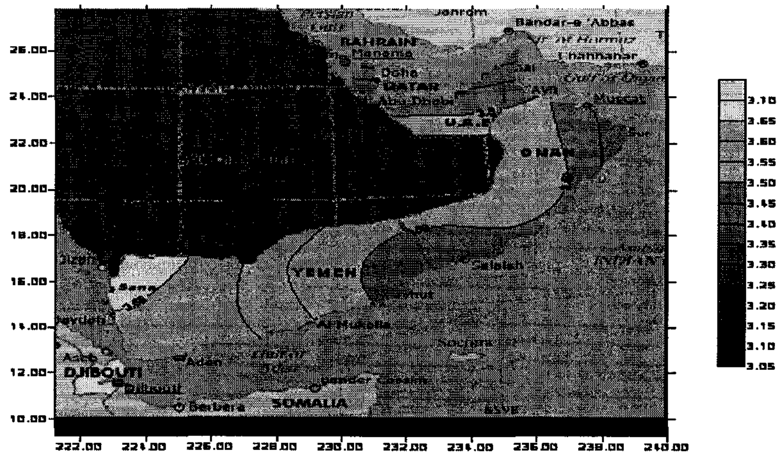


(i)

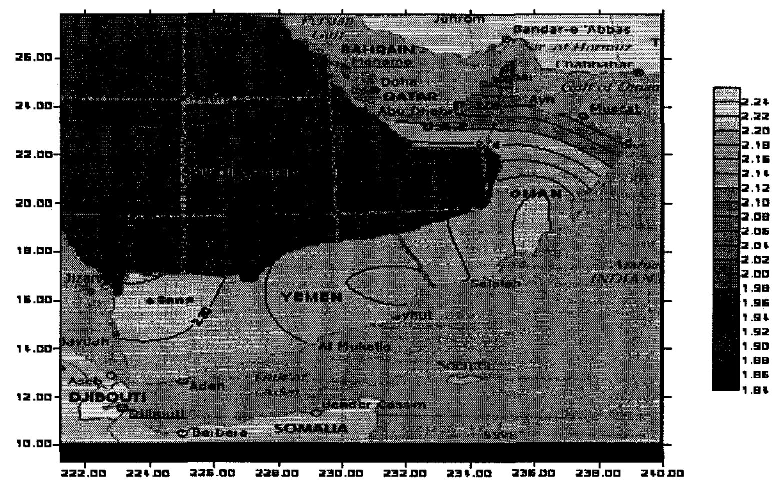


(ii)

Fig 6.22: Hadley model's 100 yr projected relative humidity variations for (i) A-2 and (ii) B-2 scenarios *(Chaudhary and Husain, 2006a)*



(i)



(ii)

Fig 6.23: CCCma model's 100 yr projected specific humidity variations for () A-2 and (ii) B-2 scenarios *(Chaudhary and Husain, 2006a)*

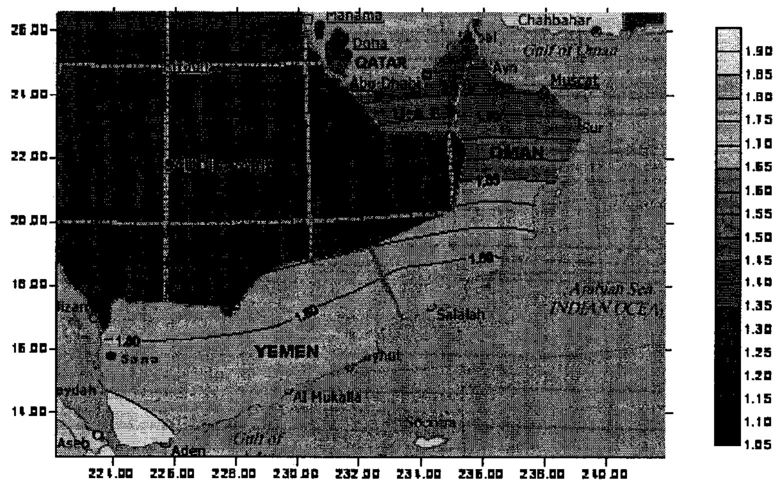


Fig 6.24: NCAR model's 100 yr projected specific humidity variations for A-2 scenario *(Chaudhary and Husain, 2006a)*

6.5 Variations in Predictive Results

As is evident from the results shown above the three Global Climate Models namely Hadley Centre UK, National Centre for Atmospheric Research (NCAR) USA and Canadian Centre for Climate Modeling and Analysis (CCCma) showed significant inconsistencies in their projections of future temperature rise, changes in precipitation and humidity levels for the same time period under same socio economic development scenarios.

It is worth mentioning here that the GCMs represent climate is usually represented in a three dimensional grid around the earth, usually having horizontal resolution range between 250 to 600 km, along with 10 to 20 vertical layers in the atmosphere even up to 30 layers. A number of physical processes like those related to cloud cover occur at smaller scales and consequently cannot be properly modeled, thus their known properties have to be averaged over the larger magnitude through a process known as parameterization. This is one of the sources of uncertainty in GCM-based simulations of climate. The other sources such as water vapor and warming, cloud and radiation along with ocean circulation etc. relate to the simulation of various feedback methods in the GCMs.

This is the main reason as to why different GCMs can simulate separate responses to the same forcing, because of the procedure in which certain processes and feedbacks are modeled

Chapter 7

Health effects caused by climate change

7.1 Introduction

Environmental changes encompass all pertinent environmental issues that can be accredited to human influences, including land degradation, deforestation, and food shortage and rapidly diminishing clean water resources etc. at global level. The anticipated climatic changes due to the increasing greenhouse gas emissions and rapid depletion of the stratospheric ozone layer will threaten ecological balance which is necessary to human development and sustainability. As a result, such disturbance to ecological balance will cause adverse health impacts on the human population (*McMichael, 2003*).

There is a growing consensus that the anticipated health impacts as a result of these changes will vary at regional levels depending upon the toxicity of the specific pollutants found in that area. The World Health Organization (WHO) estimates that more than 150,000 deaths are due to changes in the temperature and precipitation trends due to climate change in the past 30 years. (*Patz et al., 2005*)

Climatic changes cause adverse health impacts on the human population through direct and indirect ways. Direct impacts include heat stroke, increased incidences of cardiovascular and respiratory illnesses, altered geographic ranges and seasonality of vector borne diseases. The indirect impacts include suffering due increased level of air pollutants, scarcity of fresh water resources and decreased water quality, malnutrition as a result of crop failures, increased frequency of extreme weather events; their accompanying socio-economic costs, psychological issues and conflicts arising from these issues.

Health impacts due to various pathways combined together as a result of climate change are calculated on the basis of the altered rates of specific diseases, and disability adjusted life years (DALY). (*Husain and Chaudhary, 2006)*

As reported by *Husain and Chaudhary, (2006*) in the paper "Human Health Risk Assessment due to Global Warming – A Case Study of the Gulf Countries" and based on the malarial AIM/Impact model studies conducted by *Harasawa and others* it is predicted that with 2 °C increase in the temperature their will be a significant increase in the population size living under endemic malaria conditions. It is anticipated that the entire population of the UAE and Oman along with <50 % of Yemen's population are living in malaria prone regions. Though there will be no increase in the "High Risk" category of malarial disease in this region, still:

- "Low malarial risk" will remain unchanged for UAE (1.07 million affected population)
- "Low malarial risk" will reduce from 0.92 to 0.48 million affected people from Oman.
- "Low malarial risk" will rise markedly for Yemen by affecting larger population group i.e. from 1.08 to 2.38 million

There are certain health issues regarding climate change that have not yet been comprehensively quantified and hence were not considered for evaluation including: changes in air pollutants and aeroallergens; influence of changing climate on agricultural yields because of the climatic effects on plant pests and diseases; population displacement issues due to natural catastrophes, resulting psychological problems and conflicts over natural resources.

7.2 Climate-Disease Risk Identification

The risk assessment to human health is considered relative to future predictions with regards to the climatic changes due to increased GHG emissions and with exposure to entire global population, but its impact will be varied depending on demographic factors, geographic locations and socio-economic development (industrial activity). Most of the health-impact studies of climate changes have so far been empirical in nature relying on either statistical modeling techniques which involve direct link between climate variables and disease incidence, or biological modeling i.e. relying on pathogens dynamics and climate effects.

Due to lack of sufficient historical record on epidemiological data, there is a considerable uncertainty to develop linkage of revival of certain diseases to climate change. Also there are various site-specific socio-economical issues, along with advancement in medical research and drug resistance which make such linkage difficult.

The influence of non-climatic factors like reduced immunity levels, malnutrition, drug resistance have not been quantified and should be assessed with utmost care in other studies *(WHO, 2001)* as their contribution can be quite significant.

The selection criteria used to determine which diseases are influenced by climate change are outlined below:

- *Sensitivity to climate:* The incidence of diseases should correlate with the seasonal or intra-annual climate variations.
- *Important Global Health Impact:* It should rely on WHO estimates of morbidity and mortality.
- *Already modeled at Global Scale:* The disease- climate linkage is based on authenticated research and recognized by the scientific community e.g. those mentioned in the publications of Intergovernmental Panel on Climate Change in 2001 are based on the extensive literature review of over 320 relevant publications.

7.3 Mortality and DALYs Rates

The term 'Disability Adjusted Life Year (DALY)' is used for assessing the state of health of the population and refers to the years of life lost due to premature death while including the corresponding years of 'healthy' life lost because of poor health or disability. It combines the time lived with disability and the time lost due to premature death. In simpler words one DALY can be referred to as one healthy life year lost. The other important term used in the assessment is the 'burden of disease' which is simply the gap between the ideal and current health conditions. It is calculated on the basis of available quantitative data and its co-relation with specific disease incidence within population-group/region based on the dose-response health impacts. Application of similar approach based on ecosystem effects is quite difficult because of the various casual pathways (*Husain and Chaudhary, 2006)*.

DALY is the quantitative indicator of 'burden of disease' i.e. morbidity (measured by years of life lived with disability (adjusted by disability weights) and mortality due to various health issues encompassing:

- Premature mortality
- Disability-weights *(Incapacity due to non-fatal conditions)*
- Age-weights
- Time preference

DALYs= YLLs +YLDs (*7.1*)

YLL =Years of life lost

= No. of deaths x (Standard Life expectancy - age at death)

YLD = Years of life lost to disability

= No. of cases x Disability weight x duration of case till remission or death

World Health organization (WHO) has broadly categorized the globe into seven geographical regions and fourteen sub regions. The five Gulf countries included in the study area lie in the Eastern Mediterranean Region (EMRO) with Bahrain, Oman, Qatar and UAE lying in the sub-region EMRO-B and only Yemen being in EMRO-D. WHO projects mortality and DALY rates on the basis of regional divisions, sex, socio-economic development and their known relationship with cause-specific mortality rates by using mathematical models. The WHO studies indicate that the EMRO has the third highest mortalities and DALY rates after south East Asian and African regions (*WHO, 2003*).

World Health Organization (WHO) in the above report relies on the child and adult mortality data based on censuses and epidemiological studies for the different countries. It developed life tables specifying all cause mortality rates on the basis of age and sex for all the countries from available death registration data. For countries where no reliable mortality data was available, estimations were based on cause-of-death models together with data from population-based epidemiological studies

For our study we took the central population estimates of the Gulf countries for years 2025 to 2050 from Population Action International's website (*PAI, 2006*). The medium population estimates for the year 2100 were obtained by extrapolation.

Then based on the modeled results of *Hajat et al., 2002 and McMichael et al., 2004* accentuating that 1 °C increase in average temperatures will result in a 3% increase in all-cause mortality, we estimated the excess all-cause mortality and DALY rates for the five Gulf countries as listed below. Based on anticipated increases in temperature as predicted by the Hadley Center's model (HadCM3) under A-2 emission scenario during 2070-2099, the excess rates of all-cause mortality and DALY rates per 100,000 population were determined for the Gulf countries and are summarized in Tables 7.1 and 7.2 below:

7.4 Projected Increase in Mortality Rates

The anticipated increase in mortality rates for the Gulf countries as reported by *Husain and Chaudhary, (2006)* are shown below:

Table 7.1: Projected mortality rates per 100,000 population

Country	2002 Population ('000)	2002 all-cause mortality /100,000	2100 Extrapolated population estimates ('000)	2100 Projected all-cause mortality	Hadley models Projected temperature Increase (°C)	Odd Ratio	Projected temperature adjusted all-cause mortality	*Excess mortality due to temp.*
Bahrain	709	322.1	1,115	506.6	2.55-2.61	1.0774	545.8	***39.2***
Oman	2,768	301.5	30,548	3,327.4	2.62-2.82	1.0834	3,604.9	***277.5***
Qatar	601	247.2	1,044	429.4	2.57-2.82	1.081	464.2	***34.8***
UAE	2,937	303.7	4,540	484.9	2.57-2.86	1.0816	524.5	***39.6***
Yemen	19,315	887.0	145,746	6,693.1	2.64-2.93	1.0837	7,253.3	***560.2***

The above table identifies the fact that although countries like Bahrain, Qatar and U.A.E have comparatively lesser increase in excess mortality rates, but the influence of the changes in climate cannot be ruled out. Whereas for Yemen and Oman although the anticipated increase in temperature is not very high as compared to the other three countries but the mortality rates are significantly higher because of the following probable reasons:

- Higher population growth rates for both the countries

- Limited financial capability of Yemen coupled with fast population growth rate thus resulting in increased magnitude of the problem

7.5 Projected Increase in DALY rates

The anticipated increase in DALY rates for the Gulf countries as reported by *Husain and Chaudhary, (2006)* are shown below:

Table7.2: Projected DALYs per 100,000 population

Country	2002 Population ('000)	2002 all-cause DALY /100,000	2100 Extrapolated Population estimates	2100 Projected all-cause DALY	Hadley models Projected temperature increase (°C)	Odd Ratio	Projected temp-adj all-cause DALY	*Excess DALY due to temp.*
Bahrain	709	11,726	1,115	18,440	2.55-2.61	1.0774	19,868	***1,428***
Oman	2,768	13,121	3,0548	144,805	2.62-2.82	1.0834	156,881	***12,076***
Qatar	601	11,742	1,044	20,397	2.57-2.82	1.081	22,049	***1,652***
UAE	2,937	14,067	4,540	21,744	2.57-2.86	1.0816	23,519	***1,775***
Yemen	19,315	35,932	145,746	271,133	2.64-2.93	1.0837	293,827	***22,694***

As in the case with mortality rates the rate of "disability adjusted life years" per 100,000 population follows a similar trend, highlighting the fact that three countries namely Bahrain, Qatar and U.A.E show comparatively lesser increase in excess DALY rates, due to the influence of the climate change. However, for Yemen and Oman although the anticipated temperature increase is almost similar to Bahrain, Qatar and U.A.E. yet the calculated DALY rates are much higher due to relatively high population growth and limited economic situations (*Husain and Chaudhary, (2006).*

According to the statistical data gathered by WHO's and reported in its 2003 Summary of Climate Change and Human Health ~Risks and Responses the highest DALYs of 3071.5 / million population have been reported for the African region followed by the Eastern Mediterranean region which reports 1586.5 / million population. The gravity of the situation for the region can be accessed by comparing these DALYs with those of the developed countries having only 8.9 / million population as estimated for the year 2000.

7.6 Adaptation Strategies

Adaptation is an activity that is minimizes adverse impacts of climate change along with maximizing the benefits at the same time. Although human societies are adapted to a certain degree towards variations in weather and climate, but it is essential to educate them to cope with long-term climatic changes as its impact is critical and prolonged. It can only be managed if there is awareness about problems and their causes.

Adaptation capability is the individual's ability to adjust in any ecological, social, or behavioral setting with regards to the actual or anticipated climatic variations and their possible consequences/impacts. Where as adaptive capacity is defined as the he ability of any system or community to adapt to the climatic changes.

By using the term adaptation strategy we refer to the necessary steps required to enhance this capability to be able to cope with the climatic variations and its uncertainties (regarding variability and extremes).

In our investigative study future planning seems difficult, due to the predictive uncertainties in climate change, especially with reference to the adverse health impacts on human population. However, if sustained focus is maintained on the option of minimizing population's vulnerability then considerable progress can be made on this sensitive issue.

The following block diagram indicates the adaptive capacity of the system with respect to the biological, behavioral and social modes at individual, community and national levels and the different prevention stages (Adopted from *McMichael and Kovats, 2000*).

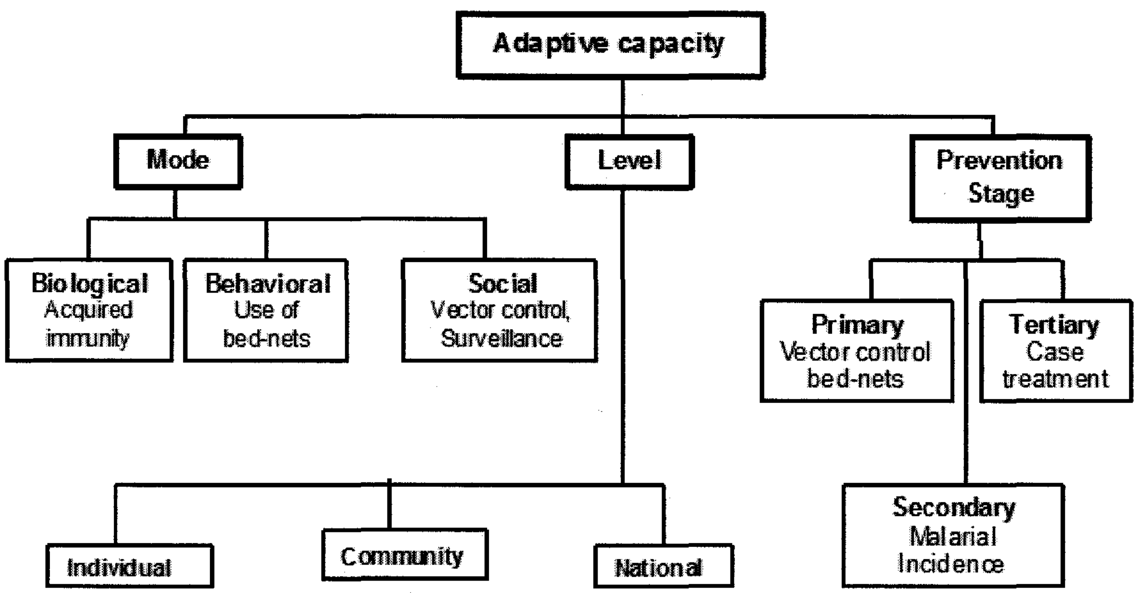


Fig 7.1: Flow chart highlighting contributors towards Adaptive capacity

The three different modes of adaptation include biological adaptation involving mental preparedness for change e.g. as is the case in summer and winters; behavioral adaptation that involve individual's willing participation in minimizing adverse impacts (e.g. using bed nets in malarial prone regions) and finally social adaptation that involve collective approaches.

The adaptive capacity of the system can be tackled at all the three levels i.e. at the national level involving governmental and non-governmental agencies; at the community level by allowing community participation and finally at the individual level by generating awareness, sense of responsibility and participation. Similarly the three prevention stages include primary, secondary and tertiary of management.

According to IPCC adaptive capacity can be determined on the basis of available resources, their distribution and available technological options for adaptation along with authentic data-quality and decision makers' credibility. Another important issue is the understanding of the significance of the problem by the public. Thus for prevention, policies with which general public is quite familiar are a prerequisite (*WHO, 2003*).

The adaptation strategy is of two types. Either reactive i.e. the one based on the climatic impacts or anticipatory in nature i.e. which emphasize on reduction of vulnerability. The implementation of adaptation strategy is crucial for assessing impacts of climate change and its vulnerabilities, on the development and evaluation of available response options, irrespective of the fact that whether necessary steps are taken or not to mitigate climate change (*WHO, 2003*). While devising an adaptation strategy for any particular community or region, the initial assessment of their vulnerabilities and the adaptive capacities of population groups should be carried out and significant focus should be devoted to the ecosystem characteristics of the region.

The fundamental adaptation strategies include seasonal changes in clothing and lifestyle with regards to the climatic exposure; behavioral, social and economic adaptations at all levels; monitoring and surveillance of the diseases with regards to food, vector population /growth in vector prone regions; improved health care facilities with new guidelines for managing long-term care; easily available and accessible heated and air-conditioned public buildings, drop-in centers and shelters; reduction in number of motor vehicles; involvement of volunteer agencies; and engaging stake holders in the process of devising policies for suitable adaptation strategy.

According to *McMichael and Kovats, (2000)* the effective adaptation strategies should cater for the following fundamental aspects:

- Environmental management involving issues like properly planned housing, sanitation control of vector populations etc.
- Reduction of poverty and economical incentives like subsidized housing
- Conventional Public health issues like vaccination, safe drinking water, food etc.
- Educating public through news media about energy conservation, announcements of extreme weather and use of insecticide-impregnated bed nets to reduce malarial transmission

Adaptation measures are vital as they have the potential to reduce many of the potential health impacts of climate change. The different plausible adaptation measures that can be implemented to minimize the adverse impacts of climate change with respect to thermal stresses, extreme weather events, vector and rodent borne diseases as listed in the IPCC are as follows (*UNEP/IVM Handbook):*

Table 7.3: List of possible adaptation strategies regarding specific health impacts of climate change *(Adapted from: Human Health, UNEP/IVM Handbook).*

Adaptation measures	Heat related Mortality	Extreme weather events	Vector borne diseases	Water borne diseases
Educate General Public	Publicize precautionary measures	----	Encourage public to destroy artificial breeding locations	Educate public on sources of infection
Surveillance and monitoring	Set up the latest weather watch / warning systems focus on adverse health affects	Plan disaster preparedness programs with proper health support system	Carry surveillance of disease incidence and vector populations or their hosts	Availability of Early Warning Systems (EWS) to predict diseases like cholera
Ecosystem intervention	Plantation of trees in urban areas to minimize	Planned land use for minimizing erosion, flash flooding and	Releasing of sterilized male insects to reduce vector	----

	urban heat-island effect	precarious residential settings	reproductively	
Infrastructure development	----	Site intakes for water facilities far enough upstream to tolerate saline intrusion from storm surges and sea level rise	Estimating effects of irrigation projects on vector breeding sites	Construction of water treatment plants and waste management facilities
Technical/ Engineering	Heat resistant building designs	Strengthening sea walls Strict adherence to building standards in coastal regions	Install window screens in insect prone areas and encourage use of prethroid impregnated bed-nets	Availability of economical water filtration systems like nylon mesh, cloths
Medical intervention	Work scheduling for avoiding peak outdoor temperatures for workers day time	-----	Sensitive health care givers in susceptible areas	----

Chapter-8

Conclusions

8.1 Summary

The present investigative study based on the three Global Climate Models (i.e. Hadley Centre UK, National Centre for Atmospheric Research USA and Canadian Centre for Climate Modeling and Analysis) showed significant inconsistencies in the projections for all of the three parameters under investigation which can be attributed to the following reasons:

1. Lack of validation of models
2. Poorly -defined boundary conditions
3. Coarser resolution usually having horizontal range of 250-600km

This higher degree of projected fluctuations result in considerable uncertainty, emphasizing the need of more robust, validated Regional Climate Model (RCM) with well defined boundary conditions. As the RCM's usually have horizontal resolution of 50 km, they incorporate local topographic features like mountains, trees, lakes etc. and can define future climate with more reliable prediction.

Our investigative study based on the empirical approaches for in-depth studies of temperature-disease mortality relationship (vital for the precise estimation of adaptation required due to climate change to minimize disability adjusted life years (DALY) and mortality rates) conclude as follows:

1. The influence of the changes in climate cannot be ruled out

2. Although the anticipated temperature increase is similar for the region yet countries like Bahrain, Qatar and U.A.E have comparatively less increase in excess mortality rates (per 100,000 population). While for Yemen and Oman the mortality rates are significantly higher because of their higher population growth rates and limited financial resources.
3. Like mortality rates DALYs rates per 100,000 population follows a similar trend indicating excess DALYS of 22,694 for Yemen and 12,076 for Oman as compared with the other Bahrain, Qatar And U.A.E, whose increase are below 2000, during the period
4. Based on the predicted data Yemen is considered to be the most vulnerable country followed by Oman towards anticipated climatic changes.

8.2 Recommendations

Based on the research work in the five Gulf countries regarding climate change and its impact on health, the following recommendations are made for better understanding of the climatic changes and in the reduction of population vulnerability as a result of the climatic changes:

- GHG emissions should be minimized and suitable cost-effective scientific and technical measures should be taken to protect the environment and ecosystem. The respective governments should undertake steps for limiting emissions by setting tougher targets.

- Respective Governments in the region should focus on environmental issues as their top priority and allocate considerable financial resources for educating and training professionals. It will enable scientific and engineering community to benefit from them and advise the decision makers of the future developments.
- Elaborate research activities on regional climatic models and their proper validation will help in better understanding the delicate relationship between climate change and its effects on human health.
- Increased adverse impacts of climatic changes on human health in above Gulf countries, apart from necessitating emission reduction, require proper adaptation and mitigation strategies
- It is extremely vital that the records hospital admissions and/or emergency room visits for illnesses such as thermal stresses and cardiovascular diseases should be available in public domain for research to access possible health impacts of future climate changes, for better future policy decisions.
- As the entire region has hot and dry climatic conditions with anticipated projections for further temperature increases due to climate change; detailed studies of the temperature–mortality relationship are essential for precise estimation of population's vulnerability and necessary degree of adaptation required in order to minimize mortality rates.
- Careful surveillance of climate-attributed infectious diseases should be carried out to monitor unusual disease incidence patterns as well as other risk indicators over

time to be better equipped with disease specific measures to handle any possible pandemic situation.

- In order to minimize climate related health risks in the region development of appropriate regionally based public health intervention strategies should be developed for reducing population's vulnerability towards direct and indirect adverse impacts.
- Necessary adaptive measures should also be taken to improve social and behavioral adaptation at individual, community and national levels throughout the region with emphasis on the basic improvements in social structures and minimization of inequalities within population groups.
- Population's vulnerability in the region towards adverse health impacts of climatic changes can be minimized through public awareness towards social and behavioral adaptation at individual, community and national levels.

REFERENCES

Ando, M., 1998, Risk Assessment of Global Warming on Human Health, *Global Environmental Research*, **2**: pp 69-78.

Ando, M., Tamura, K., Yamamoto, S., Liang, C., Wu, Y., Zhang, J., Mao, Z., Yang, M. and Chen, A., (1999), Outline of the health effects of global Climate Change, *Journal of Epidemiology,* **6**: pp 141-144.

Brian, C., O'Neill, F., Mackellar, L. and Lutz, W., (2001), Population and Climate Change, *Cambridge University Press*, U.K

British Columbia Lung Association, (2003), Methods for Estimating and Applying Relationships between Air Pollution and Health Effects FINAL Report, Health and Air Quality 2002–Phase 1, (RWDI Project: W02-304)

Bunyavanich, S., Landrigan, C.P., McMichael, A.J. and Epstein, P.R., (2003), The impact of climate change on child health, *Ambulatory Pediatrics*, **3**, n-1: pp 44-52.

Centers of disease control and Prevention CDC, 2003, Malaria, Division of Parasitic Diseases (DPD), USA.
(http://www.dpd.cdc.gov/dpdx/HTML/Malaria.asp?body=Frames/M-R/Malaria/body_Malaria_page2.htm)

Central Intelligence Agency (CIA) World Factbook, 2006.
(https://www.cia.gov/cia/publications/factbook/)

Chaudhary, J. and Husain, T., (2006a), Uncertainty Analysis of Humidity and Precipitation Changes using data from Global Climatic models with a case study, "Climate Change conference" May 10-12, Ottawa, Canada.

Chaudhary, J. and Husain, T., (2006b), Comparative evaluation of Global Climatic models in the Gulf countries, The First International Conference of The State of the Gulf Ecosystem: Future and Threats, March 05 – 07, Al-Ain, U.A.E.

Dessai, S., (2003), Heat stress and mortality in Lisbon Part II. An assessment of the potential impacts of climate change, *International Journal of Biometeorology*, **48**, n-1: pp 37-44.

Epstein, P.R., Diaz, H.F., Elias, S., Grabherr, G., Graham, N.E., Martens, W.J.M., Thompson, E.M. and Susskind, J., (1998), Biological and Physical Signs of Climate Change: Focus on Mosquito-borne Diseases, *Bulletin of the American Metrological Society,* **79**, n-3: pp 409-417

Gouveia, N., Hajat, S. and Armstrong, B., (2003), Socioeconomic differentials in the temperature-mortality relationship in Sao Paulo, Brazil, *Int'l Journal of Epidemiology*, **32**: pp 390-397

Grib Converter software (http://cera-www.dkrz.de/IPCC_DDC/GRIBGZIP.html)

Hajat, S., Kovatas, R.S., Atkinson, R.W. and Haines, A., (2002), Impact of hot temperatures on death in London: a time series approach, *Journal of Epidemiology & Community Health*, **56**: pp 367-372

Hales, S., De Wet, N., Maindonald, J., and Woodward, A., (2002), Potential effect of Population and Climate change on Global distribution of Dengue Fever: An empirical model, *The Lancet*, **360**: pp 830-834.

Harasawa, H., Matsuoka, Y., Takahashi, K., Hijioka, Y., Shimada, Y., Munesue, Y. and Lal, M., (2002), Potential Impacts of Global Climate Change, *Climate policy assessment* (Eds. Kainuma, M., Matsuoka, Y. and Morita, T.) *Springer*, pp 37-54.

Husain, T. and Chaudhary, J., (2006), Human Health Risk assessment due to Global warming – a case study of gulf countries, "The First International Conference of the State of the Gulf Ecosystem: Future and Threats" March 05 -07, Al-Ain, U.A.E.

Intergovernmental Panel on Climate Change Brochure, 2004 (http://www.ipcc.ch/about/anniversarybrochure.pdf)

Intergovernmental Panel on Climate Change, Data Distribution Centre (http://www.mad.zmaw.de/IPCC_DDC/html/SRES_TAR/index.html)

John, M. L. and Chiotti, Q.P., (2001) Climate Change and Health, *isuma: Canadian Journal of Policy research*, **2**, n-4: pp 62-69.

Kalkstein, L.S. and Greene, J.S., (1997), An evaluation of climate/mortality relationships in large US cities and possible impacts of climate change, *Environmental Health Perspective*, **105**, n-1: pp 84-93.

Kalkstein, L.S. and Jamason, P.F., (1996), The Philadelphia hot weather-health watch/warning system: Development and application, summer 1995. *Bulletin of American Meteorological Society*, **77**, n-7: pp1519-1528.

Kalkstein, L.S. and Smoyer, K.E., (1993), The impact of climate change on human health: Some international implications, *Cellular and Molecular Life Sciences*, **49**, n-11: pp 969-979.

Karl, T.R. and Trenberth, K.E., (2003), Modern Global Climate Change, *Science*, **302**, n-

5651: pp 1719-1723.

Knudson, T.R., Tuleya, R.E. and Kurihara, Y., (1998), Simulated increase of hurricane intensities in a CO_2 warmed climate, *Science*, **279**: pp1018-1020

Kovats, R. S., Menne, B., McMichael, A.J., Bertollini R.and Soskolne C., (1999), Early Human Health Effects of Climate Change and stratospheric Ozone depletion in Europe, *WHO, Third Ministerial Conference on Environment and Health, London.*

Kvarnback, M., (2001), Clear Facts about Climate Change, translated by Gary Watson, Swedish Summary of IPCC Climate Change.
(http://www.naturvardsverket.se/bokhandeln/pdf/620-8155-1.pdf)

Martens, W.J.M., (1998), Health Impacts of climate change and Ozone Depletion: An Ecoepidemiologic Modeling Approach, *Environmental Health Perspectives*, **106** (Suppl-1): pp 241-251

Martens, W.J.M., (1998), Health Impacts of Climate Change and Ozone Depletion: An Ecoepidemiologic Modeling Approach, *Environmental Health Perspectives, Supplements* Volume 106, Number S1,

McMichael, A.J. and Kovats, S., (2000), Climate Change and Climate Variability: Adaptations to reduce Adverse Health Impacts, *Environmental Monitoring and Assessment*, **61**: pp 49-64

McMichael, A.J. and Martens, W.J.M. (1995), The Health Impacts of Global Climate Change: Grappling with Scenarios, Predictive Models, and Multiple Uncertainties, *Ecosystem Health*, **1**, n-1: pp 23-33.

McMichael, A.J., Campbell-Lendrum, D., Kovats, S., Edwards, S., Wilkinson, P., Wilson, T., Nicholls, R.J., Hales, S., Tanser, F., Le Sueur, D., Schlesinger, M. and Andronova, N., (2004), 'Climate change'. In Ezzati, M, Lopez, A D, Rodgers, A and Murray, C J L (eds) *Comparative Quantification of Health Risks: Global and Regional Burden of Disease due to Selected Major Risk Factors*, World Health Organization (WHO), Geneva, : pp 1543-1649

Mellor, P.S. and Leake, C.J., (2000), Climatic and geographic influences on arboviral infections and vectors, *Revue Scientifique et Technique de l'Office International des Epizooties*, **19**, n-1: pp 41-54.

Ministry of Health Services, British Columbia, (2003), Provincial Health Officer's Annual Report 2003, Air Quality in British Columbia a Public Health Perspective, (ISSN 1195-308X)

National Commission of Atmospheric Research's Parallel Climate Model (PCM) (http://www.cgd.ucar.edu/pcm/)

Outlaw, T.G. and Engelman, R., (1997), Sustaining Water, Easing Scarcity: A Second Update, Population Action International, (http://www.populationaction.org/resources/publications/water/water97.pdf)

Pan, W.H. and Tsai, M.J., (1995), Temperature extremes and mortality from coronary heart disease and cerebral infraction in elderly Chinese, *Lancet*, **345**: pp 353-355.

Patz, J.A and Martens, W.J.M., (1996), Climate impacts on vector-borne disease transmission: global and site specific, *Journal of Epidemiology*, **6**: pp S145-S148.

Patz, J.A. (2000), Climate Change and Health: New Research Challenges, *Eco system Health*, **6**, n-1: pp 52-58.

Patz, J.A. and Balbus, J.M., (2000), Methods of assessing public health vulnerability to global climate change, *Climate Research*, **6**: pp 113-125.

Patz, J.A., Engelberg, D. and Last, J., (2000), The effects of Changing Weather on Public health, *Annual Rev. Public Health*, **21**: pp271-307.

Patz, J.A., Epstein, P.R., Burke, T.A. and Balbus, J.M., (1996), Global Climate Change and emerging infectious diseases, *Journal of American Medical Association*, **275**, n-3 : pp 210-216.

Patz, J.A., Lendrum, D.C., Holloway, T., and Foely, J.A., (2005), Impact of regional climate change on Human Health, *Nature*, **438**, n-17: pp 310-317.

Patz, J.A., McGeehin, M.A., Bernard, S. M., Kristie, L. Ebi, K.L., Epstein, P.R., Grambsch, A., Gubler, D.J., Reiter, P., Romieu, I., Rose, J.B., Samet, J.M. and Trtanj, J., (2000), The potential health impacts of climate variability and change for the US: executive summary of the report of the health sector of the US National Assessment, *Environmental health perspectives*, **108**, n-4: pp 367-376.

Pim Martens, (1998) 'Health and Climate Change - Modelling the Impacts of Global Warming and Ozone Depletion', Earthscan Publications Ltd, U.K.

Population Action International (http://www.populationaction.org/resources/publications/water/water97.pdf)

Rosendahl, K.E., (1998), Health effects and social costs of particulate pollution –a case study for Oslo, *Envi. Modeling and Assessment,* **3**: pp 47-61.

Sanders, J.L. and Brizzolara, M.S.,(1982), Relationship between Weather and Mood, *The journal of General Psychology*, **107**, n-1: pp155-156.

Slaper, H., Velders, G.H.M., Daniel, J.S., De Gruijl, F.R. and Vanderleun, J.C., (1996), Estimates of ozone depletion and skin cancer incidence to examine the Vienna Convention achievements, *Nature*, **384**, n-6606: pp 256-258

Smith, J.B. and Tirpak, D.A., (1989), The Potential effects of global climate change on the United States, US Environmental Protection Agency (EPA).

Strzepek, K.M. and Smith, J.B., (eds), (1998), As climate Changes: International Impacts and Implications, *Climate Change*, **39**, n-1: pp-135-139.

Tanser, F.C., Sharp, B. and Sueur, D. (2003), Potential effect of climate change on malaria transmission in Africa, *Lancet*, **362**: pp 1792-1798

Watson, R.T., and McMichael, A J., (2001), Global Climate Change - the latest assessment: Does Global Warming Warrant a Health Warning? *Global Change and Human Health*, **2**, n. 1:pp 64-75.

Watson, R.T. and the Core Writing Team (Eds.), Intergovernmental Panel on Climate Change (IPCC)-Climate Change 2001: Third Assessment Report (TAR), Vol-1, Cambridge University Press, U.K

WHO, (2001), Monitoring Health Impacts of Climate Change in Europe-Meeting Report London, UK, MARCH 2001, (EUR/01/502 6360)

WHO, (2004), Using Climate to predict Infectious disease Outbreaks: A Review, (WHO/SDE/OEH/04.01) Communicable Diseases Surveillance and Response (CSR), Protection of the Human Environment (PHE), Roll Back Malaria (RBM) Geneva, Switzerland.

Woodward, A., Hales, S., and Weinstein, Pl., (1998), Climate change and human health in Asia Pacific region: who will be most vulnerable? *Climate Research*, **11**: pp 31-38.

World Health Organization (WHO), (2003), Climate change and Human Health – Risks and Responses, Summary (WHO/SDE/OEH/04.02)

World Health Organization (WHO), (2003), Synthesis Workshop on the Health Impacts of Climate Variability and Climate Change in Small Island States, Maldives.