Coping with CLIMATE CHANGE

EDITED BY

SUMAN SAHAI


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Edited by	:	Dr. Suman Sahai
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WHY THIS BOOK?

In 2010 Gene Campaign had organized a national conference together with ActionAid, on the impact of climate change on food security. The two day national conference titled "Ensuring Food Security in a Changing Climate" was organized in Delhi and brought together over 200 participants from 22 states : Haryana, Uttaranchal, Jharkhand, Odisha, Uttar Pradesh, Bihar, Andhra Pradesh, Maharashtra, Rajasthan, Meghalaya, Assam, Mizoram, West Bengal, Tamil Nadu, Himachal Pradesh, Karnataka, Punjab , Madhya Pradesh, Gujarat, Kerala , New Delhi and Pondicherry.

Scientific and technical experts from government and non-government organizations, Members of Parliament and of government departments, grassroots level community organizations, civil society groups, , scientists , farmer organizations, officials of state governments , diplomats, international organizations and concerned citizens discussed the impact of climate change on agriculture and deliberated on the strategies needed to help protect agriculture, food and nutrition security as well as rural livelihoods.

My enduring impression from the conference was the rather low level of awareness among most people about climate change and its many impacts. The best understood aspect of climate change is the global warming caused by carbon emissions. There are discussions on renewable energy versus fossil fuels and solar energy is the clear favorite. But there is little understanding and less debate about what climate change will do to key sectors like natural resources, biodiversity, ecosystems , agriculture and food production. These are the most vulnerable sectors because they affect the food security of the country and the livelihoods of over two thirds of its people. Yet, they are nowhere near the center of the debate or of policy focus in our country. The National Action Plan on Climate Change (NAPCC) flags agriculture as one of the eight missions for action but fails to prioritize it.

While the national conference on climate change was on, there was a European delegation visiting India to understand the government's positions and strategies on tackling climate change and its impacts. The leader of the delegation remarked, at a reception that I attended, that it was curious that the focus of India's policy attention was almost entirely on the energy sector and substantial money was being invested in it.

They were astonished that given the existing challenges to India's food and nutrition situation, the government's primary concern was the energy issue and that agriculture, food production and livelihoods did not occupy center space in strategizing for adaptation to climate change. The fact is that South Asia along with Africa, is likely to face the worst brunt of climate change, particularly on its agriculture and food production and rural livelihoods.

In our work in different states, Gene Campaign staffers find that communities are bewildered by the rapid changes in the climate that are affecting their cropping patterns, food production and overall incomes. There are few, if any, agencies that are trying to educate rural communities about the phenomenon of global warming and climate change and what to do about it, how to protect their food production and livelihoods in this changing , turbulent situation.

In this back drop, Gene Campaign decided to do something and contribute to building greater awareness about climate change and creating a better information base about it. In 2011, Gene Campaign organized a 13 episode program on Lok Sabha Television called 'Climate Matters'. I anchored the program and invited experts to discuss the impact of climate change on subjects like predicting the weather, human security, women, livestock, water, agriculture, health, forest and wildlife, urban settlements, urban transport and energy. The program also featured discussions on the response of science to climate change and the state of international negotiations.

These TV clips can be viewed at http://www.youtube.com/user/genecampaign

Now Gene Campaign has developed an information resource as a book which deals with the impact of climate change on sectors relevance to rural communities, like agriculture, food, forests, biodiversity, water, ecosystems, soil and water management and international negotiations. It includes a section on making agriculture and food production more sustainable and better adapted to climate change.

These information materials are meant to be a resource for training and capacity building at various levels and can be used either whole or in parts by people and agencies in the manner that it suits them. Civil society groups can use it in the areas where they work and trainers can extract portions relevant to their target audience. The book can serve as an excellent resource for policy makers, students, teachers and educators, bankers, corporate executives, schools, colleges and anyone interested in climate change.

This book is the collective effort of many people. Taarini Chopra, Kirtiman Awasthi, Kanchan Saxena, Shoshanna Tharu, Roshan Kumar, Anuja Mishra and Richa Srivastava have contributed to writing the document. Tanvi and Kushal worked with us to design it. We have created this book with enthusiasm and hope it will be enjoyed and used by many people and will lead to a greater awareness about the phenomenon of climate change, its diverse impacts and how to cope with these impacts.

Dr. Suman Sahai

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Introduction

What Is Climate?

WHAT IS CLIMATE?

Climate is the average, or "mean" weather of a place, over an extended period of time. This period can be anywhere from a few months to millions of years, but is most commonly calculated for 30-year time periods. When we talk about climate, we may be referring to a range of factors, such as temperature, precipitation and wind, as well as extreme weather events and variability in weather patterns.

The climate system is not static. In fact, it is constantly evolving, shaped by its own internal patterns, as well as by external (natural) factors such as solar radiation, volcanic eruptions and ocean currents.

Climate is also significantly affected by another external factor: us. Over the past century, human or "anthropogenic" activities have increasingly been changing the composition of atmosphere, and this in turn leads to changes in climatic patterns. These changes threaten to affect human life, as well as plants, animals and ecosystems in drastic ways.

Climate is a longer-term measure of how the atmosphere behaves, and includes temperature, wind, pressure and precipitation. Climate is affected by both natural and human or anthropogenic factors.

Weather is the day-to-day state of the atmosphere, and includes temperature, humidity, wind, pressure, precipitation and cloudiness.

WHAT IS CLIMATE CHANGE

Since the mid-20th century, there has been a significant change in the Earth's climate, the most important aspect of which is a rise in the average global temperature. Even though scientists are not absolutely certain about what the specific impacts of this change will be, there is now an overwhelming consensus that this phenomenon is largely due to human activity.[1]

As defined by the United Nations Framework Convention on Climate Change (UNFCCC), climate change is **"a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability over comparable time periods."**

HOW DOES IT HAPPEN?

The Earth has a blanket of gases - known as greenhouse gases (GHGs) - that keep it warm enough to sustain life; a mean surface temperature of about 14 degrees C.

These gases trap heat, and radiate it back to the Earth's surface. In fact, of the heat that reaches Earth from the sun, only 30% is radiated back to space, while the rest is held in the atmosphere and helps warm the surface of land and water bodies (IPCC).[2] This process is called the natural greenhouse effect.

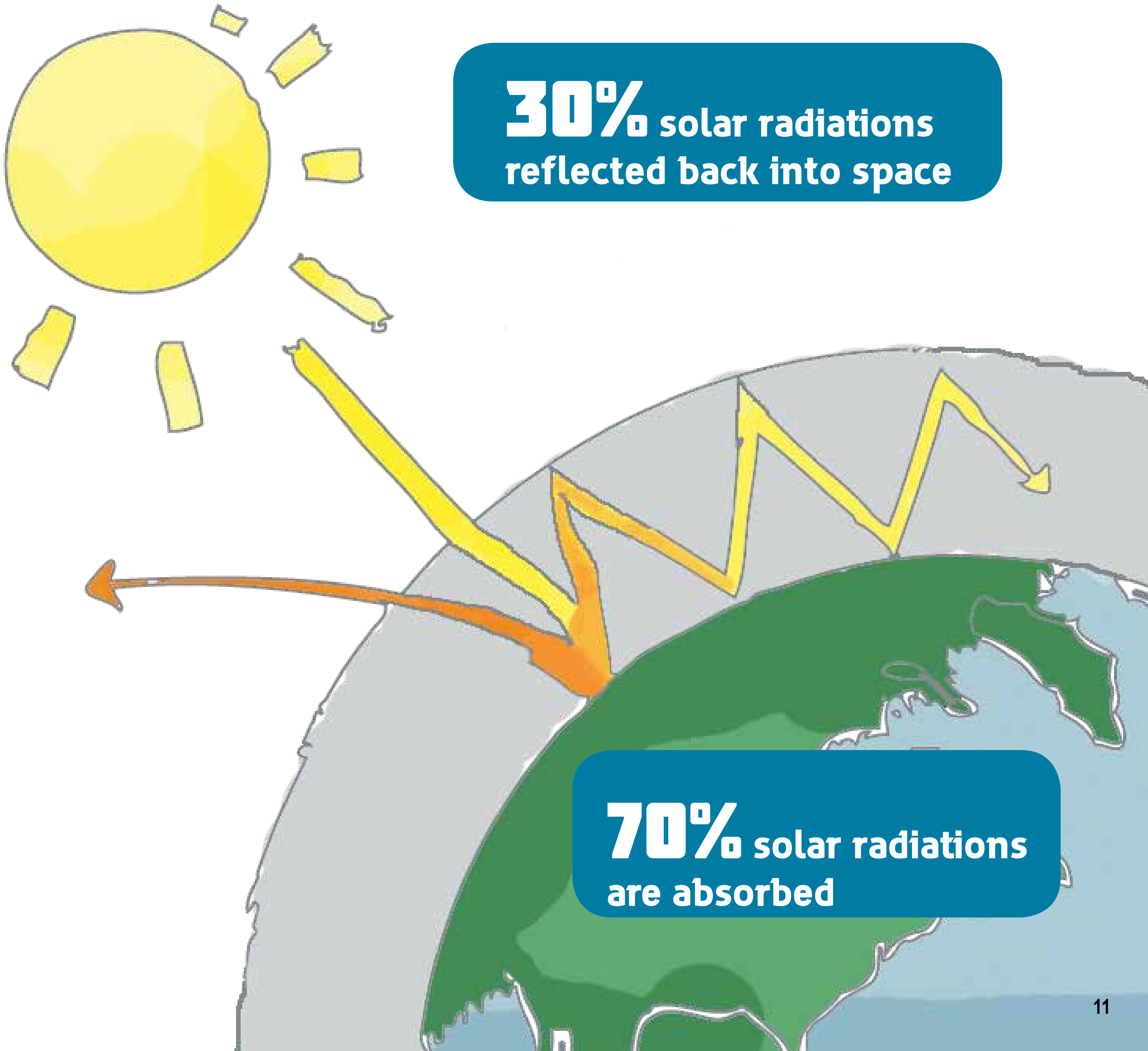
Without these gases, our world would be a much harsher place.

The average temperature would be about -18°C, and Earth would not be able to support life as it does now.[3]

This is similar to the situation on other planets: Venus, for instance, has a very thick atmosphere, which traps a lot of the sun's energy and makes the planet extremely hot. Mercury, on the other hand, does not have an atmosphere at all, making it very hot in the daytime, but very cold at night. The conditions on both these planets are unfit for life.

While the natural greenhouse effect is essential to maintain the Earth's temperature, too much heating is a problem. Over the past century, and especially in the past three decades, we have seen an increased concentration of greenhouse gases in the atmosphere, which are released when we burn fossil fuels in processes such as transportation, land-use changes and deforestation, industry, and power generation. In 2005, for instance, the concentration of carbon dioxide in the atmosphere far exceeded its range in the preceding 650,000 years.[4]

An increase in greenhouse gases leads to a greater amount of heat being trapped in the atmosphere, which in turn causes rising temperatures and several other impacts on ecosystems around the world.



Greenhouse gases are those that can absorb solar radiations and emit heat, causing warming of the Earth's atmosphere. Of about 25 GHGs, the most abundant GHG in Earth's atmosphere are water vapour (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), ozone (O_3). Other gases known for heating the atmosphere are Hydrofluorocarbons (HFCs), Perflurocarbons (PFCs) and Sulphur hexafluoride (SF_6). Of these CO_2 is the most talked about GHG as it is emitted from virtually every activity of ours like driving cars, lighting bulbs etc.

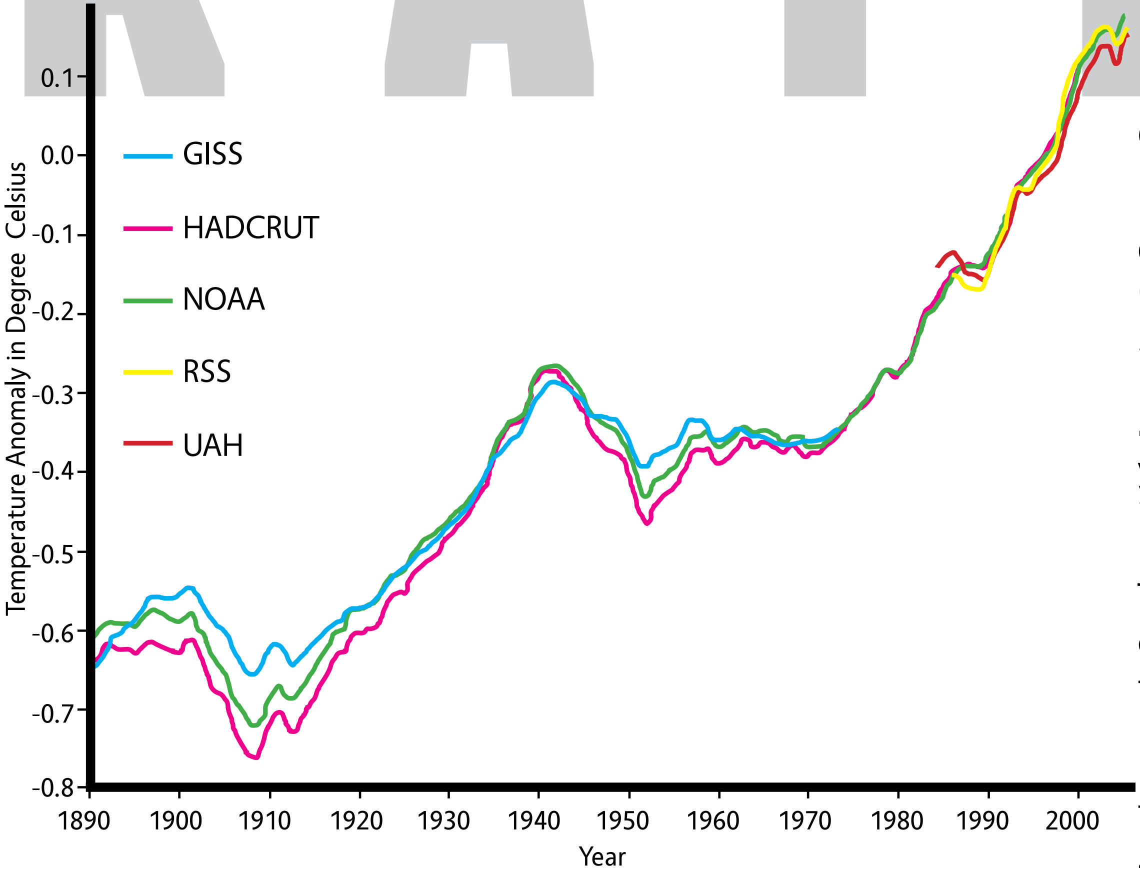
WHAT ARE GREEN HOUSE GASES?

There are other gases like methane coming from our agriculture fields; nitrous oxide coming from fertilizer use which also has potential to trap heat and contribute to global warming. Technically methane has more global warming potential than CO_2, that means one unit of methane will cause more heating of atmosphere than that of CO_2. **CO_2 is considered the most damaging because it has a longer life, remains for longer time in the atmosphere and has longer impact on climate.**

GAS	YEARS IT REMAINS IN THE ATMOSPHERE	GLOBAL WARMING POTENTIAL (100 YEARS)
CO_2	30 years, One-third of it takes few centuries and traces of it remain for thousands of year.	1
Nitrous oxide	114	298
Methane	12	25
Hydrofluorocarbons (HFC)-23	170	14,800
HFC-134a	14	1,430
HFC-152a	1.4	124
HFC-125	29	3,500
Chlorodifluoromethane HCFC-22	12	1,810
Perfluorocarbons (PFC)-14	50,000	7,390
PFC-116	10,000	12,200
Sulphur hexafluoride	3,200	22,800

Source: Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report, 2007

RATE OF



Various Measurements of Global Temperature
(133 months average)
Source: http://www.skepticalscience.com/Comparing-all-the-temperature-records.html

Greenhouse gas concentrations in the atmosphere have increased notably since 1750. **Just between 1970 and 2004, overall GHG levels are estimated to have risen by 70%. This has led to a worldwide temperature increase of 0.74 degree Celsius between 1906 and 2005.**[5] The rate of warming has been much higher in recent years. Eleven of the twelve years between 1995 and 2006, for instance, were the warmest years on record (since 1850).[6]

The measure of global warming is the mean surface temperature change. However, the worrying fact is that the Earth has warmed faster in the last 50 years than the earlier part of the 20th century.

In the first five years of this century, the rise in mean surface temperature has been widespread and comparatively faster. In fact 2005, 2010, 2003, 2002, 2006, 2009, 2007, 2004, 2001, 2011 and 2008 are the warmest years that top the chart of warmest 20 years since 1901. The year 2008 was ranked as the 10th warmest year on record in the last 150 years.

WARMING

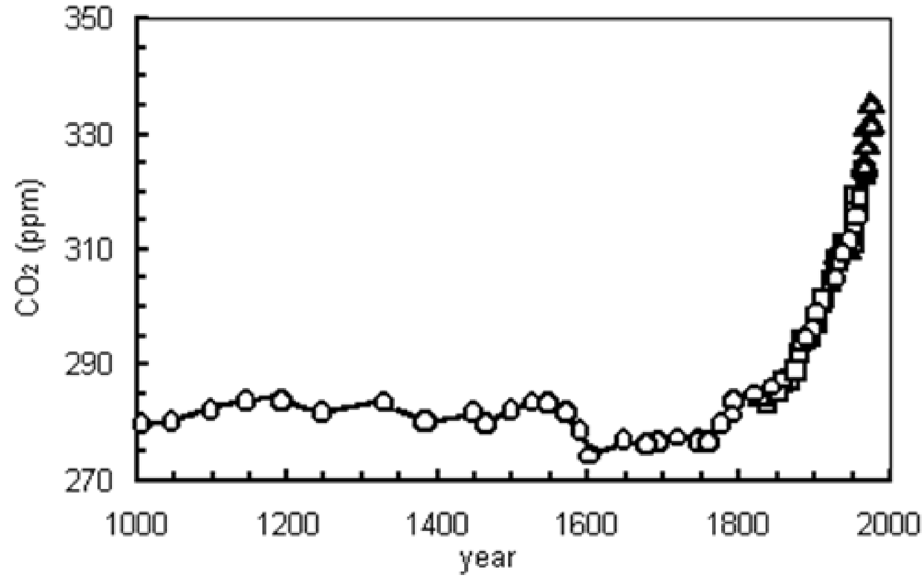
While these temperature increases may not sound very significant, they have in turn led to several other important changes. Warmer weather patterns have led to a **rise in global ocean temperatures,** which in turn has made glaciers, ice caps and snow cover, melt and shrink. Melting ice has pushed sea levels higher, and these levels are projected to continue to rise significantly in the near future. In addition, the number of heavy precipitation and **extreme weather events** such as cyclones and hurricanes has increased, droughts have become more frequent, there are fewer cold days and nights, and more heat waves and hot days and nights.[7]

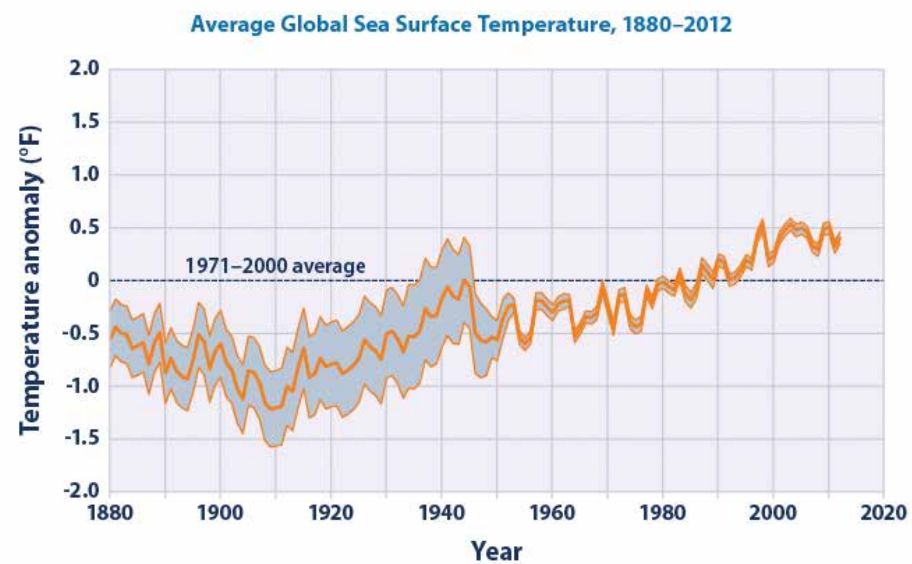
The World Meteorological Organization (WMO) declared 2009 as one of the **top 10 warmest** years on record since the beginning of instrumental climate records in 1850. Out of the 245 disasters in 2009, 224 were weather related, accounting for 55 million people out of the 58 million people affected by disasters, 7000 out of 8900 of those killed, and US$15 billion out of the US$19 billion in economic damages, according to WMO.

But it doesn't end there. As we continue to add greenhouse gases to the atmosphere over the next few decades, these patterns will continue to intensify. It is now critical that we find ways to **reduce our emissions** and **keep global climate changes to a manageable minimum**. In addition, given that our world is already changing, it is very important that we learn how to adapt to new and dynamic conditions over the next years. To do this, we have to first understand what these changes are going to look like.

The extent of the changes depends, in large part, on human activity and development patterns over the next few years. If we do nothing to mitigate current trends, and continue to expand activities that emit greenhouse gases as we are now, temperature increases will likely be towards the higher ends of those ranges. The **domino impacts** on other ecosystem functions, as well as ecological and socio-economic wellbeing, will be drastic.

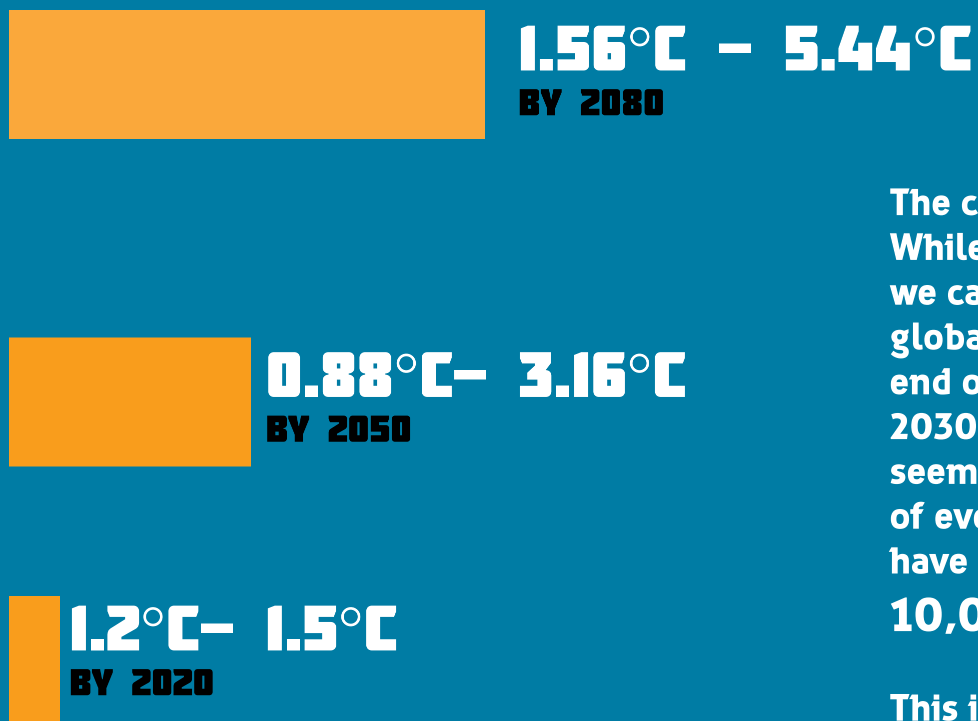
Atmospheric carbon dioxide levels from 1000 A.D. to the present.
Source: http://filebox.vt.edu/users/chagedor/biol_4684/Cycles/Cprobs.html





Sea surface temperature. Source: http://www.epa.gov/climatechange/images/indicator_downloads/sea-surface-temp-download1-2013.png

THE CLIMATE SYSTEM IS COMPLEX AND FUTURE CHANGES HARD TO PREDICT. WHILE THERE IS NO CLEAR AGREEMENT ON THE EXTENT OF WARMING THAT WE CAN EXPECT, SCIENTISTS ACROSS THE WORLD HAVE ANTICIPATED THAT GLOBAL TEMPERATURE INCREASE WILL BE BETWEEN

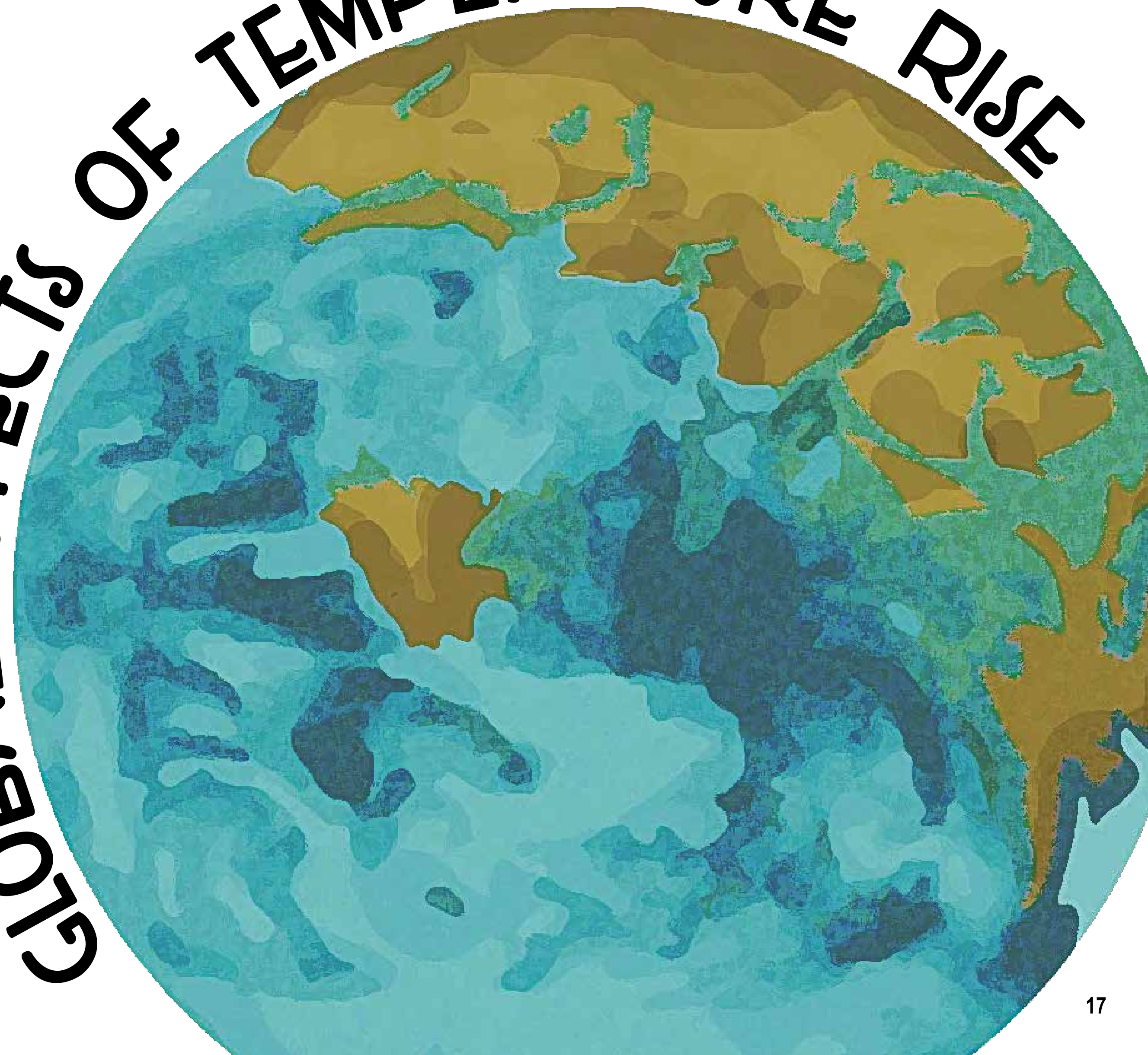


Data Source :Intergovernmental Panel on Climate Change (IPCC), 2007.Fourth Assessment Report.
Climate Change 200:: Impacts, adaptation and Vulnerability.

The climate system is complex and future changes hard to predict. While there is no clear agreement on the extent of warming that we can expect, scientists across the world have anticipated that global temperature increase will be between 1.8 and 4°C by the end of the century.[8] Most scientists have predicted that just by 2030, we will experience an increase of 0.5 to 2°C.[9] These may seem like small numbers, but they are very significant; a warming of even 1.8°C would be a greater increase in temperature than we have seen on Earth in any one century, in the past 10,000 years.

This increase will not be consistent across the country: North India will be over 4°C warmer, and South India 2-4°C warmer. It is also likely that temperature increases will be higher in winter or rabi season, than in the summer or kharif season.[10]

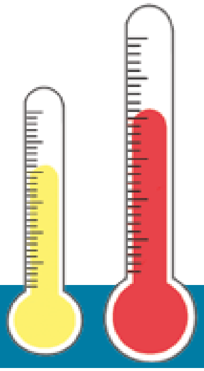
GLOBAL EFFECTS OF TEMPERATURE RISE



WHY ARE WE CONCERNED?

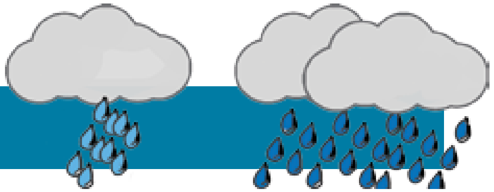
Climate change will – and has already – led to a warmer world. But that's not all. In an interconnected biosphere, temperature changes will also have several other effects. One of the most noticeable of these is sea-level rise. Higher temperatures cause ocean waters to expand. Melting glaciers and ice caps add more water to the oceans and seas, further increasing their volume. Arctic sea ice has shrunk significantly in the past three decades, as have mountain snow cover and glaciers in both hemispheres.

And, as the white colour of snow and ice is replaced by the darker colour of the ocean, more sun rays are absorbed by the earth instead of being radiated back to space, which further intensifies this warming pattern.



Rise in Temperature

At the national level, **increase of 0.4°C** has been observed in surface air temperatures over the past century. A warming trend has been observed along the west coast, in central India, the interior peninsula, and north-eastern India. However, cooling trends have been observed in north-west India and parts of south India.



Changes in Rainfall Pattern

While the observed monsoon rainfall at the all-India level does not show any significant trend, regional monsoon variations have been recorded. A trend of increasing monsoon seasonal rainfall has been found along the west coast, northern Andhra Pradesh, and north-western India (**+10% to +12% of the normal over last 100 years**) while a trend of decreasing monsoon seasonal rainfall has been observed over eastern Madhya Pradesh, north-eastern India, and some parts of Gujarat and Kerala (**– 6% to – 8% of the normal over the last 100 years**).

Extreme Weather Conditions

Rising sea levels will also lead to changes in hydrological cycles, and patterns of rainfall and drought. Globally, the areas affected by **drought have increased** significantly since the industrial revolution, and this pattern will likely continue. Northern latitudes will probably receive more rainfall while subtropical regions, many of which are already dealing with drought, will receive less. Higher temperatures and less rainfall will mean that arid areas across the world will expand, reducing green cover and leading to the contraction of 31-51 million hectares of favourable growing zones.[11]

In other parts of the world, extreme weather events like **cyclones and hurricanes** will also increase. This trend has already made itself known: between 1987 and 1998, the average number of reported natural disasters across the world was estimated to be 195 a year. In the years between 2000 and 2006, however, this number rose to an average of 365 events per year.[12]

Rise in Sea Level

Sea levels have already risen by 10 to 20 cm in the past century. By 2100 scientists are predicting that they could rise by 18-59 cm.[13]

This is especially threatening for low-lying coastal areas and islands, which will be flooded if this happens. In coastal areas of Asia, sea-level is rising at the rate between 1 to 3 mm/year that is marginally greater than the global average, according to the Fourth Report of the IPCC. A rate of sea-level rise of 3.1 mm/year has been reported over the past decade compared to 1.7 to 2.4 mm/yr over the 20th century as a whole which suggests that the rate of sea level rise has accelerated relative to the long-term average.

For India, sea level rise has been estimated between 1.06-1.75 mm per year.

Countries such as the Maldives, for instance, are well aware of this risk. In just under 100 years, most of their 1200 islands, over 80% of which are no more than 1 m above sea level, could be uninhabitable.[14]

The Sunderbans in India are another example. A 45 cm rise in sea level here would submerge 75% of the area.[15] This would force several communities to relocate their homes and livelihoods, and also cause extensive damage to 1000 square kilometres of unique mangrove ecosystem.

Sadly, such stories are not merely a prediction for the future.

In 2009, 40 families were forced to move from their flooded homes in the Carteret Island in the pacific to nearby Bougainville. These "climate refugees" are not alone.

Carteret Island will probably be entirely submerged as soon as 2015.[17]

Plants and animals are sensitive to changing climate too. Warmer ocean waters, for instance, have already seriously damaged and bleached coral reefs and the innumerable species that live in reef systems. Migratory patterns of several animals may be disrupted as temperatures in both summer and winter grounds change.

Plant and animals have also been inching polewards, as temperatures rise and the warmer season arrives earlier each year.

It is important to remember that the total amount of greenhouse gases in the atmosphere is the main determinant in temperature rise. This means that even if we were able to stop all greenhouse gas emissions today, the temperature would continue to rise due to past emissions. It is precisely for this reason that any sustainable and effective approach to climate change has to mesh together efforts to mitigate emissions, while also finding resilient and sustainable ways to adapt to the changes that are inevitable.

The United Nations estimates that as many as 50 million people may be forced to evacuate their homes and relocate due to environmental disasters such as rising sea-levels, flooding, erosion ad salinization by 2020.[16]

Over 20-30% of plant and animal species will be at risk of extinction if global temperatures rise by more than 1.5 - 2.5°C.[18]

EFFECTS OF CLIMATE CHANGE IN INDIA

The impacts of climate change are going to play out differently across the world. The Indian government predicts that by the end of the century, average surface temperatures in India will be 3 - 6°C higher.[19] This will in turn affect rainfall patterns, marginally in the monsoon months, and more significantly in the non-monsoon period.

While the total amount of monsoon rainfall may not change all that significantly in the next few decades, scientists predict that the number of rainy days in the country will decrease, but the intensity of rainfall per day will increase by 1-4mm/day.

In addition, rainfall patterns in non-monsoon months will vary across the country – some areas will see less rain, while others a great deal more. Both droughts and floods will intensify (NATCOM).

As in the global scenario, extreme weather events like cyclones and hurricanes will be more frequent and more intense in India as well.

Areas with high populations that rely on subsistence agriculture, such as the Indo-gangetic plains, are highly vulnerable in these situations. Cyclone Nargis, which left a wake of destruction behind itself in Burma and Bangladesh, may well be an example of what is to come.

India's coastline is densely populated, and the communities on the coast are particularly vulnerable to sea-level rise. One metre rise could displace 7 million people across the country.[20]

In addition, **land would be lost, soil eroded, homes and infrastructure destroyed and agricultural lands and water sources salinized.**

Low-lying areas like the **Sunderbans** as well as delta regions of the **Krishna, Mahanadi, Godavari and Cauvery** would all be under significant risk of inundation.[21]

The glaciers and snow cover of the **Himalayas** have been retreating alarmingly over the past two decades. This trend will likely continue over the next 20 to 30 years, and may well also cause flooding and avalanches. Melting glaciers will also feed into another consequence of changes in temperature and rainfall: water shortages.

Scientists estimate that river basins such as the **Sabarmati, Tapti and Mahi** will experience water shortages through the year, while seasonal shortages will be more prevalent in others such as the **Ganga, Narmada and Krishna** basins. [22] Communities living downstream in river basins will be especially affected as water supply decreases and demand increases.

Unsurprisingly, other **freshwater availability** will also be affected. With greater erosion comes increased surface water runoff, which in turn causes lower groundwater recharge. For many communities, access to water for agriculture and personal needs will become more difficult.

By 2050, one billion people are likely to face water shortages, with Indian cities being the worst hit.[23]

Climate change's impacts in India are not limited to biophysical ones. All these changes in our environment are inextricably tied to **community livelihoods and socio-economic wellbeing.**

With increasing floods, droughts, and unpredictable changes in hydrological cycles comes an **increased health risk**. Scientists predict that morbidity and mortality from **diarrhoea** will increase in parts of the country, and rise in the temperature of coastal waters could make **cholera** more prevalent, and more harmful.[24] The millions of people who live with **malnutrition** and experience poor sanitation and inadequate drinking water are especially susceptible.

Trade patterns, especially those related to food, will also likely change with the climate. As growing seasons become longer in some parts of the world, crop prices will fall; in other areas, as growing periods shorten, and weather conditions become less ideal, crop yields will fall, pushing prices up. Analysts worry that increasing crop yields in northern countries may push prices down, making access to food even harder for those in the south, possibly when they need it most.

It is important to underline, however, that these predictions are as uncertain as our projections of climatic differences in various parts of the world. It is entirely possible that countries in the north also experience lower yields due to unpredictable and extreme weather. Regardless, it is very probable that food prices will see dramatic fluctuations, and possibly an overall increase, making food access more challenging for food insecure people around the world. This price rise is expected even without the effects of climate change; with it, **rice prices are expected to increase by 32 – 37%, 52 – 55% for maize, 94 – 111% for wheat, and 11 – 14 % for soybeans.**[26]

The Indian government predicts that by the end of the century, average surface temperatures in India will be

3 - 6°C higher

Mosquitoes thrive in warm and humid climates, and the diseases they transmit thrive with them in these conditions.
Climate change may expand the window when mosquitoes and other vectors can survive and transmit diseases.[25]

Malaria

Chikungunya

Yellow fever

Dengue

Rural women in India experience inequalities at many different levels.

Lower education rates, higher unemployment rates, unequal property rights, and unequal access to information and to resources are just a few of them. Women's work, especially in rural communities, is heavily dependent on natural resources and weather patterns. They are often responsible for providing essentials such as water and food to their families. They, hence, rely on often small-scale agriculture and natural sources of fuel. Changes in productivity or access to either of these things, and to clean water, disproportionately affect their daily activities of farming, household maintenance and home businesses.

Climate related disasters will increase their workload and further exclude opportunities for education.

They are also often unequally equipped to adapt to changes. This is exacerbated by the fact that information exchange often takes place along gender lines, and excludes women.[27]

As mentioned in an earlier section, communities living in low-lying and coastal areas face a high risk of flooding and displacement, as sea waters rise. Displaced people, or **climate refugees**, are forced to give up their often meagre livelihoods, homes, and cultural or personal attachment to place in order to resettle and recreate their lives. This further exacerbates related problems of poverty, access to food and resources, and human health and wellbeing. [28]

One of the most important elements of cultural, environmental and socio-economic identity in India is **agriculture**. Employing a huge majority of the country's population, agriculture is connected to – and stands to be dramatically shaped by – both biophysical and social impacts of climate change.

Nearly **700 million rural people** directly depend on climate sensitive sectors for their subsistence and livelihoods. Climate change may alter the distribution and quality of India's natural resources and adversely affect the livelihood of its people. With an economy closely tied to its natural resource base and climate-sensitive sectors such as agriculture, water and forestry, India may face a major threat because of the projected changes in climate.

Impacts of climate change on India

- Changes in rainfall pattern and intensity

- Increase in average winter temperature

- Shifting of seasons

- Glacier melting

- More frequent and severe drought

- Increase in extreme rainfall events

CLIMATE CHANGE, ITS SYMPTOMS AND IMPACTS ON VARIOUS SECTORS

Phenomenon and direction of trend	Likely future projections for 21st Century	Agriculture, forestry and ecosystems	Water resources	Human health	Industry, settlement and society
Over most land areas, warmer and fewer cold days and nights, warmer and more frequent hot days and nights	Virtually certain	Increased yield in colder environments; decreased yield in warmer environments; increased insect outbreaks	Effects on water resources relying on snow melt; effects on some water supplies	Reduced human mortality from decreased cold exposure	Reduced energy demand for heating; increased demand for cooling; declining air quality in cities; effects on winter tourism
Warm spells/heat waves. Frequency increases over most land areas	Very likely	Reduced yields in warmer regions due to heat stress; increased danger of wildfire	Increased water demand; water quality problems	Increased risk of heat-related mortality,	Reduction in quality of life for people without appropriate housing; impacts on the elderly, very young and poor
Heavy precipitation events, Frequency increases over most areas	Very likely	Damage to crops; soil erosion, inability to cultivate land due to	Adverse effects on quality of surface and groundwater;	Increased risk of deaths, injuries and infectious,	Disruption of settlements, transport and societies

Phenomenon and direction of trend	Likely future projections for 21st century	Agriculture, forestry and ecosystems	Water resources	Human health	Industry, settlement and society
		water logging of soils	contamination of water supply	respiratory and skin diseases	due to flooding; pressures on urban and rural infrastructures; loss of property
Area affected by drought increases	likely	Land degradation; lower yields/crop damage and failure; increased livestock deaths; increased risk of wildfire	More widespread water stress	Increased risk of food and water shortage; increased risk of malnutrition; increased risk of water/ food – borne diseases	Water shortages for settlements, industry and societies; reduced hydropower generation potentials; potential for population migration
Intense tropical cyclones activity increases	likely	Damage to crops; uprooting of trees; damage to coral reef	Power outages causing disruption of public water supply	Increased risk of deaths, injuries, water- and food-borne diseases; post-traumatic stress disorders	Disruption by flood and high winds; withdrawal of risk coverage in vulnerable areas by insurers; population migrations, loss of property
Increased incidence of extreme high sea level	likely	Salinization of irrigation water, estuaries and freshwater systems	Decreased freshwater availability due to saltwater intrusion	Increased risk of deaths and injuries by drowning in floods; migration-related health effects	Costs of coastal protection versus costs of land-use relocation; potential for movement of population and infrastructure

Source: Fourth assessment report, IPCC, 2007

HOW DID WE GET HERE?

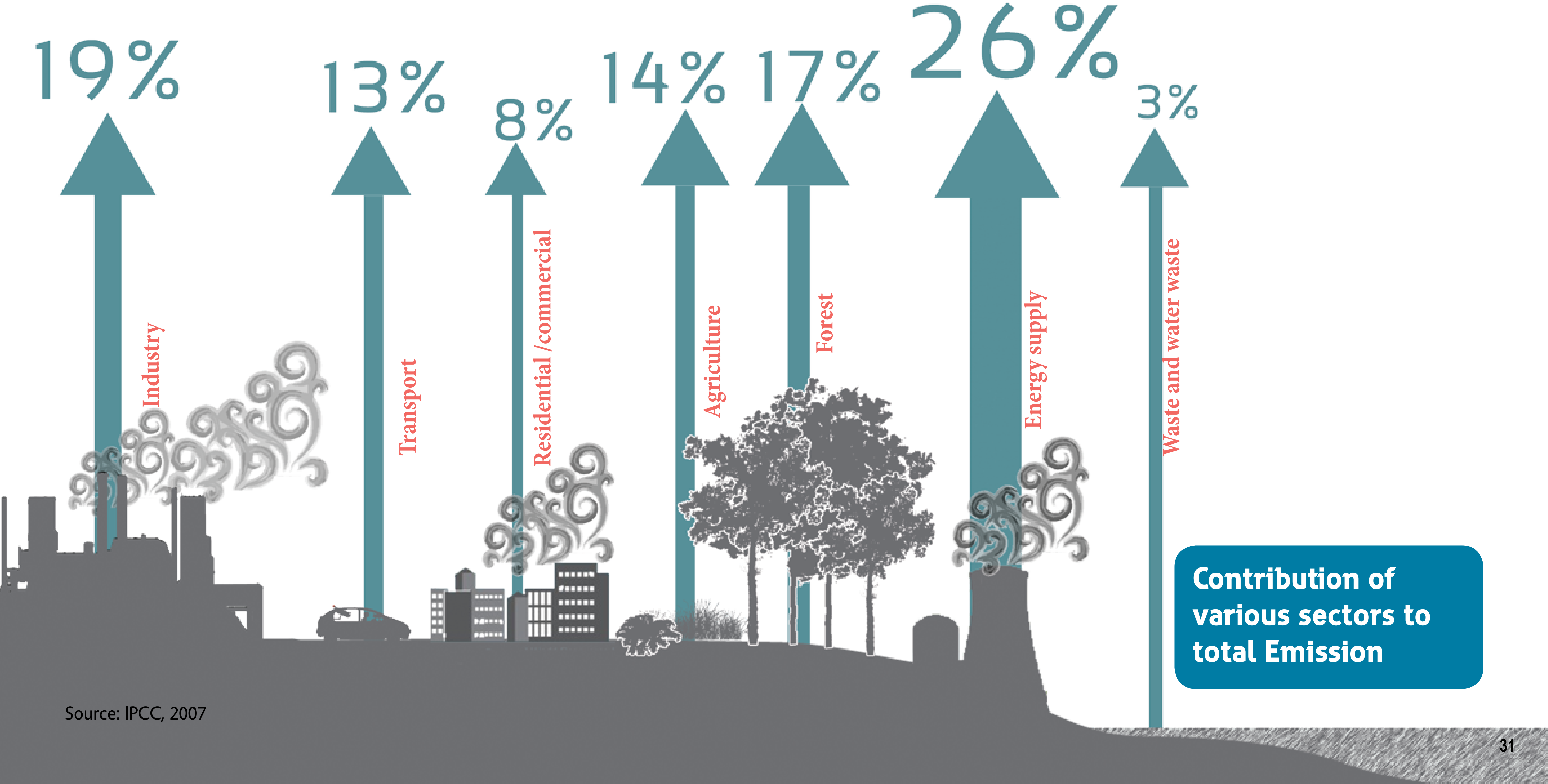
The climate change story is not a new one. As with several other issues, the warming we have seen over the past years has been caused by an increase in human activities that cause environmental damage. As our populations, our demands and the industrial models of growth we use to answer those demands grow, so do the greenhouse gases in our atmosphere.

Primary among these is **carbon dioxide (CO_2)**, which is emitted every time we burn fossil fuels (coal, oil, natural gas, petroleum) to run vehicles, bring electricity to our homes, and generate power to fuel machines in factories. The energy sector is responsible for three-quarters of total CO_2 emissions. Processes such as land clearing and deforestation, as well as some agricultural practices also emit CO_2.

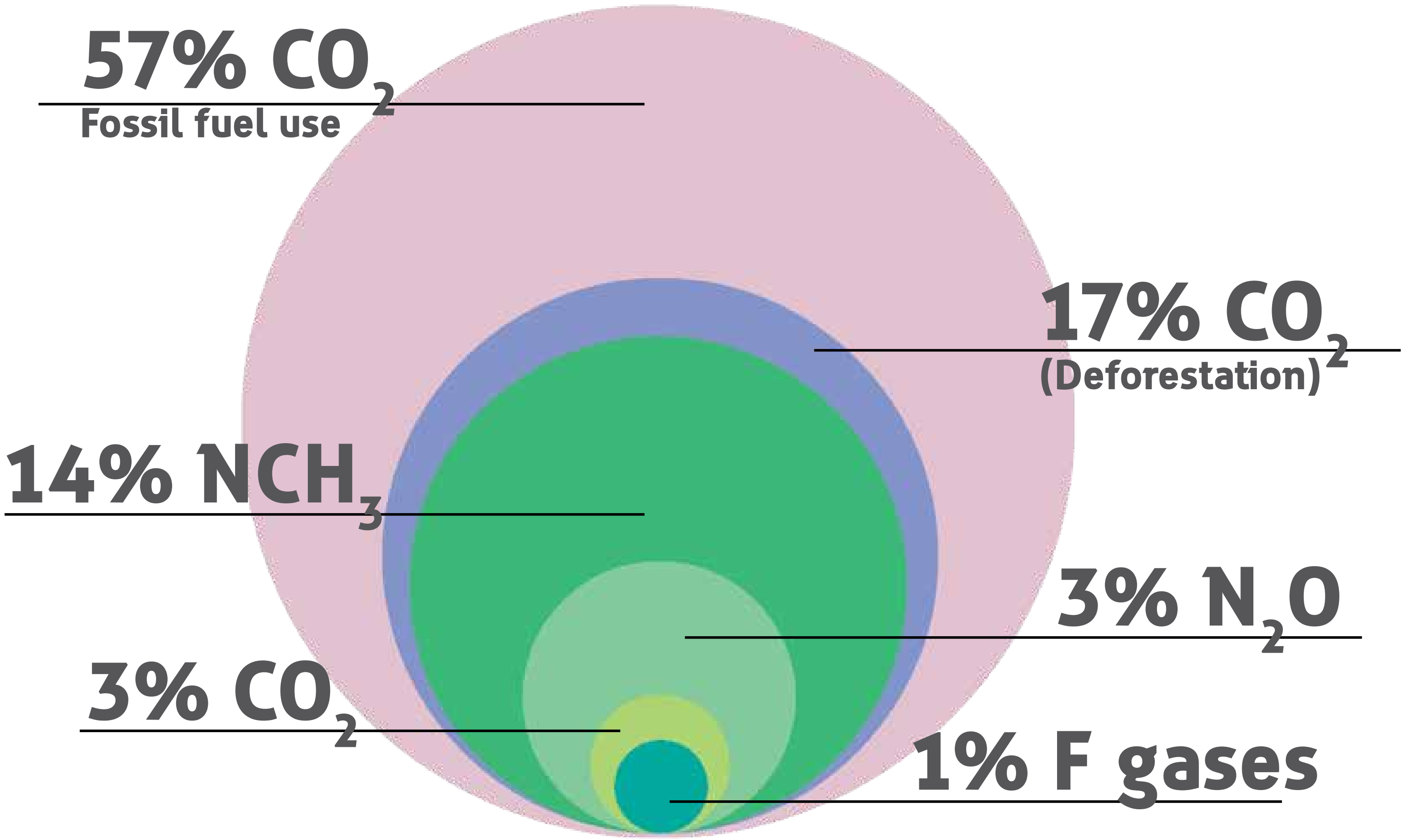
Methane or CH_4, is another important cause of climate change. This gas is predominantly created in agricultural processes and land-use change. Livestock such as dairy cows, goats, pigs, buffaloes, camels, horses and sheep all release methane to the atmosphere. Smaller, but still significant quantities of CH_4 are added to the atmosphere through landfills and dumps, oil drilling and coal mining.

Other greenhouse gases include **Nitrous Oxide or N_2O**, which is primarily produced in agricultural practices such as poor soil management, overuse of nitrogen fertilizers, and manure and sewage treatment; and a group of gases called **F-gases,** which include hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride. These gases are used in refrigeration, air conditioning, and the manufacturing of electronics, cosmetics and pharmaceuticals.

Since 2007, India has produced approximately 1.7 billion tonnes of greenhouse gases every year (India climate portal). Much of these are CO_2 emissions from burning coal, which is used to generate electricity. In addition, we burn fossil fuels to fuel factories and industrial processes, homes and cars. This energy production accounts for 61% of the country's emissions. Agriculture accounts for another 15% of the country's emissions, through land clearing, livestock, manure management and the use of nitrogenous fertilizers.[29]



Source: IPCC, 2007



Contribution of GHGs to total emissions

Data Source: http://www.epa.gov/climatechange/ghgemissions/global.html

CLIMATE CHANGE
PROCESSES, CHARACTERISTICS AND THREATS

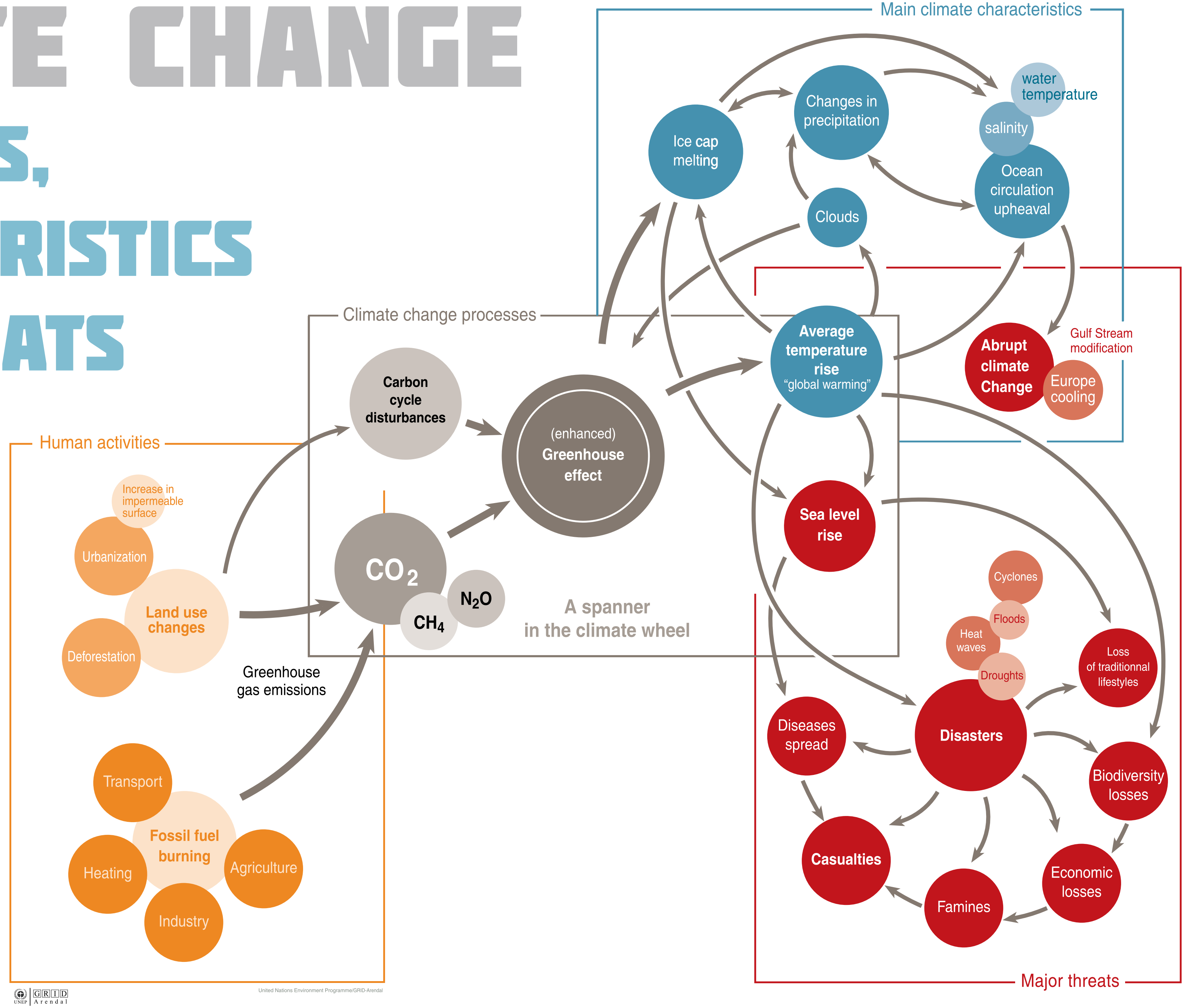


Image Credits: Philippe Rekacewicz, UNEP/GRID-Arendal
Image Source: http://www.grida.no/graphicslib/detail/climate-change-global-processes-and-effects_9cc5#climate-change-processes-characteristics-and-threats_15a8

# UNEQUAL CONTRIBUTION UNEQUAL VULNERABILITY

Not all peoples and countries have contributed equally to climate change.

The US is the largest emitter of greenhouse gases in the world. It accounts for 4% of the global population, but emits approximately 25% of the world's emissions. The United States' 290 million residents emit over 20 times as much CO_2 as India's 1 billion emit per person, or 5.5 times the total amount the country does.[30]

In 2010, India was home to 1.17 billion people. This represents 17% of the world's population, which lives on 3.28 million square kilometres, of 2.4% of the global land surface.

India is responsible for 4.1% of global greenhouse gas emissions. Developing countries, taken together, represent 79% of the world's population, and produce 42% of global emissions. High-income OECD countries, in contrast, account for 14% of the global population, and generate 41% of global greenhouse gases. The least developed countries of the world account for an imbalanced 1% contribution to worldwide emissions of greenhouse gases.[31]

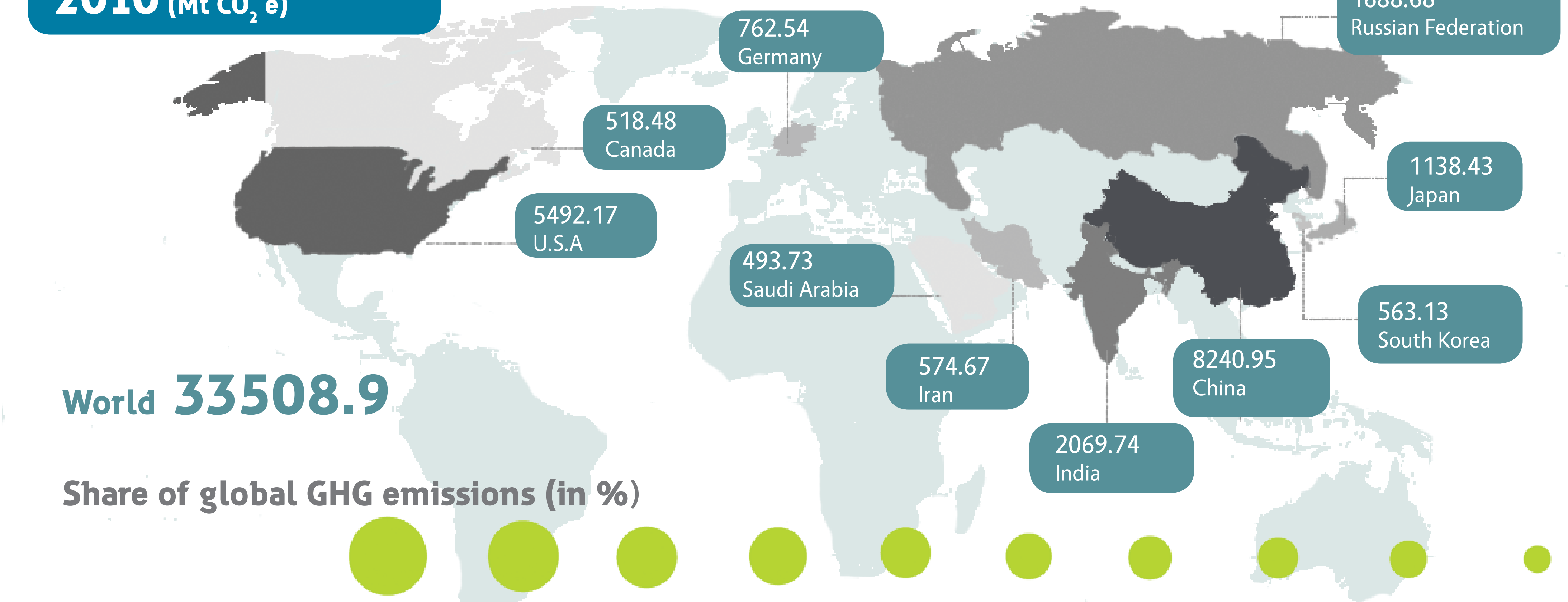
Climate change is also not going to affect different parts of the world in the same way. Lower latitude developing countries in Asia, Africa and Latin America are much more vulnerable to rising temperatures. According to the UN, developing countries suffer 99% of the casualties caused by climate change.[32] India is one of these countries. One of the reasons for this unequal impact is that many ecosystems (including agricultural crops) in tropical areas are already functioning at the limit of the temperatures they can tolerate.[33] Higher temperatures will reduce yield and damage ecosystems. In temperate climates however, just the opposite will happen: an increase in even up to 3°C, may benefit several plants, and will increase crop yields.[34]

Our global trade and market system today is affected by crop yields in several parts of the world. Even though economic and social impacts are often harder to predict than biophysical ones, it is probable that if crop yields in one part of the world increase, they will push international food prices down. Changing weather patterns may also create greater food price volatility. Both eventualities could make food access and security even more challenging for communities in areas where crop productivity declines due to climatic changes.

A large majority of farmers in India are subsistence growers with small land holdings. Approximately 60% of the net sown area in the country is rain-dependent agriculture. Changes in rainfall patterns and extreme weather events stand to severely impact these farmers and their livelihoods. That this threat is disproportionately distributed is evident from **the 262 million people affected annually by climate disasters between 2000 and 2004, more than 98% lived in developing countries.[35]**

Total GHGs emission in 2010 (Mt CO_2 e)

Source: United States Department of Energy's Carbon Dioxide Information Analysis Center (CDIAC) for the United Nations



World 33508.9

Share of global GHG emissions (in %)

Country	Share (%)
china	24.6
U.S.A	16.4
India	6.1
Russian Federation	5.0
Japan	3.4
Germany	2.28
Iran	1.7
South Korea	1.69
Canada	1.55
Saudi Arabia	1.47

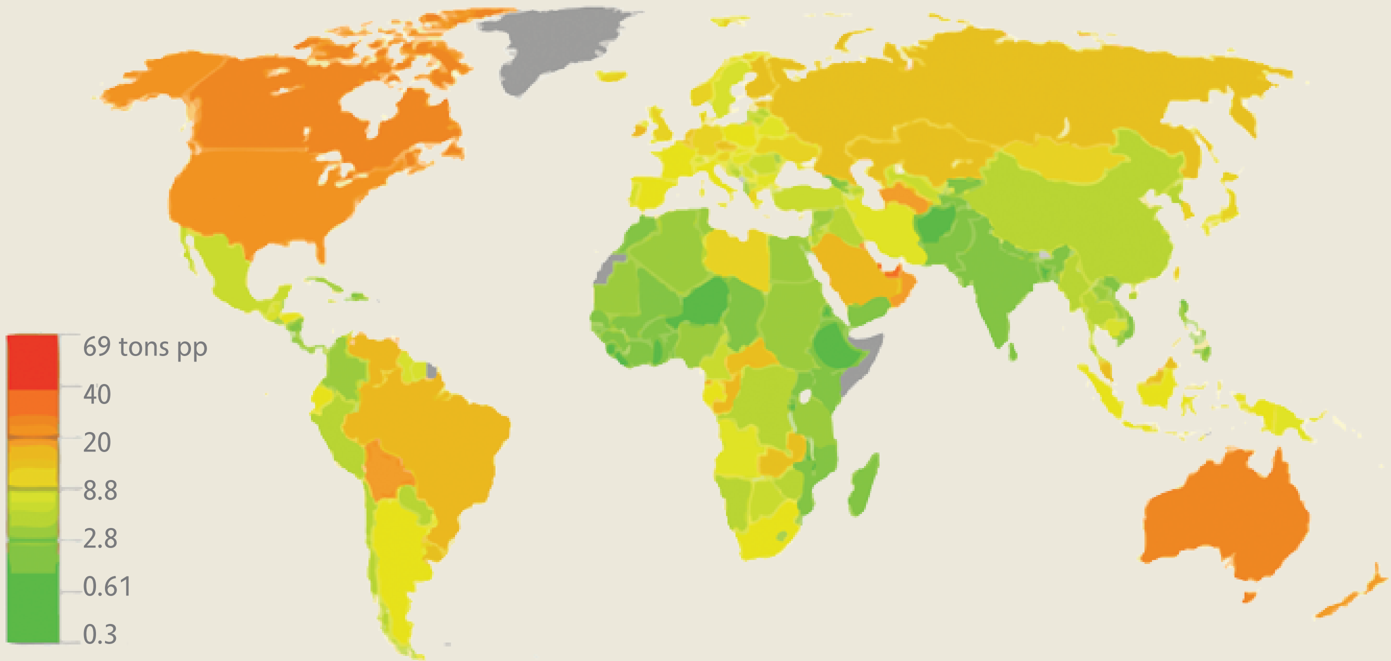
Per Capita GHG Emission (in Tonnes CO_2)

4.9 World

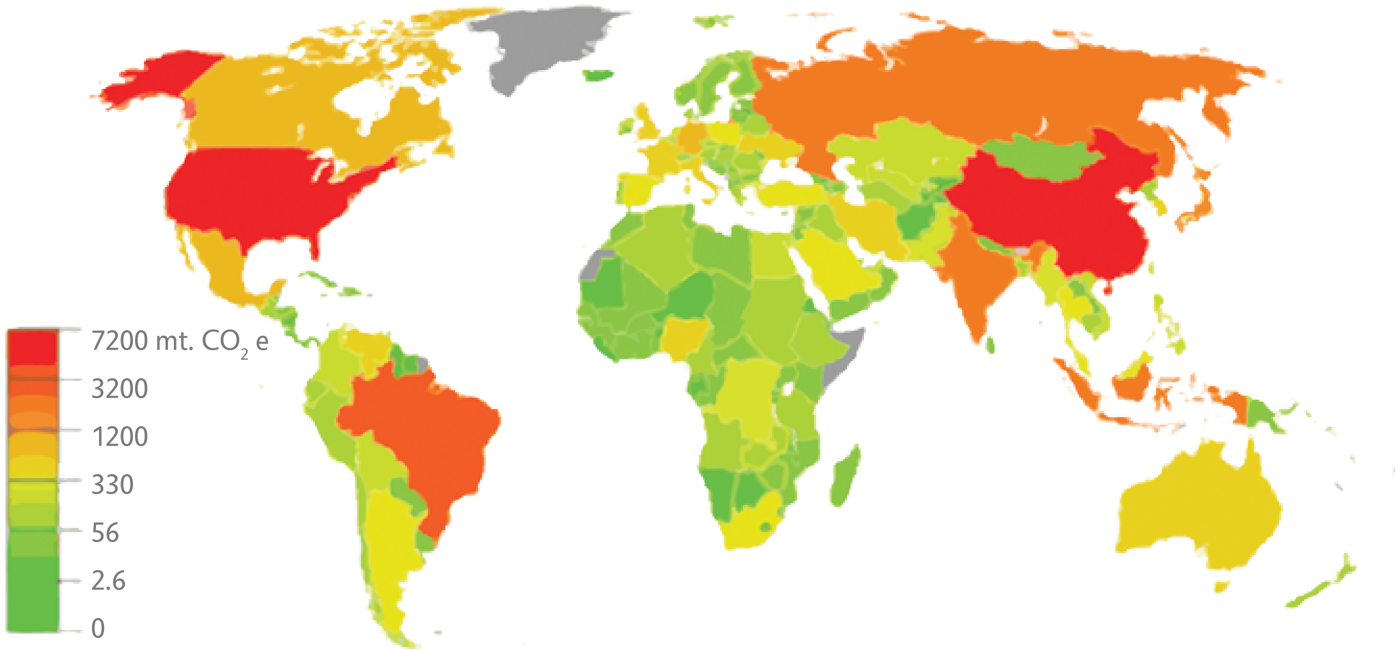
Country	Per capita (tonnes CO_2)
Saudi Arabia	18.2
U.S.A	17.6
Russian Federation	11.8
South Korea	11.5
Canada	14.9
Germany	9.3
Japan	8.9
Iran	7.6
China	6.2
India	1.7

Comparison of total GHG emission vs per capita emission in 2005

Country wise-
Per Capita
GHG Emission



Country wise-
Total GHG emission



COPING WITH CLIMATE CHANGE

Climate change is going to have drastic impacts on farmers across the world, and especially those in the global south. India's 700 million rural farmers, many of whom live below the poverty line, and depend on agricultural subsistence for their livelihood, are in this category.

Food insecurity is already a profound problem in the country, especially amongst children, almost half of whom are malnourished. Many of the existing poverty and hunger issues in the country may be exacerbated by climate change.

Fortunately, Indian farming stems from generations of agricultural knowledge that is based on principles of environmental and economic sustainability. Much of this information is still held by farmers today. While industrial agricultural practices have become more popular over the past few decades, and many traditional systems have fallen into disuse, farmers across the country are now realizing the value of prioritizing environmental and social well-being, along with productivity.

The World Bank considers India to be one of 12 the countries most vulnerable to floods, drought, and agricultural changes caused by climate change.

The **adaptation and mitigation methods** described here are all suggestions. The most important feature of any effective measure is how specifically it is designed for the ecosystem and community it is going to be implemented in and by. A successful adaptation plan will draw on the needs and the strengths of the farming community that will be designing and managing it, as well as the long-term integrity of the natural systems it is embedded in.

Temperature and its associated seasonal patterns are critical components of agricultural production systems. Rising temperature associated with climate change is likely to have a detrimental impact on crop production, livestock, fishery and allied sectors. It is predicted that **for every 2°C rise in temperature estimated by 2030, the GDP could reduce by 5%**.

Accelerated warming has already been observed in the recent period 1971-2007, with intense warming in the recent decade 1998-2007. This warming was mainly the winter and post-monsoon seasons, which have increased by 0.80°C to 0.82°C in the last 100 years. The pre-monsoon and monsoon temperatures also indicate a warming trend.

Indian agriculture is doubly vulnerable to climate change. First, as around 60% of India's total agricultural areas are rain-fed, and second, more than 80% of farmers in India are small and marginal (having less than 1 ha of land), thus, having very little capacity to cope. India's 200 backward districts as ranked by the Planning Commission, are distinguished by the large-scale practice of rain-fed agriculture. In most agro-climatic regions, farmers have stopped cultivation of millets which are climate resilient and nutritious. But with the changing food habits and market conditions, consumers and farmers prefer wheat or rice in most parts of the country. Climate change is projected to have serious implications for these major crops especially wheat and studies have already projected greater significant losses in wheat production.

The key characteristics of Indian agriculture that could increase its vulnerability to climate change are

- **The high level of subsistence agriculture with small land holdings**
- **Majority of agriculture being rain-fed**
- **Frequent occurrence of extreme weather events such as droughts and cyclones and**
- **The wide variation in agricultural productivity across the country.**

Climate change will affect different parts of India in different ways. While large areas in **Rajasthan, Andhra Pradesh, Gujarat, Odisha and Uttar Pradesh are frequented by drought**, approximately 40 million hectares of land in the **north and north-eastern belt is flood-prone**. India may also be exposed to a greater number of floods due to the intensification of the Indian monsoon. Climate change will affect all four dimensions of food security, namely - **food availability, stability of food supplies, access to food and, food utilization**.

Existing projections indicate that future population and economic growth will require a doubling of current food production, including an increase from **2 billion to 4 billion tonnes of grains annually**. However, agricultural production in many countries including India would be severely compromised by climatic variability and climate change.

Increase in frequency and patterns of extreme weather events will affect the stability of food supplies as well as access to food. Increasing the frequency of crop loss due to extreme events may overcome any positive effects of moderate temperature increases.

In forests ecosystems, the increased risk of forest fires, insect/ disease outbreaks, and other forest disturbances may affect ecosystem services that support food production. These factors are likely to disproportionately impact smallholder farmers and artisanal fishers.

Until recently, most assessments of the impact of climate change on the food and crop sector have focused only on the implications for crop production, other components of the food production system and how different food production systems are inter-related has not received as much attention. In India **livestock are an integral part of the agriculture systems** and their viability is interlinked to availability of fodder the availability of which will suffer when ecosystems are degraded.

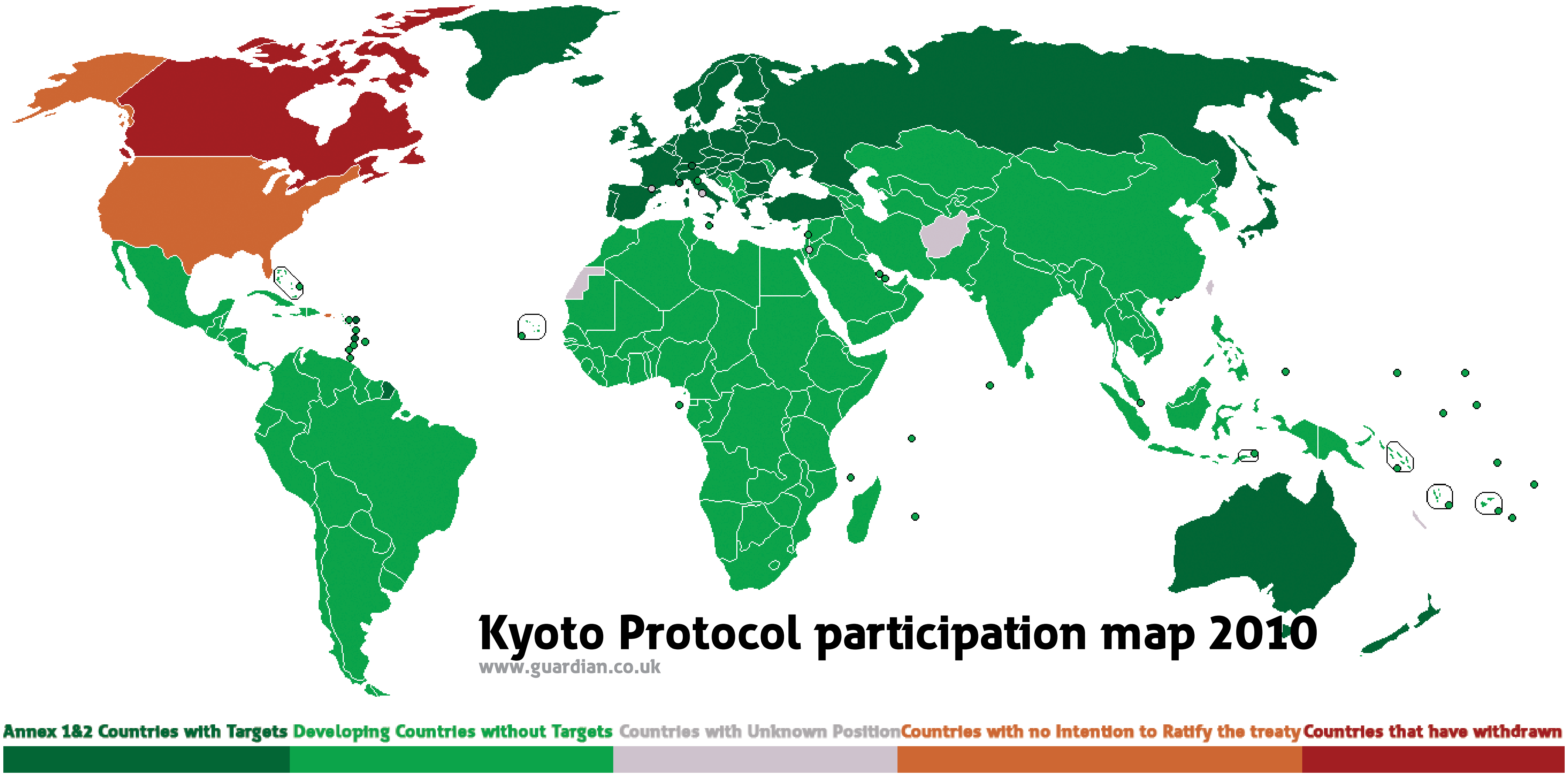
Dealing with climate change would require **strengthening the resilience of farmers and rural communities to help them adapt**. The key, to developing appropriate and targeted adaptation efforts, is to understand impact of climate change on diverse aspects of agriculture in different agro-climatic regions. For instance, the impact of climate change on behaviour of pests and diseases still remains largely unclear, but the economic implications of changing pest profiles are being increasingly felt.

Scientists have been trying to understand climate change and assess its impacts for several years. In fact, in the 1980s, scientists and others began to realize that what had begun as a very uncertain hypothesis may in fact be accurate, and its impacts profound. In 1988, responding to a need for more research on the topic, the United Nations Environment Program and the World Meteorological Organization jointly set up the **Intergovernmental Panel on Climate Change**, commonly known as the IPCC.

Thousands of scientists working with the IPCC, assess existing data from across the world, to produce scientific, technical and socio-economic reports on the current and predicted impacts of climate change, as well as policy recommendations for governments. So far, the IPCC has published four assessment reports, the most recent of which was published in 2007. Much of the data and statistics in this manual have been taken from information compiled in AR4, as this report is commonly called. IPCC's next report, AR5, will be published in 2014.[36]

MULTI LEVEL RESPONSES INTERNATIONAL

Driven by growing knowledge about climate change, governments from across the world signed a treaty to curb greenhouse gas emissions in their countries, at the United Nations Conference on Environment and Development in Rio de Janeiro in 1992. This treaty was called the **United Nations Framework Convention on Climate Change (UNFCCC)**. It was then updated in 1997 to set out legally binding targets that countries had to meet in reducing their national emission levels. There are currently 194 countries that are party to the updated treaty, which is called the **Kyoto Protocol**. Unfortunately, however, there is much debate and disagreement between governments about their individual contributions to global emissions reductions, and no significant progress or agreement has been reached at any of the annual UN climate change meetings held since then.



The Kyoto protocol stipulates that all countries will do their part to limit their global greenhouse gas emissions. Based on their historical emissions, some countries have specific limits they have to meet, while others have made a general commitment to reduce their emissions.

The United States, Afghanistan and South Sudan have not ratified the agreement, and the Canadian government, which had originally ratified, withdrew from the agreement in December 2011.

IPCC scientists hold that we need to make an urgent and global effort to cap global temperature increase at a **maximum of 2°C**. Recently, however, climate change researchers have said that this may be an optimistic goal, given our current emission levels.[38] Even if global emissions were to fall significantly, temperatures would continue to rise for some time, due to the effects of carbon dioxide already in the atmosphere.[39] This is a reminder of how urgent the need for global agreement and action is. If multilateral negotiations between countries are unsuccessful and fail to set concrete and robust emission targets, there is a good chance that global temperatures will increase beyond 2°C. This will have severe biophysical and socio-economic consequences across the world.

NATIONAL

Mitigation and Adaptation Efforts

In December 2009, governments met in Copenhagen to discuss and update global climate change reduction commitments. At this meeting, India pledged to reduce its emissions by 20-25% from 2005 levels, by 2020. At this stage, India had already launched its National Action Plan on Climate Change, or NAPCC.[40] This plan lays out a strategy for the country to address climate change, and emphasises understanding the effects of climate change, energy efficiency, natural resource conservation, mitigation and adaptation. These goals are organized under eight programs, called national missions.

In addition to this programme, India also has a National Farmer's Policy, which was released by the Ministry of Agriculture in 2007. Amongst other things, this policy clearly identifies that farmers in the country are particularly vulnerable to climate change. It recommends training "Climate Managers" for different parts of the country, to have knowledge in ways to adapt to floods, droughts, and other irregular weather and rainfall irregularities. It also emphasizes the need for farmers to be able to access low-interest credit in an easy and timely manner, and recognizes the need for improvements in the insurance system for farmers in the country.

National Missions

National Solar Mission
National Mission for Enhanced Energy Efficiency
National Mission on Sustainable Habitat
National Water Mission
National Mission for Sustaining the Himalayan Ecosystem
National Mission for a Green India
National Mission for Sustainable Agriculture
National Mission on Strategic Knowledge for Climate Change.

National Mission on Sustainable Agriculture

is managed by the Ministry of Agriculture, and focuses on four priority areas that it considers relevant and urgent. These are dryland agriculture, access to information, risk management and use of biotechnology.

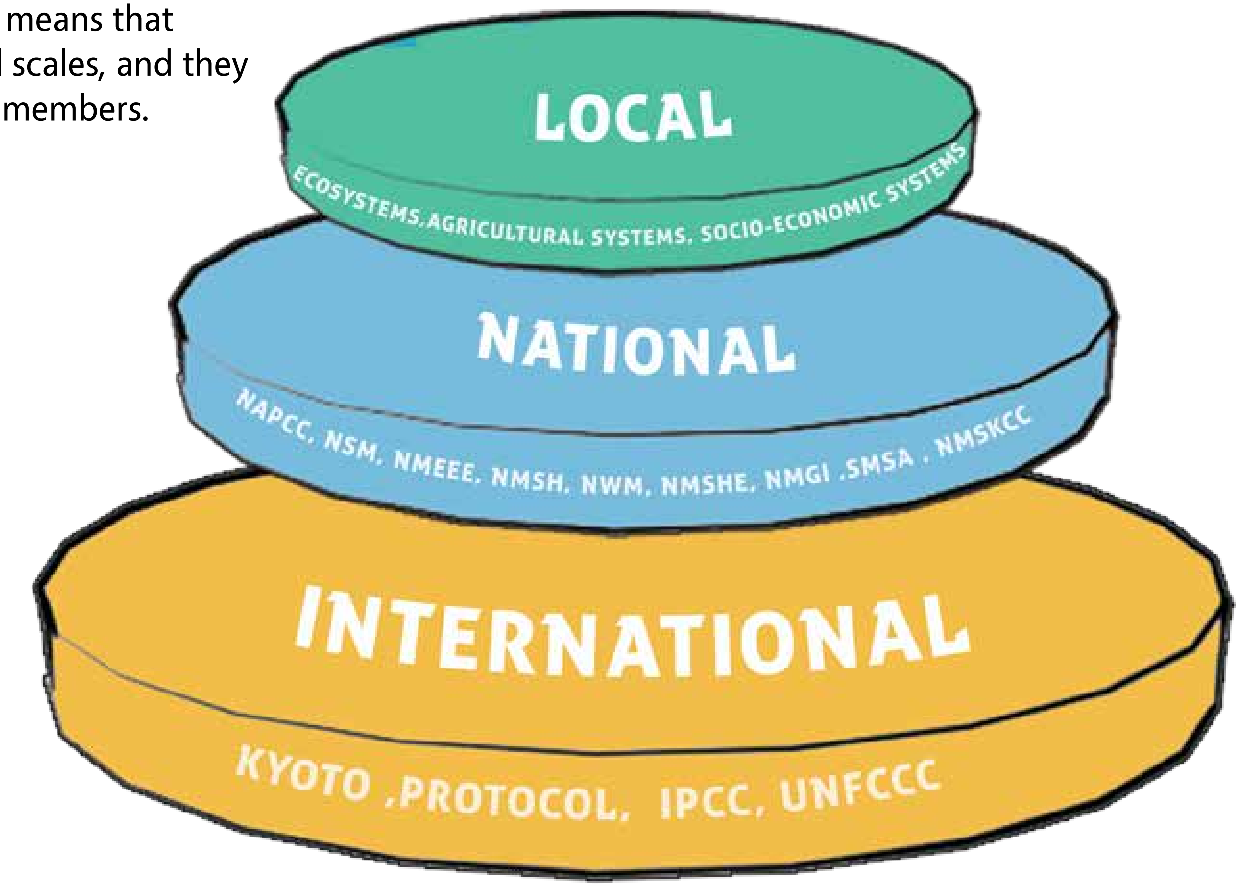
Specific measured outlined under these areas include researching ways to conserve soil and water, developing drought resistant and pest-resistant crop varieties conducting training workshops and consultations with farmers, providing farmers with financial support for adaptation and mitigation, strengthening weather insurance programs, mapping vulnerable areas and developing contingency plans for those areas.

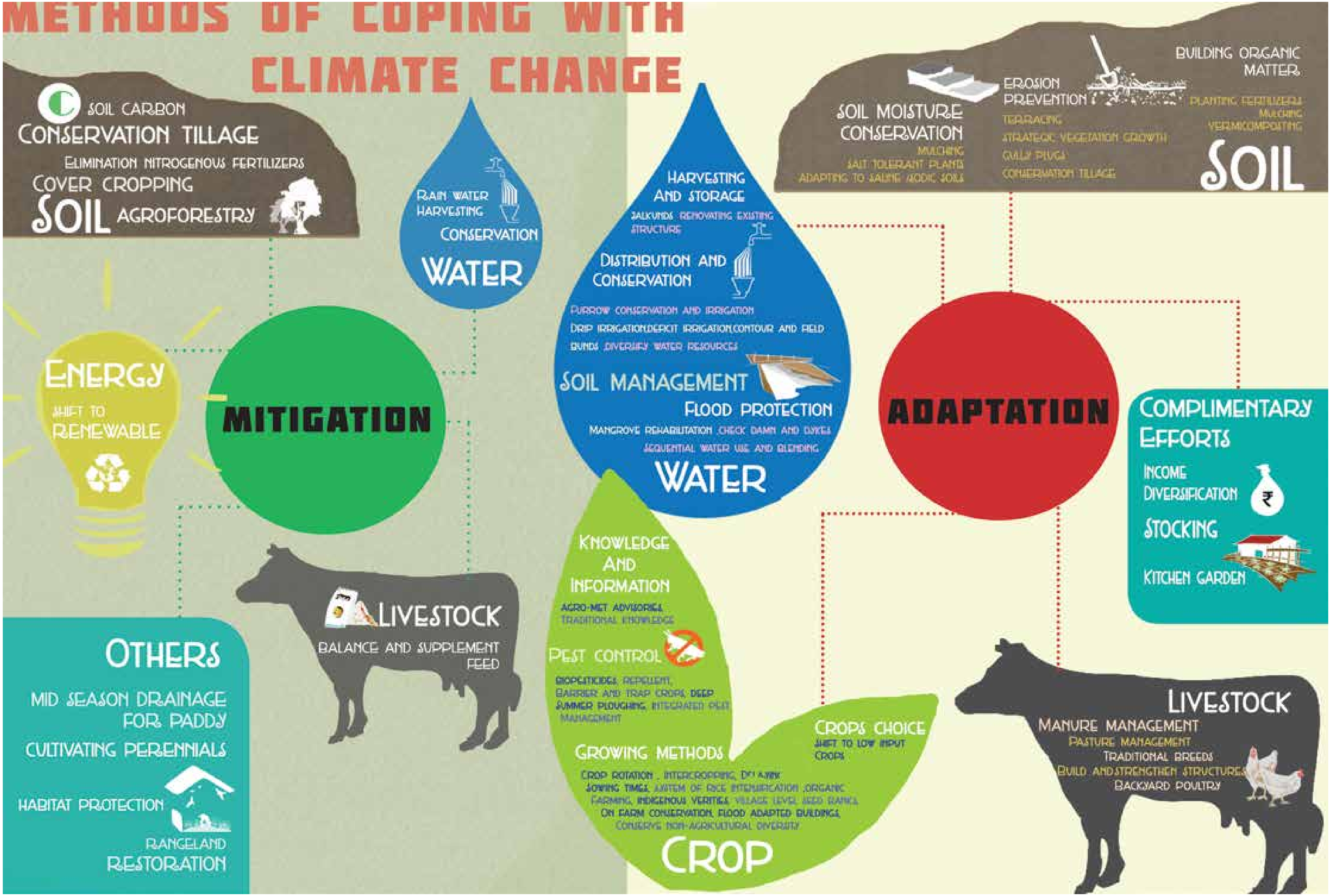
LOCALLEVEL

Mitigation and Adaptation Efforts

While it is crucial that governments create effective agreements, policy decisions and actions at international, regional and national levels, much of the real work of mitigating and adapting to climate change and its impacts needs to happen at the local level.[41] With agriculture, in particular, adaptations must be shaped to specific, local-level ecosystems, agricultural systems and socio-economic conditions and needs. This also means that these initiatives will be relevant at community and individual scales, and they will be shaped, run and managed by farmer and community members.

These local efforts, while being based on common principles, will look different in different parts of the country. Mitigation and adaptation efforts can only be effective and successful when they are shaped to the very specific conditions of the villages and ecosystems they are being applied in. The ideas in the rest of this manual are starting points that can be further moulded and modified to be useful and relevant. Several of these practices are not new. Many have been used in farming families for generations, and we now need to be re-adopt them in order to make our agricultural systems sustainable and resilient.




METHODS OF COPING WITH CLIMATE CHANGE
SOIL CARBON
CONSERVATION TILLAGE
ELIMINATION NITROGENOUS FERTILIZERS
COVER CROPPING
SOIL
AGROFORESTRY
RAIN WATER HARVESTING
CONSERVATION
WATER
ENERGY
SHIFT TO RENEWABLE
MITIGATION
LIVESTOCK
BALANCE AND SUPPLEMENT FEED
OTHERS
MID SEASON DRAINAGE FOR PADDY
CULTIVATING PERENNIALS
HABITAT PROTECTION
RANGELAND RESTORATION
HARVESTING AND STORAGE
JALKUNDS, RENOVATING EXISTING STRUCTURE
DISTRIBUTION AND CONSERVATION
FURROW CONSERVATION AND IRRIGATION
DRIP IRRIGATION,DEFICIT IRRIGATION,CONTOUR AND FIELD BUNDS ,DIVERSIFY WATER RESOURCES
SOIL MANAGEMENT
FLOOD PROTECTION
MANGROVE REHABILITATION ,CHECK DAMS AND DYKES
SEQUENTIAL WATER USE AND BLENDING
WATER
KNOWLEDGE AND INFORMATION
AGRO-MET ADVISORIES
TRADITIONAL KNOWLEDGE
PEST CONTROL
BIOPESTICIDES, REPELLENT, BARRIER AND TRAP CROPS, DEEP SUMMER PLOUGHING, INTEGRATED PEST MANAGEMENT
GROWING METHODS
CROP ROTATION , INTERCROPPING,
SOWING TIMES, SYSTEM OF RICE INTENSIFICATION ,ORGANIC FARMING, INDIGENOUS VERITIES, VILLAGE LEVEL SEED BANKS, ON FARM CONSERVATION, FLOOD ADAPTED BUILDINGS, CONSERVE NON-AGRICULTURAL DIVERSITY
CROPS CHOICE
SHIFT TO LOW INPUT CROPS
CROP
SOIL MOISTURE CONSERVATION
MULCHING
SALT TOLERANT PLANTS
ADAPTING TO SALINE SODIC SOILS
EROSION PREVENTION
TERRACING
STRATEGIC VEGETATION GROWTH
GULLY PLUGS
CONSERVATION TILLAGE
BUILDING ORGANIC MATTER
PLANTING FERTILISERS
MULCHING
VERMICOMPOSTING
SOIL
ADAPTATION
COMPLIMENTARY EFFORTS
INCOME DIVERSIFICATION
₹
STOCKING
KITCHEN GARDEN
LIVESTOCK
MANURE MANAGEMENT
PASTURE MANAGEMENT
TRADITIONAL BREEDS
BUILD AND STRENGTHEN STRUCTURES
BACKYARD POULTRY

MITIGATION

Adapting our agricultural systems to climate change is crucial. However, it is not enough. If current greenhouse gas emission levels are not significantly limited, temperatures will continue to rise for a long time, and the effects that follow may be too drastic for adaptations measures to be effective. There is an urgent need for everyone to do their part in reducing sources of emissions and increasing the sinks. This intervention is called mitigation.

As with adaptation, mitigation measures must be shaped to the specific conditions of the locale in which they are going to be applied. They must cater to both human and non-human communities, and prioritize long-term sustainability. **“No-regret” options**, which are beneficial for the social and environmental health of agricultural systems even without the pressures of climate change, are the strongest efforts. Most successful mitigation efforts do not demand farmers to make sacrifices – they actually benefit the long-term productivity and overall health of agricultural systems as well.

The next sections outline some measures that can help mitigate greenhouse gases in agriculture. Importantly, several of these practices are also useful adaptations to climate change. Such efforts – that help farms and farmers mitigate their contributions to climate change, while also adapting to its inevitable impacts – are particularly valuable.

Soil Carbon

Soil is an important carbon "sink." A sink absorbs or stores carbon, and in doing so, removes carbon dioxide from the atmosphere. This process of removing carbon dioxide from the atmosphere is called carbon sequestration. Oceans sequester carbon naturally all the time, as do the trees in forests, since they use carbon dioxide for photosynthesis.

Along with these natural processes, however, some human activities can increase carbon sequestration as well. Managing soil sustainably is one of them. In intensive industrial agricultural systems, farmland is a major emitter of greenhouse gases, primarily in the form of **methane from livestock, nitrogen from fertilizers and CO_2 from land clearing**. Organic agricultural practices can shift soil from being the source of these emissions to being an overall carbon sink. Studies estimate that the widespread adoption of organic farming practices across the world could sequester 1.5 billion tonnes of carbon a year, offsetting 11% of all global greenhouse gas emissions for 20 years. This is a significant proportion.

The primary soil carbon sink in agriculture is grasslands. Every time grasslands or forests are cleared to be converted to cultivated land, large amount of soil carbon is released to the atmosphere. Ensuring that no more land is cleared than necessary, that grasslands are maintained and grown as much as possible, and that farm properties have the maximum possible green cover, in the form of trees, shrubs, grasses and cover crops for fallow lands will increase soil carbon. Using farmyard manures and compost instead of nitrogen fertilizer, and practices such as agroforestry are greatly beneficial as well.

These practices are no-regret options. Along with sequestering carbon, they also strengthen soil, build organic matter, prevent erosion, and encourage healthy soil biology. Even without the pressures of climate change, these practices bring several improvements to farms and farming.[42]

Conservation Tillage

Conservation tillage minimises the amount of carbon that is released (as CO_2) from the soil when it is turned and tilled. Leaving cover crops on the land, and ploughing in crop residues from previous seasons prevents this carbon loss, and also prevents erosion.

Minimum-tillage and no-tillage are both most beneficial, however, when paired with organic farming practices such as composting, crop rotations etc.

Eliminating Nitrogenous Fertilisers

Much of the nitrous oxide released to the atmosphere from human sources originates from farm fields. Widespread application of nitrogen-based fertilizer accounts for a large percentage of these emissions.

Replacing nitrogenous and other synthetic fertilizers with **organic compost** and manure and **legume cultivation** is a very important mitigation effort. As farmers have repeatedly described, these fertilizers degrade the soil over time, which merely increases the need for a greater amount of fertilizer. This vicious cycle is not only environmentally damaging, it is also expensive, and lowers productivity. Natural composts and fertilizer mitigate these emissions, are cheaper and more reliable, and can help re-build degraded soil.[43]

Agroforestry

Trees use carbon dioxide for photosynthesis. Because of this, forests are significant carbon sinks. They also **maintain diversity, healthy soils, and prevent erosion**, a particularly important feature in arid and semi-arid soils. Clearing forests to cultivate crops releases huge amounts of carbon dioxide and causes significant environmental degradation. As soils are eroded and their productivity is lost, farmers find their yields decreasing.

Combining sustainable forest management and stewardship with farming can break this pattern. Farmers around the world are growing plantation crops under the shade of forest trees. This ensures that the crops get healthy soils and good yields, and also gives the farmer access to forest products. Agroforestry systems can be created within existing forestland, or by planting trees (including high value trees that provide fruit, nuts, oils or fodder) on fallow land.

Agroforestry also works very well with animal rearing. Silvopastoral systems integrate pastureland with forested areas, again ensuring that soils remain healthy, and emissions are kept to a minimum. This is a common practice in many parts of India, and like with crops, can be carried out in existing forests, by encouraging pasture grasses to grow on already treed areas, or by growing trees and grasses in fallow or existing pasture land.[44] Forest products add significant supplementary income and environmental benefit.

Cover Cropping

Fallow lands are prone to severe soil erosion and release large amounts of soil carbon. While soil does need time to recover and rejuvenate between plantings, this can be done much more effectively by growing cover crops, which prevent soil erosion, smother weeds, and in the case of leguminous plants, help return nitrogen to the soil. Grains like buckwheat and legumes like pigeon pea and sun hemp are common cover crops in India.

Organic farming methods are almost all effective mitigation measures. Along with the specific practices mentioned here, composting, mulching, green mulching, increasing tree and hedgerow cover, and implementing practices to prevent erosion all strengthen soils, and mitigate climate change.

Conservation

The most effective mitigation measure, as far as water resources are concerned, is to use less of it. One way of doing this is to grow crops that use less water. A shift from input-intensive crops like cotton, wheat and maize, to millets and pulses, for instance, saves significant amounts of water.

Re-using and cycling water though various uses (such as domestic, livestock and crop irrigation), irrigating fields only when necessary, and using low-water cultivation methods such as SRI are all conservation methods as well. These practices reduce overall water consumption, and are also good adaptation measures in case of water shortages.

Rainwater Harvesting

Water conservation is well complemented by **increasing water capture and storage**. As mentioned earlier, rainwater harvesting is a crucial adaptation to unpredictable rainfalls, higher temperatures and possible water shortages and droughts. However, it is also an important mitigation measure, since it conserves water and often, by capturing water that would otherwise have run off the fields, prevents erosion.

Mid Season Drainage (Paddy)

Flooded paddy fields are the perfect environment for anaerobic decomposition, which leads to significant methane emissions. Emission levels can however be reduced by a practice called mid-season drainage. This is when farmers initially flood their fields, but drain them halfway through the season. Scientists have found that this practice can stop much of the methane being produced in the fields, while also conserving water and increasing yields.[45]

Other methods of cultivating rice, such as irrigating intermittently instead of flooding the fields, and water conservation methods such as SRI also significantly reduce methane emissions.

Habitat Protection

There are 4 billion hectares of forest in the world, and 5 billion hectares of grassland.[46] Together, these habitats are an immense carbon sink. As the plants in both systems grow, they use carbon dioxide. This carbon is removed from the atmosphere and stored in their roots and converted to energy.

Clearing these habitats for crop cultivation releases huge amounts of greenhouse gases, as does deforestation. It is crucial to reverse this pattern by protecting natural habitats and the biodiversity they harbour. Along with mitigating climate change, protecting these systems also offers tremendous agricultural benefits.

Vegetation-covered areas prevent soil erosion, offer good pasture, and in the case of forests, provide numerous other products.

OTHERS

MID SEASON DRAINAGE FOR PADDY

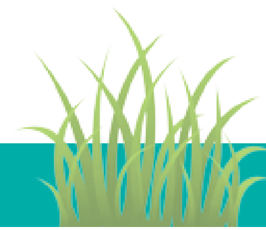
CULTIVATING PERENNIALS

HABITAT PROTECTION

RANGELAND RESTORATION

Rangeland Restoration

Along with protecting forests and other natural habitats, restoring rangelands that have been overgrazed or cleared for crops is also very important. Restoring vegetation to these areas greatly reduces emission levels, while also restoring watershed functions and ground water table recharge, and preventing erosion. Rangelands provide important pasture, as well as additional value through plants and trees that provide fodder and fuel.



Cultivating Perennials

Perennial crops such as **grasses, palms and trees** use carbon from the atmosphere and store it in their large root systems. Since these crops are not replanted every year, this carbon storage is constantly maintained. They also **provide consistent vegetative cover and reduce erosion**. Shifting some amount of annual production to perennials, or adding more perennials to the vegetation mix on agricultural lands has huge potential for mitigating emissions while also providing other services, such as fodder, vegetable oils and non-timber products.

Shifting to renewable sources

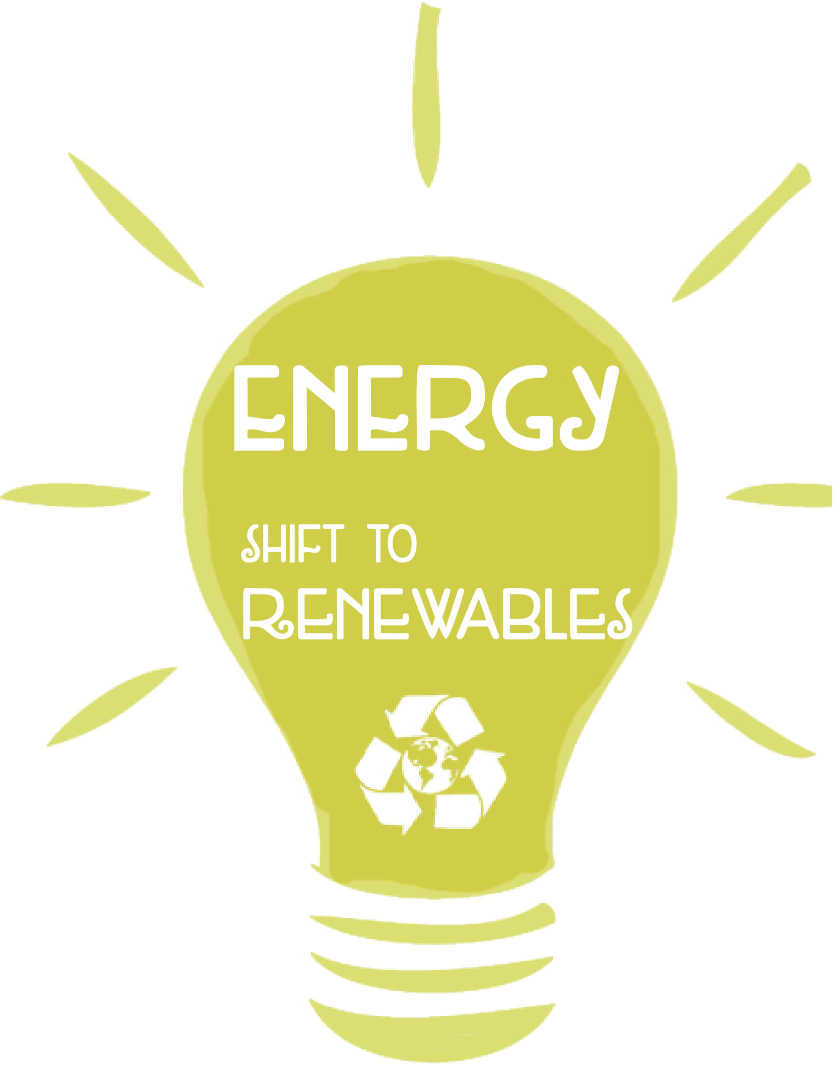
Fossil fuels are the biggest contributors to climate change. Coal-based power production, fuel used by cars, trucks and tractors, and fertilizers and pesticides made with fossil fuels are primary emitters of green house gases.

There are two major ways to mitigate these emissions. One is to **conserve and use less energy**. Using less – or eliminating – synthetic fertilizer and chemical pesticides and herbicides is one important measure. Using less fossil-fuel based transportation is another.

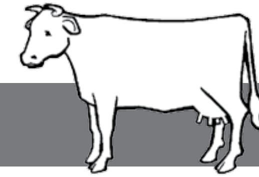
Another very important mitigation effort is to **shift from non-renewable sources of energy** (those that are generated with fossil-fuels), to renewable sources of energy. These are energy sources that can be used to generate power, without depleting the resource they are drawing on. Wind and solar energy, for instance, are renewable in that they will not get "used up," regardless of how much power we generate from them.

The government of India is currently developing renewable energy generation programs. The National Solar Mission and the National Mission for Enhanced Energy Efficiency, both of which are part of the National Action Plan on Climate Change, emphasize this goal. These programs are working towards developing India's wind and solar power generation sectors, specifically.

At a low-tech, community level, systems like home **biogas production** offer the most potential. These systems are easy and cheap to install, use readily available cow dung, reduce emissions significantly, and create a healthier home environment by reducing smoke.



Balance and Supplement Feed



Changing animal feed can greatly reduce methane emissions from animals. It also influences milk production of cattle. Growing and feeding livestock traditional, resilient fodder varieties is beneficial for the animals, as well as for the soil. Feed can also be supplemented with a mineral mixture that is specifically designed to compensate for deficiencies that animals may be facing in a particular region.[47]

Livestock rearing is a major emitter of methane around the world. In addition to balancing and modifying livestock feed to reduce emissions, several other measures are also useful for mitigating climate change. Many of these are also useful adaptation measures. **Manure management, pasture management and agroforestry methods that integrate pasture land and forests**, all offer great potential in reducing the emissions causing effects on livestock breeding, while also benefiting farming families across the country.

ADAPTATION

To adapt means to modify something in order to make it more suitable to a new set of conditions. In the case of climate change, adaptation refers to the various practices and changes adopted by communities across the world, in response to changing weather and climate patterns – either those that have already changed, or those that are expected to change in the future.

Agriculture, as a sector, will be drastically affected by climate change. Governments are working on strategies and programs that will help agricultural communities around the world adjust to changing conditions. The most important work of adaptation, however, is going to have to take place at the local level, in the fields. Farmers are going to see – and in several cases, have already seen – changes in the environmental conditions that their cultivation is so reliant on. Even if mitigation efforts are very successful, we are going to inevitably feel some effects of the greenhouse gases already in the atmosphere. For this reason, there is an urgent need to develop practices that will help farms and farmers cope.

Successful adaptation strategies will specifically cater to human and environmental vulnerabilities, and strengthen the adaptive capacities of both. Working towards creating sustainable, resilient and biodiverse agricultural systems that minimise food insecurity is fundamental in this process.[48] Techniques will have to be shaped specifically to the locations they will be implemented in.

While looking ahead and planning for the future, it is important to keep an eye on our past and remember how we got here. Industrial agricultural practices have been very damaging for farm ecosystems and communities alike. An approach that advocates more of the same practices that caused the problem cannot possibly be a viable solution. It is necessary now to focus on carefully managing our limited resources – **water, soil and biodiversity** – and shifting from a system that values only production to one that values environmental and social health as well. This system is knowledge intensive, instead of input-intensive.[49] It recognizes that a challenge like climate change is inherently linked to other environmental, social and economic problems, and the solutions to one cannot exclude solutions to the others.

The impacts of climate change on agricultural systems will be both significant and serious, but farmers have an abundance of innovative and resourceful options that, if implemented thoughtfully and urgently, promise to be extremely effective.

NO REGRET

OPTIONS FOR ADAPTATION

No-regret options are those adaptations that would be beneficial 'environmentally, socially or economically' even without climate change. Practices that conserve soil and water, for example, yield several benefits, and will do so even if climate change were to have no impact at all. Such options are safe and balanced options, and should be prioritized. (MoEF and GIZ, 2011).

CHOOSING ADAPTATION MEASURES

Adaptation initiatives should be designed specifically for the community and ecosystem they are going to be implemented in. Some steps to keep in mind:

* Assess climatic changes in your region.
  How have weather patterns changed?
  How are they predicted to change?

* Assess impacts of these changes on agriculture.
  How do livestock, fisheries, storage areas etc stand to be affected?

* Identify the most vulnerable sections of the community, agricultural and surrounding ecosystems.

* Assess adaptive capacity.
  where does the greatest potential for change lie?
  What are the available resources - financial, community collaboration, infrastructure, knowledge, seeds etc.?

* Design a plan based on what most urgently needs to be addressed, and what resources can be used to do so. Prioritize options that will show the most benefit for the longest period of time.

Building up the soil, especially in areas where it has been degraded due to overuse, is one of the most important adaptations. Healthy soils not only ensure better yields, but they are also more resilient to changing conditions as they provide crops with essential nutrients and can provide and conserve vital moisture in dry years.

Balance and Supplement Feed

Good yields depend on the organic matter in soil. Industrial farming methods in many parts of the country have led to nutrient depletion, erosion and weakened soil microbiology. Such methods advocate increasing the use of fertilizers to compensate for this loss. However, as the effects of climate change increase, this approach will be increasingly impractical and unsustainable. Fertilizers are often petroleum based, and fossil fuels are increasingly more environmentally and economically expensive. Natural methods of strengthening soils are much more promising.

Planting "Fertilizer" Trees and Hedgerows

Several plants and trees provide essential nutrients to the soil. **Leguminous plants are the most important of these, because they help "fix" nitrogen.** Nitrogen is an essential nutrient for plants. However, even though 78% of our atmosphere is composed of nitrogen, crops cannot use it in its atmospheric form. Certain plants and trees, however, host bacteria, called rhizobia, in their root systems that are able to convert nitrogen from the air into nitrogen that can be used by plants. Planting these trees and shrubs around a farm property is greatly strengthens the soil.

Mulching

Mulching is the process of placing a layer of protective material over the soil or around plants. It mimics a natural process that takes places in forests, when trees shed their leaves, needles and woody material. This organic matter falls to the forest floor, where it slowly decays to form nutrient-rich organic matter and top soil. This organic matter is essential for seedlings and saplings to grow.

Mulches in cultivated fields work in a similar way. They help the soil hold in water and prevent erosion. This is particularly important in dry seasons, or in years when rainfall is unreliable. **Scientists have found that mulching with plant biomass can reduce soil temperatures by as much as two degrees Celsius**.

Leguminous Plants and Trees

Plants: Calliandra,centrosema, crotalarias, desmodium, dolichos lab lab, gliricedia, indigofera, mucunautilis (velvet bean), phaseolus, sesbanias (over 300 varieties), Stylosanthes, tephrosia, vignas, fenugreek.

Trees: Flame of forest, dalbergia latifolia (Rose wood), dalbergia sissoo (Red sandal wood), pongamia pinnata(Indian kino).

Medicinal Plants: Clitoria ternata, liquorice root, abrus pruriens, mucuna pruriens, pueraria tuberosa, babchi, sesbania grandiflora, desmodium gangetium, psuedarthrea viscida, desmodium motorum, desmodium trifolium, indigo feratinctoria.

Nandish, BN. 2009. Organic farming through green culture, weeds and mulching.Presentation from South Asia conference on Outstanding Organic Agricultural . Techniques. Bangalore, Organic FarmingAssociation of India. Available at: http:// www. indiawaterportal.org/taxonomy/term/7339

This is, of course, a vital adaptation to rising temperatures. Some mulches, if applied early in the season, can prevent weeds from taking over the plants, reducing the need for mechanical or manual weeding and further soil disturbance. Mulches also reduce soil erosion and slow down rates of evapotranspiration, two problems that will be exacerbated with rising temperatures.[50]

Several different materials can be used as mulches. **Straw, hay and any other grain husk/residue, wood chips or sawdust** are some examples. Crop residues, **plant debris (such as leaf litter) and farm yard manure (or a mix of these materials)** makes a nutrient-rich mulch that also enriches the soil and improves fertility.

Mulch is often applied in the earlier part of a season, before weeds have emerged and the soil has had time to lose its moisture. While some farmers prefer their fields to be covered with it all the time, and plant their crops into the mulch, most prefer to lay the mulch down around plants, after they have germinated.

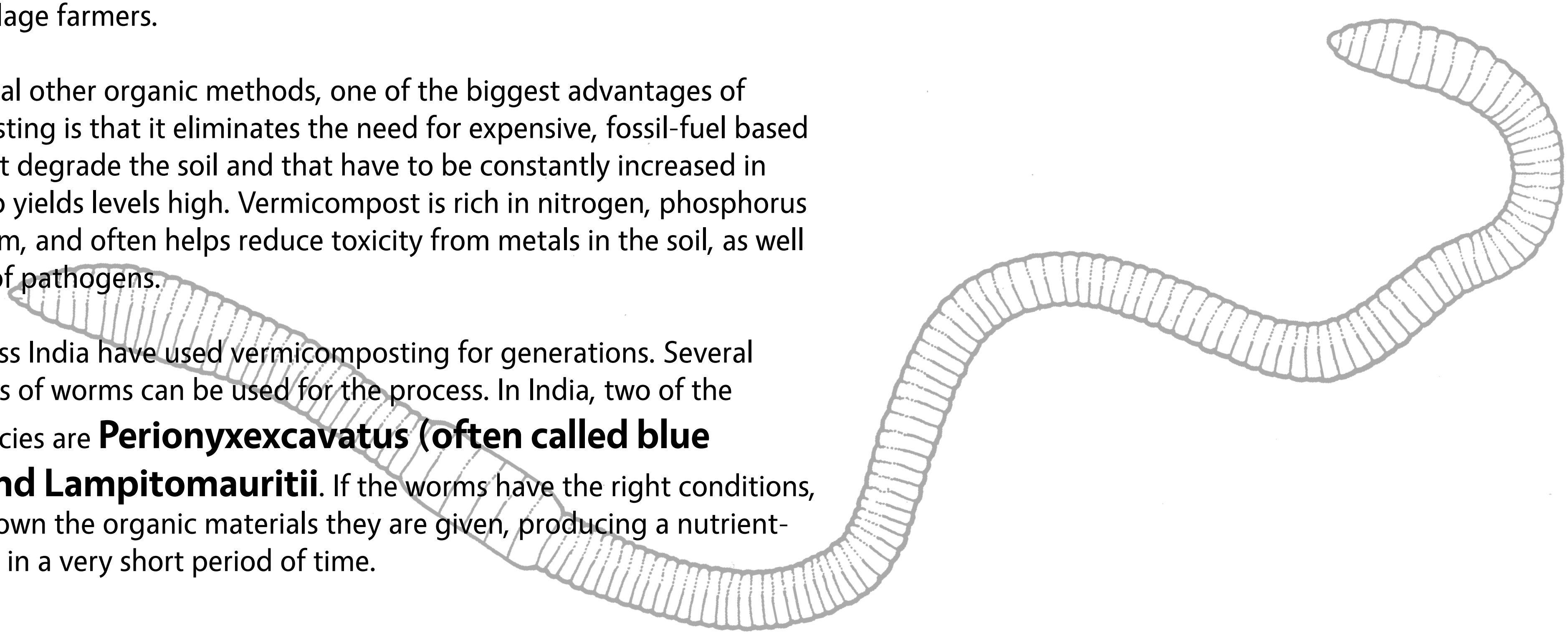
Another mulching method is **"live mulching."** Here, instead of covering fields with plant debris, certain plants are actually grown between crops. Nitrogen fixing plants, in particular, make a good live mulch. These plants also aerate the soil with their roots, prevent erosion by anchoring the soil, provide shade, and provide a suitable environment for beneficial microbes. Weeds such as cassias, crotolarias, indigos and desmodium work well as live mulches. Wild varieties of leguminous plants such as mung, black gram and horse gram are effective too.[51]

Vermicomposting

Vermicomposting is the process of using worms to produce organic fertilizer from biodegradable waste materials. The final product is nutrient-rich, helps retain moisture, and is easy to apply. It also reduces farm waste, and may be a source of extra income if sold to those who do not produce their own compost. The process can also be set up and maintained collectively. Villages in India, for example, often have vermicompost operations run by women's collectives. Extra compost can be sold to village farmers.

As with several other organic methods, one of the biggest advantages of vermicomposting is that it eliminates the need for expensive, fossil-fuel based fertilizers that degrade the soil and that have to be constantly increased in order to keep yields levels high. Vermicompost is rich in nitrogen, phosphorus and potassium, and often helps reduce toxicity from metals in the soil, as well as numbers of pathogens.

Farmers across India have used vermicomposting for generations. Several native species of worms can be used for the process. In India, two of the common species are **Perionyxexcavatus (often called blue worms) and Lampitomauritii**. If the worms have the right conditions, they break down the organic materials they are given, producing a nutrient-rich compost in a very short period of time.



Vermicomposting can be done in any tank or pit in a cool, shady spot. Building a basic concrete or brick tank is often useful. If this is not possible, any container – plastic or wooden crates with holes drilled at the bottom, 25-litre buckets, or even four stacked tyres – can be used to start a vermicompost. Alternately, vermicomposting will work by building a pile of organic matter on a "pucca" or even "kuccha" floor that is compacted enough to prevent earthworms from burrowing downwards. The size of the pit can differ depending on the amount of organic material that is going to be added to it. Small drains or water outlets should be built into one or two ends to ensure that excess water can drain out of the pit. Farmers often build a narrow water channel or "moat" around the tank to prevent ants from climbing into it. Once the tank is prepared, cover the bottom with a thin layer of **sand, gravel and broken bits of brick**. Above this, add a thicker layer (about 15–20 cm) of **moist soil**. Add the **worms** to this soil. (As an approximation, about 100–150 worms can be added to a tank that is 2m x 1m x 0.75 m.) Now add some handfuls of **cattle dung**, and then a thin layer of **hay, straw, dry leaves** or other agricultural crop residue. Sprinkle with **water** to moisten, and leave for about 30 days, watering whenever it gets dry. This time allows the worms to get used to their new habitat. The material in the pit should always be moist, but never soggy or flooded. If birds are picking at the material, the pit can be covered with gunny bags or mesh.

While the "vermibed" is getting ready, it is time to prepare the material to be composted. Put cattle dung, other animal waste, household garbage and other crop residues to be composted in a tank or bucket. Moisten the mix, cover and leave for approximately a fortnight to begin partial decomposition. After the vermibed has been sitting for about 30 days, spread the "pre-digested" mix in the tank. For the next month, continue to water to keep the mix wet (but not soggy). Aerate occasionally (once a week) by turning the organic matter layers gently. Do not turn the vermibed at the bottom. Continue adding waste material every two weeks, if needed.

Collecting Earthworms

Native earthworms can be found in most farm fields. However, there are some easy ways to collect a large number of them. Identify an area of soil that has worms in it (you can tell by the castings they leave on the surface). Dissolve equal parts cow dung and jaggery (approx 500 gm) in 2 litres of water. Sprinkle it on an area about 1m x 1m. Layer straw over it and cover it with a gunny bag. Water it every few days to keep it moist. In about 20-30 days, several worms would have moved to the area, and the soil can be lifted and added to a vermicompost pit.

Compost is ready when it is dark, crumbly and moist. This can be anywhere from 40 to 90 days, depending on the size of the pit. Stop watering the pit a few days before harvesting to encourage worms to burrow away from the surface. Sieve the compost –the bigger chunks and worms will get left behind, and can be returned to the pit. The finer chunks can be spread on the fields at any time, though composting when seedlings are approximately 10–15 cms in height, and/or before a rainfall or irrigation is particularly beneficial.

A common system of vermicomposting in rural areas is the **four-tank system**. In this system, farmers build a tank 4m x 4m, and 1m deep, with water outlets in the outer walls. They then divide the tank into four equal sections by building two intersecting walls in the tank. Leave holes in the bricks to allow worms and air to move in between tank sections. Build the vermibed up at the bottom of all sections. Collect organic matter– dung, household waste and farm residue in the first tank. Water it and allow it to "predigest." After about 2–3 weeks, add worms. At the same time, add organic matter to the second tank for pre-digestion. The worms will break down the material in the first tank, and gradually migrate over to the second tank. Repeat the same process in the third and fourth tanks, timing each one to be ready for composting as the one before is almost ready to be harvested. Harvest each tank as it is ready and then add more organic matter to it.

This system can also be built as a **two-tank system**, which is more useful at a smaller scale, and when you have more household waste and less farm residues and cattle dung.

While this is a general outline of the vermicomposting process, the specifics of the structure and methods followed can be modified to suit specific ecosystems and the needs of those who are maintaining it.[52]

Composting of Farm Yard Manure

Organic matter can also be converted to compost in an open pile or pit. This type of composting will also likely attract some worms, but not in the numbers that vermicomposting is set up to do. Again though, the final product is rich in nutrients, necessary enzymes and useful soil microorganisms, and prevents pathogens from developing in soils and on crops.

The composting process is simple and intuitive, and is used by farmers across the country. It can be done in a pit that is well ventilated, in a simple wooden structure that has open areas for ventilation, or in an open pile. Farm and fodder residue, cattle dung and urine, and household wastes are layered with dry leaves and twigs. The heap should be turned at least once or twice, to help break any bigger pieces of organic matter down, as well as to aerate the pile. If the pile gets very dry, it can be sprinkled with water. Organic matter can be added continuously to the top of the pile. If the pile is too wet, or smells bad, dry materials–**hay, straw, dry leaves, sawdust and twigs**–should be added to it.

If the pile gets large, it can be turned by shovelling it into a new heap. This aerates the pile, and moves the parts on the top and outside to the bottom. **The end product, which may be ready between 2–4 months**, is crumbly, light and moist, but shouldn't be soggy or smell bad. Ready compost can be dug out of the bottom of the pile if the material on the top is not yet composted.[53]

Green Manure

Rich nutrients and organic matter can also be added to the soil by growing live plants that are then ploughed into the soil, or that add nitrogen in the soil. This process is calling green manuring, and can be carried out in several ways. The most common of these is to plant fast-growing legumes. Sunhemp (*Crotalaria juncea*) and varieties of Sesbania are common.

Dhaincha grows fast, and can withstand both water logging and drought. These crops are grown for about 40–50 days, and then turned under before they flower, and before the next crop is sown into the field.

Green manures can also be grown in the off-season, or instead of keeping fields fallow. Cover crops such as **buckwheat**, for instance, prevent erosion, keep weeds down, return nitrogen to the soil, and when ploughed back in, add important organic matter to the soil. Plants can also be grown off the fields and then their leaves can be collected and ploughed into the area where crops will be sown. **Gliricidia, varieties of Cassia, Thespesia and Calotropis** are all used in this way. Some, such as neem, keep pests away. Calliandra and Gliricidia repel snails and rats.

Green manures also provide several other important functions. Several bushy shrubs and trees, such as Gliricidia, provide shade, and are grown in young orchards or in coffee plantations. They can also be grown to shade any other crop in dry or drought-ridden areas. Once the crop is strong enough to handle the heat, the manure plant can be ploughed into the soil. Others, such as **caster, hibiscus, sun hemp, lab lab, velvet beans, indigo, lantana, sorghum and cassia,** act as "trap" plants, attracting pests that would otherwise attack crops.

Carefully chosen green manures can act as barriers to animals, or alternately as fodder. **Gini grasses** are used in the south of the country as fodder, and also help by hosting the beneficial fungi. Planted strategically, they can act as wind-breakers or natural fences. Plants such as **niger and cockscomb** also add potash to the soil. Other common green manures are **wild indigo, cowpea, cluster bean (guar), sun lower, green gram, berseem, pink morning glory and madras indigo.** Green manure plants have to be chosen, as with all other organic methods, to suit the specific ecosystem and climate type they are going to be used in. Some plants may do better in dry areas, while others need constant rainfall.[54]

Shrubs and Trees used as Green Manure

Shrubs
Cassia auriculata,
Derris indica
Ipomoea cornea
Jatropha
Tephrosiacandida

Trees
Thespesiapopulnea, Neem
Glyricidia, Cassia tora
Vitexnegundu
Tephrosiacandida

Green Leaf Manure
Leucaenaleucocephala
Calotropisgigantea
Cassia Occidental
Hibiscus viscosa, Delonixregia

Source: http://agritech.tnau.ac.in/agriculture/agri_majorareas_greenmanuring_intro.html

Erosion Prevention

As rainfalls become intense in some areas, conserving water and reducing soil erosion are both going to become increasingly important. Below are several techniques to adapt to such conditions.

Terracing

(Hilly and sloped areas, especially those with heavy rainfall)

Terrace farming is very common in hilly regions in India. The process involves building flat, wide ridges into the sides of hills on which crops are grown. The slope then looks like a series of wide steps, which are supported by packed earth or stone walls. The steps slow down water runoff and reduce soil erosion. Terraces bring areas that would otherwise have been uncultivable under crops, and are also useful for plants such as rice, which need water to grow.

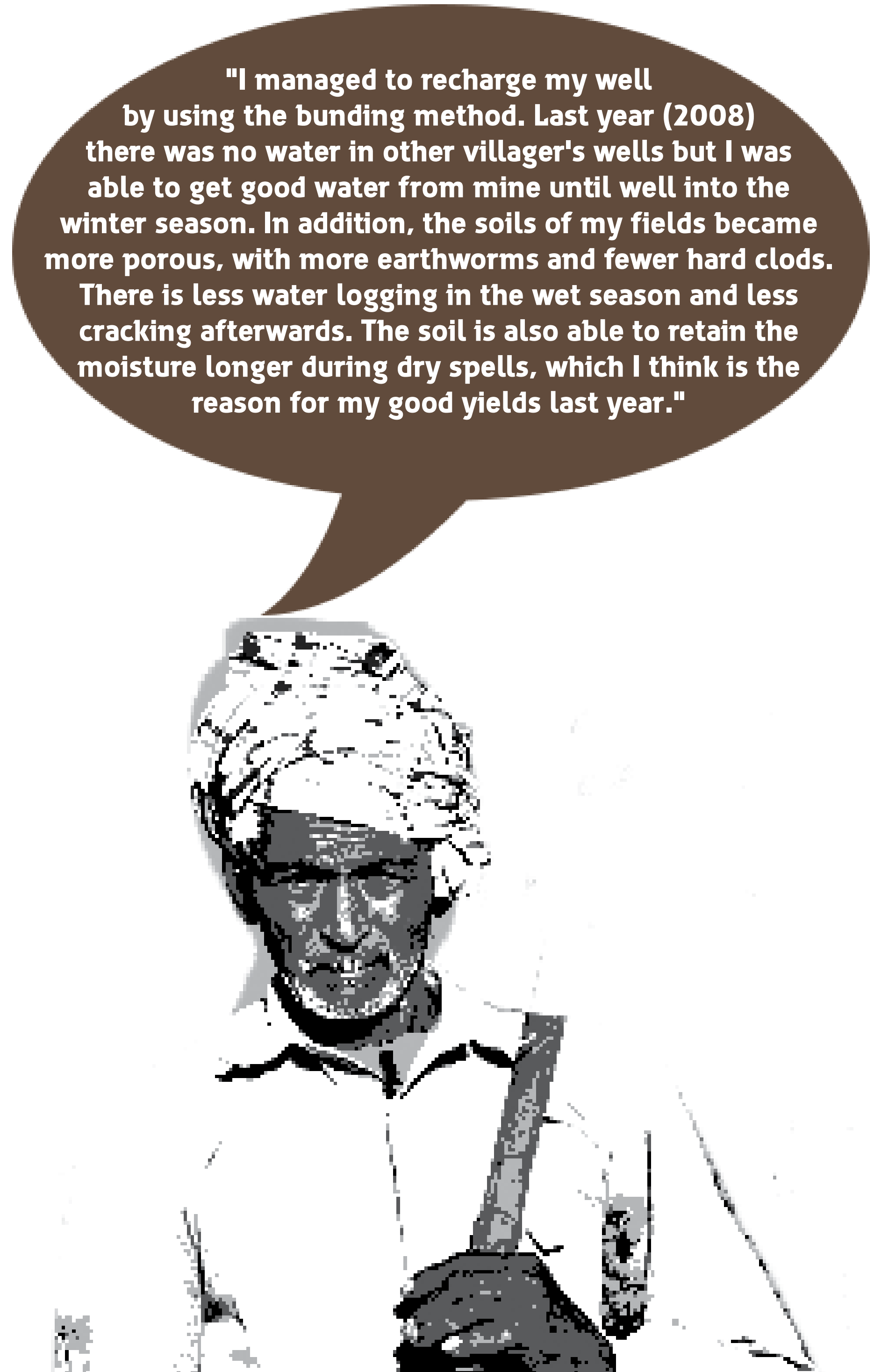
Contour Ploughing and Bunding

(Slightly sloped areas; dry areas)

A method used in areas that are slightly sloped and experiencing soil erosion is to plough across or perpendicular to the slope, along the elevation lines. The ridges formed by the plough slow down the water runoff, and prevent soil erosion. Once crops are planted into these ridges, the roots are able to absorb the water more effectively. Studies show that contour ploughing can increase crop yields significantly–from 5% to 50%, depending on the situation.

Contour bunding is a similar technique. This is when ridges are built up, either with soil or stones, across the slope of the land. Water pools behind the bunds, and has a chance to infiltrate into soil, be taken up by crops and recharge groundwater. It also reduces soil erosion. Crops are planted in between bunds, and leguminous trees can be planted at the edges of fields or on the downstream sides of the bunds at the ends of the field to further build soil.

Though a small amount of land that goes under the bunds cannot be cultivated, the benefits from added moisture and nutrients outweigh any lost yield. In fact, this technique has repeatedly been used across the world to rehabilitate degraded soils, and is consistently successful. It is a low-cost approach that is easy to implement, and further reduces the need for external fertilizers.[55]



Strategic Vegetation Growth

Planting trees and shrubs around a property can help immensely with slowing water runoff, holding moisture in the soil and preventing erosion. Planted strategically along the edges of a field, a line of trees can act as a successful wind barrier, natural fence for cattle or other animals or as a sun barrier. And these trees can provide other services too – fruit, timber, food, fodder and fuel. Some trees and shrubs act as catch plants, while others can build soil by fixing nitrogen.

Gully Plugs

(High rainfall, high erosion, hilly areas)

In hilly areas where heavy rainfall has led to severe soil erosion, rainwater often creates channels or trenches as its runs off the slopes. These trenches or "gullies" then widen, further increasing soil erosion.

In these situations, a low-tech, low-cost barrier, or "gully plug" does an adequate job of stemming water flow and slowing down soil erosion. **Gully plugs are most easily made by building a dry stone masonry wall across the gully, using locally available boulders and rocks.** The water flow slows down (though it can still pass through the gaps between rocks) giving it a chance to permeate into the soil and recharge the groundwater. Any soil and topsoil that is being washed away is retained at the wall, and if needed can be removed and spread in the fields. Gully plugs can be built at regular intervals along the length of the gully.[56]

Conservation Tillage

One of the ways in which soil is eroded, especially when it is dry, is by intensive ploughing or tilling. When soil is turned and organic matter removed from it, topsoil and nutrients can flow away with water or wind, soil dries out and loses its capacity to hold moisture.

Conservation tillage is the practice of leaving crop residue on the field, to prevent erosion and increase water absorption. In the case of mechanized farming, conservation tillage also reduces soil compaction from tractors and reduces fossil-fuel consumption. In no-till farming, all the crop residue is left on the field, and the land is never ploughed. This technique may need to be combined with others such as mulching and growing trap crops in order to keep weeds under control.[57]

Soil Moisture Conservation

Mulching

Along with providing essential nutrients for the soil and keeping weeds down, mulching also prevents erosion and conserves soil moisture.

Adapting to Saline/ Sodic soils

One of the biggest threats that climate change poses is to coastal and low-lying areas. As temperatures and sea levels rise, these areas risk being inundated. These saline soils that can be very damaging for agriculture. There are, however, a few adaptations that can help manage this eventuality.

Salt Tolerant Plants

Several Indian crops can be grown in saline conditions. **Bajra** is one of them. In fact, in the coastal dunes of Gujarat, bajra seedlings were established with freshwater, but irrigated with seawater, and yielded good harvests. **Indian almond** (Terminatia catappatree) is also grown in many parts of coastal India, and provides a food source in the form of the nut as well as timber. Sesbania bispinosa or **dhaincha** is another common Indian plant that is salt tolerant.

Meswak, whose seed oil is used to make soap, and also produces useful fruit, fodder and fuel, grows well in saline, coastal areas. **Pongamia** grows well in saline areas in Bengal, **flame of the forest** in many parts of the country, **Pithecellobiumdulceor gangaimli**, which is used for fuel, fodder and the fruit, can tolerate saline soils and is also drought resistant. Plants like **peppermint, menthol and kewda** are all grown in saline areas, and used to produce value-added products such as perfumes and oils. In addition, there are several **traditional varieties of millets, barley, wheat and rice** that are extremely tolerant to saline waters and sodic soils.

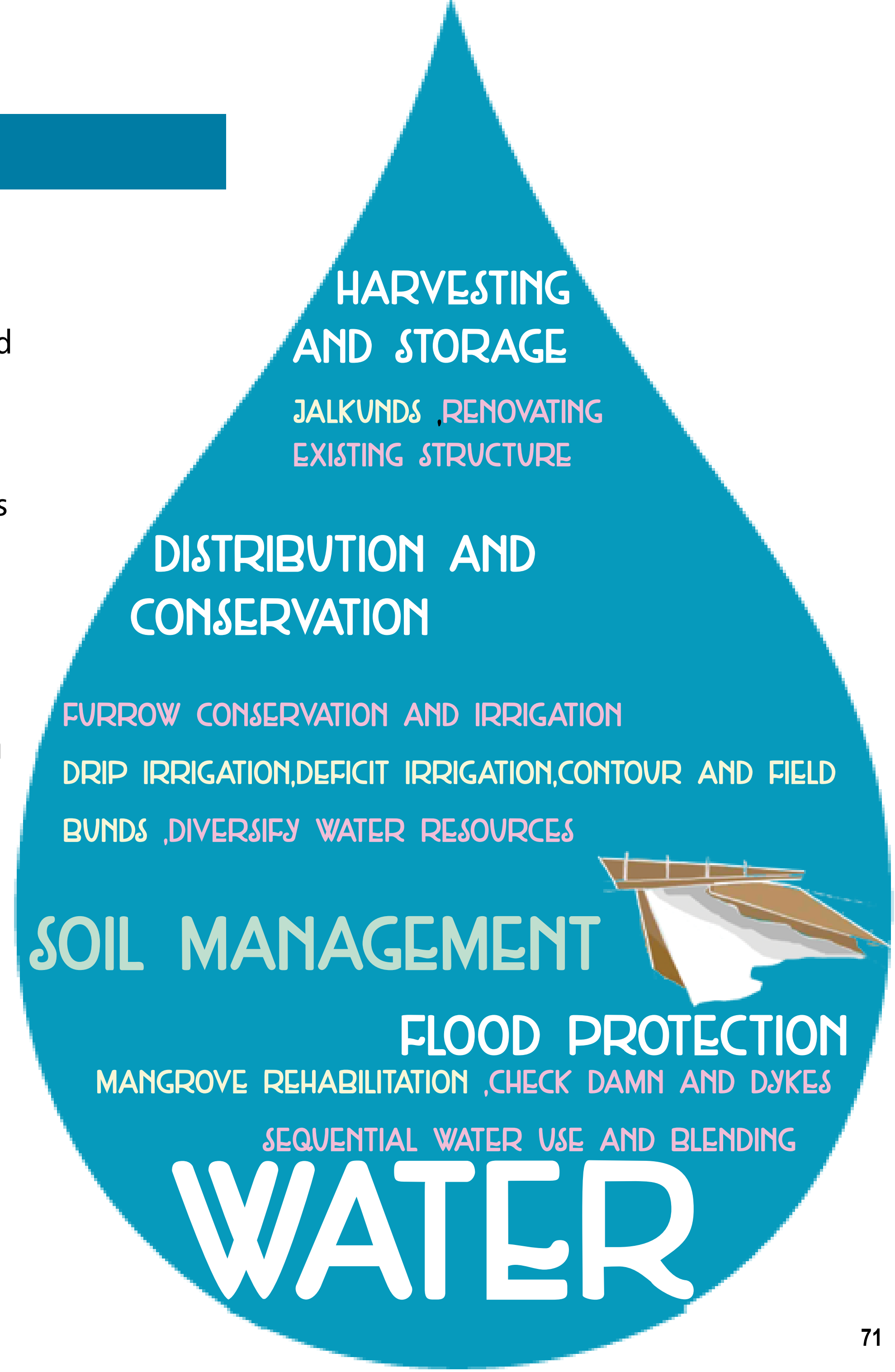
It is now more important than ever to conserve, use, save and develop the seed of these varieties, in seed banks, as well as in the fields.[58]

Harvesting and Storage

Perhaps the most important way to combat water shortage is conservation and storage. There are several ways to harvest rainfall and store water. Rainwater harvesting is an antique practice in almost all rural areas in the country, and most regions have traditional rainwater harvesting methods and structures that are suited to their environments and climates. Many of these, however, have fallen into disuse in the past decades. With rainfall becoming more unreliable, and water availability possibly scarcer, we need to revive urban and rural rainwater harvesting practices, and innovate new methods as well. Given below are just a couple of examples.

Jalkunds

Jalkunds are artificially created ponds that can both catch and store rainwater and also trap runoff. They store water in times of heavy rainfall, that can then be used in dry seasons, and will be particularly useful in areas where the number of rainy days is expected to decrease, while rainfall intensity increases.



Jalkunds can be built with low investment and time.

1. The first step is to dig a large pit.

2. After digging, the walls and bed of the pit should be levelled and rocks and stones removed.

3. The entire inner surface should then be plastered with a mixture of clay and cow dung.

4. Then the entire inner surface should be layered with some form of cushioning– leaves or dry pine needles etc – to protect the lining material. This layer should be approximately 3 – 5 cm deep.

5. A strong tarp (agri-film or Silpauline sheet, for instance) should be used to loosely line the entire tank, making sure that a good margin of the sheet extends out around the perimeter.

6. This margin can then be buried with soil in a narrow trench around the perimeter of the tank, to hold the sheet in place.

7. Feeder channels can be built into the jalkund from areas where runoff accumulates.

This increases water harvest and curbs erosion. Jalkunds that are going to source most of their water from direct rainfall should be built on a hilltop, while those that will be getting water from runoff as well should be built on the bottom of a slope. In dry seasons, tanks should be covered with thatch to prevent evaporation. Addition of neem oil to the water helps prevent evaporation as well. Feeder channels can also be built from the kund to the fields.

Jalkunds can be built in any size. **A 4 x 2 x 1.5 m tank is estimated to be able to irrigate 500 square metres of farmland in the hills.** State agricultural departments may subsidize building costs in some areas. Households can also build their own smaller-scale tanks to supplement water access for domestic needs.[59]

Renovating Existing Structures

Several villages and rural areas in India have traditionally used a variety of rainwater harvesting structures to store water for dry seasons. Many of these have fallen into disuse. Along with building new rainwater harvesting structures where needed, an important adaptation to climate change is to renovate and update these structures where they already exist. This is a cheaper and less labour-intensive option, and these structures are often already very well suited to the specific micro-environment and climate of their regions. This is already being done in several parts of the country.

Bawari Restoration in Rajasthan

Communities in Rajasthan have gotten together to restore old earthen ponds, bawaris and jhalaras that have fallen into disuse. Villagers collectively contribute labour and financial contributions in exchange for free water for irrigation and livestock. Water structures are maintained collectively, and the village chooses a committee to manage access rights.

*** The number of traditional rainwater harvesting techniques in India is hard to count. Each is best suited to the area it used to be – or still is – used in. A good source of information for these methods, organized by region, is the Centre for Science and Environment's website: www.rainwaterharvesting.org/index.html[60]**

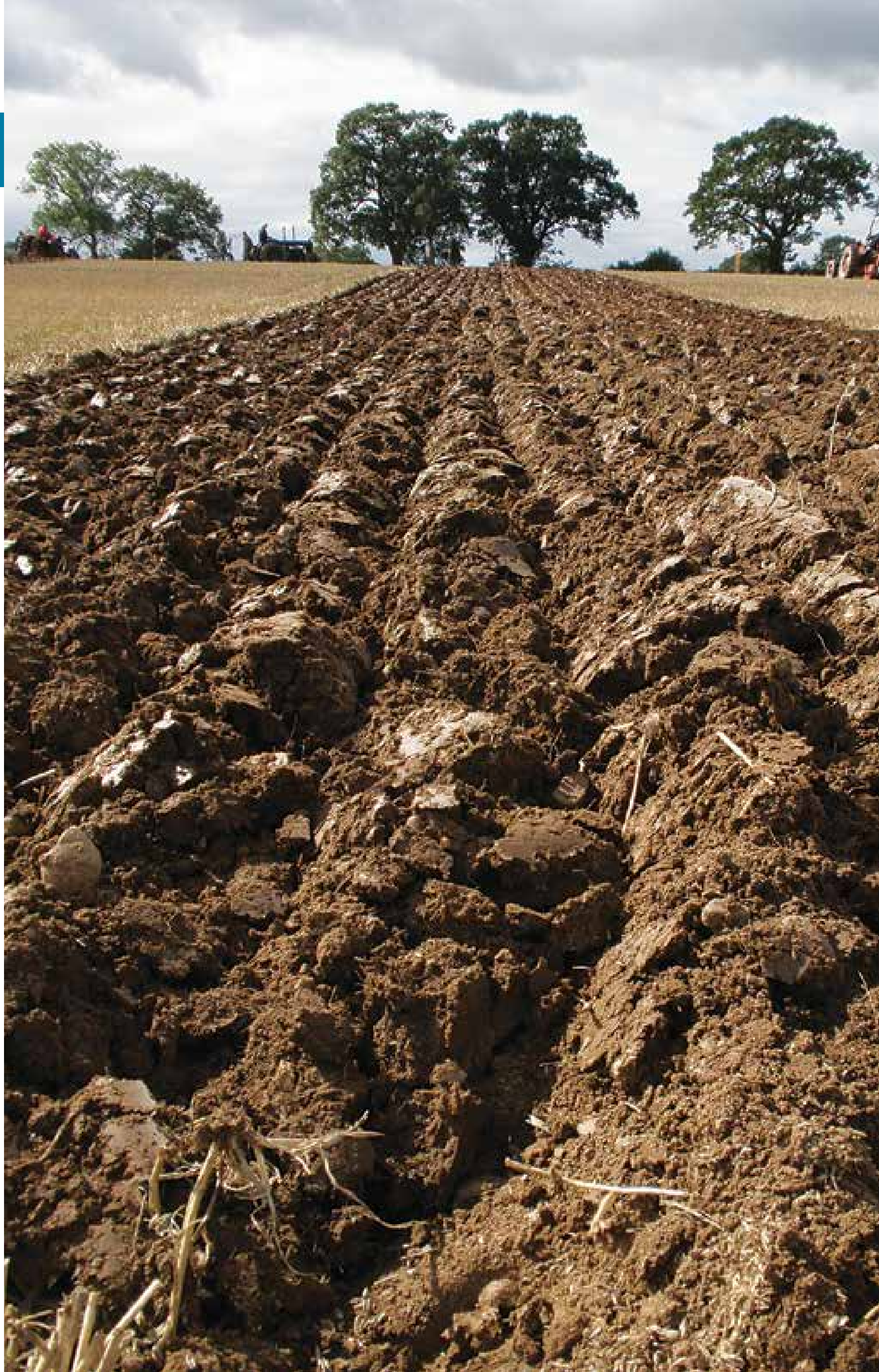
Distribution and Conservation

Along with increasing water capture and rainwater harvesting, adaptations that encourage conservation through efficient use and distribution are also very important.

Furrow Conservation and Irrigation

Often partnered with other practices such as field bunding, furrow irrigation is the **process of digging parallel narrow trenches through fields**. Crops are grown on the ridges in between furrows. Water collects in these furrows instead of running off, is absorbed by the soil and can be taken up the plants. This practice can be used in several different soil types, though it is not ideal for coarse sands, as water in the furrows is lost to fast percolation.

Some farmers dig furrows in their fields, and then intentionally divert water to flow into them as an irrigation method. In this case, while a slight slope encourages water to move through the field and not overflow in the case of heavy rainfall, it is important to not incline furrows too much as this may lead to soil erosion. Furrows can be built into terraced farms as well. Furrows in sandy soils should be shorter, deeper and narrower than in clay soils, so that water can reach from one end to the other. **Spacing of furrows will differ depending on the soil and plant type**; it is important to make sure that they are close enough that the water percolation from furrows beside each other overlap, so that the roots of the plants on the ridges in between are not in a dry zone.[61]



Drip Irrigation

Water saving methods such as drip irrigation can lead to significant water conservation over the course of a season. Modern drip irrigation systems often require some capital investment to set up, and agricultural departments may have subsidy schemes for this in some areas.

Alternately, traditional systems, such as the **bamboo drip irrigation system** in Meghalaya, is over 200 years old, cheap to set up and maintain, and incredibly successful.[62]

Deficit Irrigation

While the practice of intentionally reducing the amount of water that crops in irrigated systems may seem counter-intuitive, farmers in dry areas around the world (including in cotton-growing regions in India) are starting to use it to conserve water. **In this practice, crops are irrigated in the stages when they are most drought-sensitive (this is different for different crops, but initial seedling stages commonly need water), while irrigation at other times in the crop's growth is limited or stopped entirely.** The water saved can be used for a larger amount of land, and overall yield may be increased. This technique, of course, works only in some areas and for some crops. Assessing the right time to reduce irrigation is key to the success of this method.[63]

Contour and Field Bunds

Building contour bunds helps curb soil erosion. However, this practice also helps slow water runoff, which in turn gives water time to percolate into the soil where it recharges groundwater and can be taken up by crops. Another similar method often used in both hilly areas and in the plains is to build up earthen walls or ridges around fields. This ensures that water does not run off fields where it is most needed, and curbs erosion as well.

Diversify Water Sources

Several of the practices mentioned above can be implemented simultaneously, and may also complement other existing or traditional water conservation methods well. An important security system is to have several sources of water within a farm, community or village. This ensures that if water from one source does not collect or yield a large amount of water, other methods may still afford availability and access.

Villages where an entire community has been relying on a single well for their water are already experiencing this problem, as groundwater tables drop. In these cases, instituting water conservation methods so that the groundwater can recharge, and building or renovating water-harvesting structures that allow community members to access other sources of water is very important.

Gonchi system in Andhra Pradesh

In Madirepalli, villagers and a local NGO revived the traditional Gonchi system of managing surface water from the river. Overuse and a growing number of wells were depleting the groundwater, and over half of the villagers found themselves without water.
The villagers formed a users association, drafted a resolution of better practices, and collectively built channels distribute water to fields. All users contribute to the Gonchi through labour or wages.

Social Management

Methods of social regulation and management of water sources have been very successful in several parts of the country. The key principles of such systems is **self-restriction, self-regulation and equal and collective sharing of the available resource**.

Community members set up committees that coordinate conservation measures, reduce water consumption and ensure that available groundwater is distributed equally. Often this involves drafting a contract or resolution that all community members have to agree on. This contract is based on the water needs and supplies in the region, and can include clauses that stipulate that no one will drill new tube wells (or specify a maximum number), no one will grow high-water crops such as paddy, or outline which practices farmers should or should not use.

In some states, irrigation management is handed over by the government to community organizations called **Water User Associations.**[64]

Flood Protection

Adaptation measures are going to be particularly urgent in coastal and low-lying areas that may be inundated with rising sea levels.

Mangrove Rehabilitation

The rare mangrove forests of coastal regions in India play several incredibly important roles in stabilizing costal ecosystems. One of the most important of these is preventing soil erosion. **Healthy mangrove forests protect the shoreline from storms and floods and also provide significant habitat for several other species that are economically useful.**

The most important adaptation here is to conserve and protect existing mangroves. In some cases and areas, rehabilitation programs are also being carried out. These involve afforestation programs that assess, in detail, the natural conditions of existing mangroves to identify their community ecology, rate of reproduction and distribution. A site that has very similar conditions is then chosen, and seedlings are planted to reproduce natural patterns of reproduction.

At a low-tech scale, however, the most useful measure is to protect existing habitat. Mangrove forests should be able to reproduce and restore themselves given the right conditions.

Check Dams and Dykes

A temporary adaptation to areas that are experiencing inundation is to build earthen and stone check dams and dykes to protect fields that are low-lying. Channels can, in some cases, be built from the pools formed behind check dams to storage tanks for use in dryer seasons.

Sequential Water Use and Blending

In areas where water is becoming saline because of encroaching sea levels, farmers are practicing water "blending." This is the process of mixing non-saline water (from piped sources or collected rainwater) with saline water, and using this to irrigate plants. For plants that can tolerate a low amount of salinity, this method dilutes the water enough to allow growth.

Another option is to "recycle" or re-use water. Best quality water is used for the crops that are most sensitive, and as water drains off and becomes more saline, it flows down-slope and irrigates those plants that are more tolerant.
In addition, water that has been used for relatively "light" uses such as domestic activities can be collected and reused for animals and crops.[65]

Manure Management

Careful management and treatment of animal manure can significantly reduce emissions, and yield multiple benefits. **Composted animal manure is a fantastic fertilizer for crops**, and reduces the need to buy fossil-fuel based fertilizer and supplements.

Another useful product that dung can be used for is **biogas**. Home biogas systems can significantly reduce emissions, eliminating the need to use wood as a fuel (and along with that the need for women to regularly have to harvest it) and burns cleaner than wood, reducing smoke and the smoke-related health problems that commonly afflict women who regularly cook over wood fires and in closed spaces. Small-scale biogas systems are easy to install, and do not cost much money. The process requires a large, concrete lined and sealed pit underground. A mixture of animal dung and water is pushed into this pit, where it an aerobically decomposes (without oxygen), releasing methane. This methane is then piped into the kitchen, where it can be used to cook with. Human waste can also be diverted and used to produce biogas. In some areas, government subsidies will cover the cost of biogas set up.

Pasture Management

Overgrazing is a major emitter of greenhouse gases. Denuded grasslands are also more prone to soil erosion. Setting up **rotational grazing systems**, in which cows, buffaloes, goat and sheep graze one area and then are moved to another area in a regular cycle breaks this pattern. During the period when it is not being grazed, the pasture has adequate time to recover and for the vegetation to re-grow.

In addition to giving pasture enough recovery time, certain areas can also be protected from grazing by building barriers, or planting bushes and trees that are thorny or that cattle do not like to eat. This often protects pastureland from wild animals as well.

Growing high quality fodder shrubs and native grasses is good for the animals, protects the soil and reduces emissions. It is also important to shift pasture from arable lands that could be used for crop cultivation to range and grassland.

Traditional Breeds

Over the past years, diversity in breeds of livestock in India has greatly decreased. Traditional breeds have gradually been replaced with high-performance cross breeds or non-native breeds. However, traditional breeds are often much more resilient to change, adapted to the conditions in a particular region, and require less inputs (fodder and water), which promises to become an increasingly beneficial trait as weather patterns change.

Build Structures for Animals to Keep Cool

Temperature changes are going to affect farm animals. Higher temperatures, in particular, can lead to several health problems in cattle. One way to combat this is to make sure that cattle have adequate shady and cool areas to take shelter in or under. In some cases this may be best done by building simple shelters with mud or thatch, that are shaded and well-ventilated, while in others it may mean strengthening and updating existing shelters. These structures will also be useful during heavy rains, and in storm-prone areas.

Backyard Poultry

Part of adapting to climate change is increasing alternate food sources. Growing enough food to feed one's own family and household is an important part of this process, as is expanding this to include a few animals. Backyard chickens and laying hens do not need too many resources, and provide useful source of protein in eggs and meat, as well as a source of additional income.

Crop Choice

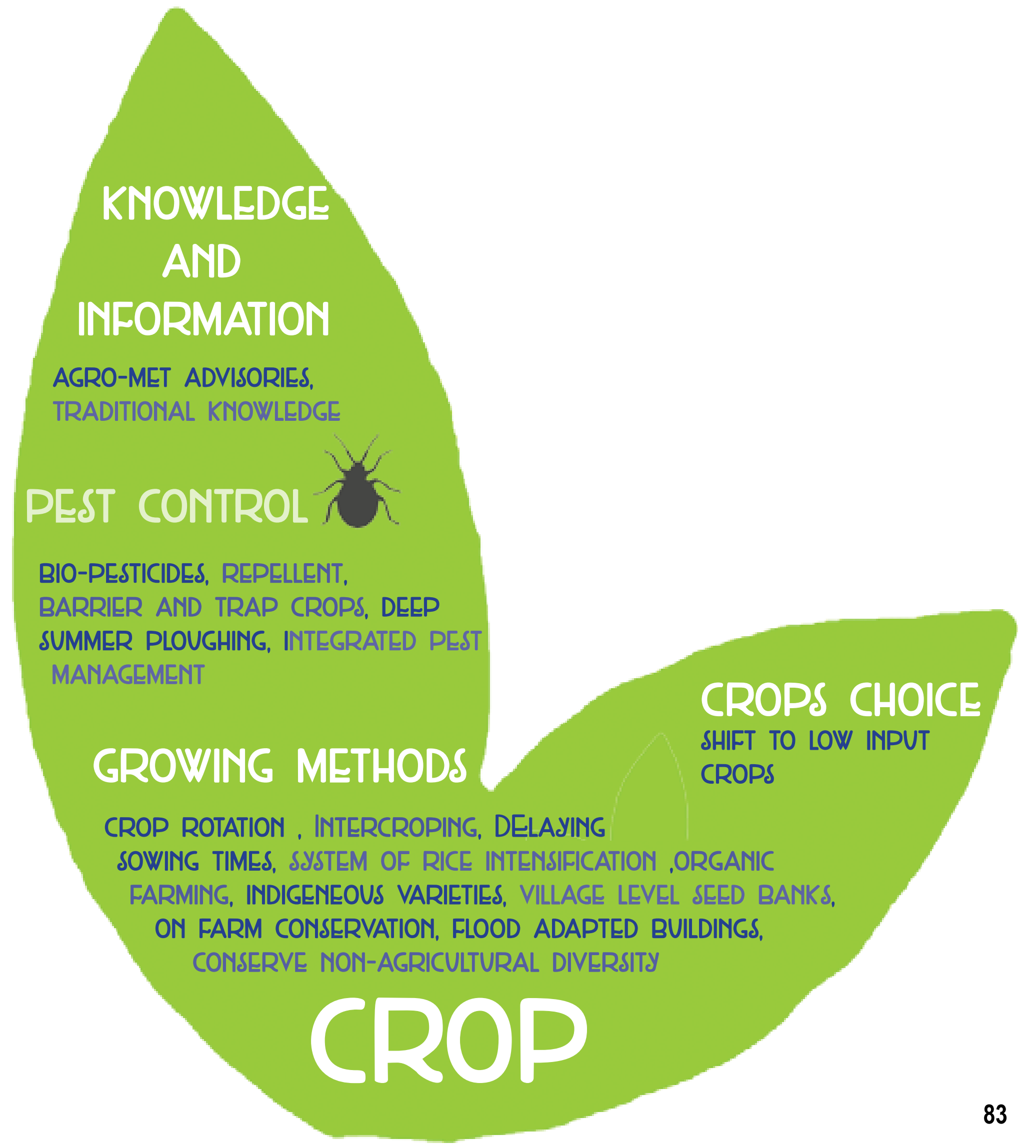
Shift to Low-input Crops

Higher temperatures and unpredictable rainfall are going to make crops, that are heavy feeders and need many inputs, harder to grow. Shifting to low input crops and varieties will ease the pressure on limited water and other sources, and is also better for the soil. Different parts of the country are best suited for different crops.

In semi-arid areas such as Rajasthan, for example, millets and sorghum, which are drought tolerant, will fare better than crops such as wheat and maize. Many farmers in this area have reduced the amount of wheat they grow, and stopped growing crops such as cotton and chickpeas entirely. Instead, they find that pearl millet, black gram, green gram, mustard, cumin, sesame and some oilseeds are much more successful.

In Andhra Pradesh, farmers are shifting to a rotation system that includes finger and pearl millets, with short duration pulses such as red gram. These crops are heat and drought resistant, need less water than rice and have shorter growing cycles. In addition, millet residues make good fodder, and farmers frequently dry and store them for cattle feed.

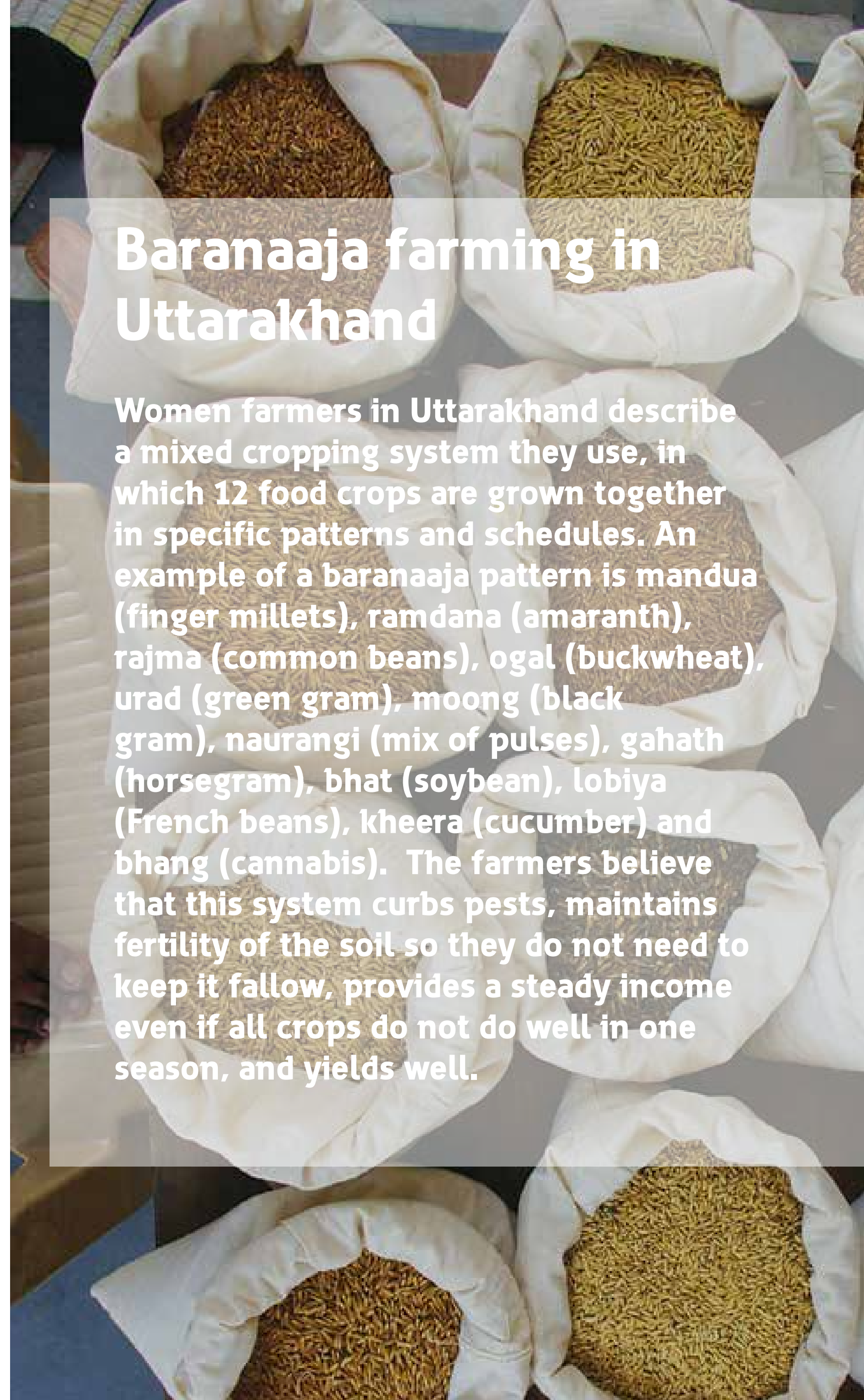
In Uttarakhand, suitable drought resistant crops include millets like mandua, jhangora, kauni, gahat and bhat. Farmer's have found that finger millet (ragi) can withstand severe drought, and can germinate with just one rainfall.



Another way to build resilience in agricultural systems is to grow several different varieties of a crop at the same time. If each of them have different characteristics, there is a better chance that some will have good yields even in unpredictable conditions.

Traditional varieties of crops such as ***"desi gehun"*** are often more resilient, and need less inputs than their hybrid counterparts. Due to their incredible diversity, it is also often possible to find drought-resistant, saline-resistant, flood-resistant, short-season and early-maturing varieties of various crops. These are going to play a fundamental role in successful adaptation to climate change.

Using at least some of the available arable area in a farm to grow food crops ensures that families have a ready source of food at all times. Cash crops are often more dependent on water and other inputs, and their success depends very closely on market prices, which may continue to fluctuate in the next years.[66]



Baranaaja farming in Uttarakhand

Women farmers in Uttarakhand describe a mixed cropping system they use, in which 12 food crops are grown together in specific patterns and schedules. An example of a baranaaja pattern is mandua (finger millets), ramdana (amaranth), rajma (common beans), ogal (buckwheat), urad (green gram), moong (black gram), naurangi (mix of pulses), gahath (horsegram), bhat (soybean), lobiya (French beans), kheera (cucumber) and bhang (cannabis). The farmers believe that this system curbs pests, maintains fertility of the soil so they do not need to keep it fallow, provides a steady income even if all crops do not do well in one season, and yields well.

Zero Energy Gene –Seed Banks

Recognizing the importance of agro biodiversity to ensuring viable agriculture under difficult situations like that predicted by global warming and climate change, Gene Campaign began a few years ago to collect, characterize and conserve the agro biodiversity of local crops like rice, millets, legumes, vegetables and oilseeds.

The seeds of traditional crop varieties are collected from the fields of farmers in remote areas, along with information about their properties.

The seed samples are scientifically processed to reduce moisture level and stored in glass jars for medium term storage and in baskets for short-term storage. Gene Campaign collaborates with agriculture research institutions, to test the agro biodiversity for desirable traits like drought tolerance and disease resistance. So far five drought tolerant rice varieties have been identified and two new genes conferring resistance to Bacterial Leaf Blight have been identified.

Cold Gene Banks vs Zero Energy Gene Banks

The international network of Gene Banks consists of cold Gene Banks which are very different from farmer level field gene banks. The former is an energy intensive bank maintained at low temperature, for long-term storage of genetic material. The latter, a model promoted by Gene Campaign, is a labour-intensive bank with no energy costs. The Zero Energy Gene-Seed Banks being set up by Gene Campaign have no carbon footprint. They are located in the village, owned by the community, which administers and uses the bank.

Multiplication and renewal of the seed samples is done by a cycle of growing out each sample every year so that the seed retains its viability. This also exposes the crop varieties to the prevailing weather and climate conditions, helping them to adjust and adapt. The seed material that is returned to the bank after every grow-out season is adapted to the environment, which includes the climate as well as pests and disease. The material frozen in the cold Gene Bank does not get a chance to adapt to the local climate and when it is taken out at a time of crisis, it may or may not have the adaptive capacity to provide an efficient crop under the prevailing conditions.

Crop Rotation

Rotating crops has always been an important feature of traditional farming systems in India, and increases crop and soil resilience to the kinds of fluctuations that climate change may cause. **Crop rotation is the practice of growing a planned sequence of crops from one season to another and year after year.** Different crops are grown on the same piece of land, making sure that the soil has time to rejuvenate in between particular crops. This is different to the practice of monocropping, which grows the same crop across an entire field, and season after season. Crop rotations can follow two-year cycles, where two crops are alternated, or longer cycles, where crops are not grown on the same area for several years.

Crop rotation is beneficial for several reasons. When leguminous plants are grown in between other crops, they return nitrogen to the soil. They can also help check erosion, by not leaving land fallow. They greatly reduce the risk of pests, which build up when one crop is continuously grown in the same soil. They also mitigate loss due to climate risk, since different crops are tolerant to different conditions.

Several factors should be considered when planning a crop rotation. Planting legumes after non-leguminous plants is highly beneficial, as is alternating plants with different pests and feeding habits.

In Rajasthan, farmers have found that rotating mustard and green gram works very well. **In Andhra Pradesh**, groundnut grows well with pigeon pea, and eggplant, tomatoes and okra complement corn and millets. Growing one food crop with one cash crop can be a strong system for both income generation and food security. **In cotton growing areas**, for instance, a rotation that includes sorghum and millets provides a good source of food and fodder, and also rebuilds the soil. **In parts of Tamil Nadu**, pearl millet is followed by finger millet, and then by groundnut, rice and sugar cane. **In Uttarakhand**, maize is often grown with ginger or turmeric. **In Maharashtra**, farmers are greatly benefiting from a shift from cotton and soybean to rotations and intercropped systems that include arhar, sorghum, green gram, black gram, millets and pigeon pea.[67]

Intercropping

Intercropping has similar benefits to a crop rotation system, and both practices complement each other well. Intercropping is the practice of growing two or more crops close to each other, at the same time, and on the same land. This can be done in alternating rows, strips, or larger sections of a field.

Intercropping, like crop rotation, ensures that soils are not depleted by any one kind of crop. Growing two crops together that attract different pests, or even one that repels the pests attracted to other crops, keeps pests and diseases to a minimum. In unreliable weather conditions, an intercropping system presents a better chance of generating a larger yield; even if one crop fails, another may still do well. Intercropped plants may also give farmers a chance to have a more continuous harvest, if they mature at different times. Growing high-feeding crops like maize, with leguminous crops like pulses, is an example of a popular intercropping system.

Growing crops in different parts of a farm property adds another layer of insurance to final yields. If one area of a field are attacked by pests, or crops weakened by a lack of water or extreme weather, crops in a different part of the property may be buffered and produce better.

Self Reliant Farming in Maharashtra

Along with the NGO ChetanaVikas, farmers in Wardha district of Maharashtra have shifted from growing cotton and soybean to growing a wide variety of crops on their lands. Each farmer experimented with different combinations from the list below, and came up with a model that worked for her/him. Some farmers are growing as many as 25 crops on two acres of land, with great success.

(Source: Pande and Akermann, 2010)

Cereal
1. Sorghum
2. Maize
3. Pearl Millet
4. Green Amaranths
5. Coarse Millet

Pulses
1. Pigeon Pea
2. Moth
3. Black Gram
4. Green Gram
5. Cowpea

Vegetables
1. Beans
2. Tomato
3. Cluster Bean
5. Lady Finger
5. Gourd
6. Cucumber
7. Ridge Gourd

Oil Seeds
1. Peanut
2. Soybean
3. Sesame

Spices
1. Turmeric
2. Chilli

Other Crops
1. Cotton
2. Sun Hemp

Delaying Sowing Times

While this is not an ideal adaptation in some conditions, delaying the sowing times for certain crops may be essential in dry years or as monsoons start arriving later in the year. If plants are sown before a rainfall, there is a much higher chance that they will germinate. In addition, in some cases, delaying sowing times will mean that plants overlap with other crop successions, ensuring a continuous harvest.

System of Rice Intensification (SRI)

SRI was developed in the 1980s and is essentially a system of growing rice that uses less water but aims to increase productivity. SRI is already being practiced extensively in several parts of the country, including Kerala, Tamil Nadu, Himachal Pradesh and Uttarakhand. In SRI, rice fields are not flooded, but instead are kept continuously moist. This prevents the development of anaerobic conditions and allows important soil microbiology to thrive.

Seedlings are raised in unflooded nurseries, and have to be carefully planted when they are 8 – 14 days old (instead of when they are 3 – 4 weeks old), in a square pattern or grid approximately 25cm x 25cm, to give the roots and leaves adequate room to develop. Farmers often use markers to score these squares in the soil before planting.

Plants are given organic fertilizer and have to be weeded. This is most commonly done with a manual rotary weeder, and instead of weeds being removed from the field, they are pushed into the soil, where they help fertilize and aerate it. **This method is more labour intensive than conventional rice growing, but uses 40% less water, signi ıcantly less seed, and has increased yields by 30 – 80% across the country.**

Farmers in parts of the country cultivate rice in traditional methods that are very similar to SRI. One such example is in Uttarakhand, where farmers grow rice using the **"Thakuli"** or plate method. As in SRI, young seedlings are planted further apart, which gives their roots room to develop and be able to withstand drier conditions when the plants are bigger.[68]

Organic farming

Many of the farming methods mentioned above do not use chemicals and are more ecologically sensitive than conventional agricultural practices. They all fall under the umbrella concept of organic farming – **ecologically based farming that does not use chemical pesticides, herbicides or fertilizers, and works instead to build up soil and maintain healthy natural and agricultural ecosystems.** Organic farming practices include mulching, using green and animal-based manures, composting, crop rotations and inter-cropping and increasing farm biodiversity. Organic farmers have to experiment to find out which combination of practices and crops they want to cultivate on their farms, and this decision is closely linked with the climate, soil, and traditional knowledge base in that area.

Such chemical-free cultivation has been the traditional way of farming in India for centuries. While methods introduced in the past decades have moved away from organic farming, farmers, consumers and policy-makers are realizing the value in a shift back to this system. This potential is further heightened because of its capacity to mitigate and adapt to climate change.

The Indian government is now encouraging and supporting organic agriculture programs across the country. In addition to these national initiatives, several state governments are also promoting organic practices. In fact, Andhra Pradesh, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Mizoram, Nagaland, Sikkim, and Uttarakhand have drafted policies to promote organic agriculture in their states, and Mizoram, Nagaland, Sikkim, and Uttarakhand governments have declared that they are aiming to be 100% organic in the future. With this growing support and awareness, some people estimate that the **organic food market in India is going to grow by 15% just between 2011 and 2013.**[69]

Seeds and Diversity

Biodiversity creates resilience. Systems with high wild and cultivated diversity in plant and animal species are inherently able to adapt to changing climates and other environmental conditions better. Building this biodiversity, especially in areas that are particularly vulnerable to climate change, and where genetic diversity has been wiped out by unsustainable practices, is a key strategy in adaptation. There are several ways to re-build genetic diversity in agricultural systems.

Indigenous Varieties

As mentioned in earlier sections, using a wide range of indigenous and traditional varieties of crops, and breeds of livestock, is highly beneficial for several reasons. Along with building up diversity and hence adaptability, **these varieties often use less inputs, are tolerant to drought and salinity, strengthen the soil, and produce better yields in years with lower rainfall.** Planting several species of crops together – through crop rotations or intercropping – also makes plants more resistant to pest and disease attacks.

Hybrid, high-yielding, genetically modified and non-native species have been widely introduced to farms across India, with the aim of increasing yields and performance. However, these crops (along with the other problems they pose, such as crop failure in dry years, high input use etc) greatly decrease overall genetic diversity, making agricultural systems much more vulnerable to environmental changes. Non-native varieties often outcompete indigenous species of plants and animals, and hybrid seeds have dominated the seed market, making it harder for farmers to access traditional crop varieties. Fortunately, however, this diversity can be re-built from existing seed stocks in several ways.

Village-level Seed Banks

Community and village-level seed banks are not a new idea. They are hundreds of them across India, and the **seeds they store play a crucial role in maintaining diversity, and in providing food security and a source of income, especially in years with extreme weather conditions when conventional crops would not have done well.** In ensuring crop yields, even in drought of flood years, they also stabilize prices of food.

Seed banks are designed to be multi-functional. They are collectively owned and managed by community members. The seeds that are saved in seed banks include several varieties of food crops – those best suited for emergencies and extreme weather, as well as others that yield well in good weather conditions – as well as crops used for fodder, green manure and fuel.

Different systems are used for storage and drying, depending on the region the seed bank is in. Buildings can be made of mud, brick, stone or concrete, as long as the seeds are stored in a cool and dry space.

Local youth can be trained to set up and manage seed banks, including them in important adaptation measures and ensuring that traditional knowledge about crops and their varieties is passed on through generations.

On Farm Conservation

Perhaps the most important element of saving traditional varieties of seed and ensuring biodiversity is "on-farm conservation." **This refers to the idea that while storing seed in a seed bank is an important part of building diversity, growing those seeds in the field environment, so that they stay viable, and have a chance to adapt along with changing climate, is even more important.**

Portions of seed saved in a gene bank should continuously be grown, and seed from the resulting crop saved, dried and returned for storage. In addition to this, as species adapt and environmental conditions change, farmers may notice particular varieties of crops doing better in some conditions than others. These varieties should carefully be stored, labelled, and also continuously grown, to develop those beneficial traits even further. Seed should be saved every year to replenish stocks in the seed bank, and maintain a diversity of crops and varieties. **This ensures that farmers will always have assured access to seed, and will not have to depend on the market and seed prices to be able to grow exactly what they need.**

Flood-adapted Buildings

In areas of the country that experience heavy rainfall, and in parts where this pattern and flooding may increase with climate change, it is necessary to upgrade seed bank buildings to be flood-resistant. Containers that seeds are saved in should also be lined or sealed to prevent the seeds from being destroyed in case of floods.

Some useful examples of building adaptations are **using heavier and higher foundations, building flat roofs on seed bank buildings that allow for emergency storage, building shelves so that seeds can be moved off the ground, if needed, and routing all electrical wiring on the ceiling instead of near the floor.**[70]

Conserve Non-agricultural Diversity

No ecosystem exists in isolation. **Strengthening agricultural systems and building up their diversity** is important, but equally important is the work of conserving the non-agricultural diversity around them. In coastal areas, protecting mangrove forests, seawater and delta, river and ocean habitats and species is essential. In land-based agricultural systems, conserving forest resources and ensuring that forest systems are healthy directly affects agricultural biodiversity and well being too.

Pest Control

Bio-pesticides

Indian farming has used several techniques of pest control over generations. Each recipe is best suited for the conditions in its own area. These techniques are going to play a very important role in pest control as we shift away from using fossil-fuel based pesticides and herbicides.

Preparations made with plants such as neem are well known around the world. **Mixing neem with cow dung, cow urine and water, for instance, kills pests such as aphids, mealy bugs and white flies.** Regional, traditional pesticide recipes such as "panchgavya" are also popular. This concoction is a mix of five cattle products – urine, dung, milk, ghee and curd. **Other recipes use dung, urine and jaggery. Buttermilk is sometimes used as a fungicide, and agniastra, or a mix of green chillies, tobacco, garlic and neem leaves that are boiled in cow urine and fermented, are used in against bollworm.**

PANCHGAVYA

Mix the following ingredients in a large (20 litres at least) open-mouthed container: 5 kg of fresh cow dung
4 litres of cow urine
3 litres of cow's milk
2 litres of cow's curd
1 kg cow's ghee
Stir the solution well. Cover the pot. Stir daily for 21 days.
Optional: Add honey, jaggery and ripe bananas.

Repellant, Barrier and Trap Crops

Every region in India has its own host of native plants and trees. Many of these can be used to keep pests away. **Neem,** for instance, is a tree that every farmer in India knows about. Its leaves and oil are used as a powerful pest repellent. **Garlic, onions, radish, coriander and anise repel pests such as aphids, and can be grown alongside other crops.**

Some plants can be used as "trap crops" to attract pests away from the cultivated crops they would otherwise attack. Trap crops can be grown around the perimeter of a field if pests often attack from the borders, or in rows in between crops. **Basil, nasturtium, mustard and marigold**, for example, can be grown with vegetables and garlic. **Sesbania** can be grown with grains such as soybean. **Beans and legumes** all act as trap crops for cotton, as does castor. **Mustard** is a very popular trap crop in many parts of the country. Bitter plants such as **Niger, Sesbanias, Gliricedia and Ipomea** are distasteful to many pests and animals.[71]

Deep Summer Ploughing

In semi-arid areas that experience hot summers, such as **Rajasthan and parts of Andhra Pradesh**, farmers often plough their fields in the summer, turning up the soil and exposing weeds and pests that may be hibernating in the soil. **The extreme dry heat of midsummer kills weeds and pests, and destroys disease-causing organisms.**

Integrated Pest Management

Integrated pest management is an approach to pest control that is holistic and ecologically sensitive. While pesticides are used in IPM when absolutely necessary, methods (many of which are presented in previous sections), such as **growing barrier and trap crops, taking care of soil, preventive measures such as growing pest-resistant varieties, maintaining diversity, water and fertilizer management and using bio-pesticides are prioritized.**

Non-pesticidal management is an approach that utilizes many of these methods as well, but does not use pesticides at all, not even as a last resort. NPM, which is being used in many parts of Andhra Pradesh, is based on the fundamental concept that pest numbers are naturally kept in control when an ecosystem is in a state of balance. This balance is achieved by sound ecological agricultural practices.

Knowledge and Information

Agro-met Advisories

In 2008, the Indian government launched the **District-Level Agrometeorological Advisory Service (DAAS)**. This programme aims to provide detailed, region-specific information. This would include weather forecasts and agro-met advisories. With such a system, farmers can take advantage of beneficial weather, and also prepare adequately for bad weather. Agro-met information can be accessed on **radio, TV, in print and through the internet.**

Traditional Knowledge

Many of the methods mentioned above are not new. They have been used by farmers across the country for generations. As we revive these methods and modify them to adapt to changing climatic conditions, we also need to revive the traditional knowledge that accompanies them.

Along with saving seeds in seed banks, we need to know the characteristics of each seed, the best way to save and store it, and the conditions under which it should be re-grown. We need information about traditional practices that have been successful in different regions, recipes for medicines, composts, fertilizers and pesticides that have worked against particular pests and diseases, and information about water saving methods that have and haven't worked in the past. All this information needs to be meshed with new lessons about climate change, and adapted to the particular situations and issues we are going to be facing in the future.

Importantly, as we revive and respect old information, and learn new practices, we also have to remember to **train community youth and involve them in this process of adaptation,** so they are equipped to continue this work.

Income Diversification

Agricultural incomes can be supplemented by several other practices. Women in northern parts of the country, for example, sell wool and knitting; others from various states sell jewellery, handicrafts, preserved goods such as jams, pickles and chutneys, weaving and artwork.

These activities all provide extra income, which is particularly important in years when weather conditions are not ideal and crop yields are lower.[72]

Stocking

As weather patterns become more unpredictable, stocking surplus food and fodder in years when yields are good is going to become increasingly important. This practice is already widely used in several parts of the country. **Farmers in various regions, for example, store fodder for cattle** in the form of small hut-shaped piles. These are shaped to deflect rainwater, and keep the inside sections dry even in rainfall. In areas that get heavier rainfall, however, building rain-proof structures to store fodder is essential. **In Rajasthan, women stock surplus grain in small mud granaries.** Sorghum and millets can be stored this way for years, while maize can be stored for shorter periods of time. Neem and ash mixtures are used to keep pests and rodents away. As climate change impacts increase, however, we will need to focus on expanding, strengthening and upgrading these structures, and growing crops that are resistant to post-harvest pests.[73]

Kitchen Gardens

The best adaptation to potential food insecurity is to grow food!

Women in various parts of the country have been maintaining kitchen gardens, or smaller scale gardens where they grow a range of vegetables, pulses and grain. The quantities are enough to feed their families, without having to rely on the market or on their other crops to sell. Diverse gardening on this scale is much less prone to risks and losses, and it is not difficult to ensure a steady supply of food for a few people. Even if some crops do not grow well, or if a cash crop's prices fall, kitchen gardens ensure that families will not go hungry.

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IMPACT OF CLIMATE CHANGE ON FORESTS AND BIODIVERSITY

IMPACT ON BIODIVERSITY

Increase in net source of carbon in terrestrial vegetation

Extinction of fresh water species with increase of 4 degrees temp

Mass mortality of coral reefs

20-30% of plants and animals at high risk of extinction

Change in distribution and life-cycle of the species

IMPACT ON FOREST

Deforestation due to industrial activities

Disease infestation

Changes in rainfall, temperature and potential evapotranspiration

Forest fires and pest

Degradation of watershed

Shift of forest boundaries

Habitat degradation

Increase in NPP 75% of forest ecosystems

Shift in species assemblage

IMPACT ON MANGROVE FOREST

Trees suffering from top-dying disease

Imbalance in growth of flora and fauna

Trees extinction due to increase in salinity water

Decrease in sweet water flow in Sundarbans

IMPACT ON LIVELIHOODS

Reduction in food supply

Increase in water expenses

COPING STRATEGIES

Mitigation measures

Reforestation and afforestation

Increasing the quality of forest

Reducing deforestation

Encouraging biodiversity linked sustainable livelihoods

Using NREGA for afforestation

Adaptation measures

Sustainable water management

Disaster risk reduction

Understanding Climate Change

Climate change has emerged as a development challenge. More and more scientific evidence is emerging; more and more impacts of it are showing up regularly. The impacts are complex and have long-term effects on us, ecology, economy and human societies. Whether it is an outbreak of a vector borne disease like malaria in a remote hilly area or the devastating floods in Assam, there is a link to climate change. Whether early flowering of rhododendron in Uttarakhand or upward migration of pine forests into the high altitude region in the Himalayan region, there is a link to climate change. Climate change affects each of us in every aspect of our lives.

Let's Understand More about Climate Change

As defined by the United Nations Framework Convention on Climate Change (UNFCCC),[1] climate change is "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability over comparable time periods."

HOW DOES IT HAPPEN?

The Earth has a blanket of gases – known as greenhouse gases (GHGs) – that keep it warm enough to sustain life; a mean surface temperature of about at 140 C. GHGs have ability to trap heat coming from the sun. But over a period of time, this blanket of gases has thickened thus increasing the trapping of more and more heat in Earth's atmosphere. That is, **we have more GHGs in the atmosphere than the Earth's natural capacity.**

In the last 150 years, human activities have caused more and more GHGs to be emitted. They come from industrial activities and sources like transport. Nature has in-built mechanisms – forests and oceans – to absorb GHGs. But the GHGs emission has been so high that they are no more able to perform their natural duty. Besides, **deforestation, degradation of forests, loss of wetlands and grasslands has reduced the capacity of the natural ecosystems to absorb GHGs.**

WHO IS RESPONSIBLE

Increase in global temperature is due to increase of GHGs concentration like CO_2 in the atmosphere. Scientists have established that an unnatural increase of GHGs in the atmosphere has been **due to human activities like industrial emissions and deforestation.** Concentration of CO_2 and that of other GHGs in the atmosphere has been rising constantly since industrial activities started. According to the latest assessment of the Intergovernmental Panel on Climate Change (IPCC), CO_2 concentration has increased by about 105 parts per million (PPM), compared to pre-industrial revolution level (about 290 ppm). In 200 years since the industrial activities started, CO_2 increased by 50 PPM. The next 50 PPM rise was reported in just 30 years from 1970 to 2000. Between 2000 and 2012, CO_2 concentration increased by another about 25 ppm. By 2012 the CO_2 was about 395 ppm.

India is ranked among the top 10 emitters due to size of its economy and population. However, it has per capita CO_2 emissions of just 1.7 tonnes compared to world average of 4.9 tonnes. Thus, Indian economy has a relatively low carbon footprint. India's CO_2 emission from fuel use in 2010 was about 6% of the world total.

HOW IS CLIMATE CHANGING

The measure of global warming is the mean surface temperature change. However, the worrying fact is that the **Earth has warmed faster in the last 50 years than the earlier part of the 20th century.** In the first five years of this century, the rise in mean surface temperature has been widespread and comparatively faster. In fact 2005, 2010, 2003, 2002, 2006, 2009, 2007, 2004, 2001, 2011 and 2008 are the warmest years that top the chart of warmest 20 years since 1901. The year 2008 was ranked as the 10th warmest year on record in the last 150 years. The World Meteorological Organization (WMO) declared **2009 as one of the top 10 warmest years on record** since the beginning of instrumental climate records in 1850. Out of the 245 disasters in 2009, 224 were weather related, accounting for 55 million people out of the 58 million people affected by disasters, 7000 out of 8900 of those killed, and US$15 billion out of the US$19 billion in economic damages, according to the WMO.

WHY ARE WE CONCERNED

There has been consistent evidence that weather patterns are indeed changing and resulting in more floods, droughts and higher temperatures. Climate change is leading to extreme weather patterns, sea level rise, increased melting of glaciers etc.
Impacts of climate change on India can be seen as:

Changes in rainfall pattern and intensity

Increase in average winter temperatures

Shifting of seasons

Glacier melting

More frequent and severe drought

Increase in extreme rainfall events

Impact of Climate Change on Forests, natural Ecosystems and Biodiversity

How natural resource base support life?

Natural ecosystems provide many goods and services that are vital for the functioning of the biosphere, and provide the basis for the delivery of tangible benefits to human society. Broadly, these can be divided into four categories:

i. Supporting services, such as primary and secondary production, and biodiversity.

ii. Provisioning services, such as food (including roots, seeds, fruit, fodder), fibre (including wood, textiles) and medicinal products (including aromatic plants).

iii. Regulating services, such as carbon sequestration, climate and water regulation, protection from natural hazards such as floods, water and air purification, and disease and pest regulation.

iv. Cultural services, which satisfy human spiritual and aesthetic appreciation of ecosystems and their components.

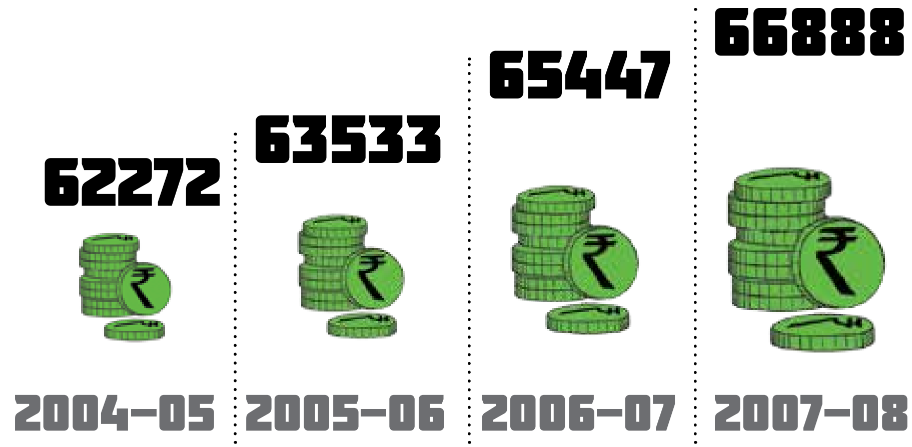
Ecosystems and associated services are sensitive to changes in its climate and anthropogenic changes such as land use change, pollution and invasion of exotic species. Land-use change and related habitat loss and fragmentation have long been recognized as important drivers of past and present ecosystem change, particularly of biodiversity. Invasive species represent a major threat to endemic or native biodiversity.

Natural ecosystems of India comprise of forests, grasslands, wetlands (freshwater and estuarine), mangroves and coral reefs, lakes and rivers. India's rural economy is closely linked to its ecology, particularly to the forests. With nearly 200,000 villages classified as forest villages, there is obviously large dependence of communities on forest resources. It is estimated that around 275 million people are dependent on forests or forest produce for survival. Forests meet 40%of the total energy needs of the country and 80% of those living in rural areas. Forest products contribute significantly to the Gross Domestic Product of the country.

The State of Forest Report of India released in 2011 puts total forest and tree cover of India at 78.29 million Ha. This is 23.81% of the total geographical area of the country.[1] In comparison to the previous assessment (2009), there is a decrease of 367 square km in country's forest cover. India accounts for 8% of the world's species of flora and fauna and is also among centre of origin and diversity of crops plants. India has 16 major forest types, varying from the alpine pastures in the Himalayas to temperate, sub-tropical and tropical forests, and mangroves. Thus Indian forests are a rich source of biodiversity.

That is why it is important to assess the likely projected impacts of climate change on forests and develop and implement strategies for both biodiversity conservation and the livelihoods of forest dependent people.

SHARE OF FORESTRY AND LOGGING IN GDP (AT 2004-05 PRICES)



Data Sources: Quick Estimates of National Income, Consumption Expenditure, Saving and Capital Formation, 2010-11 (Jan 2012), Central Statistical Organisation, Govt. of India

HOW DOES CLIMATE CHANGE EFFECT FOREST?

Forests in India are subject to multiple stresses, including **deforestation due to industrial activities, over extraction, insect outbreaks, forest fires and other anthropogenic pressures.** Climate change brings an additional stress that can result in serious impacts on the forests. Increasing temperatures usually result in increase in the frequency of forest fires and pest and disease infestation in forests. Intermittent occurrences of drought and floods also result in increase in soil erosion and degradation of watershed, thereby affecting the forest cover. About 70% of the vegetation in India is vulnerable to the adverse climatic conditions as well as to the increased biotic stresses.[2] The changes in the complexion and character of ecosystems coupled with habitat degradation and fragmentation shall further weaken their ability to continue provisioning various ecosystem goods and services.

Study on impacts of climate change on India's forests in 2050's and 2080's indicates shifts in forest boundary, changes in species-assemblage or forest types, changes in net primary productivity, possible forest die-back in the transient phase, and potential loss or change in biodiversity. Enhanced levels of CO_2 are also projected to result in an **increase in the net primary productivity (NPP) of forest ecosystems** over more than 75% of the forest area. It is projected that in 2050's most of the forest biomes in India will be highly vulnerable to the projected change in climate and **70% of the vegetation in India is likely to find itself less than optimally**

adapted to its existing location, making it more vulnerable to the adverse climatic conditions as well as to the increased biotic stresses .

The effects of climate change on vegetation are such that **invasive species with shorter lifecycles and higher reproductive capacities are more likely to survive** climate change. While the increase in CO_2 concentrations should enhance the productivity of trees and crops, associate increase in temperature may destroy tree species which cannot sustain higher temperatures and moisture stress. The increase in temperature in forests also affects faunal biodiversity.

A study has shown that **increasing atmospheric CO_2 levels are projected to favor C3 plants** over C4 grasses, but the projected **increase in temperature would favour C4 plants.** C3 and C4 are two types of plants differentiated on how they perform photosynthesis. C3 photosynthesis is the typical photosynthesis that most plants use, and such plants are more efficient under cool and moist conditions like wheat and rice. C4 plants photosynthesize faster under high temperatures and high light intensity and have better water use efficiency like maize and millets.

The effects of climate change have already begun to appear in the Himalayan Region in the form of **shift in the arrival of monsoon, long winter dry spells** (5 – 6 months as experienced in 2008 – 09), **increased frequency of forest fires during winter, the early flowering/fruiting of native trees,** such as Rhododendron spp. and Myrica esculenta etc. With current level of increase in mean annual temperature over various parts of the Himalayas, an **upward movement of plants** is expected. Several field studies in different parts of the world indicate that climate warming earlier in the 20th century (up to the 1950s and 1960s) has caused advances in the tree limit.

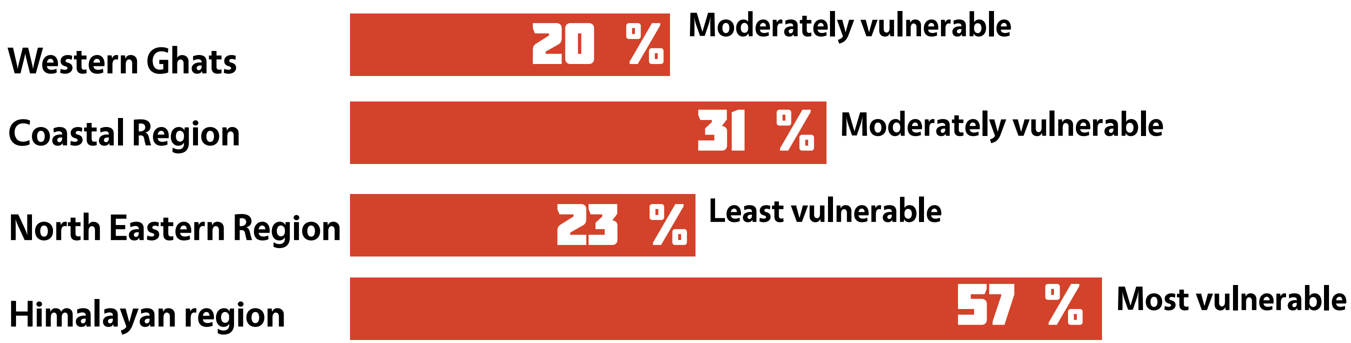
Unprecedented enhancement in growth during the last few decades in the five tree-ring width chronologies of Himalayan conifers (Cedrus deodara D.Don.; Picea smithiana Boiss) from the high-altitude areas of Kinnaur (Himachal Pradesh) and Gangotri (Uttarakhand) regions has been reported. As such, it partially attributes to the overall warming trend seen over the region. The forest ecosystems of the **Himalayan eco-region are the most vulnerable** to climate change. The coastal regions and Western Ghats are moderately vulnerable to climate change. It is also inferred that forests in the North-Eastern region are projected to be minimally impacted by climate change in the short term. Ministry of Environment & Forests under the aegis of Indian Network for Climate Change Assessment (INCCA) has carried out an assessment of how climate change would affect Indian forests by 2030.

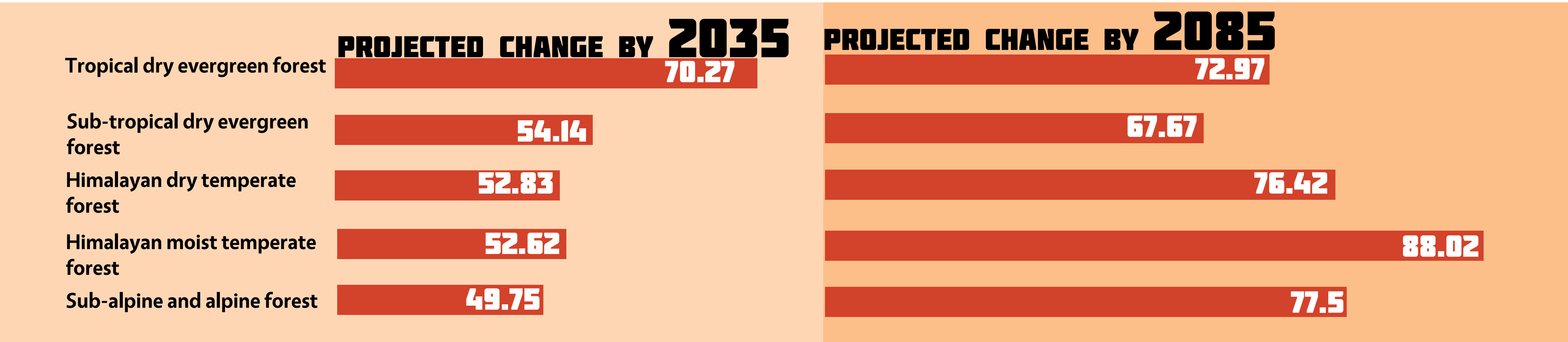
Other natural ecosystems like **mangroves form an important part of the forest ecosystem in India covering 4,871 sq. km area.**[3] Mangroves are mainly distributed along the east coast of the country and to a lesser extent along the west coast. With the exception of the mangroves of the Andaman and Nicobars, the mangroves of the country are already considerably degraded. According to one estimate the mangrove cover of the country reduced by 35% during the period 1987 – 1995 alone. Studies indicate that the extent and composition of mangroves in India may undergo major change, depending on the rate of climate change and anthropogenic activities. It is expected that the diversity in mangroves may improve at higher latitudes like the Gulf of Kutch. The **adaptation and survival chance of mangroves in deltaic region like Sundarbans will be higher** than mangroves on Andaman and Nicobar Islands.

Impact on mangrove forests will **depend upon the rate of sea level rise and sediments supply from rivers, storm surges, fresh-water flows in rivers** both from precipitation in their catchments as well as from snow melt in the mountains and temperature changes. Sea-level rise would submerge the mangroves as well as increase the salinity of the wetland. Extent of high tidal mudflats constitutes major share of the tidal mud flats, especially in Gujarat State. This will provide great potential to the mangroves of the region for adjustment and adaptation against sea level rise.

This would **favour mangrove plants that tolerate higher salinity.** At the same time, increased amount of snow melting in the western Himalayas could bring larger quantities of fresh water into the Gangetic delta. This would have significant consequences for the composition of the Sundarbans mangroves. Changes in local temperature and precipitation would also influence the salinity of the mangrove wetlands and have a bearing on plant composition.

REGION WISE PROJECTIONS FOR FORESTS AND ECOSYSTEMS BY INCCA





Data Sources: Climate Change and India: A 4X4 Assessment; A Sectoral and Regional Analysis for 2030S

Impact of Climate Change on Mangrove Forests

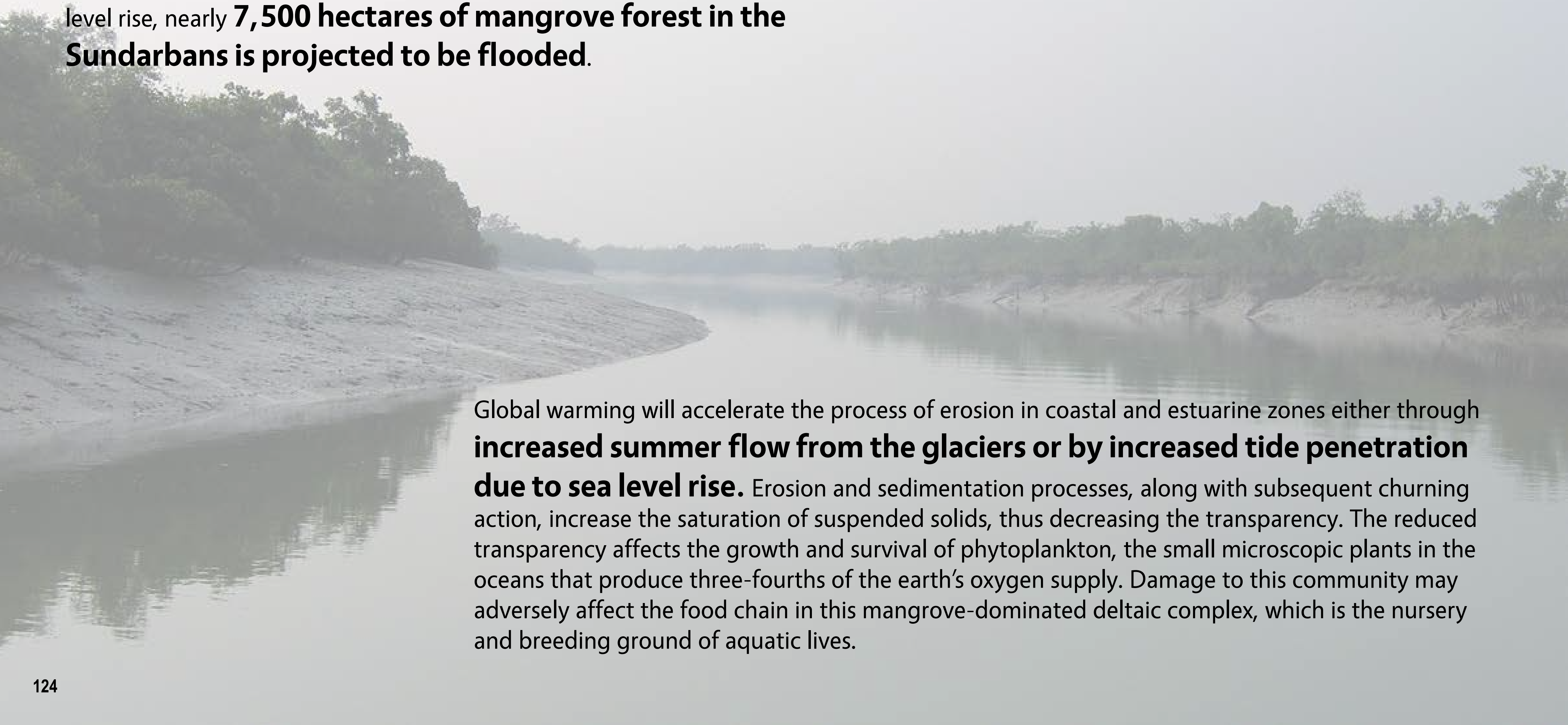
The Sundarbans is the largest mangrove forest in the world where about 300 species of trees and herbs and about 425 species of wildlife including the Royal Bengal Tiger exist. The Sundarbans, also a World Heritage Site, covers about 4.2% of the total Bangladesh where forests cover only 10.2% of the land area. Out of a total area of 0.6 million hectares of the Sundarbans, 0.4 million hectares are forest areas, and the remaining part comprises water bodies mostly flowing through to the sea at the south.

This mangrove forest generally bears the salt-tolerant forest ecosystem excepting some amongst which about 856.7 million Sundari (Heritiera fomes) trees are less salt-tolerant. These trees are now on the verge of extinction primarily due to suffering from top-dying disease caused mainly due to increasing salinity in surrounding waters. Climate change due to global warming is predicted to cause an annual temperature rise of 0.4 degrees Celsius in Bangladesh and result in greater frequency and intensity of cyclonic storms. The sea level is also predicted to rise by 4 millimeters every year. These phenomena will result in an increase in salinity and a decrease in the sweet water flow in the Sundarbans.

The Sundarbans has experienced balanced growth of flora and fauna in association with the fresh water of the Ganges and the salty sea water of the Bay of Bengal. But the balance is now being threatened and siltation is increasing due to decreasing downstream flow of rivers running through and around. Increasing fresh water flow particularly in dry periods is proved to be the only answer to mitigate the crisis. Construction of a barrage at the upstream might be the only option to store water for the dry spells along with other tools for adaptation in this regard.

The Sundarbans is already affected by climate change, importantly from increasing salinity and extreme weather events like tropical cyclones. Some researchers predict that top dying of Sundari trees is likely to be the consequence of **slow increase of salinity** over a long period of time. Salinity increase also affects the species combination and regular succession patterns in the Sundarbans as some non-woody shrubs and bushes replace the tree species, reducing the forest productivity and habitat quality for valuable wildlife. WWF estimates that due to sea level rise, nearly **7,500 hectares of mangrove forest in the Sundarbans is projected to be flooded**.

A 2009 study has shown that surface water temperature has been rising at the rate of 0.5 degree Celsius per decade over the past three decades in the Sundarbans, eight times the rate of global warming rate of 0.06 degree Celsius per decade that makes the Sundarbans one of the worst climate change hotspots on the globe. The study found a change of 1.5 degrees Celsius from 1980 to 2007, indicating a clear challenge to the survival of flora and fauna in this forest.



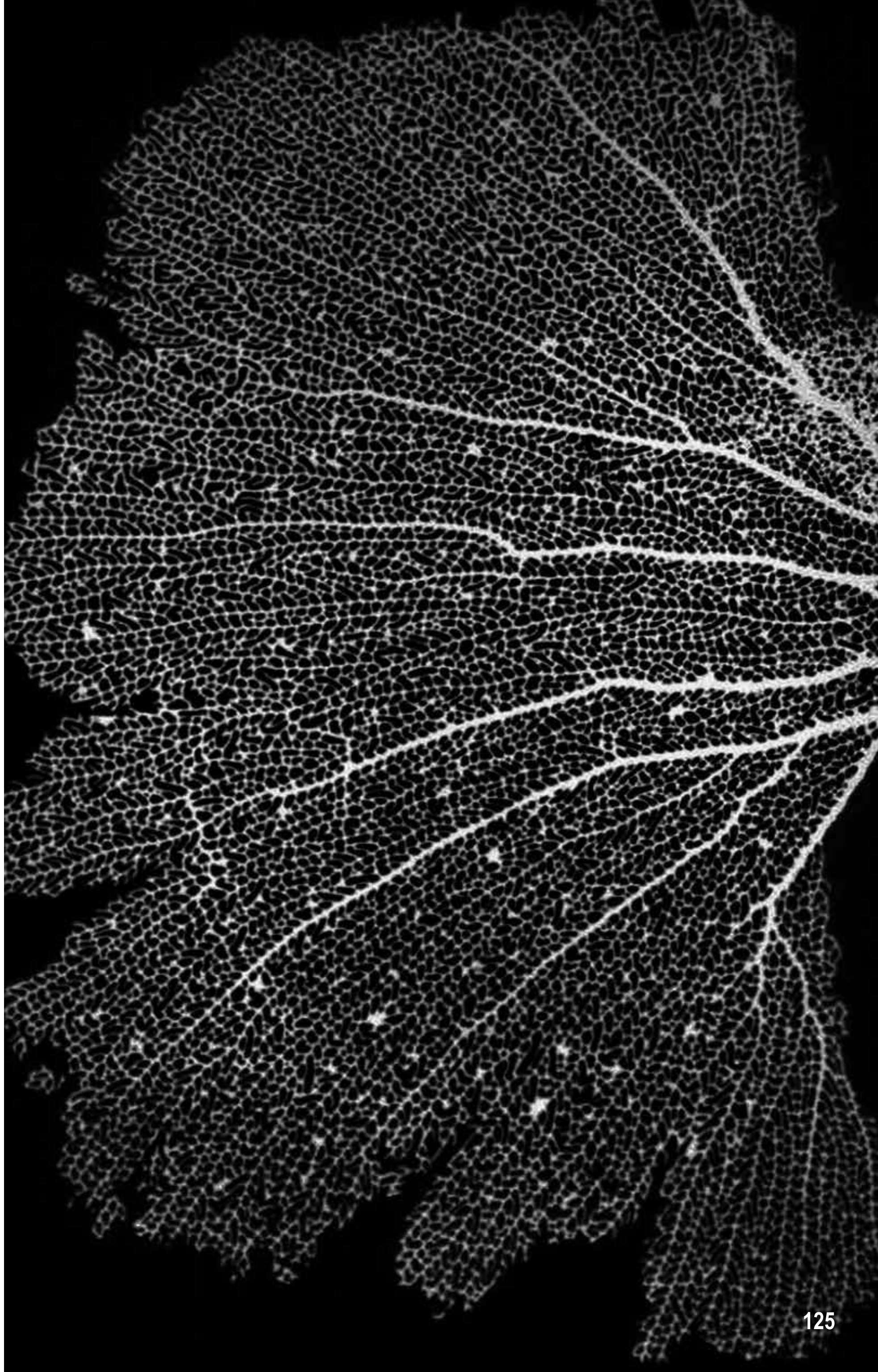
Global warming will accelerate the process of erosion in coastal and estuarine zones either through **increased summer flow from the glaciers or by increased tide penetration due to sea level rise.** Erosion and sedimentation processes, along with subsequent churning action, increase the saturation of suspended solids, thus decreasing the transparency. The reduced transparency affects the growth and survival of phytoplankton, the small microscopic plants in the oceans that produce three-fourths of the earth's oxygen supply. Damage to this community may adversely affect the food chain in this mangrove-dominated deltaic complex, which is the nursery and breeding ground of aquatic lives.

Increase in temperature will lead to **bleaching of corals**. Coral reefs could also be potentially impacted by sea-level rise. Though it has been observed that healthy reef flats are able to adapt to the rise in sea-level through vertical reef growth of 1 cm per year, that is within the range of projected sea-level rise over the next century.

The total area of coral reefs in India is estimated at about 2,375 sq km. The major coral reef formations in India are restricted to the Gulf of Mannar, Gulf of Kachchh, Andaman and Nicobar and Lakshadweep Islands. Scattered coral growth has also been reported along certain inter-tidal belts and submerged banks both on the east and west coasts of the country. There are significant patches of reef growth on the West Coast, for example, coral reefs at Ratnagiri and Malvan. The reef condition is generally poor and declining in near shore waters and areas of high population density. The number of coral species known so far from Indian reefs is 206. Corals reefs contribute to the economy of the nation by attracting large number of tourists every year.

In the past 20 years, there has been an **increasing intensity and spread of forest fires in India**.[4] This is largely attributed to the rise in temperature, decline in precipitation and increase in aridity in combination with land use changes.

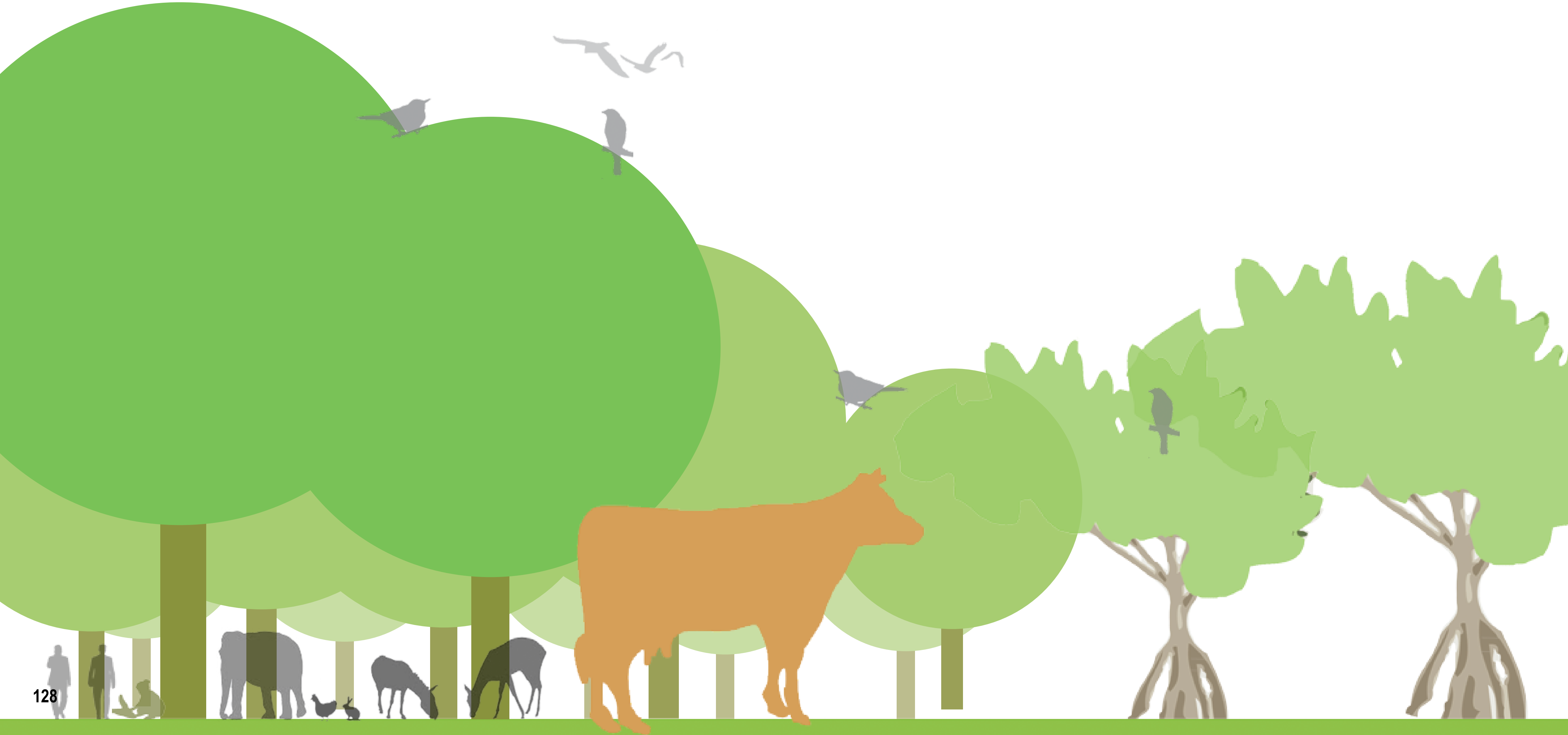
Natural grasslands include the alluvial floodplains of rivers in NE India, semi-arid zone grasslands of Deccan plateau and Indo-Gangetic basin and Montane grasslands of Western Ghats and Himalayas. Rural economy and livestock in India is closely linked to sustainable use of grasslands. India has more than 500 million livestock, **more than half of fodder demand is met through these grasslands.** Grasslands also support number of bird species by providing breeding and nesting grounds like Great Indian Bustard, Lesser Florican, and big animals like Indian Rhinoceros, Nilgiri Tahr, Wild Buffalo etc.



CORAL REEF REGIONS	FAUNA AND FLORA	STATUS OF REEF & DISTURBANCE / DEFICIENCIES
Gulf of Kutch	Leatherback (Dermochelys coriacea), Olive Ridley (Lepodochelys olivacea) and Green turtle (Chelonia mydas)	a)The dredging of sand for the cement industry has caused substantial destruction of the natural habitat. The associated increase in turbidity may be the most important factor in the decline of marine life. b)Mangroves are cut intensively for fuel and have been virtually destroyed in some areas. c)Another most important threat for this region is growing urbanization and industrialization. This coast is the site for a large number of mega-industries including petroleum refineries.
Lakshadweep Islands	Leatherback (Dermochelys coriacea), Olive Ridley (Lepodochelys olivacea), Hawksbill (Eretmochelys imbricate) and especially Green turtles (Chelonia mydas) are found in Lakshadweep. Marine life is abundant and the molluscs include giant clams Tridacna spp. and tritons Charonia sp.	a)Reefs near densely populated islands have degraded a lot whereas uninhabited islands retain pristine reefs. b)The 1998 mass bleaching, however, has led to 70 – 80% mortality of corals in all islands. c)The islands are being developed for domestic tourists for sport fishing and diving. d)Apart from fishing, turtles and shells are collected for commercial purposes.
Gulf of Mannar	Green turtle, sea cow, Olive Ridley turtle and pro-chordate Balanoglossus, Windowpane oyster Placuna placenta	a)The high turbidity of the water is due to large scale coral mining and coastal erosion from mainland causing deterioration of the reefs. b)Exploitation of coral & shells for lime industries and hunting of dugong & turtles is still prevalent. c)Large quantities of molluscan shells for the ornamental trade are collected in this area

CORAL REEF REGIONS	FAUNA AND FLORA	STATUS OF REEF & DISTURBANCE / DEFICIENCIES
Andaman and Nicobar Islands	The islands have important nesting beaches for Leatherback Dermochelys coriacea, Hawksbill Eretmochelys imbricata, Olive Ridley Lepidochelys olivacoes and Green Turtle Chelonia mydea. The sea cow Dugong dugong is also seen frequently in these islands. Several hundred estuarine crocodiles occur in densities inversely proportional to human population. Beside these, sea shells of different sizes, varieties of fish like sardines, tuna, baracuda, mullets, mackerels and flying fishes are abundant. Sharks, whales and dolphins have also been spotted.	a)Massive siltation of the marine environment is resulting from widespread and uncontrolled deforestation in the hills is a serious problem. b)Several resources like green turtles, crocodiles, sea cow and molluscan shells are overexploited by the islanders. c)Fishing is an important industry along the coast. Harvest of molluscan shells especially of Trochus and Turbo species is on commercially important scale. d)Tourism is a fast-developing industry.
West Coast of India: Malvan	--	a)Siltation is of high rate and salinity may drop to 20 ppt during monsoon in some habitats, which may restrict the growth of ecologically sensitive forms of ramose corals. b)So far no status survey has been conducted in this area and recently the Government of India is planning to protect this area from anthropogenic disturbances.

Impact of Climate Change on Biodiversity



There is probably no single indicator of the impacts of climate change on biodiversity. Impact on biodiversity can be seen through **changes in distribution pattern, changes in life cycles, or the development of new physical traits as species struggle to adapt to the changing climatic conditions.** The changing temperatures, whether average, minimum or maximum, can be important determinants of plant distribution. It is believed that approximately 20% to 30% of plant and animal species are likely to be at increasingly high risk of extinction as global mean temperatures rise 2 to 30 Celsius above pre-industrial levels. Small, fragmented ecosystems are more affected by changes in climate parameters like temperature than large contiguous ecosystems. Trends in connectivity/ fragmentation of ecosystems can also give indication of how vulnerable are ecosystems to climate change.

According to the **Millennium Ecosystem Assessment,** climate change is likely to become one of the most significant drivers of biodiversity loss by 2100. Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR4) Approximately 20 to 30% of plant and animal species are likely to be at increasingly high risk of extinction as global mean temperatures exceed warming of 2° to 3° C above preindustrial levels, according to IPCC.

But which species will be most vulnerable to climate change? Which species, ecosystems and regions should we prioritize for conservation? These questions have become increasingly relevant to scientists, policy and decision makers and the communities.

Climate change will affect different areas of the world to different degrees. But it is also widely recognized that not all species will respond in the same way, even to similar levels of climatic change. In addition, a species' individual susceptibility to climate change depends on a variety of biological traits, including its **life history, ecology, behavior, physiology and genetic makeup.** Species that are in greatest danger of climate-change driven extinction are those with high susceptibility to climatic changes, that also have distribution ranges that will experience large climatic changes and where their adaptive capacity is low.

-Terrestrial ecosystems and biodiversity:

With a warming of 3°C, relative to 1990 levels, it is likely that global terrestrial vegetation would become a net source of carbon. A global mean temperature increase of around 4°C (above the 1990 – 2000 level) by 2100 would lead to major extinctions around the globe.

-Marine ecosystems and biodiversity: A warming of 2°C above 1990 levels would result in mass mortality of coral reefs globally.

-Freshwater ecosystems: Above about a 4°C increase in global mean temperature by 2100 (relative to 1990 – 2000), many freshwater species would become extinct.

Effects of climate change on flora are such that invasive species with shorter life cycles and higher reproductive capacities are more likely to survive climate change. Boundaries between vegetation types are generally determined by summer warmth. **Species with long life cycles and/or slow dispersal are likely to become extinct** as they may not be able to adapt fast enough to climate change. Isolated species like those found in the arctic and alpine regions are particularly vulnerable and coastal species will be 'squeezed' between human settlements and rising sea levels.

Climate change may affect species survival by affecting their time-keeping. Both climate and the availability of food are important to determine whether animals can reproduce and survive in a given habitat. The critical constraint on animals, through which these factors have their effect, is time because it limits an animal's ability to harvest sufficient resources to meet its physiological requirements.

Climate change too can create an environment that is suitable for invasive species. Poison ivy grows faster and is more allergenic when CO_2 levels are high. Changes in climate can cause dominant native species to perish because they cannot adapt to new conditions. These then can be replaced by invasive species which thrive in the changed environment. The invasion of new pests (emergence of new species of snails in the wet terrace cultivation and larger variety of resistant mosquitoes) and changes in forest composition further demonstrate the impacts of climate change on biodiversity.

While the increase in CO_2 concentrations should enhance the productivity of trees and crops, associate increase in temperature may destroy tree species which cannot sustain higher temperatures and moisture stress. Such effects are already visible in the **shifting of pine forests upwards (being replaced by oak forests)** in Uttarakhand and Himachal Pradesh and change in life cycles leading to early flowering in rhododendron in Uttarakhand.

The increase in temperature in forests also affects fauna particularly reptiles. Lowland species are moving to higher elevations while many of the high altitude endemic species may not be able to find suitable habitats thus leading to imminent extinction. Amphibians are very sensitive to subtle changes to environment and increased moisture stress is expected to affect their numbers significantly.

While climate change may become the major driver of biodiversity loss in the future, currently there are a number of challenges facing biodiversity and are the direct drivers of biodiversity loss—**habitat change, the introduction of invasive alien species, overexploiting and nutrient loading.** Such drivers are projected to either remain constant or to increase in the near future. Figure below illustrates the relative importance of these drivers for the various ecosystem types:

		Habitat Change	Climate Change	Invasive Species	Over-Exploitation	Pollution (nitrogen, Phosphorous)
FOREST	Boreal	Low ↗	Low ↑	Low ↗	Low →	Moderate ↑
	Temperature	High ↘	Low ↑	Low ↑	Moderate →	Moderate ↑
	Tropical	Very High ↑	Low ↑	Low ↑	High ↗	Low ↑
DRYLAND	Temperate Grassland	Very High ↗	Low ↑	Moderate →	Low →	Very High ↑
	Mediterranean	High ↗	Low ↑	High ↑	Moderate →	Low ↑
	Tropical grassland and Savana	High ↗	Moderate ↑	Low ↑	Very High →	Moderate ↑
	Desert	Low →	Moderate ↑	Moderate →	Low →	Low ↑
INLAND WATER		Very High ↑	Low ↑	High ↑	Moderate →	Very High ↑
COASTAL		Very High ↗	Moderate ↑	High ↗	High ↗	Very High ↑
MARINE		Moderate ↑	Low ↑	Low →	Very High ↗	Low ↑
ISLAND		High →	Low ↑	Very High →	High →	Low ↑
MOUNTAIN		High →	Moderate ↑	Low →	Low →	Low ↑
POLAR		Low ↗	High ↑	Low →	Moderate ↗	Moderate ↑

Driver's Impact on Biodiversity Over the Last Century

- Low
- Moderate
- High
- Very High

Driver's Current Trend

- Decreasing Impact ↘
- Continuing Impact →
- Increasing Impact ↗
- Very rapid Increase of the Impact ↑

Source: Millennium Ecosystem Assessment 2007

Wetlands and lakes are already shrinking/ drying up due to various human pressures. Reduced water availability in rivers or drying up of wetlands and lakes due to erratic water supply due to climate change will further affect aquatic biodiversity. Marine ecosystems will be impacted due to increase in sea level and salinity changes. This is already visible in the Sunderbans where the rise in sea level is flooding ecologically sensitive coastal inter-tidal habitats.

Mangrove forests are facing threat of increased salinity and decrease in species biodiversity as only the highly salt resistant varieties can survive in such situations. The increase in CO_2 will lead to the acidification of oceans which will create oceanic dead zones where the water contains too little oxygen to support life. Acidification, the rise in elevated sea surface temperature and surface water temperature is leading to coral bleaching and mortality.

In changed climatic conditions, each species will respond in an individual fashion, according to its climate tolerances and its ability to disperse into a new location, alter its phenology or adapt to shifting food sources. (See table)

ECOSYSTEM TYPE	KEY CLIMATIC VARIABLES	IMPACT ON BIODIVERSITY
Wetlands	a) Mean summer temperature b) Mean annual precipitation c) Flooding	a) Increased variability in the hydrological cycle leaving inland wetlands to dry out with lower species diversity b) Warming of 3 – 4°C. Could eliminate 85% of all remaining wetlands globally
Coastal marshes	a) Relative rate of sea-level rise, changes in hydrological balance b) Storm frequency and severity	a) Habitat loss of estuaries and deltas, particularly where these are backed by agricultural or urban land, preventing natural retreat b) Implications on migratory species and their flyway patterns
Forests (general)	a) Changes in rainfall, temperature and potential evapotranspiration. b) Increased frequency of fire and storms.	a) Major changes in vegetation types, forests may disappear in certain areas at a rate faster then the potential rate of migration to, or re-growth in, new areas
Alpine / Mountains	a) Mean annual temperature b) Snow fall and melt c) Growing season length	a) Altitudinal migration of habitats, with invasion of alpine meadows by forest systems, highest altitude habitats may be unable to migrate
Low-lying islands	a) Relative sea-level rise b) Storm frequency and severity	a) Loss of land area, seabird nesting colonies. Increased human demands on remaining terrestrial habitats

ECOSYSTEM TYPE	KEY CLIMATIC VARIABLES	IMPACT ON BIODIVERSITY
Arid and semi-arid areas	a) Precipitation patterns b) Minimum winter temperatures	a) Desertification b) Salinization c) Loss of grassland d) Loss of arable land
Coral Reefs	a) Sea-surface temperature, b) Increase in sea water salinity (chemical effects of higher CO_2 concentrations in the water)	a) Prolonged exposure to even minor (>1^{o}C) rises in temperature causes coral bleaching/ coral death b) Impacts may be compounded by increased water salinity
Mangroves	a) Relative rate of sea-level rise b) Changes in hydrological balance in estuarine systems c) Storm frequency and severity	a) Decrease in extent of coastal zone

Table Source: Based on Sensitive Ecosystems Analysis (2000); UNEP/ WCMC

CASE IN POINT

Climate change is forcing plants and animals away from their native habitats to more suitable ones. A recent survey of plants in the United Kingdom found that species favoring higher temperatures, like orchids and ferns that used to be found in southern parts of the country, are now flourishing in the north, too. Changes have been observed in populations and distribution of as many as one-third of all species since 1987, says the survey carried out by Plant life International, a UK-based conservation organization, and the Botanical Society of the British Isles. Climate change such as warming up of the atmosphere affects habitat, forcing plants and animals to disperse and migrate. But if a physical barrier prevents movement, then species could die out. "We are going to see a lot of extinctions, particularly of species that are not able to move quickly enough," says Katherine Stewart of Plant life International. Climate change has hit insects (like butterflies) and birds the hardest.

Migratory birds that cover large distances have been unable to cope. The breeding period of birds usually matches with a time when food is available in plenty. But climate change has thrown this system out of gear. According to a study conducted at the Groningen University in the Netherlands, climate change has led to food shortage during the breeding period of several species, causing their populations to decline (Nature, 17 May 2001). According to State of UK's Birds 2004, numbers of some species considered secure were declining alarmingly. Seven of the nine common species of wading birds shifted from the "warm west" to the "colder east" in response to milder winters.

Climate change is also affecting the seas. In the North Bering Sea, which is frozen for most of the year, the seasonal melt is starting earlier and there is less ice in general, says a US study (Science, 10 March 2006). This is causing grey whales to move farther north to follow the cold water, while animals like the walrus and sea birds are facing a food shortage.

Climate change models in the 1990s had predicted change in species' distribution, habitat, emergence of new diseases and sea level rise – all of which are coming true. In one of its worst effects, climate change altered patterns of a fungal infection, leading to the extinction of two-thirds of tropical harlequin frog species in Central and South America (Nature, 12 January 2006).

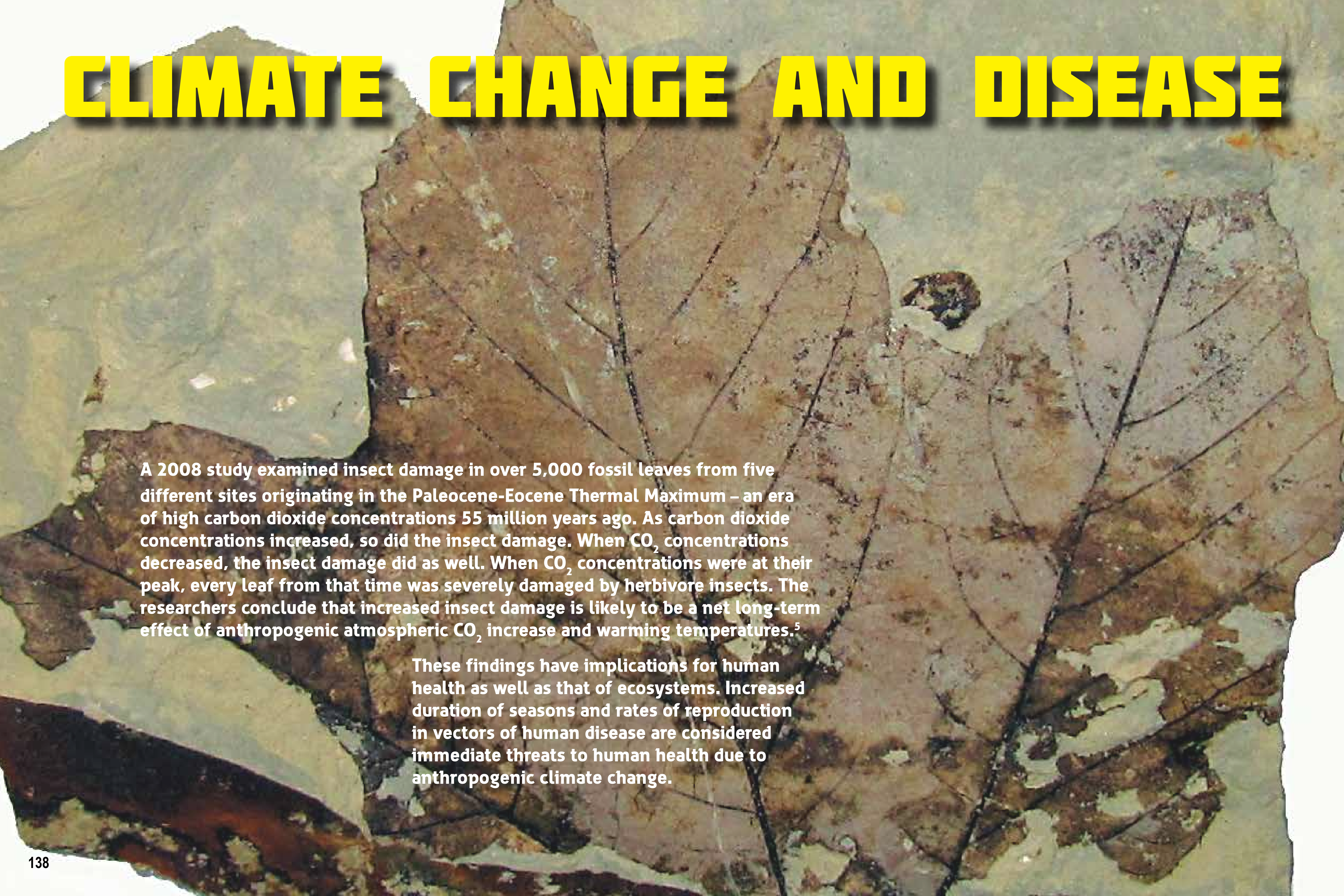
Impact of Climate Change on Livelihood

Various estimates including that of IPCC suggest that climate change would be a major driver for biodiversity loss by 2050 globally. Due to climate change alone it has been estimated that by 2100 on average 20% to 30% of species assessed are likely to be at increasingly high risk of extinction from climate change impacts possibly within this century as global mean temperatures exceed 2°C to 3°C relative to pre-industrial levels.

Losses of biodiversity will probably lead to decreases in the provision of ecosystem goods and services. There could also be trade-offs between ecosystem services – projected gains in provisioning services like food supply, water use could be at the expense of other regulating and supporting services including genetic resources, habitat provision, climate and run-off regulation.

Projected changes may also increase the likelihood of ecological surprises that are detrimental for human well-being. Ecological surprises include rapid and abrupt changes in temperature and precipitation, leading to an increase in extreme events such as floods, fires and landslides, increases in eutrophication, invasion by exotic species, or rapid and sudden increases in disease. This could also entail sudden shifts of ecosystems to less desired states through, for example, the exceeding of critical temperature thresholds, possibly resulting in the irreversible loss of ecosystem services, which were dependent on the previous state.

Climate change and associated ecological changes also pose threats to the viability of many economic and social structures, even where people are not displaced or in serious physical risk. This is particularly true where they will lead to decline in the availability or quality of natural resources such as water or land on which the livelihoods of many poor people are based.



CLIMATE CHANGE AND DISEASE

A 2008 study examined insect damage in over 5,000 fossil leaves from five different sites originating in the Paleocene-Eocene Thermal Maximum – an era of high carbon dioxide concentrations 55 million years ago. As carbon dioxide concentrations increased, so did the insect damage. When CO_2 concentrations decreased, the insect damage did as well. When CO_2 concentrations were at their peak, every leaf from that time was severely damaged by herbivore insects. The researchers conclude that increased insect damage is likely to be a net long-term effect of anthropogenic atmospheric CO_2 increase and warming temperatures.[5]

These findings have implications for human health as well as that of ecosystems. Increased duration of seasons and rates of reproduction in vectors of human disease are considered immediate threats to human health due to anthropogenic climate change.

BUT HOW DO LIVELIHOODS RELATE TO CLIMATE CHANGE INDUCED VULNERABILITIES?

The range of vulnerabilities that poor people face in different parts of the world encompasses all aspects of life, with most not directly related to climate change (though many are affected in some way by it). There are many ways to approach the relationship between climate change and vulnerability, but the 2001 IPCC Working Group II report on Impacts, Adaptation and Vulnerability gives insights that are as good a starting point as any.

"**Populations are highly variable in their endowments [of different capitals] and the developing countries, particularly the least developed countries… have lesser capacity to adapt and are more vulnerable to climate change damages, just as they are more vulnerable to other stresses. This condition is most extreme among the poorest people.**"
(IPCC 2001 Working Group II, page 8)

Sea level rises will displace millions of the poor, with the areas least likely to be protected those where people are poorest. Small island states and low coastal areas and deltas are most at risk. In many cases, those displaced will have few opportunities to re-establish their lives except in urban areas, where livelihood opportunities are limited without the skills, capital and contacts needed to cope with urban life. Even where people are not physically displaced, rising seas will reduce the natural capital in ecosystems such as coastal fisheries, mangroves and wetlands that are essential to the current livelihood patterns of many poor communities, while the dangers of salination of water supplies will affect these and other coastal communities. Mangroves are important nurseries for fish, prawns and other aquatic species.

Climate change impacts on mangroves would thus have serious consequences for the livelihoods of people. **India is a major seafood exporting country.** The fishery sector occupies a unique status in the national economy and provides employment opportunities and food and nutritional security to the growing population in the country, while also contributing to the GDP. About 1 million people in 3,651 villages of India situated along the coast are employed in marine capture fisheries. Indian fishery also supports several **ancillary activities such as boat building, processing plants** etc.

Changes to temperature and rainfall patterns are widely predicted, with many semi-arid parts of the developing world likely becoming even hotter and dryer with even less predictable rainfall. These changes will both directly affect crop yields and will produce changes to ecosystem distributions and species ranges. This will dramatically affect the livelihoods of many poor people, particularly through **declining food security and problems with the viability of many livelihood activities**, including livestock raising, fishing and the use of forest products as well as agricultural production. Secondary impacts will likely include increases in urban food prices and greater problems with services such as water supply and sanitation (exacerbating pressures that rapid urbanization will bring) that affect the urban poor.

The changing climate patterns, and especially the increased frequency and/or severity of extreme events, will **increase vulnerability to natural disasters**, both slower-onset ones such as droughts and rapid-onset disasters such as floods and cyclones. These will affect many areas, but semi-arid areas (droughts) and coastal and deltaic regions (floods and storms) are particularly vulnerable. **Dangers of erosion, landslides and flash floods** will also increase, particularly in many hilly and mountainous areas.

Changing climate patterns and more extreme events will have impacts on new livelihood activities such as **tourism,** that will limit diversification of opportunities which, combined with damage to infrastructure and other types of physical capital, will affect the wider range of vulnerabilities (such as limited access to markets) the poor face. The poor social and political capital, along with extremely limited access to financial capital, mean that these communities are least likely to be protected by investments in infrastructure or disaster mitigation and relief systems. Predicted adverse health risks will affect the poor in particular throughout the developing world. These risks are in particular those associated with **water-borne (such as dysentery or cholera) and vector borne (such as malaria) diseases, as well as heat stress morbidity and mortality.** These health impacts pose a double jeopardy for poor people's livelihoods: the contribution of key productive members of the household is lost and the cost of health care is expensive and time consuming. Such risks will be widespread, but the dearth of medical care systems in many more remote, poorer areas of Africa and Asia in particular mean that the poor in these areas are the most vulnerable to these risks. The **deterioration of the availability or quality of water supplies** in many areas (again due to wider resource stresses that climate change will exacerbate) will significantly increase many of these health risks, while poorer nutritional states caused by **declining food security** will make many poor people more vulnerable to the effects of diseases when they do strike.

TABLE: FISH PRODUCTION IN INDIA (IN LAKH TONNES)

Year	Marine	Inland	Total
1950 – 51	5.34	2.18	7.52
1960 – 61	8.80	2.80	11.60
1970 – 71	10.86	6.70	17.56
1980 – 81	15.55	8.87	24.42
1981 – 82	14.45	9.99	24.44
1982 – 83	14.27	9.40	23.67
1983 – 84	15.19	9.87	25.06
1984 – 85	16.98	11.03	28.01
1985 – 86	17.16	11.60	28.76
1986 – 87	17.13	12.29	29.42
1987 – 88	16.58	13.01	29.59
1988 – 89	18.17	13.35	31.52
1989 – 90	22.75	14.02	36.77
1990 – 91	23.00	15.36	38.36
1991 – 92	24.47	17.10	41.57
1992 – 93	25.76	17.89	43.65
1993 – 94	26.49	19.95	46.44
1994 – 95	26.92	20.97	47.89
1995 – 96	27.07	22.42	49.49
1996 – 97	29.67	23.81	53.48
1997 – 98	29.50	24.38	53.88
1998 – 99	26.96	26.02	52.98
1999 – 2000	28.52	28.23	56.75

TABLE: FISH PRODUCTION IN INDIA (IN LAKH TONNES)

Year	Marine	Inland	Total
2000 – 01	28.11	28.45	56.56
2001 – 02	28.30	31.26	59.56
2002 – 03	29.90	32.10	62.00
2003 – 04	29.41	34.58	63.99
2004 – 05	27.79	35.25	63.05
2005 – 06	28.16	37.56	65.72
2006 – 07	30.24	38.45	68.69
2007 – 08	29.19	42.07	71.26

Sources :

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Department of Agriculture & Cooperation Annual report 1990 – 91
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Addressing the impact of Climate Change

There are number of challenges facing biodiversity are the direct drivers of biodiversity loss—habitat change, climate change, the introduction of invasive alien species, overexploiting and nutrient loading. Such drivers are projected to either remain constant or to increase in the near future.

We can meet the challenge of climate change two ways: by **mitigation** and through **adaptation**. Mitigation is an anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases. In general it is the measures taken to reduce adverse impacts on the environment. Adaptation is adjustment in natural or human system to a new or changing environment. Adaptation to climate change refers to adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.

WHAT STEPS CAN BE TAKEN TO USE FOREST FOR CLIMATE CHANGE MITIGATION?

At global level, forests absorb about 30% of all CO_2 emissions from fossil fuel burning and net deforestation.

India's forests serve as a major sink of CO_2. Studies have shown that the annual CO_2 removals by India's forest and tree cover is enough to neutralize 11.25% of India's total GHG emissions (CO_2 equivalent) at 1994 levels. This is equivalent to offsetting 100% GHGs emissions from all energy in residential and transport sectors; or 40% of total emissions from the agriculture sector. Therefore, our forest and tree cover is serving as a major mode of carbon mitigation. With increase in forest cover the capacity of Indian forests to sink carbon has been increasing at annual rate of 138 million tones of CO_2.[6]

But at the same time there is an overall degradation in quality of forests that may impact its capacity to absorb carbon. An estimated **41% of India's forest cover has been degraded** to some degree in the past several decades. There are a number of major strategies available to mitigate carbon emissions through forestry management activities such as:

- **Reforestation and afforestation:** India needs to take up extensive afforestation programmes to increase its forest cover.

- **Increasing the quality of forest:** It is not only the extent of forests but also the quality of it, that speeds up effective carbon absorption. India has large chunk of degraded forest lands that need to be regenerated. There are over 100,000 committees under the Government's Joint Forest Management programme that envisage the management of such areas with local community involvement. India has around 1.2 million Ha of degraded forests that can be regenerated into well stocked forests. Reasons for degradation include human removal of forest biomass that is not recycled into soil nutrients, grazing pressure, fire and over cutting.

- Reducing deforestation: Reducing deforestation and forest degradation is the first line of defense towards climate protection. Global deforestation occurred at an alarmingly high rate of 13 million hectares per year during the period 1990 – 2005; and, net change in forest area in the period 2000 – 2005 was 7.3 million hectares per year. As a result of this continued deforestation and forest degradation, carbon stocks in forest biomass are lost by 1.1 Gt of carbon annually, and contribute to approximately 17.4% of annual GHG emissions, which is equal to 5.8 Gt CO_2/yr (IPCC 2007b).

- Encouraging biodiversity linked sustainable livelihoods: Biodiversity can best be protected by ensuring the livelihoods of the communities dependent on it. Indigenous communities have been enjoying traditional access and rights over local natural resources. Depletion of natural resources triggers poverty among local communities. Thus, as part of climate change mitigation, these communities must be encouraged to protect the local resources while eking out livelihoods out of it. The JFM programme and the Forest Rights Act are based on this principle of natural resource protection.

- Using NREGA for afforestation: Under the Mahatma Gandhi Rural Employment Guarantee Programme, afforestation is a key activity to be taken up. This programme is guided by a village plan approved by the local residents. So, it provides an effective platform to push for forestry activities at village level. The programme enjoys the full patronage and priority of the government.

Reducing Emissions from Deforestation and Degradation

Forestry, land use change and agriculture are major issues for climate change, accounting for almost 45% of emissions in developing countries. Reducing emissions from deforestation and forest degradation (REDD) has been identified as one of the most cost-effective ways to lower emissions.

REDD holds promise for linking carbon to improved biodiversity conservation and related benefits, since it relies on protection and improved management of natural forests. There is some controversy over how REDD should be funded and how emissions will be measured and monitored. Ascertaining deforestation trends is difficult, especially if payments are linked to incremental reductions in rates of deforestation. The IPCC has provided guidelines for monitoring and measuring GHG emissions from deforestation and forest degradation.

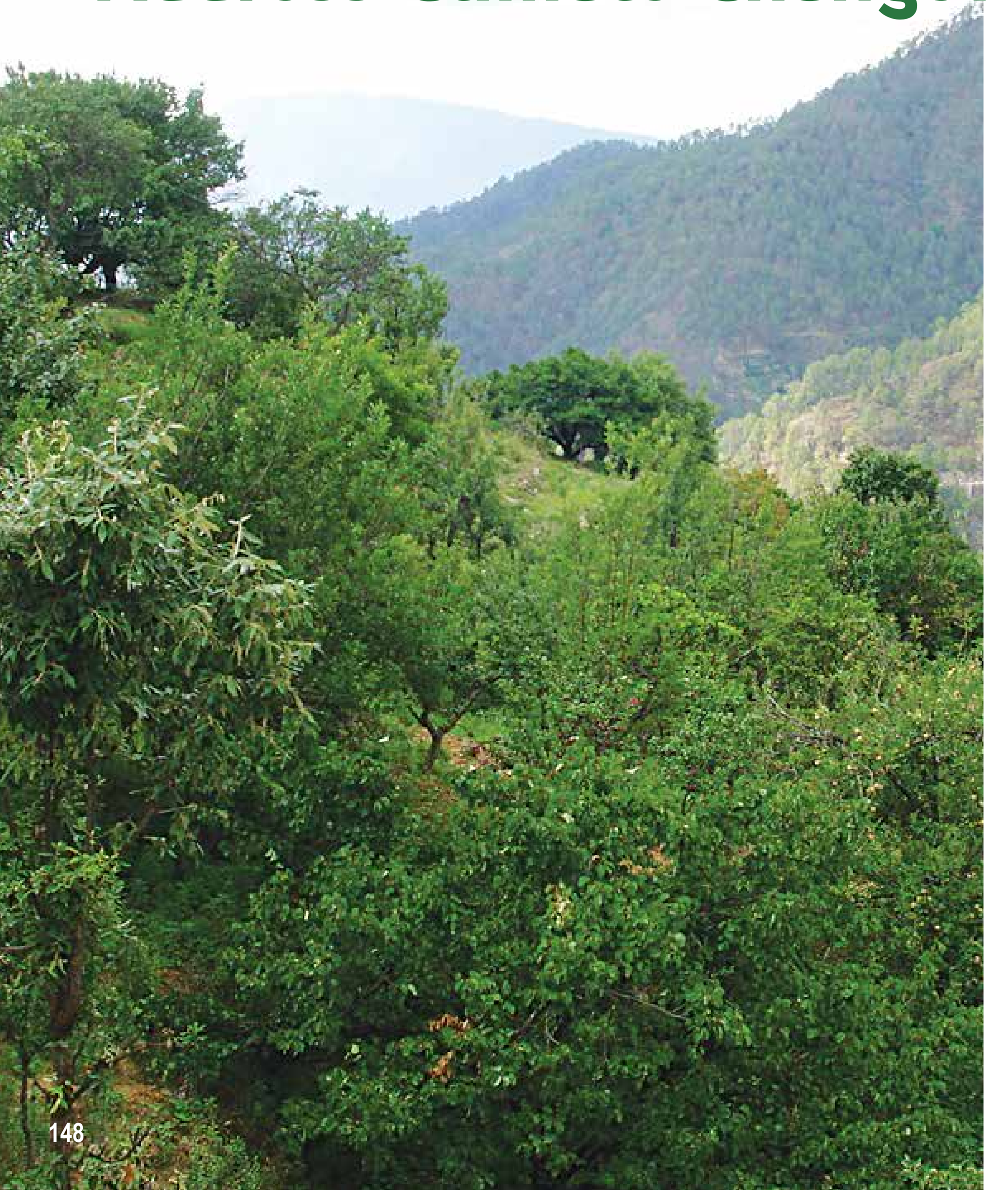
ADDRESSING CLIMATE CHANGE THROUGH ADAPTATION

While efforts are undergoing to mitigate adverse effects of climate change by reducing GHG emissions, **there have been some irreversible impacts for which adaptation will be required**. Addressing the impacts that are already being experienced by people and ecosystems while mitigation measures take effect, and building resilience to future impacts.

Climate change has come as an additional threat. In order to address impact of climate change on biodiversity, it is important to address existing pressures. Anthropogenic activities such as mining, over-fishing, pollution and unsustainable development activities have disturbed coral reefs in the Gulf of Mannar. Invasion of exotic seaweed, algal bloom, trap fishing, sewage disposal and seaweed collection have emerged as other major threats to biodiversity.

There have been number of **studies that project loss of biodiversity due to climate change.** These studies have highlights impact of climate change on forest cover and forest composition in India; some studies have focused on shift in forest types because of projected increase in temperatures.

Are Natural Resources an Effective Mechanism to Address Climate Change?



There is profound interconnection between climate change and natural ecosystems. Ecosystems like forests provide a wide range of services—**provisioning** (e.g., food and fibre), **regulating** (e.g., climate and floods), cultural (e.g., recreational and aesthetic) and **supporting** (e.g., soil formation). These are critical to human well-being including human health, livelihoods, nutritious food, security and social cohesion.

Conserving natural ecosystems (whether these are forests, wetlands, rivers, estuaries, coastal) and **restoring degraded ecosystems** is essential for addressing climate change. Ecosystems play a key role in the global carbon cycle and in adapting to climate change, while also providing a wide range of ecosystem services that are essential for human well-being and the achievement of the **Millennium Development Goals.** We learnt in the previous module that forests acts as net sink of CO_2 if managed effectively.

While **ecosystems are generally more carbon dense** and biologically more diverse in their natural state, the degradation of many ecosystems has significantly reduced their carbon storage and sequestration capacity, leading to increases in emissions of GHG and loss of biodiversity at the genetic, species and ecosystem level.

Climate change itself is coming as an additional stress on ecosystems and can exacerbate the effects of other existing stresses, including from habitat fragmentation and degradation, over-exploitation, invasive alien species, changes in land use pattern and pollution. Human induced climate change could **shift the net natural carbon cycle towards annual net emissions** from forests and other terrestrial sinks like grasslands and further accelerate climate change.

Thus the goal of any adaptation strategy should be to maintain the greatest amount of ecological integrity of the natural ecosystems. This would require **nature-based responses to climate change** as they are an integral part for building a climate-resilient society with the benefits and co-benefits of ecosystem-based adaptation that uses ecosystem services as part of an overall adaptation strategy. Ecosystem-based adaptation, which can be integrated into community-based adaptation, is a cost-effective way to protect vulnerable communities from the adverse effects of climate change. Healthy and well-managed ecosystems also have great potential for climate change mitigation. So it is a win-win solution for both adaptation and mitigation.

The climate change adaptation is not just about biodiversity conservation but also an issue of food security, coping with extreme weather and natural disasters, and dealing with the potentially massive re-locations of people and land-uses in the face of sea level changes and shifting ecosystems and species ranges.

Climate Change Adaptation Adds to Food Security

Conserving, restoring and sustainably managing ecosystems, as part of an adaptation strategy can also help conserve biodiversity and a wider range of ecosystem services through providing important habitats and biological resources, and maintaining landscape connectivity. For example, the conservation or restoration of wetlands to ensure continued water flow in periods of drought also conserves plant and animal species that live or breed in these systems. The establishment of diverse agroforestry systems with native plant species as an adaptation measure can similarly help conserve biodiversity. The creation or expansion of community conserved areas in dryland regions can not only provide additional fodder resources for pastoralist, but also provide habitat for native dryland species. Similarly, the establishment or creation of networks of marine protected areas can ensure the continued provision of ecosystem services for adaptation, as well as biodiversity conservation.

Ecosystem-based Adaptation (EbA) integrates the use of biodiversity and ecosystem services into an overall strategy to help people adapt to the adverse impacts of climate change.

It includes the sustainable management, conservation and restoration of ecosystems to provide services that help people adapt to both current climate variability, and climate change. Ecosystem-based Adaptation contributes to reducing vulnerability and increasing resilience to both climate and non-climate risks and provides multiple benefits to society and the environment. According to the Convention on Biological Diversity (CBD), an ecosystem-based approach uses biodiversity and ecosystem services and generates socio-economic as well as ecological benefits.

WHAT IS ECOSYSTEM BASED ADAPTATION

Climate change is projected to affect availability of freshwater, agriculture productivity, coastal areas through sea level rise, distribution of rainfall and biodiversity. Accordingly, many recent climate change adaptation initiatives have focused on the use of technologies and the design of climate resilient infrastructure. These infrastructure developments will be required for coastal defense and flood control, to meet the demand for new irrigation facilities and new reservoirs. However, there is growing recognition of the **role healthy ecosystems can play in helping people adapt to climate change**. Healthy ecosystems provide drinking water, habitat, shelter, food, raw materials, genetic materials, a barrier against disasters, a source of natural resources, and many other ecosystem services on which people depend for their livelihoods.

Forests, wetlands or other natural habitats play an important role in protecting high-quality water supplies. Similarly, natural ecosystems can reduce vulnerability to natural hazards and extreme climatic events and complement, or substitute for, more expensive infrastructure investments to protect coastal and riverine settlements. Floodplain forests and coastal mangroves provide storm protection and coastal defenses and serve as safety barriers against natural hazards such as floods, hurricanes, and tsunamis, while wetlands filter pollutants and serve as water recharge areas and as nurseries for local fisheries.

Thus, **protecting forests, wetlands, coastal habitats and other natural ecosystems can provide social, economic and environmental benefits**, both directly through more sustainable management of biological resources and indirectly through protection of ecosystem services. Natural ecosystems maintain the full range of goods and ecosystem services, including water supply, fisheries etc on which human livelihoods depend; these services are especially important to the most vulnerable sectors of society. Protected areas can protect watersheds and regulate the flow and quality of water, prevent soil erosion, influence rainfall regimes and local climate, conserve renewable harvestable resources and genetic reservoirs, and protect breeding stocks, natural pollinators etc which maintain ecosystem health.

As natural buffers, ecosystems are often cheaper to maintain, and often more effective, than physical engineering structures, such as dykes or concrete walls. Ecosystem-based Adaptation, therefore, offers a means of adaptation that is readily available to the rural poor; it can be readily integrated into community-based adaptation and addresses many of the concerns and priorities identified by the most vulnerable countries and people. In addition, healthy ecosystems, such as forests, wetlands, mangroves and coral reefs, have a greater potential to adapt to climate change themselves, and recover more easily from extreme weather events.

ECOSYSTEM BASED ADAPTATION IN PRACTICE

Ecosystem-based adaptation can be applied at different geographical scales **(local, regional, national)** and within various time frames **(short to long term)**. It can be implemented as projects and as part of overall adaptation programmes. It is most effective when implemented as part of a broad portfolio of adaptation and development interventions, such as early warning systems, education, and physical infrastructure. EbA involves a wide range of ecosystem management activities to **increase resilience and reduce the vulnerability** of people and the environment to climate change. Ecosystem-based adaptation can be applied at regional, national and local level, at both project and programmatic levels, and over short or long time scales.

Tree Wall as Adaptation Strategy, Midnapur, West Bengal

Jargram Block in the district has been facing severe impacts of such violent super-cyclones since 2004. After the Aila cyclone, local communities supported by CBOs planted tree wall as adaptation strategy to withstand cyclones and violent storms. The community takes care of the plants and monitoring activities. The local community has appreciated the urgency of climate change adaptation and adapted to the change which has proved to be beneficial.

These activities include:

1. **Sustainable water management,** where river basins, aquifers, flood plains and their associated vegetation are managed to provide water storage and flood regulation services;
2. **Disaster risk reduction,** where restoration of coastal habitats such as mangroves can be a particularly effective measure against storm-surges, saline intrusion and coastal erosion;
3. **Sustainable management of grasslands and rangelands**, to enhance pastoral livelihoods and increase resilience to drought and flooding;
4. **Establishment of diverse agricultural systems,** where using indigenous knowledge of specific crop and livestock varieties, maintaining genetic diversity of crops and livestock, and conserving diverse agricultural landscapes secures food provision in changing local climatic conditions;
5. **Strategic management of shrub lands and forests** to limit the frequency and size of uncontrolled forest fires; and
6. **Establishing and effectively managing protected area systems** to ensure the continued delivery of ecosystem services that increase resilience to climate change.

BENEFITS OF ECOSYSTEM BASED ADAPTATION

Ecosystem-based Adaptation reduces vulnerability to both climate and non-climate risks and provides multiple economic, social, environmental and cultural benefits including:

Disaster Risk Reduction

Ecosystem-based Adaptation measures frequently complement disaster risk reduction objectives. Healthy ecosystems play an important role in **protecting infrastructure and enhancing human security**, acting as natural barriers and mitigating the impact of (and aiding recovery from) many extreme weather events, such as coastal and inland flooding, droughts, extreme temperatures, fires, landslides, hurricanes and cyclones.

Climate change has accentuated exposure to various natural hazards. At the same time degradation of natural ecosystems and ecosystem services have increased the exposure to the disaster risks. The Global Assessment Report of the United Nations ISDR113 also recognizes the decline of ecosystems and the associated **degradation of ecosystem services as one of the three main drivers of disaster risk.** Degradation of mangrove ecosystem in Sunderbans increased the exposure to the cyclone Aila. The local communities in Paschim Medinipur, West Bengal are now planting mangrove seawall as an adaptation strategy to withstand cyclones and violent storms. While climate-related disasters such as droughts, floods and cyclones cause loss of lives, they also destroy livelihoods especially for the poor.

Ecosystem-based adaptation options are often more accessible to the rural poor than adaptation interventions based on infrastructure and engineering. The poor are often the most directly dependent on ecosystem services and thus benefit from adaptation strategies that maintain and enhance those services. Ecosystem-based adaptation can be consistent with community-based approaches to adaptation; can effectively build on local knowledge and needs; and can provide particular consideration to the most vulnerable groups of people, including women, and to the most vulnerable ecosystems. **There can be multiple social, economic and environmental co-benefits for local communities from the use of ecosystem-based adaptation.** Communities that are managing ecosystems specifically to adapt to climate change impacts can also benefit from these interventions in other ways, if they are designed and managed appropriately. For example, the restoration of mangrove systems can provide shoreline protection from storm surges, but also provide increased fishery opportunities, and carbon sequestration. As such, ecosystem-based adaptation can sometimes achieve adaptation benefits for many sectors through a single investment.

Livelihood Sustenance and Food Security

By protecting and restoring healthy ecosystems to be more resilient to climate change impacts, Ecosystem based Adaptation strategies can help to ensure continued availability and access to essential natural resources so that communities can better cope with current climate variability and future climate change. In this context, Ecosystem-based Adaptation can directly meet the needs of **Community Based Adaptation and poverty reduction initiatives.**

Ecosystem-based approaches that implement crop rotations, choose crops with less intensive nutrient and water requirements, control invasive alien species, maintain local landraces and crop varieties, and protect reefs and mangroves for sustainable fisheries.

Biodiversity Conservation

Protecting, restoring, and managing key ecosystems helps biodiversity and people to adjust to changing climatic conditions. Ecosystem-based Adaptation can safeguard and enhance protected areas and fragile ecosystems. It can also involve **restoration of fragmented or degraded ecosystems, or simulation of missing ecosystem processes** such as migration or pollination.

Carbon Sequestration

Ecosystem-based Adaptation strategies can complement and enhance climate change mitigation by **conserving carbon stocks, reducing emissions from ecosystem degradation and loss, and enhancing carbon sequestration.** Sustainable management of forests can store and sequester carbon by improving overall forest health, and simultaneously sustain functioning ecosystems that provide food, fibre and water resources that people depend on. Conservation and, in some cases restoration, of peatlands can protect very significant carbon stores. Additional mitigation efforts can be realized through **land and water management practices** that sustain essential natural resources while minimizing additional greenhouse gas emissions. Similarly, the conservation and restoration of other natural ecosystems (such as savannahs, grasslands and wetlands) can result in both adaptation and mitigation benefits.

Sustainable Water Management

Managing, restoring and protecting ecosystems can also contribute to sustainable water management by, for example, **improving water quality, increasing groundwater recharge and reducing surface water run-off** during storms. About one third of the world's largest cities obtain a significant proportion of their drinking water directly from forested protected areas.

Ecosystem-based approaches can contribute to adaptation strategies through the following:

- **Maintaining and restoring natural ecosystems and the goods and services they provide**
- **Protecting and enhancing vital ecosystem services, such as water flows and water quality**
- **Maintaining coastal barriers and natural mechanisms of flood control and pollution reduction**
- **Reducing land and water degradation by actively preventing and controlling the spread of invasive alien species**
- **Managing habitats that maintain nursery, feeding and breeding grounds for fisheries, wildlife, and other species on which human populations depend**
- **Providing reservoirs for wild relatives of crops to increase genetic diversity and resilience.**

PRINCIPLES OF EFFECTIVE ECOSYSTEM BASED ADAPTATION

Experience of EbA Ecosystem-based Adaptation projects, suggests some fundamental guiding principles for developing effective EbA strategies. These principles include:

Focusing on reducing non-climatic stresses

Reducing ecosystem degradation is a no regrets, win-win approach to adaptation. Ecosystem-based Adaptation strategies should include a focus on minimizing other anthropogenic stresses that have degraded the condition of critical ecosystems, and thereby undermine their resilience to climate change. Such stresses include, inter alia, **unsustainable harvests, habitat fragmentation, nonnative species and pollution**.

Involving local communities

Community participation is an important element in all of the case studies profiled. Ecosystem-based Adaptation measures are more successful when the local population participates in both planning and implementation.

Multi-partner strategy development

Many of the case studies profiled here involve **multi-partner funding and cooperation.** Ecosystem-based Adaptation presents a tangible opportunity to solve climate change problems by aligning conservation, development, and poverty alleviation interests. Such synergies benefit from collaboration between indigenous and local communities, conservationists, natural resource managers, relevant private sector stakeholders, development specialists, and humanitarian aid specialists

Participatory Approach to Vulnerability Assessment and Adaptation,

West Midnapur

Working on participatory tools for community adaptation to Climate Change in West Midnapur district shows that communities facilitated by local CBOs could be used for assessing vulnerability and designing adaptation strategy. Under the programme, two Self Help Groups with the help of local CBO first generated data on incidences of super cyclones and decided on setting up a tree wall as adaptation strategy to withstand the cyclones like Aila.

Building upon existing good practices in natural resource management

The most effective Ecosystem-based Adaptation strategies apply established best practices in land, water, and natural resource management to confront some of the new challenges posed by climate change. The application of the ecosystem approach for the integrated management of resources is particularly appropriate to the implementation of Ecosystem-based Adaptation.

Adopting adaptive management approaches

Ecosystem-based Adaptation strategies should support adaptive management options that facilitate and accelerate learning about appropriate adaptation options for the future. Climate impacts and EbA measures should be monitored carefully so that management actions can be appropriately adjusted in response to changing conditions.

Integrating Ecosystem-based Adaptation with wider adaptation strategies

Successful adaptation depends upon integrating Ecosystem-based Adaptation initiatives with other risk management components, such as early warning systems and awareness-raising, and in some cases with physical infrastructure interventions. It is important to encourage and enable technology transfer and dialogue between planners and practitioners with expertise in hard engineering, and in ecosystem management.

Communicating and educating

Successful Ecosystem-based Adaptation depends on knowledge transfer, capacity building, integrating science and local knowledge and raising awareness about climate change impacts and the benefits and potential of sound ecosystem management.

ECOSYSTEMS

THE WIN-WIN LINK BETWEEN MITIGATION, ADAPTATION AND SUSTAINABILITY

An ecosystems approach can fulfil objectives for both mitigation of, and adaptation to climate change as well as being the foundation for long term sustainability. Protecting ecosystems provides multiple benefits, both directly through sustainable management of biological resources and, indirectly through protection of ecosystem services:

Social – Secure livelihoods, particularly the poor; health; cultural and aesthetic values; community support.

Economic – Resilient ecosystems secure service provision to support all forms of economic activity.

Climate regulation – Ecosystems function as tools for mitigation, through appropriate management to reduce natural sources of emissions or increase absorption capacity.

Environmental – Resilient healthy ecosystems have the capacity to support long-term sustainability.

Despite the relatively high costs as compared to conservation of existing intact ecosystems, restoration of ecosystems can still be part of a cost-effective adaptation strategy. Restoration activities include limiting activities such as grazing or extraction to allow ecosystems to recover, or restoring ecological components such as connectivity or hydrological regimes, through activities such as re-flooding wetlands. For example, **flood plain restoration** can be a useful alternative to constructing additional dams or reservoirs for increased flood-water storage, and reforestation of degraded areas can be an effective strategy to enhance land productivity.

SMS Alert for Weather Forecasting, Sunderbans

In changing climatic conditions, it is the unpredictability of monsoon that makes farmers most vulnerable. To overcome this, scientists from the Krishi Vigyan Kendra in Sunderbans are trying to help farmers by making certain predictions based on meteorological data. The information is sent across using SMS service of mobile phones. Through this, farmers are able to prepare themselves better for facing any undesirable situation.

Enhancing Farmers' Capabilities for Informed Decision

As part of the initiatives to enhance farmers' capabilities to make informed decisions at the community level, Andhra Pradesh Farmers Managed Groundwater System (APFAMGS) project worked with 638 villages. Their experience shows improvement in groundwater levels and improved efficiency in use of irrigation water. They also demonstrated that knowledge generated though collective sharing process gets internalized within the community.

ENHANCING OUR UNDERSTANDING

BARRIERS, LIMITS AND KNOWLEDGE GAPS

Like all adaptation activities ecosystem-based adaptation is not without complexity, uncertainty, and risk. There could be number of barriers which can include a **lack of finance, land use conflict and community opposition.** Knowledge gaps can also be a problem; there is a lack of information about the costs and benefits of EbA measures, for example.

As with all adaptation interventions, there are inevitably limits to Ecosystem-based Adaptation. Healthy, resilient ecosystems cannot protect communities from all climate or extreme weather-related impacts. In some situations, engineering solutions will still be required instead of, or alongside, Ecosystem-based Adaptation measures. There will also be **ecological limits to Ecosystem-based Adaptation.**

Opportunities to increase ecosystem resilience to future climate change may only be effective for lower levels of climate change (≤2 – 3°C), since beyond certain levels of climate change, impacts on ecosystems are expected to be severe and largely irreversible. Indeed, thresholds of resilience for many ecosystems are likely to be exceeded over the longer term unless greenhouse gas emissions are sharply and quickly reduced and **temperature rise is kept within a 2°C limit.**

UNDERSTANDING VULNERABILITY

Ecosystem-based adaptation includes a range of **local and landscape scale strategies** for managing ecosystems to increase resilience and maintain essential ecosystem services and reduce the vulnerability of people, their livelihoods and nature in the face of climate change.

In order to provide suitable adaptation strategy against deleterious effects of climate change, it is important to first assess how communities/ecosystems/regions are vulnerable to various Climate Change impacts. **Vulnerability assessment to Climate Change has to be location/ region specific.** This is primarily because the regions differ vastly in agro-climatic characteristics and extreme climatic conditions that they face.

Risks to biodiversity from climate change can be initially assessed using available vulnerability and impact assessment guidelines. However, further development and validation of tools is necessary because uncertainties limit our ability to project climate change impacts on biodiversity and ecosystem services.

However, there is no universally accepted methodology available to assess climate vulnerability at the local level. One of the important methodologies is **Participatory Disaster Risk Assessment (PDRA), which is based on the well known Participatory Rural Appraisal (PRA) technique.** PRA is an excellent technique to collect basic information about the resources and vulnerability of the village and gram panchayats.

Using Participatory Disaster Risk Assessment to Address Climate Change Related Issues

Assessment of vulnerability could be done through a Detailed Vulnerability Mapping along with the community through Participatory Disaster Risk Assessment (PDRA). Climate change management issues have been addressed in the preparation of a Village Disaster Management Plan in Kanyakumari District.

Using PRA for Vulnerability Assessment

Participatory Rural Appraisal (PRA) can be used for collecting basic information about the village and gram panchayat resources and vulnerability. A map for Thoothukudi District Disaster Management Plan in Tamil Nadu has been developed using scientific data on land use, geomorphology, hydro geological situation etc. Such data along with PRA resources, provides clear picture of a village vulnerability. Based on this a suitable participatory adoption strategy can be designed.

How does India plan to address climate crisis?

Because of the speed at which change is happening due to global temperature rise, it is urgent that the vulnerability of communities of India to climate change is reduced and their capacity to adapt should be increased. The vulnerabilities arising out of climate change are multidimensional and interlinked, with vulnerability in one sector compounding vulnerabilities in others. Changes in rainfall pattern are likely to lead to severe water shortages and/or flooding. Melting of glaciers can cause flooding and soil erosion. Rising temperatures will cause shifts in crop growing seasons which affects food security and changes in the distribution of disease vectors putting more people at risk from diseases such as malaria and dengue fever. Temperature increases will potentially severely increase rates of extinction for many habitats and species. Increasing sea levels mean greater risk of storm surge, inundation and wave damage to coastlines. A rise in extreme events will have effects on health and lives as well as associated environmental and economic impacts.

The Government of India in its response on climate change put forth a National Action Plan on Climate Change (NAPCC) in 2008, which emphasized the need for dealing with the challenges of global climate change without compromising on sustaining its high economic growth path. The NAPCC has identified eight different sectors, which are climate sensitive and indicated the nature of government interventions in these sectors, which it construes as adaptation. These sectors are **Crop improvement, Drought proofing, Forestry, Water resources, Coastal regions, Health, Risk financing and Disaster management.** The quantum of government expenditure on adaptation across all these sectors is more than 2.6% of GDP as of year 2006 – 07 as reported in the action plan.

NAPCC has envisaged eight national missions to address challenges posed by climate change both for mitigation and adaptation. These eight national missions include:

- **National Solar Mission,**
- **National Mission for Enhanced Energy Efficiency,**
- **National Mission on Sustainable Habitat,**
- **National Water Mission,**
- **National Mission for Sustaining the Himalayan Ecosystems,**
- **National Mission for a Green India,**
- **National Mission for Sustainable Agriculture,**
- **National Mission on Strategic Knowledge for Climate Change.**

WHAT IS GOVERNMENT DOING FOR OUR FORESTS AND BIODIVERSITY?

India has initiated a series of forestry programmes on sustainable forest management. India's forest planning and development programmes are aimed at addressing the likely impacts of climate change and appropriately adopt various policy imperatives and management practices to minimize the adverse impacts and vulnerability. Adaptation strategies are also being developed to ensure a proper balance between demand and supply of forest products.

The National Mission for a Green India, under NAPCC is a lead programme for augmenting the forest cover from the existing 23.84% to 33%. Under the Mission, six million Ha of degraded forests would be afforested with the participation of the local communities.

National Mission for Sustaining the Himalayan Ecosystems is aimed at evolving adaptation and management measures for sustaining and safeguarding the Himalayan glacier, mountain ecosystem and biodiversity.

State Level Adaptation Strategies

With the formulation of a national policy on climate change, it has become imperative to achieve coherence between the strategies and actions at national and state levels. Adaptation challenges are experienced most acutely at the state level. States are in the process of preparing their respective State Action Plan on Climate Change (SAPCC) with focus on adaptation to climate change aimed at major sectors including that of forests and biodiversity.

WHAT CAN 'WE' AS A COMMUNITY DO?

- Document and communicate local experience and knowledge of dealing with climate-induced changes, including through working with local NGOs;
- Undertake participatory appraisal of resources, needs and options
- Become actively involved in local and district level planning for adaptation;
- Advocate where possible for sub-national, national, regional and international adaptation policy that is locally focused and community based, taking account of traditional knowledge and the importance of ecosystems and their services, and that addresses the needs of the most vulnerable countries, communities, ecosystems and livelihoods. This needs to be supported by scaled up new, additional, stable and flexible funding.
- Share community, traditional and indigenous knowledge (based on free, prior and informed consent) to help ensure effective and locally appropriate adaptation.

ADAPTATION PLANS AND PRACTICES IN FORESTRY & BIODIVERSITY SECTOR

The Forest Conservation Act 1980, provides for conservation of forests by avoiding deforestation and controlling degradation of forests. In addition India has a large afforestation programme that aims to **increase forest cover by 33%** of total geographic area.

Under the National Afforestation and Eco-development Board, it promotes afforestation, ecological restoration and eco-developmental activities in the country with special attention to regeneration of degraded forest areas and land adjoining forest areas, national parks, sanctuaries and other protected areas.

The **National Biodiversity Action Plan** of the Union Ministry of Environment and Forest, a comprehensive documentation of India's diverse biodiversity and local knowledge of its management, aims at **protecting the flora and fauna with active community participation.**

INTERNATIONAL POLICY FRAMEWORK

India has signed a number of **multilateral environmental agreements** that set a relevant policy framework for conservation, sustainable management of forests and biodiversity as well as addressing climate change such as United Nations Convention to Combat Desertification (UNCCD), the Convention on Biological Diversity (CBD), and the UN Framework Convention on Climate Change (UNFCCC).

These conventions have also identified synergies to address the interacting effects of **desertification, biodiversity loss and climate change impacts**. The interlink between desertification and biodiversity loss in the world's drylands has induced the Secretariats of the CBD and UNCCD to agree a **Joint Work Programme (JWP) in 2003, focusing on the biological diversity of dry and sub-humid lands.** The CBD renewed the Programme of Work on Protected Areas to address more specifically the role of protected areas in responses to climate change, in liaison with other CBD programmes. The UNFCCC has recognized protected areas as tools for mitigation and adaptation to climate change, and has opened up key climate change related funding mechanisms, including REDD and adaptation funds, to the creation, enhancement and effective management of protected area systems.

The United Nations Framework Convention on Climate Change (UNFCCC) agreed in 1992 to an **international template for fighting climate change**. The Convention is meant to stabilize GHGs emission to a level that would allow the ecosystems to adapt naturally to climate change.

Time Line Climate change in context

2011 : The Durban Platform for Enhanced Action agreed by governments that provides for a path to negotiate a new agreement for emission reduction agreement to come into effect by 2020.

2010 : Cancun Agreements provides for Cancun Adaptation Framework for enhanced action on adaptation, including through international cooperation.

2007 : IPCC's Fourth Assessment Report released. Bali Action Plan agreed that provides for enhanced cooperation on mitigation, adaptation, technology and financing.

2005 : Entry into force of the Kyoto Protocol Nairobi Work Programme on Adaptation accepted and agreed on.

2001 : Release of IPCC's Third Assessment Report. Marrakesh Accords adopted setting up new funding and planning instruments for adaptation.

1997 : Kyoto Protocol came into existence that introduces legally binding commitments for GHGs emission reduction for the developed countries known as Annex-I countries.

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IMPACT OF CLIMATE CHANGE ON WATER

IMPACT ON GLACIERS

Melting of Glaciers leading to water shortage and sea level rise

Formation of glacial lakes and glacial lake outburst floods

Melting of polar ice leading to increased solar absorption, raising temperature.

IMPACT ON PRECIPITATION

Increased rainfall in higher latitudes and a decrease in tropical areas

Changes in hydrological balance and ocean salinity

Increase in floods, droughts, landslides, intense storms, and tropical cyclones

IMPACT ON WATER RESOURCES

Decline in glaciers and snowfields in the Himalayas

Increased drought-like situations due to the over-all decrease in the number of rainy days over a larger parts of the country

Increased flood events due to the overall increase in rainfall intensity

Effect on groundwater quality in alluvial aquifers due to increased flood and drought events

Influence on groundwater recharge due to changes in precipitation and evapotranspiration

Increased saline intrusion of coastal and island aqui-fers due to rising sea levels

Impact on Mountain Snow

Declining snow fall and reduced moisture for growing crops

Rain, rather than snow, even at higher altitudes Of polar ice caps and glaciers

More frequent flash floods

Accelerated soil erosion

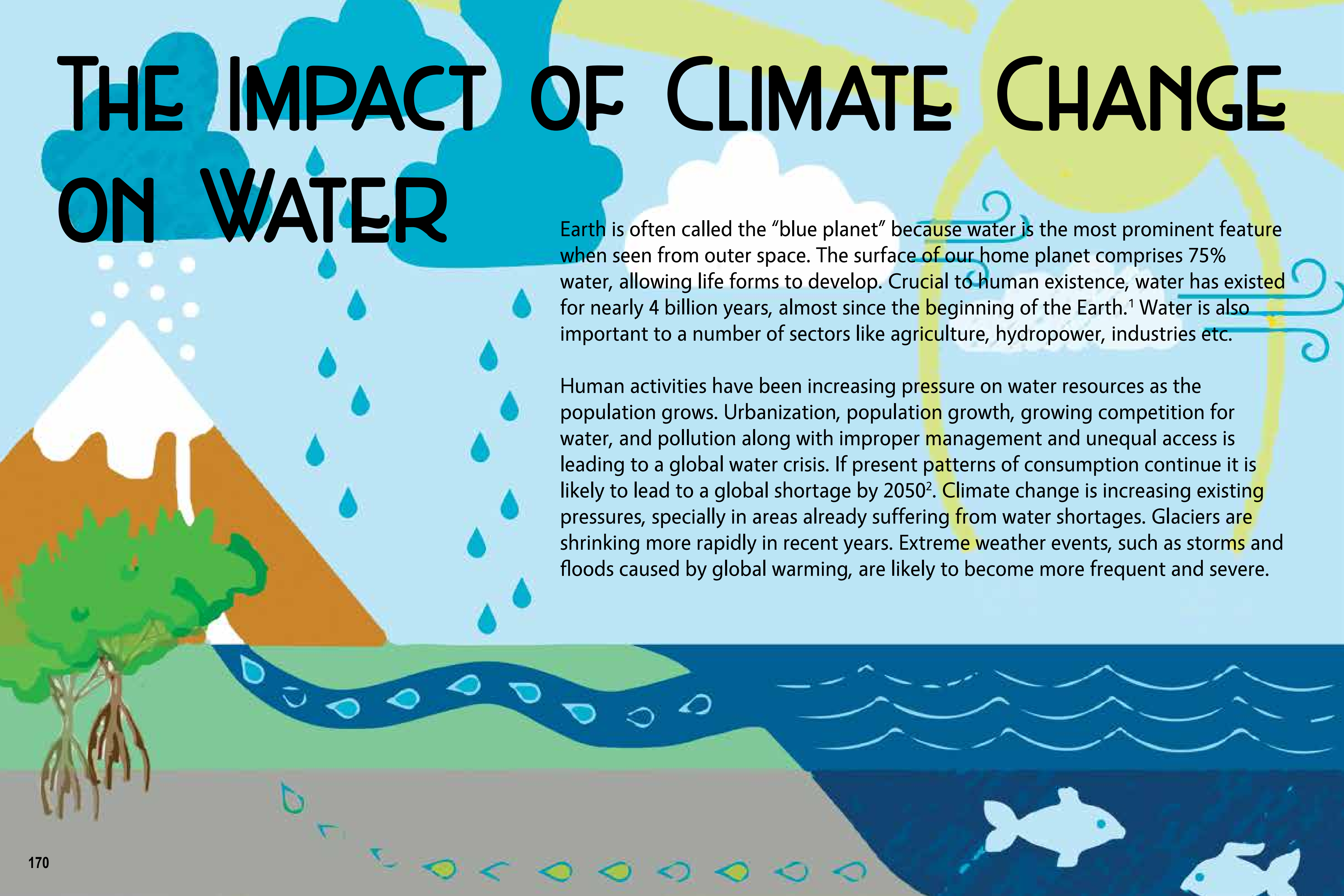
IMPACT ON SEA LEVEL

Sea level rise is likely to lead to coastal erosion, wetland and coastal plain flooding, salinization of inland aquifers and arable land and a loss of habitats for wildlife like fish, birds and plants

IMPACT ON AQUIFERS AND DRINKING WATER

Contamination of fresh water

The Impact of Climate Change on Water



Earth is often called the "blue planet" because water is the most prominent feature when seen from outer space. The surface of our home planet comprises 75% water, allowing life forms to develop. Crucial to human existence, water has existed for nearly 4 billion years, almost since the beginning of the Earth.[1] Water is also important to a number of sectors like agriculture, hydropower, industries etc.

Human activities have been increasing pressure on water resources as the population grows. Urbanization, population growth, growing competition for water, and pollution along with improper management and unequal access is leading to a global water crisis. If present patterns of consumption continue it is likely to lead to a global shortage by 2050[2]. Climate change is increasing existing pressures, specially in areas already suffering from water shortages. Glaciers are shrinking more rapidly in recent years. Extreme weather events, such as storms and floods caused by global warming, are likely to become more frequent and severe.

CLIMATE CHANGE & WATER

According to the IPCC 4th Assessment Report (AR4), climate change is unequivocal but how climate change will affect water resources is not altogether clear. New research suggests that climate change is making existing stress even worse. Scientists agree that extreme weather events stemming from global warming, such as storms and floods, are likely to be more frequent in the future. However, based on current knowledge, scientists can only make general predictions about the impact of climate change on water resources.[3]

One type of water resource that has been clearly affected by climate change is glaciers. Scientists have long observed that land and mountain glaciers are shrinking, and this trend has accelerated considerably in recent years. Studies have confirmed that climate change will result in an **intensification and acceleration of the global hydrological cycle**. This will lead to change in rainfall patterns that will reduce groundwater recharge due to faster surface runoff. As a result floods and droughts will increase. Besides impacting quality of water sources, there will also be **scarcity of fresh water.** These changes will in turn affect irrigation, agriculture and food production, water supplies and sanitation.

Water Resources in India

India has about 16% of the global population but it has only 4% of global water resources. The irrigation sector is the main consumer of this resource. The **main water resource in India consists of snow and rainfall** – estimated to be around 4,000 cubic kilometers per year (km^3/year) and trans-boundary flows, which it receives in its rivers and aquifers from the upper riparian countries. The **Ganga–Brahmaputra–Meghna system** is the major contributor to the total water resource potential of the country. It constitutes about 60% of the total water of the various rivers. Precipitation over a large part of India is concentrated in the monsoon season during June to September/October. Precipitation varies from 100 mm in the western parts of Rajasthan to over 11,000 mm at Cherrapunji in Meghalaya. Out of the total precipitation, including snowfall, the availability from surface water and replenishable groundwater is estimated at 1,869km^3. [4]

The average water yield per unit area of the Himalayan rivers is almost double than that of South Peninsular river systems. This indicates the importance of snow and glacier melt to the Himalayan region. Rainfall contribution to river flows is greater in the eastern region, while the snow and glacier melt contributions are more important in the western and central Himalayan region. Most of the rivers in southern India like the **Cauvery, the Narmada and the Mahanadi are fed through groundwater discharges** and are supplemented by monsoon rains. So these rivers have very limited flow during non-monsoon periods. The flow rate in these rivers is independent of the water source and depends upon the precipitation rate in the region.

Major glacier-fed Himalayan rivers, along with glaciated catchments, have regional importance—the water from the glacier melt sustains stream flow through the dry season. The "frozen water" in the Himalayas is crucial for the people inhabiting the mountain areas as well as for those in downstream regions. The **Indus basin** has a total glacier cover of 33,679 km^2 and an ice volume of 363.10 km^3. The **Ganga basin** has a glacier cover of 2,857 km^2 and ice volume of 209.37 km^3. Snow contribution to the runoff of major rivers in the eastern Himalayas is about 10% but more than 60% in the western Himalayas. The Himalayas cover a surface area of permanent snow and ice of about 97,020 km^2, with a volume of 12,930 km^3. In these mountains, it is estimated that **10–20% of the total surface area is covered with glaciers** while an additional area of 30–40% has seasonal snow cover. These glaciers, provide snow and glacial melt waters and keep our rivers perennial.[5]

The other major source of water is **groundwater, which has two components—static and dynamic**. The static fresh groundwater reserve of the country has been estimated at 10,812 billion m^3. The dynamic component, which is replenished annually, has been assessed as 432 billion m^3. According to the national water policy, development of groundwater resources is to be limited to utilization of the dynamic component of groundwater. The present development policy, forbids utilization of the static reserve to prevent groundwater exhaustion.[6]

Water Resources in India

In India, extreme conditions of floods and droughts are a common feature, which affect the availability of water for various uses. An estimated **40 million ha of area is flood-prone** and this constitutes 12% of the total geographical area of the country. On the other hand, about 51 mha , amounting to **16% of the total geographical area is drought prone.**

Exacerbating this situation is the growing demand for water. With the growing population and depleting water resources, the per capita availability of water in the country has decreased from 5,177 cubic metres per year (m^3/year) in 1951 to 1,654 m^3/year in 2007. It is further projected to decline to about 1,341m^3/yr in 2025. This estimate however does not include the impacts of climate change on water resources.[7]

According to the 2006 Human Development Report, **South Asia is facing high water stress** that is likely to get worse. Consuming more than 25% of the world's groundwater at 230 cubic kilometers annually; the World Bank reports that India is the world's leading user. More than half of Indian agriculture depends on irrigation systems based on groundwater. This rate of use could mean water stress for 60% of the country's aquifers by 2050.[8]

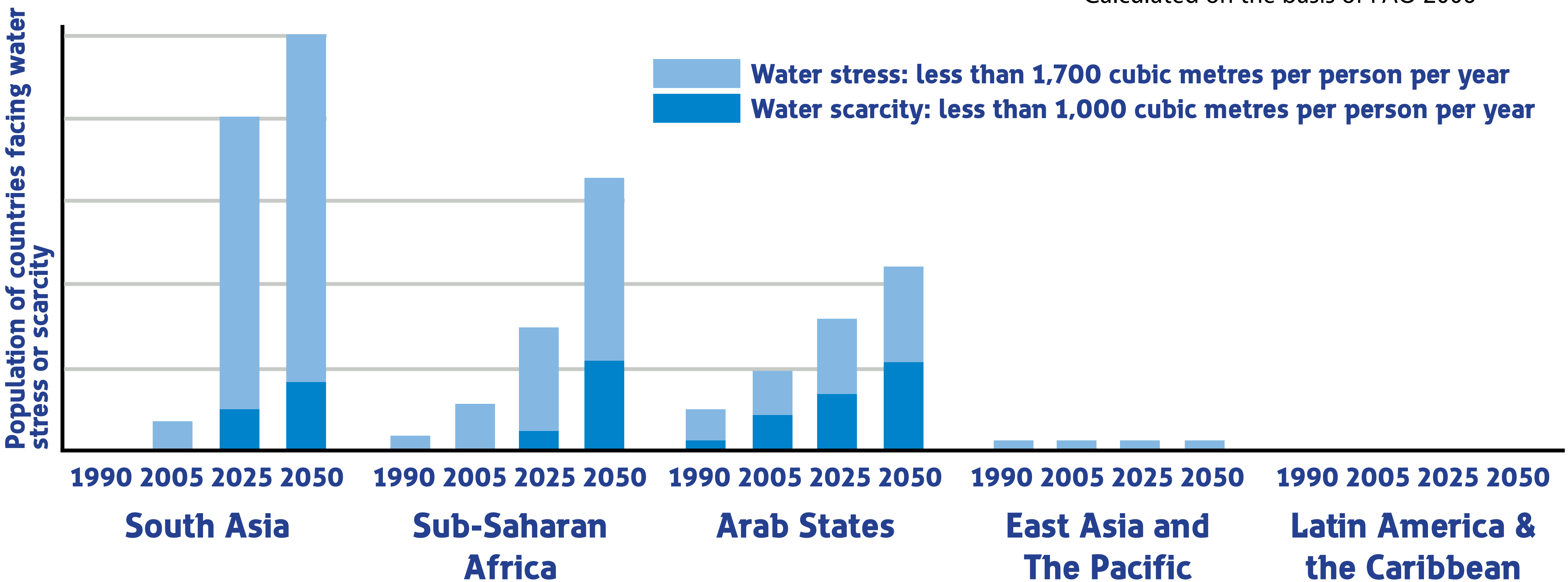
Climate factors are affecting ecosystems in different geographic regions. The temperature is anticipated to rise by 0.5 degrees Celsius before 2030[9] resulting in changes to ecosystems, the hydrological cycle, soil erosion, river flows and cropping patterns. The Himalayan region will see **rapid melting of ice and permafrost**, leading to sea-level rise. Rivers will first overflow from the thawing of permanent ice and snow then start running dry when snow cover is starkly reduced.

The low-lying areas of the coastline will become inundated with rise in sea levels.[10] The Western Ghats, a biodiversity hot spot area, receives 3,000 to 4,000 mm rainfall annually from the South-West monsoon.[11] The North-East Region has forest cover over half the area and is vulnerable to flooding from the Brahmaputra and Meghna Rivers.[11] Semi-arid and arid areas including the Deccan Plateau are prone to droughts whereas the fertile Indo-Gangetic Plain will witness unstable periods of heavy rainfall and wet-spells. Overall, **greater risks of flooding, drought, heat waves and natural disasters** are likely to increase throughout India.

Source – UNDP. "Beyond scarcity: Power, poverty and the global water crisis," UNDP Human Development Report 2006 (New York: 2006), 136.

Water Stress is projected to accelerate in intensity in several regions

Calculated on the basis of FAO 2006



IMPACT OF CLIMATE CHANGE ON WATER RESOURCES

Global environmental changes observed during the past decade can be attributed to anthropogenically enhanced climate change and include: **sea level rise; melting of snow and ice; changes in the frequency and/or intensity of extreme weather events; changes to ecosystems and biodiversity patterns**. Changes due to climate change are expected to further aggravate water-related hazards and water scarcity, increasing the vulnerability of socio-ecological systems. Each country and each river basin faces a unique set of climate change-related water challenges. Depending on the hydrologic regime, regional and sub-regional hydrology and climate variability have a direct but differential impact on the various water use areas. Studies on impacts on climate change on river runoff in various river basins of India indicate that the quantity of surface runoff would be reduced but would vary across river basins as well as sub-basins.

According to India's Initial National Communication to United Nations Framework Convention on Climate Change (NATCOM, 2004) climate change is likely to adversely affect the water balance in different parts of India due to changes in precipitation and evapotranspiration and rising sea levels, leading to **increased saline intrusion into coastal and island aquifers.** Increased frequency and severity of floods may affect groundwater quality in alluvial aquifers. Increased rainfall intensity may lead to **higher runoff and possibly reduced recharge.**[11]

The National Water Mission,has identified the following threats to water resources due to climate change:

- Decline in glaciers and snowfields in the Himalayas;

- Increased drought-like situations due to the overall decrease in the number of rainy days over a larger parts of the country;

- Increased flood events due to the overall increase in rainfall intensity;

- Effect on groundwater quality in alluvial aquifers due to increased flood and drought events;

- Influence on groundwater recharge due to changes in precipitation and evapotranspiration;

- Increased saline intrusion of coastal and island aquifers due to rising sea levels.

CLIMATECHANGE

ITS SYMPTOMS AND IMPACTS ON VARIOUS SECTORS

Phenomenon and Direction of Trend	Likelihood of Future Trends based on Projections for 21st Century	Water Resources
Over most land areas, warmer and fewer cold days and nights, warmer and more frequent hot days and nights	Virtually certain	Effects on water resources relying on snow melt; effects on some water supplies
Warm spells/heat waves. Frequency increases over most land areas	Very likely*	Increased water demand; water quality problems
Heavy precipitation events. Frequency increases over most areas	Very likely	Adverse effects on quality of surface and groundwater; contamination of water supply; water scarcity
Area affected by drought increases	Likely**	More widespread water stress
Intense tropical cyclones activity increases	Likely	Power outages causing disruption of public water supply
Increased incidence of extreme high sea level	Likely	Decreased freshwater availability due to saltwater intrusion

Source: Intergovernmental Panel on Climate Change IPCC 4th Assessment Report 2007, http://www.ipcc.ch/publications_and_data/publications_and_data_reports.shtml#1

IMPACT ON GLACIERS

Glacier monitoring services in Switzerland report that **glaciers have retreated globally by 12 meters** from 1980 to 2008. This has put a question mark on the very existence of some of the glaciers including in the Himalayas.[13]

The melting of glaciers has major impacts. The areas that rely on the runoff from the melting of mountain glaciers will experience **severe water shortages** as the glaciers disappear. Less runoff will lead to a reduced capability to irrigate crops as freshwater dams and reservoirs go dry. Water shortages could be especially severe in parts of South America and Asia, where summertime runoff from the Andes and the Himalayas, respectively, is crucial for fresh water supplies. In areas of North America and Europe, glacial runoff is used for hydroelectric power generation, sustain fish breeding and irrigate crops as well as supply domestic needs. As the volume of runoff decreases, all sectors depending on it will be adversely affected. The melting of glaciers and ice sheets will **add water to the oceans and contribute to sea level rise**.

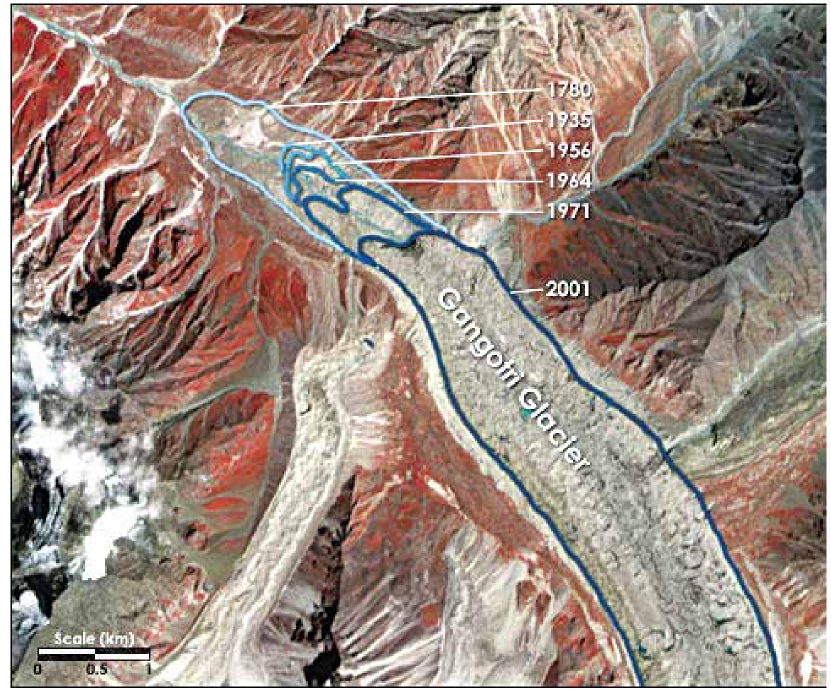
The Himalayas and other mountain chains of Central Asia have large glaciers. These are critical water resources for arid countries like Mongolia, western China, Pakistan, Afghanistan and India. Like glaciers worldwide, Asian glaciers are losing mass rapidly. This loss will have a tremendous impact on the ecosystems of the region. Melting of glacier in Himalayas will **affect availability of water in all the rivers originating in the Himalayas** like Ganga and Yamuna.

The Himalayas are huge and have the largest concentration of glaciers after the polar caps at 33,000 km^2. This **"Water Tower of Asia"** provides around 8.6 X 106 m^3 of water annually.[14] Himalayan glaciers feed seven of Asia's great rivers: the Ganga, Indus, Brahmaputra, Salween, Mekong, Yangtze and Huang Ho. They ensure a year round water supply to millions of people.

The Himalayan glaciers in the Indian region are broadly divided into the three-river basins of **Indus, Ganga and Brahmaputra**. The Indus basin has the largest number of glaciers (3,538), followed by the Ganga basin (1,020) and then the Brahmaputra (662). Researchers have estimated that about 17% of the Himalayas and 37% of the Karakorum range is presently under permanent ice cover. The principal glaciers of Himalayas and Karakorum region are Siachen (72 km); Gangotri (26 km); Zemu (26 km); Milam (19 km) and Kedarnath (14.5 km). **67% of glaciers in the Himalayas are retreating** at alarming rates and the major causal factor has been identified as climate change.[15]

Glaciers in the Mount Everest region of the Himalayas are all retreating. The Rongbuk Glacier, draining the north side of Mount Everest into Tibet, has been retreating 20 m per year. In the Khumbu region of Nepal along the front of the main Himalayas all the 15 glaciers examined from 1976 – 2007 retreated significantly. The Khumbu Glacier retreated at a rate of 18 m per year. The 30.2 km-long Gangotri Glacier is also receding more rapidly now than 200 years ago. The Gangotri Glacier in India retreated 34 m per year between 1970 and 1996, and is losing 30 m per year on average since 2000. In Sikkim all 26 glaciers examined from 1976 to 2005 were retreating at an average rate of 13.02 m per year.[16]

From 1980 to 2003, of the 51 glaciers studied in the main Himalayan Range of India, Nepal and Sikkim, all were found to be in retreat, at an **average rate of 23 metres per year.** In the Karakoram Range of the Himalayas there was a mix of advancing and retreating glaciers with 18 advancing and 22 retreating glaciers.[17]



Retreat of the Gangotri Glacier (Garhwal Himalayas) snout during the last 220 years

Photographed examples of glacial retreat in the Himalayas

Images Source: Supplementary Materials for the "State and Fate of the Himalayan Glaciers" Published 20 April 2012, Science 336, 310 (2012) DOI: 10.1126/science.1215828

Glacial Lakes

Some of the most devastating effects of glacial meltdown are the formation of potentially dangerous glacial lakes. This is happening in the Hindu Kush-Himalayan region.[18] As the glaciers retreat they leave large crater like spaces behind and water fills the depression earlier occupied by the ice. These lakes are structurally weak and unstable and undergo constant changes due to slope changes and land slides, presenting the danger of the lake bursting out of its confines. **Glacial lake outburst floods (GLOFs) are catastrophic discharges of water.** An accelerated retreat of the glaciers in recent times has led to the formation of several glacial lakes.

GLOFs are characterized by sudden releases of huge amounts of water, rushing downstream. This water is mixed with mud and stone and causes devastation for downstream riparian communities, hydropower installations and other infrastructure. In the Asian Himalayan region, **the frequency of GLOF events has increased in the second half of the 20th century** taking a toll on the lives and property of the people of India, Nepal and China.

Whereas climate change initially leads to widespread flooding because of excessive snow melt, over time, as the snow disappears there will be shortage of water and droughts in the summer. In the Ganga, the loss of glacier meltdown would reduce July – September flows by two thirds, causing **water shortages for 500 million people** and 37% of India's irrigated arable land.[19]

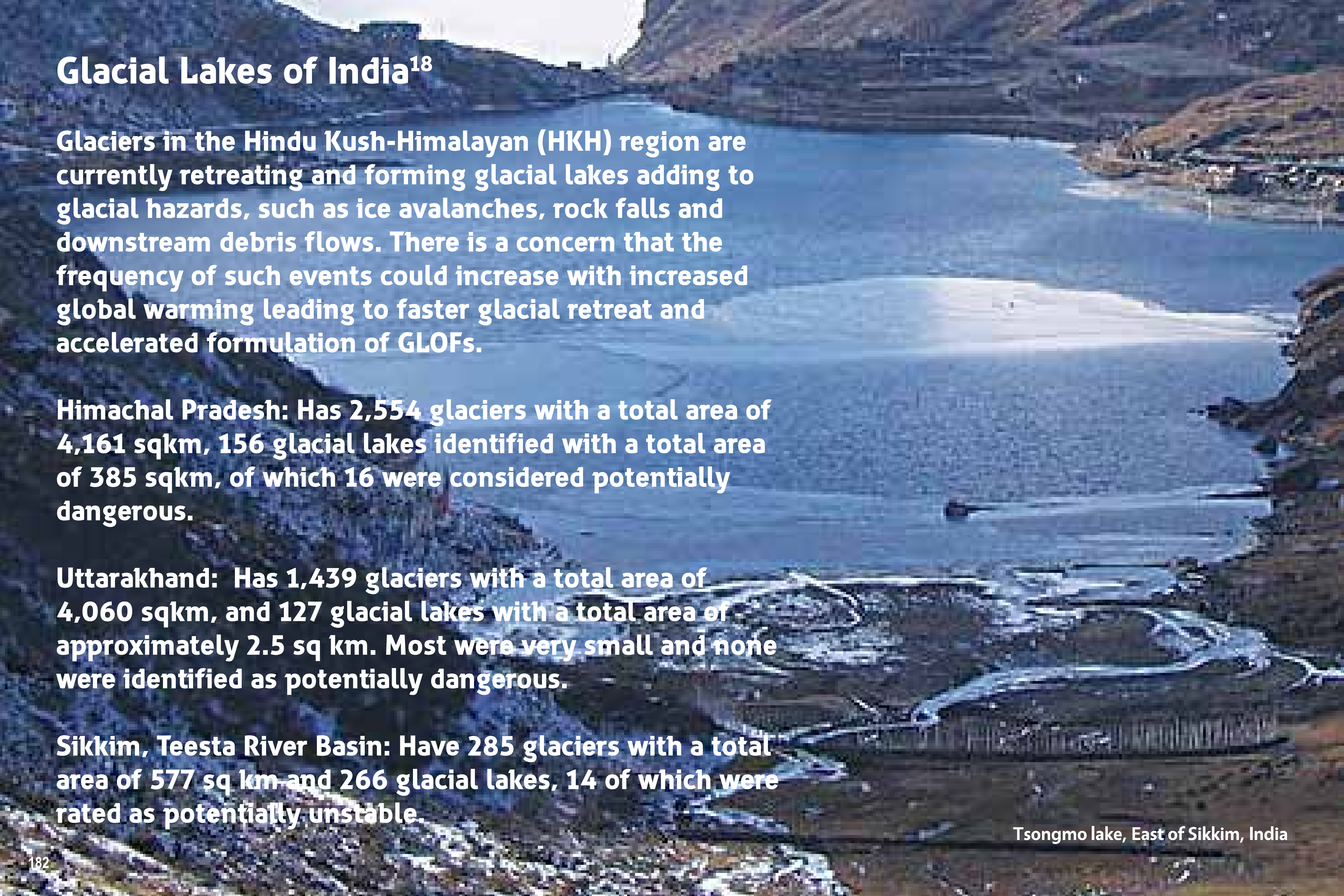
Glacial Lakes of India[18]

Glaciers in the Hindu Kush-Himalayan (HKH) region are currently retreating and forming glacial lakes adding to glacial hazards, such as ice avalanches, rock falls and downstream debris flows. There is a concern that the frequency of such events could increase with increased global warming leading to faster glacial retreat and accelerated formulation of GLOFs.

Himachal Pradesh: Has 2,554 glaciers with a total area of 4,161 sqkm, 156 glacial lakes identified with a total area of 385 sqkm, of which 16 were considered potentially dangerous.

Uttarakhand: Has 1,439 glaciers with a total area of 4,060 sqkm, and 127 glacial lakes with a total area of approximately 2.5 sq km. Most were very small and none were identified as potentially dangerous.

Sikkim, Teesta River Basin: Have 285 glaciers with a total area of 577 sq km and 266 glacial lakes, 14 of which were rated as potentially unstable.



Tsongmo lake, East of Sikkim, India

Polar Ice

Polar ice includes the Arctic ice pack of the Arctic Ocean at the North Pole and the Antarctic ice pack of the South pole. Polar ice packs typically change their size with the season but underlying this seasonal variation is a more general process of the melting of the Greenland ice sheet and overall Arctic shrinkage attributable to climate change. Satellite images shows that Arctic sea ice is thinning at the rate of 11.5% per decade, compared to the average.[29]

The floating sea ice in the Arctic region plays an important role in maintaining global climate due to its albedo effect. The large white surface of ice floats reflects sunlight, thus preventing warming. Melting of this sea ice will lead to increased solar absorption, raising temperature. Loss of sea ice also leads to melting of permafrost regions in the sea and on land leading to further loss of ice cover. As the cold air blowing over ice is replaced by warmer air after ice melt, the heat melts the permafrost around the Arctic.

IMPACTS ON PRECIPITATION

As temperatures rise and the air becomes warmer and drier, more water evaporates into the atmosphere. More moisture in the air generally means more rain and snow (precipitation) and heavier rainfall. But this **extra precipitation is not spread evenly** around the planet. Some places might get less precipitation than before and some more. That's because climate change causes shifts in air and ocean currents, which can change weather patterns. **Precipitation is expected to increase in higher latitudes and decrease in areas closer to the Equator**, the tropical areas. In this century from 1900 to 2005 precipitation has increased in areas north of 30°N but has declined over the tropics since the 1970s. Globally, there has been no statistically significant general trend in precipitation over the past century, although trends have varied widely by region and over time. Northern Europe and the eastern part of the North and South American continent as well as the northern and central Asian region have become wetter. South Asia along with the Sahel, the Mediterranean and southern Africa have become drier.

There has been an increase in the number of heavy precipitation events during the last century. There has also been an increase in droughts—in the tropics and subtropics after 1970s. Changes in the hydrological balance (precipitation and evaporation) over the oceans are affected by the **declining salinity** of mid- and high-latitude waters because they receive more precipitation; and the increased salinity in lower latitude waters, which are getting less precipitation and have higher evaporation rates due to higher temperatures.[20]

After a heavy downpour , there is less water vapour in the atmosphere and this can led to longer dry spells. When there is a dry spell, the higher heat exacerbates drying and can contribute to even longer and more intense drought periods.

Monsoon and Rainfall Patterns

The ability of the Himalayas to regulate monsoon wind patterns is not as constant as before. Global warming is raising surface temperature and glacial melt is cooling the ocean; creating new uncertainties in the temperature and moisture of air flows that determine the build-up of the monsoon, this in effect means **higher moisture content and greater precipitation** can be anticipated.[21]

Under normal circumstances, the main period of the southwest monsoon of central importance to India and South Asia, is from June to September. There are two streams of the monsoon that together bring rainfall to Northern India. In June, one stream approaches over the Arabian Sea and extends further inland. The second is the Bay of Bengal monsoon which sweeps across Assam in June then continues in the northwest direction over the Indo-Gangetic Plain; merging with the first sometime in July.[22] In October and November the northeast monsoon brings rain to the southern tip and states like Tamil Nadu and Kerala receive rain , but the northeast monsoon does not have as significant an impact as the southwest monsoon.[11] The **timing of the monsoons is everything for farmers**, and knowing ahead of the planting schedule when the monsoon will come helps them to plan when to sow which kinds of seeds. They rely on timely rainfall during the growing season because it comprises the main water for the entire year .

In India, the states of Punjab, Rajasthan, and Tamil Nadu are expected to receive reduced rainfall but other parts should get approximately 20% more rain from the southwest monsoon.[23] Because of the uneven effects of hydrological patterns due to climate change, the semi-arid zones of Andhra Pradesh, Gujarat, Madhya Pradesh and Maharashtra could receive even less rain than now.[2] Rainfall fluxes of 10% can trigger severe flooding and drought[24], where excessive rain can damage crops, scarce precipitation can lead to crop failure. Some evidence seems to suggest that future Indian monsoons could be of a greater magnitude. **Floods, droughts, landslides, intense storms and tropical cyclones** are all expected to become more common affecting the agriculture and food production and the livelihoods of people overall.

According to all estimates, the total number of rainy days in India is set to decrease by 15 days but the intensity of rain is expected to increase. This means greater surface run off and more soil erosion.

IMPACT ON MOUNTAIN SNOW

In Ladakh, the northern most region of India, all life depends on the amount of snow received. Ladakh is a high altitude desert and gets only 50 mm of rainfall annually. Its main water sources are the snow melt from glaciers and the snow that falls on the ground.

Reduced snowfall means less snow in glaciers, and less snow melt to feed streams. Climate related higher temperature and shorter period of snowfall prevents the snow from turning into hard ice crystals, so more of the glacier tends to melt when the summer comes. With declining snow fall and reduced moisture for growing crops, farming is being abandoned in village after village.

Climate change has led to rain, rather than snow, even at higher altitudes. This accelerates the melting of glaciers. Heavy rainfall which was unknown in the high altitude desert has become more frequent, causing flash floods, washing away homes and fields, trees and livestock and resulting in displacement of people.

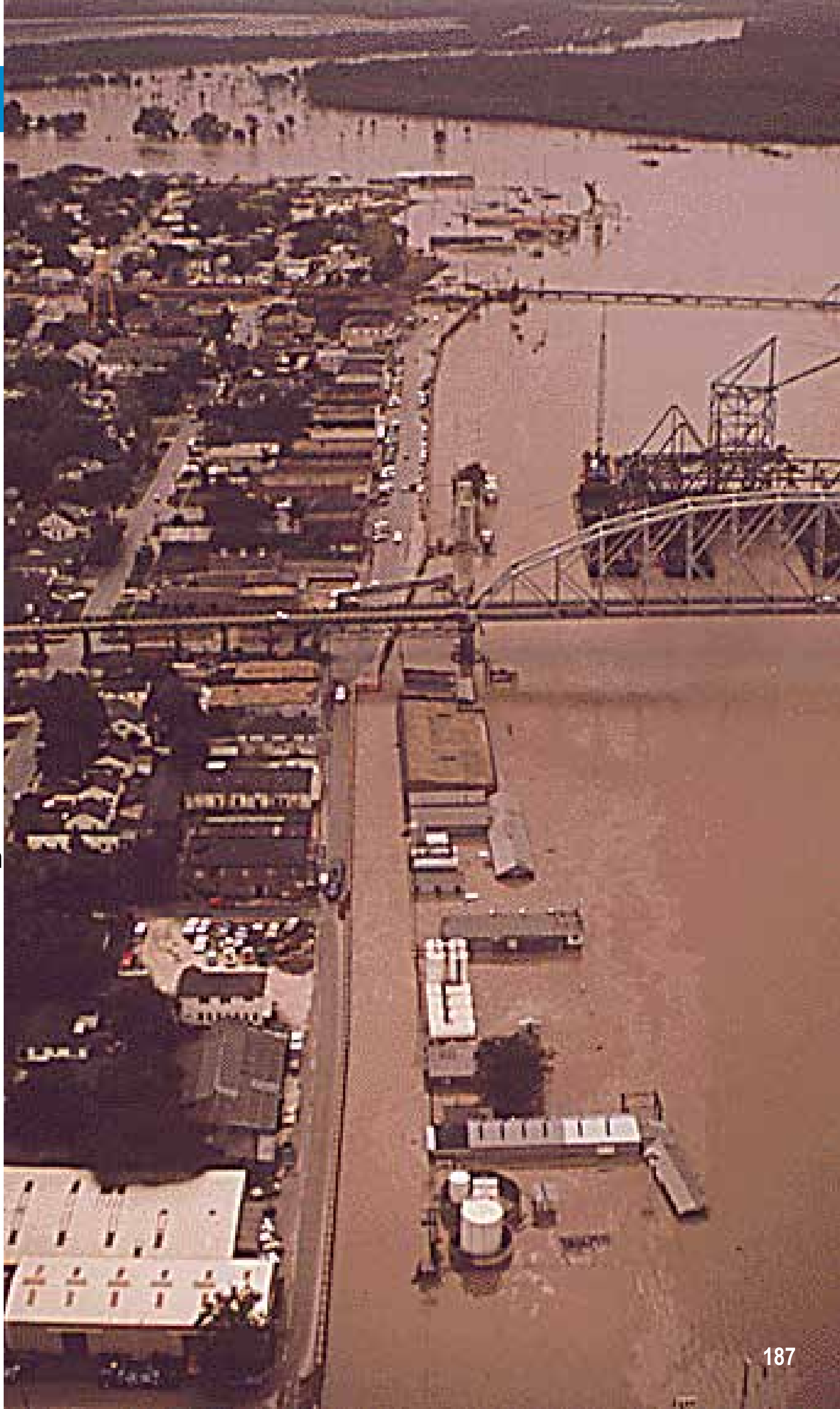
Rain instead of snow means faster surface run off especially on slopes. This accelerates soil erosion and does not allow the water enough time to be absorbed by the earth and fails to recharge aquifers. Snow lies on the ground and melts slowly, recharging the ground water. It is also beneficial for trees since the melting snow irrigates the roots over a longer period of time than rain. Snow that slowly enters the aquifers recharges mountain streams the principal water source of mountain communities.

Sea Level Rise

Until now global sea level has been almost constant allowing cities to flourish and prosper. Sea level began to rise since the mid 19th century and during the 20th century, sea level rose about 15 – 20 centimeters at the rate of 1.5 – 2.0 mm/year. Several million people live along the coast line of different countries. Satellite data over the past decade, shows that sea level rise is accelerating and has increased to about 3.1 mm/year. Although mired in controversy, there are projections suggesting that the **rate of sea level rise is likely to increase** significantly during the 21st century.[25]

As climate change increases ocean temperatures, first the surface warms, then the deeper water. This causes the water to expand, giving rise to sea level rise due to thermal expansion. **Thermal expansion is thought to have contributed about 2.5 cm to sea level rise** during the second half of the 20th century, and this rise is increasing. Another cause of sea level rise is the **melting of glaciers and ice caps.** The IPCC's (Intergovernmental Panel on Climate Change) Fourth Assessment estimated that during the second half of the 20th century, melting of mountain glaciers and ice caps led to about a 2.5 cm rise in sea level. For the 21st century, the IPCC projects that melting of glaciers and ice caps will contribute roughly 10 – 12 cm to sea level rise. This would reflect a melting of roughly 25% of the total amount of ice frozen in mountain glaciers and small ice caps.[26]

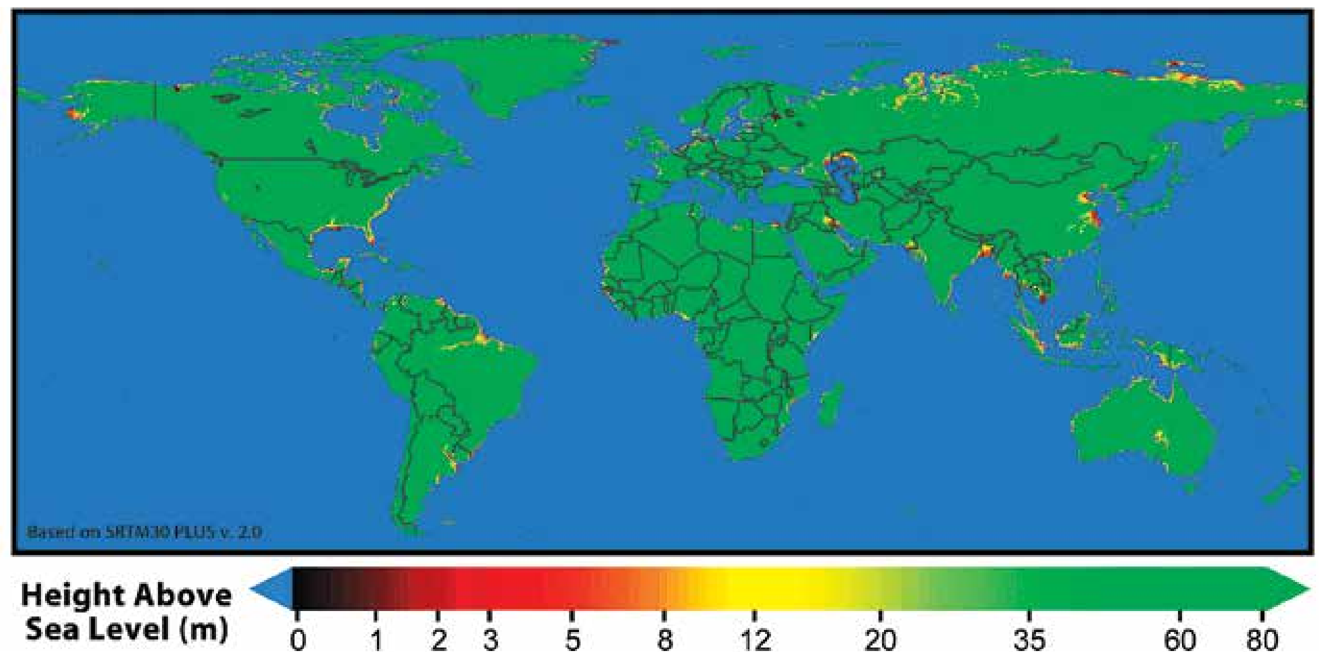
Over half a billion people live in coastal areas that are not even 10 meters above sea level, and two-thirds of the world's medium sized cities (populations over five million) are located in vulnerable areas. With sea level projected to rise at a faster rate for the next several decades, very large numbers of people on or near the coast are going to lose their homes. These climate refugees will need to relocate to new homes, possibly in different countries.



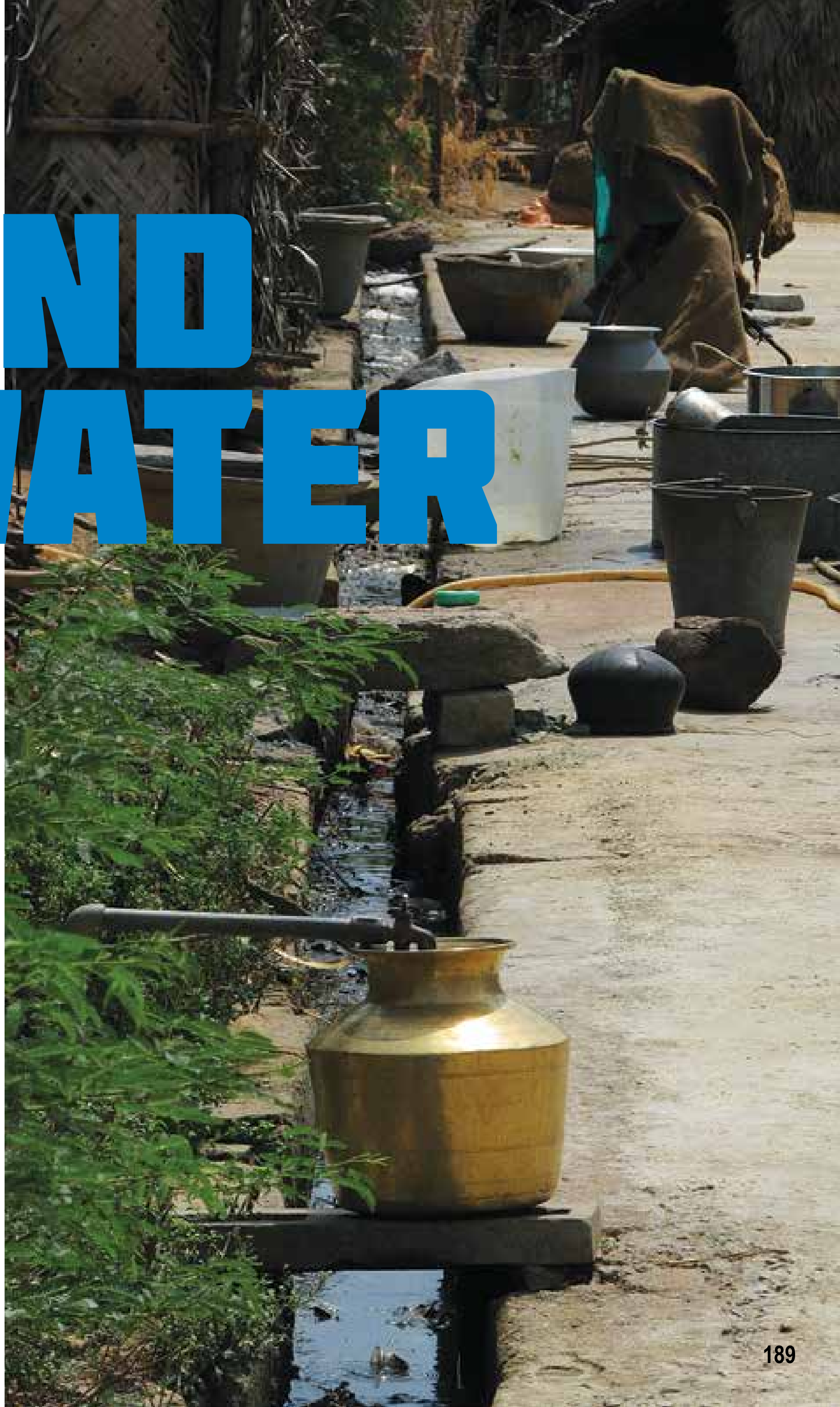
Island nations such as the **Philippines, Indonesia, Maldives and Vanuatu are especially vulnerable** because they do not have enough high land to accommodate displaced coastal populations. Island nations also face the risk of losing their fresh-water supplies as sea level rise pushes saltwater into their aquifers.[27] It is the poorer nations along the coast that do not have the resources to prepare for sea level rise. Bangladesh, Vietnam, India, and China have large populations living in low lying coastal areas such as deltas, where river systems enter the ocean.

Sea level rise is likely to lead to coastal erosion, wetland and coastal plain flooding, salinization of inland aquifers and arable land and a loss of habitats for wildlife like fish, birds and plants.[28]

In India, the nearby 6,000 km coastline is vulnerable to climate related hydrological change. Increased salinity of the oceans and its movement inland has been found in the Sunderbans – home of the vital mangrove forest. Salt water flowing into rivers and groundwater supplies would make freshwater saline and unfit for drinking and agriculture.



IMPACT ON AQUIFERS AND DRINKING WATER



An aquifer is a body of water saturated rock through which the water can move. Aquifers are both **permeable and porous** and include such rock types as sandstone, fractured limestone and unconsolidated sand and gravel. Fractured volcanic rocks such as columnar basalts also make good aquifers. Rocks such as granite and schist make poor aquifers because they have a very low porosity. However, if these rocks are highly fractured, they can make good aquifers. Sea level rise and inward incursion of salt water will penetrate aquifers and contaminate the fresh water. This phenomenon, already observed in coastal areas has negative implications for agriculture and can create a shortage of drinking water, affecting human and animal populations in the most elementary way.

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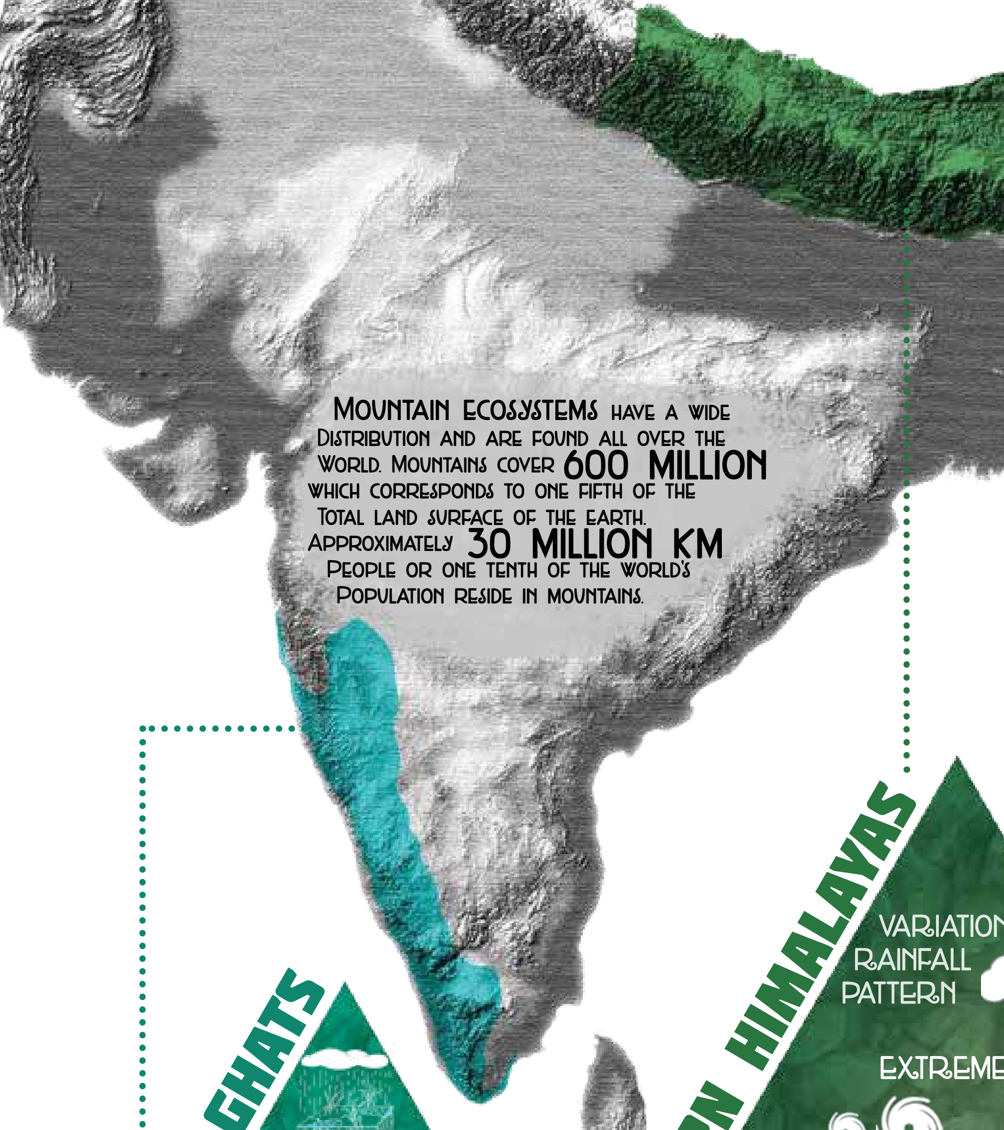
IMPACT OF CLIMATE CHANGE ON MOUNTAINS ECOSYSTEMS



Mountain ecosystems have a wide distribution and are found all over the world. Mountains cover 600 MILLION which corresponds to one fifth of the total land surface of the earth. Approximately 30 MILLION KM people or one tenth of the world's population reside in mountains.

WESTERN GHATS

Disturbance To water Percolation

Effect on livelihood of People depending on Rivers

Fewer number Of rainy days

Seriously impact the flow of water in rivers

EASTERN HIMALAYAS

Variation in rainfall pattern

Extreme weather conditions

Soil erosion

Low soil fertility

Reduced livestock productivity

Food insecurity

Effect on livelihood

Pest and diseases effecting plants

Effect on rangelands

MOUNTAIN ECOSYSTEM

Impact on Species Distribution

Species and Population Migration

Incidence of pests And diseases

Variation in land use pattern and land cover

Impact on wetlands, glaciers, surface water availability and on permafrost

EVOLUTIONARY IMPACTS

Extinction Of species

Landscape level changes

Life cycle changes

Impact on Alpine ecosystem

Impact on human well beings

Livelihoods and health

COPING STRATEGIES

Measures By NAPCC

Protecting poor and Vulnerable sections

Ecology sustainability

Technologies for mitigation and adaptation

Promote sustainable Development

Implementation of programmes

INTRODUCTION

WHAT IS A MOUNTAIN ECOSYSTEM?

An ecosystem is a community of organisms that includes plants, animals and viruses, that is, biotic components that interact with each other and with their environment which comprises of soil, water, atmosphere and other abiotic components. A variety of living organisms, the organic matter they generate, the environment that they live in and exchange elements, and the various interactions between all the biotic and abiotic components comprise an ecosystem. Ecosystems are significant components of the environment and provide a range of goods and services which are of great importance to individuals as well as communities.

The equilibrium between the various abiotic and biotic components of an ecosystem makes it possible for living organisms to thrive, and for goods and services to be available at optimal levels. Mountain ecosystems have a wide distribution and are found over the world.

MOUNTAIN ECOSYSTEMS HAVE A WIDE DISTRIBUTION AND ARE FOUND ALL OVER THE WORLD. MOUNTAINS COVER **600 MILLION** WHICH CORRESPONDS TO ONE FIFTH OF THE TOTAL LAND SURFACE OF THE EARTH. APPROXIMATELY **30 MILLION KM** PEOPLE OR ONE TENTH OF THE WORLD'S POPULATION RESIDE IN MOUNTAINS.

Furthermore mountains help **sustain two billion people**, providing them with food, electricity, timber etc. Half the world's population depends on water originating in the mountains and on other mountain resources.

Since mountainous regions have large variations in altitude and steep slopes over a relatively small geographical area, they typically have a wide range of soil types, temperature, rainfall and other physical parameters. These features make mountains some of the most biodiverse regions of the world. **Mountains are home to a quarter of the world's terrestrial biodiversity.** Almost half of the world's biodiversity hotspots are located in the mountains. Mountain areas contribute significantly to global plant and animal production. Mountains are also extremely important as sources of water and are considered as water towers as they feed several of the world's major river systems that originate in the mountains.

Mountains are influenced by both natural and anthropogenic drivers of change. Some of these changes include volcanic eruptions, earthquakes, flooding, global climate change and the loss of vegetation and soils due to industries as well as due to forestry and agriculture that are not practised in a sustainable manner. The sloping terrain and thin layer of soils make mountain ecosystems particularly fragile; they either recover very slowly from major disturbances or do not recover at all. Mountain biota thrive in relatively small ranges of temperature, altitude and precipitation and do not withstand any major change from these small windows.

Agriculture and forestry are the main sources of food security and subsistence livelihoods in the mountains. Mountain dwellers apply their indigenous knowledge and employ traditional practices to utilize natural resources in a sustainable manner. Mountain farming systems which are a mix of agriculture, horticulture, livestock and silviforestry are practised in a way that maintains a balance between utilization and conservation of resources so that ecosystems are not exploited beyond their renewable capacities and are able to recover with time. Unfortunately, the demands on these ecosystems are now taking them beyond their renewable capabilities. Greenhouse gas (GHG) emission, air pollution, land use conversion, deforestation and land degradation are decreasing the resilience of mountain ecosystems and putting their communities and the environment at risk. The livelihoods of mountain dwellers, as well as that of billions of people living downstream, are being threatened.

There are several goods and services that mountain ecosystems provide us with.

1 Mountains act as water towers, storing water in glaciers, permafrost, snowpack, soil and groundwater.

2 They play a critical role in the provision of clean water and are a major source of water that is used to generate hydroelectricity.

3 They help in purifying water, regulating water runoff and in moderating floods.

4 Transport routes and settlements rely heavily on the stability of mountain ecosystems.

5 Mountain vegetation and soils are important in lowering the risk and damage caused by natural hazards.

6 Mountains also help build soils and decrease soil degradation.

7 They are home to a remarkably wide array of living organisms and serve as a reservoir of the earth's genetic and species diversity.

8 Mountain forests prevent avalanches and rockfall; their capacity to hold water helps replenish ground water and decreases stream flow.

9 They are a major carbon pool, and process and store carbon as well as other nutrients.

10 They provide timber for use as fuel as well as non-timber products like game, food, shelter, fodder, and medicinal plants.

11 Mountains are also important for grazing and subsistence farming and help in assimilating waste.

12 Mountains all over the world are also a very important source of recreation and tourism because of their relatively low populations, scenic beauty, rich vegetation and cool or cold climate. Mountain tourism contributes significantly to many regional and national economies.

Chapter 13 of Agenda 21 which was adopted by the United Nations Conference on Environment and Development in Rio de Janeiro, 1992 (UNDEP 1992) states that mountains are a very important part of the global ecosystem and also reveals the alarming fact that the environment of most mountain ecosystems is being adversely affected to varying degrees.

Ninety percent of the world's mountain population resides in developing countries or countries in transition; one third lives in China and half in the Asia-Pacific region. Close to 90 million mountain people and nearly the entire mountain population residing above 2500 metres live in poverty. All these people are very vulnerable to food insecurity.

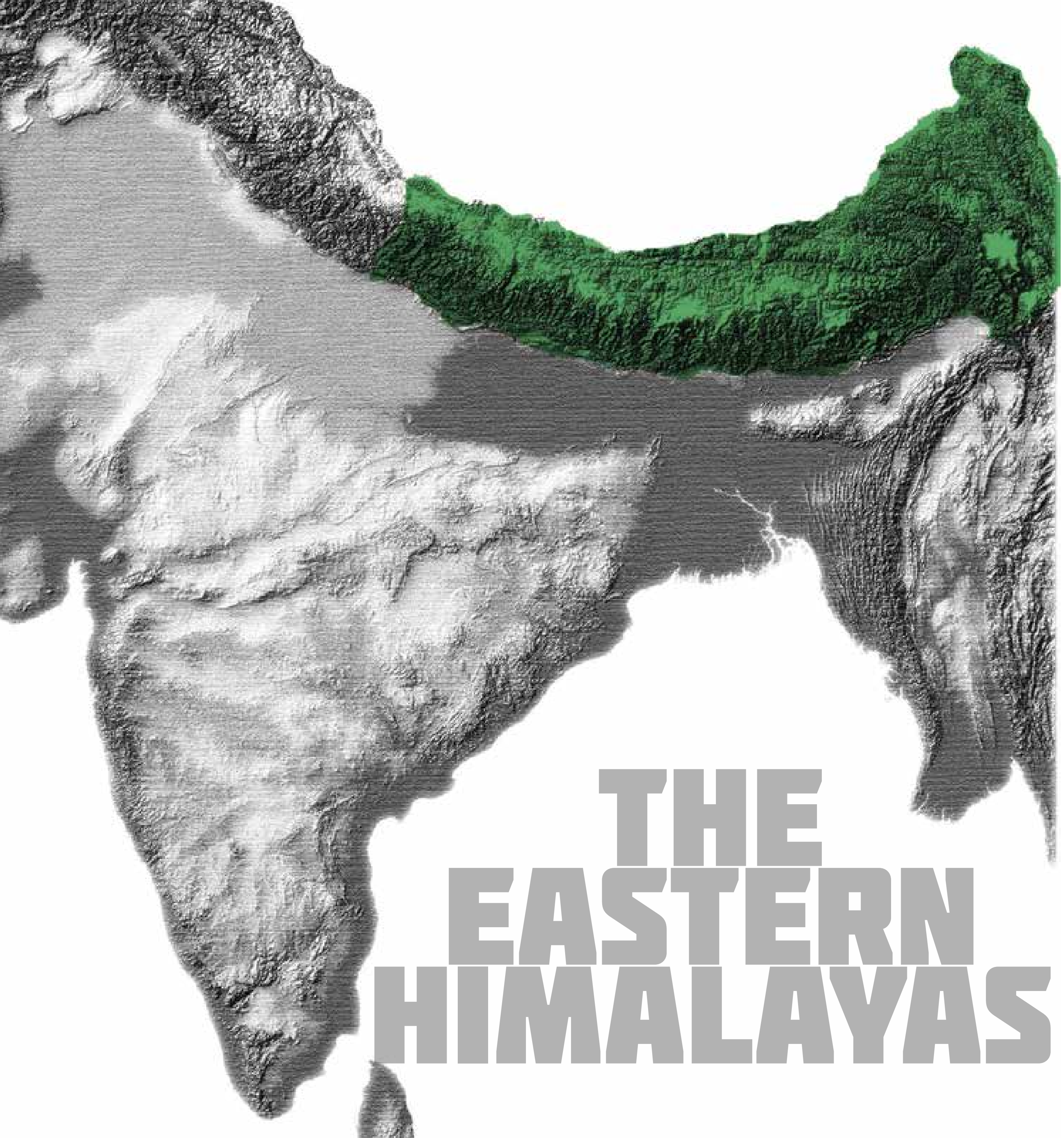
Half the world's population depends on the goods and services provided by various mountain ecosystems. Another very important feature of these ecosystems is their ability to regulate and rejuvenate the environment and thereby maintain stability in the earth system.

Climate has a strong influence on mountain ecosystems. Organisms that are a part of these ecosystems have gradually adapted to the climatic conditions they are exposed to. Climate change can act synergistically with other stressors and adversely affect the goods and services that we derive from these remarkable ecosystems that support millions of livelihoods and provide water to half the world's population.

India has been experiencing climate change in the form of rising temperatures and increased frequency of natural disasters like floods and drought over the last decade. In 1998, a heat wave caused 650 deaths in Odisha. The Eastern Himalayas and the Western Ghats, where heavy rainfall is the norm, have seen drought in the recent past. Rajasthan on the other hand has experienced floods. Besides the immediate damage caused by these extreme events, there has been a major impact on agriculture. **A rise in temperature coupled with water scarcity could severely affect food grain production and increase the price of food and elevate hunger and malnutrition.**

The Eastern Himalayas and the Western Ghats are two of the major mountain ranges in India.
It is important to realize the importance of these mountains, study the kind of impact that climate change can have on these important mountain systems and to be aware of some of the changes that are already being observed.

THE EASTERN HIMALAYAS



The Eastern Himalayas (EH) cover an area of **524,190 sq. km**, and span **five countries**, that is, India, Myanmar, Nepal, Bhutan and China. It is characterized by large variations in topography, soil and climate. Some of the most diverse mountain forests are found among the peaks, valleys and flood plains of this mountain range, which also has a high level of crop related diversity.

The Eastern Himalayas contain several critical habitats and species, most of which are under protected area systems.

After the polar caps, the high Himalayas and inner Asian ranges have the **largest concentration of glaciers in the world**, spread over an area of 33,000 sq. Km. The glaciated region of the greater Himalayas contains **15,000 glaciers** and covers an area of more than 112,000 sq. km (Table 2). The 70 kilometer long Siachen glacier situated at the border of India and Pakistan is the second longest glacier in the world outside the polar ice caps. The higher reaches of the Himalayas are snowbound throughout the year and form the source of a number of large perennial rivers most of which drain into two large basins, the Indus basin and the Ganges-Brahmaputra basin.

A substantial proportion of precipitation falls as snow at higher altitudes, feeding these glaciers. Rising temperatures and decrease in precipitation, associated with climate change are causing these glaciers to retreat.

CRITICAL ECOSYSTEMS IN THE EASTERN HIMALAYAS WITH RESPECT TO CLIMATE CHANGE

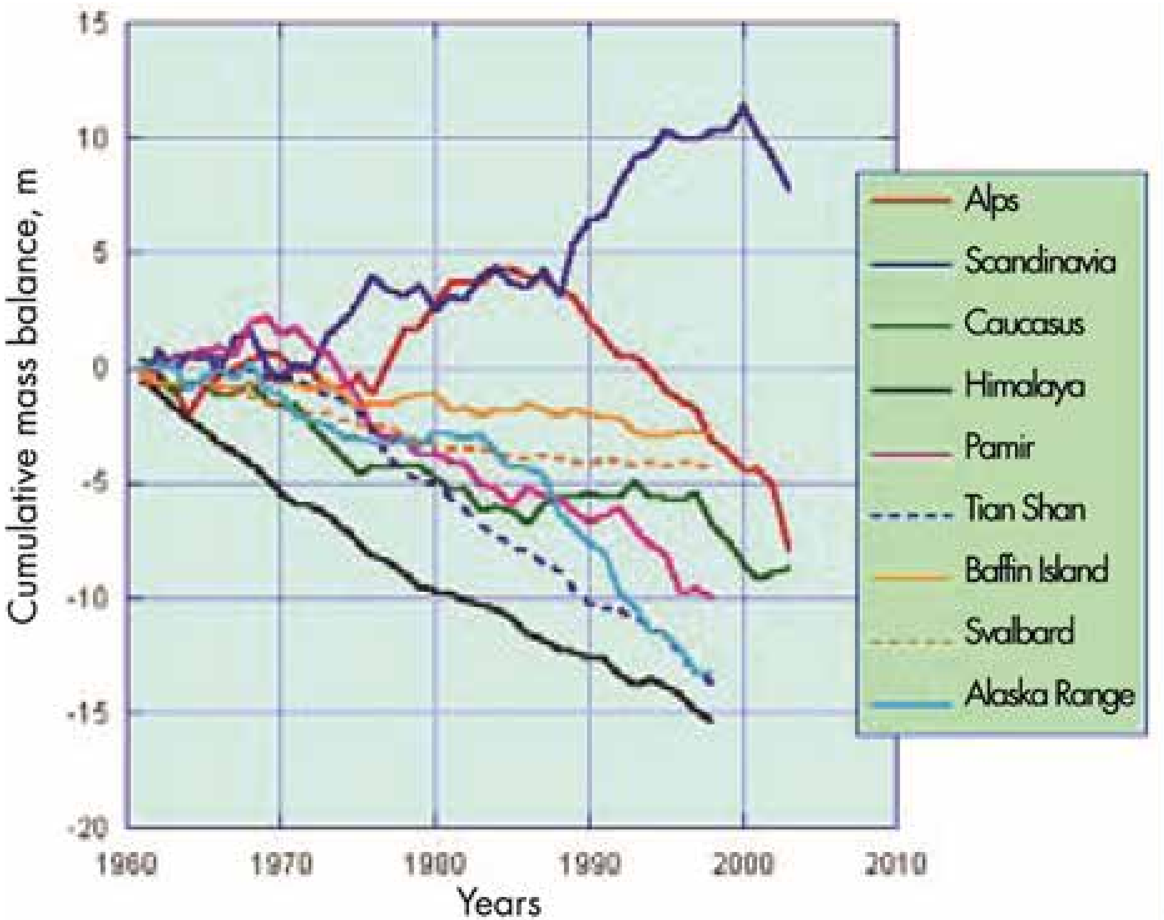
Critical habitat	Change indicator	Example of observed changes	Vulnerable entities
Alpine/sub-alpine ecosystems lying between the tree line at 4,000 m and the snow line at 5,500m	• Changes in ecotones • Desertification • Declining snowfall,glaciers events • Growth in unpalatable species,decreasing productivity of alpine grasslands	Transformation of earlier *Quercus-betula* forest into the ‘Krummholz-type’ of vegetation comprising species of Rhododendron, Salix and Syringia	Ungulate species, Himalayan pica, high value medicinal plants, botanically fascinating species (bhootkesh, rhododendron, etc), curious species (succulents, Ephedra), alpine scrub flora
Cool – moist forests	• Changes in ecotones • Loss of habitat • Blockage of migration routes	Decline in population of species of *Mantesia, flex and insectivorous* plants	Habitat specialists such as red panda, blood pheasant, micro flora and associated fauna
Cloud forests at temperature elevations where moisture tends to condense and remain in the air	• Less participation and cloud formation during warmer growing season • Loss of endemics/specific flora and fauna • Upward range shift • Desertification of soil affecting the water retention capacity of forests		Endemic epiphytes and lichen, wildlife dependent on cloud forest vegetation (diversity of insects)
Areas with intensive agriculture	• Reduced agro-biodiversity (monoculture) • Low employment/gradual loss of traditional knowledge • Degradation of soil quality • Potential increase of GHG emissions	Loss of traditional varieties such as upland varieties of rice, indigenous bean,cucurbits and citrus varieties; pest increase in citrus species	Crops, cereals, and vegetables
Freshwater wetlands	• Loss of wetlands due to sedimentation, eutrophication,drying,drainage • Successional shift to terrestrial ecosystems • Increase salinity in aquifers	Decrease in population of sus salvanius; beels and associated biodiversity and changing	Large mammals, such as crocodiles, river dolphins, wild buffaloes, wetland plant species; migratory avian species

Critical habitat	Change indicator	Example of observed changes	Vulnerable entities
Riparian habitats nurtured by silt deposited by overflowing rivers	• Damage or destruction of riparian habitats by floods/GLOFs/riverbank erosion • Degradation due to increased/reduced deposition of sediments • Reduced stream flow • Disrupted successional stage	Loss of pioneer species such as *Saccharum spontaneum* and other tree species leading to a change in species composition of alluvial grasslands	Large mammals, such as crocodiles,river dolphins, wild buffaloes,wetland plant species; migratory avian species
Ephemeral stream habitats	• Loss of ephemeral stream habitats • Increased salinity • Riverine systems impacted	Riverine island ecosystems such as Majuli Assam are being threatened	Ephemeral stream species, especially herpetofauna

Source: Compiled from information provided during the consultation process

Rapid Retreat of Greater Himalayan Glaciers in Comparsion to Global Average

Source: Dyurgerov and Meier 2005



The Himalayas are the source of 10 of the largest rivers that flow in Asia. Over a billion people inhabit the basins of these rivers. The natural resources in these river basins contribute substantially to the GDP of the region and provide important environmental services. These rivers also support considerable irrigated agriculture.

GLACIATED AREAS IN GREATER HIMALAYAN REGION

Mountain Range	Area (Km^2)
Tien Shan	15,417
Pamir	12,260
Qilian Shan	1,930
Kunlun Shan	12,260
Karakoram	16,600
Qiantang Plateau	3,360
Tanggulla	2,210
Gandhishi	620
Nianqingtangla	7,540
Hengduan	1,620
Himalayas	33,050
Hindu Kush	3,200
Hinduradsh	2,700
Total	112,767

Source : Dyurgerov and Meier 2005

PRINCIPAL RIVERS OF THE HIMALAYAN REGION–BASIC STATISTICS

	River		River basin			
River	Annual mean discharge m^3/sec[a]	Percentage of glacier melt in river flow[b]	Basin area (km^2)	Population density (pers/km^2)	Population x1000	Water availability (m^w/person/year)
Amu Darya	1,376 deg	not available	534,739	39	20,855	2,081
Brahmaputra	21,261 deg	~12	651,335	182	118,543	5,656
Ganges	12,037 deg	~9	1,016,124	401	407,466	932
Indus	5,533 deg	up to 50	1081,718	165	178,483	978
Irrawaddy	8,024 deg	not available	413,710	79	32,683	7,742
Mekong	9,001 deg	~7	805,604	71	57,198	4,963
Salween	1,494 deg	~9	271,914	22	5,982	7,876
Tarim	1,262 deg	up to 50	1,152,448	7	8,067	4,933
Yangtze	28,811 deg	~18	1,722,193	214	368,549	2,465
Yellow	1,438 deg	~2	944,970	156	147,415	308
Total					1,345,241	

The data were collected by the Global Runoff Data Centre (GRDC) from the following most downstream stations of the river basins: Chatly (Amu Darya), Bahadurabad (Brahmaputra), Farakka (Ganges), Pakse (Mekong), Datong (Yangtze), Huayuankou (Yellow)
Estimated of the meltwater contribution is difficult and varies in an upstream and downstream situation: approximates are given here:
Source: IUCN et al. 2003 ; Mi and Xie 2002 ; Chalise and Khanal 2001 ; Merz 2004 ; Tarar 1982 ; Kumar et al. 2007 ; Chen et al. 2007
Note : The hydrological data may differ depending on the location of the gauging stations. The contribution of glacial melt is based on limited data and should be taken as indicative only

The forests of the EH shelter an enormous diversity of flora and fauna. The EH house several important mammals (45 species), birds (50 species), reptiles (16 species), amphibians (12 species), invertebrates (2 species) and plants (36 species). **A third of the world's flora is endemic to the EH.** The lesser panda, the clouded leopard and the rare golden langur are some of the extraordinary mammals that inhabit these mountains.

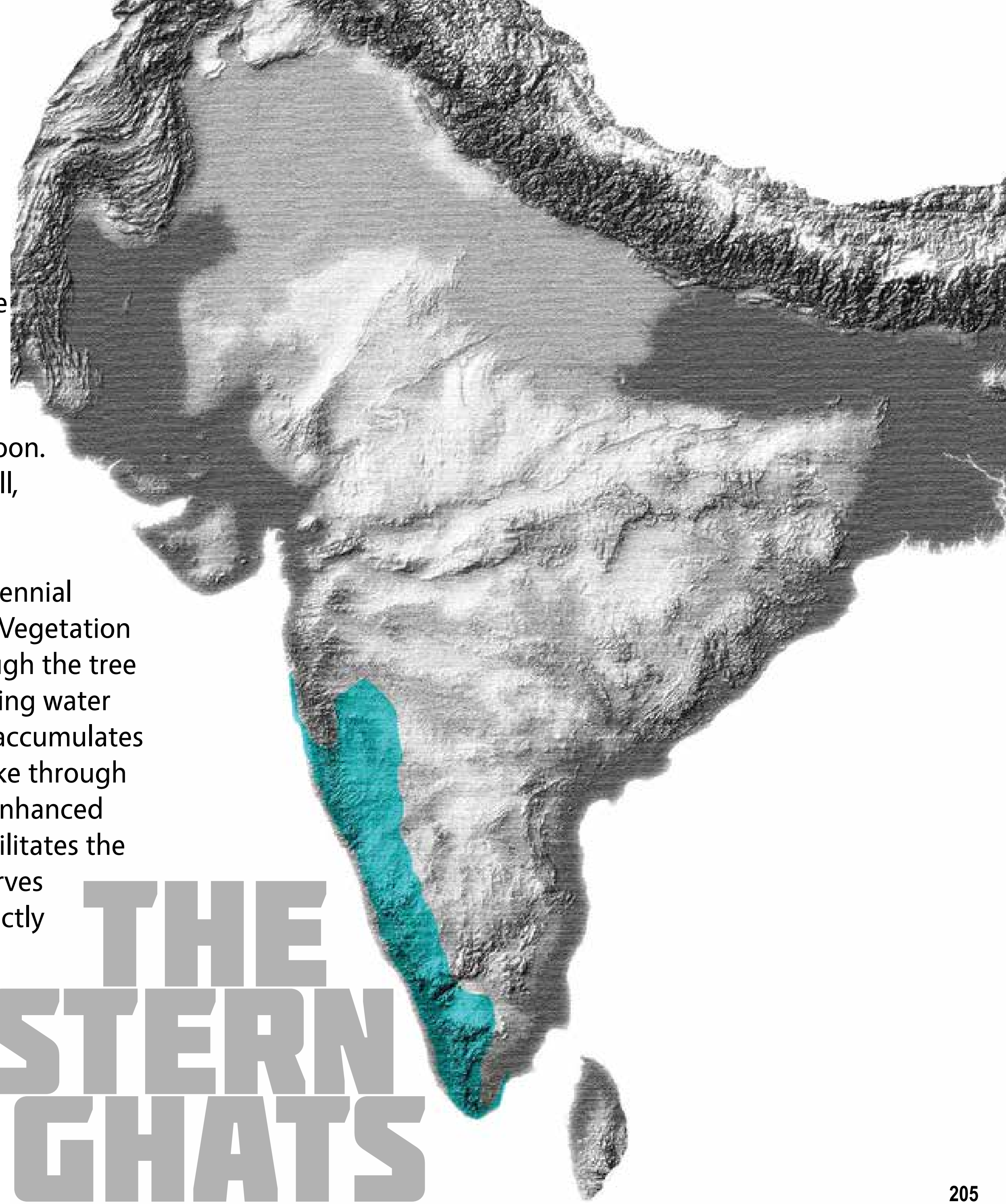
Pastoralism, agriculture and agroforestry, practiced in a sustainable manner using indigenous knowledge, are the main sources of livelihood in the EH. The EH is also the centre of origin for more than 50 important tropical and subtropical fruits, cereals and rice.
Large variations in rainfall patterns, temperature and precipitation, and increased incidence of extreme events of temperature and precipitation that are already occurring and will intensify in the future, could severely affect the high-altitude rangelands in the EH. Precipitation events of high magnitude could lead to soil erosion. This coupled with increased temperature and higher rates of evapotranspiration could bring down the fertility of the soil, and increase the risk of food insecurity. Adverse effects of variations in temperature and moisture, and a shortage of feed and fodder could reduce livestock productivity and the activity of pollinators. Alien invasive species could have severe effects on native communities. This would change ecosystem dynamics and make them less useful to plants, animals and man. Climate change could also increase the number of pests and diseases that are able to infect plants, animals and human beings. All this would drastically affect the livelihoods of people who depend entirely on these mountain systems.

THE WESTERN GHATS

The Western Ghats (WG) or Sahyadris are a mountain range that run north to south along the western edge of the Deccan plateau and separate the plateau from a narrow coastal plain that runs along the Arabian sea. These ranges span an **area of 160 square km** and form the catchment of a complex riverine system that **drains 40% of India**. These ranges are a UNESCO heritage site and one of the 10 hottest biodiversity hotspots in the world.

The WG receive 75% of their rainfall from the Southwest Monsoon. The Monsoon lasts for 60 to 100 days bringing abundant rainfall, ranging from 2,500 mm to 7,500 mm.

The forests of the WG play a very critical role in providing a perennial supply of water to the many rivers that are fed by these Ghats. Vegetation intercepts torrential rains and facilitates trickling of water through the tree architecture on branchlets, creating stem flow. The slowly trickling water gradually percolates to the deeper layers where sub-soil water accumulates and finds its way as subterranean flow. Besides this, water uptake through evapotranspiration and rainwater seepage in numerous ways, enhanced by anthills, burrows and galleries built by a variety of fauna, facilitates the flow of rainwater to the subsurface. The multi-tiered canopy serves as an effective insulator and ensures that the ground is not directly exposed to sunlight; it brings the surface temperature down by 8 – 10 ˚C.



The surface is covered by trees, shrubs, herbs, as well as humus, leaf mulch, leaf meal, and an **extensive interlocked root system** that serves to hold the soil together. The root system provides crevices to facilitate the flow of rainwater to the underground layers. This is extremely useful during torrential rains, and minimizes runoff. This complex architecture which is a combination of vegetation, leaf mulch humus as well as numerous galleries and burrows holds an enormous amount of water, which contributes substantially to subsurface flow. This subsurface flow percolates steadily into streamlets, streams, and tributaries of river systems, ensuring a perennial supply of water. Any kind of damage to the complex architecture of these forests can disrupt this system of water percolation, subterranean flow and perennial water supply and have a serious impact on all the people who depend on these rivers for their livelihood.

The rich vegetation of the WG supports tremendous biodiversity, has many major roles and provides an array of goods and services. It acts as a carbon sink, is a source of food for a diverse range of animals, and supplies medicine and industrial raw material. It also plays a significant role in **soil regeneration, soil and water conservation, nutrient recycling, maintenance of biodiversity, mitigation of climate change and carbon sequestration**.

Over 5,000 species of flowering plants, 139 mammalian species, 508 bird species and 179 species of amphibians are found in the WG.

The largest population of Asian elephants is found in the Nilgiri biosphere. The largest number of herds of vulnerable Gaur and fairly large populations of the endangered Nilgiri Langur are found in the WG which is also home to 10% of India's critically endangered tiger population. The WG is also **home to 325 globally threatened species**. The western facing slopes of this range are covered with dense rainforests. Due to their inaccessibility, some
regions are extremely rich in biodiversity, and support a wide and rare variety of flora and fauna.

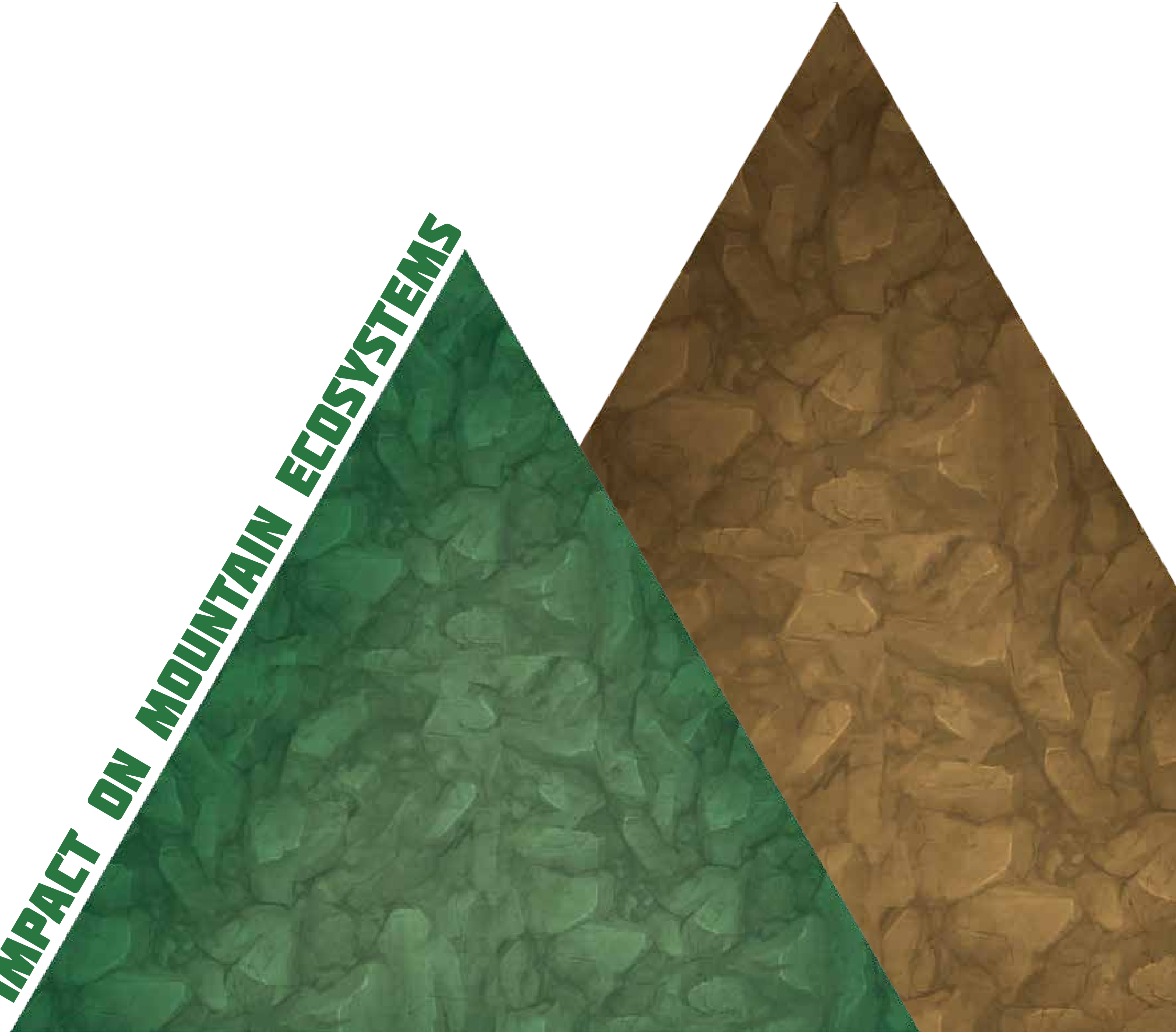
The nocturnal Malabar Large-Spotted Civet, a critically endangered mammal, the endangered Lion-tailed Macaque and the vulnerable sloth bear inhabit the WG. This region also serves as an important corridor which allows the seasonal migration of the endangered Asian elephant. The WG also houses an extremely diverse and unique collection of amphibians.

The WG houses close to a third of all flowering plants found in India and are one of the major tropical evergreen forest regions in India. **Forty percent of the 450 species of plants found in this region are endemic.** The endemic species of trees and plants include, teak, jamun, cashew, hog plum, coral tree, jasmine and crossandra. **Pepper first originated in this region**. What is remarkable about the WG is its tremendous biodiversity and the fact that many species of flora and fauna found there are yet to be identified.

Agriculture is widely practised and is an important source of livelihood in the WG. A wide variety of crops, fruits and spices are cultivated in this region. Conditions in this region are also favorable for the growth of rain-fed crops and fruits.

The forests of the Western Ghats play a very critical role in harnessing rain water and thereby make it available for the rest of the year. This helps sustain flow in the rivers originating in the Western Ghats, in the dry period. **Over the next two decades the temperature of the region is expected to rise by 1.7 to 1.8 ˚C and there will be fewer number of rainy days,** even though the rainfall may increase both in quantity and intensity. This will seriously impact the flow of water in rivers originating in the Western Ghats, one of the three major water sheds of the country. The flow in several of these rivers is already severely compromised due to various upstream interventions such as sand mining, installation of dams and use of water for irrigation and for human consumption. Furthermore a substantial part of the forested areas have been replaced by plantations which are far less effective than natural forests at harnessing water.

IMPACT ON MOUNTAIN ECOSYSTEMS



Various aspects of mountain ecosystems such as mountain hydrology and water resources, biodiversity, wetlands and human wellbeing are sensitive to climate change.

Species Distribution

Climate change has resulted in substantial species range contractions and extinctions in the past and is expected to influence species persistence and create an abnormal distribution of species along ecological zones.

In the EH, an estimated increase in temperature of 0.01˚C to 0.04˚C is expected to cause a 20 to 80 m shift per decade in altitudinal vegetation belts. According to projections, the EH will be very vulnerable to climate change. The maximum shift is likely to take place in the Himalayan Subalpine and Alpine zones, and to a lesser extent in the Himalayan Moist Temperate zone. The shifts will be more acute at higher altitudes where the rate of increase in temperature is greater. With time this would lead to major changes in the profile of species inhabiting different ecosystems.

The range of plant and animal species is moving upwards both towards higher altitudes as well as pole-ward. This shift of species range towards higher elevations will be more acute in the future. Shifts in plant species will be more gradual and the complex terrain and steep slopes of the EH will be a tough challenge for successful colonization. Satellite observations since the early 1980's suggest an **early greening of vegetation in the spring** that has been associated with the longer thermal growing season due to increasing temperatures.

It has been predicted that climate change will have an impact on the boundaries and areas of different types of forests, primary productivity, species and population migration, incidence of pests and diseases, and forest regeneration. Increased levels of GHGs will influence the species composition and structure of ecosystems which in turn will have an impact on ecosystem function.

Primary productivity is expected to increase by 1 to 10%. Warmer temperatures and drier conditions will increase the abundance and extend the range of the pests such as the North American Pinewood Nematode. A substantial **decrease in alpine and cryospheric ecosystems** has been predicted, while tropical zones are expected to gradually cover most of the middle mountains and inner valleys of the region. There are very limited habitats available for Alpine plants above the tree line; these plants can undergo acute fragmentation, suffer habitat loss or become extinct if they are unable to extend their range upward. In contrast, warmer temperatures may increase the habitats available for water hyacinth.

Yaks, which live at very high altitudes and can climb as high as 20,000 ft., are among the most useful animals in the Himalayas. They inhabit alpine tundra, grasslands and cold desert regions of the northern Tibetan plateau and cannot survive in warmer climates. In the winter, they move to lower valleys.

The trans-Himalayan trade between Nepal and Tibet relies mainly on yaks which are able to carry heavy loads and walk over dangerous trails and snow covered passes in the Himalayas. They are used to plough fields and provide milk, butter, wool and their dung is used as fuel.

The rising temperatures are making it difficult for yaks to survive in their natural habitat. Ideally they require a **temperature below 13 ˚C**. As they move to higher altitudes where temperatures are more optimal their food is becoming scarce. The population of these animals is rapidly decreasing. In Himachal Pradesh, for example, the yak population decreased from 6,000 to 2,000 in just 12 years.

Land Cover and Use

A number of anthropogenic threats and land use patterns are leading to the degradation of forests, especially in the WG making them especially vulnerable to climate change.

WG forests are expected to be moderately vulnerable to climate change. **The maximum shift is expected in the tropical semi-evergreen and tropical moist deciduous forests.** The endangered Tiger has lost more than a quarter of its range over the last 30 years. The leopard, considered to be a resilient species, has also undergone range contraction. There has been a catastrophic decline in the population of golden jackals, Nilgiri tahr and lion-tailed macaque. The king cobra is losing its habitat. Such range contractions and habitat loss make animals more sensitive to climate change.

Changes in land cover and land use can result in **deforestation, habitat modification, land degradation, biotic attrition and forest fragmentation**. They also provide positive feedback to the climate system and hasten the process of climate change. There has been a **25% decrease in snow cover, 8% decrease in grassland and 3% decrease in forests in the EH between 1970 and 2000**.

LAND COVER AND LAND COVER CHANGE IN THE EASTERN HIMALAYAS FROM THE 1970s TO 2000s (SQ.KM)

DECREASE

INCREASE

Data Source:
http://isebindia.com/09-12/12-01-2.html

FOREST

1970- **273,426**

2000- **264,117**

Change %- **−3.4**

CULTIVATED LAND

1970- **112,631**

2000- **113,233**

Change %- **0.5**

SHRUB LANDS

1970- **43,050**

2000- **60,443**

Change %- **40**

GRASSLANDS

1970- **39,902**

2000- **36,639**

Change %- **−8.2**

SNOW COVER

1970- **27,514**

2000- **20,741**

Change %- **−24.6**

BARE LAND

1970- **22,589**

2000- **23,953**

Change %- **6.0**

WATER BODIES

1970- **4,119**

2000- **4,108**

Change %- **−0.2**

The WG lost close to 40% of its forest cover between 1920 and 1990; 76% was converted to open or cultivated lands, 16% to coffee plantations and the remaining to tea plantations and hydroelectric reservoirs. Over the last two decades, Karnataka has lost 12% of its forests and there has been nearly 100% increase in coffee cultivation in Kodagu, with a concomitant loss of 18% of forest area.

25% of the WG is under forest cover. Intense logging has caused severe fragmentation of these forests. Forests are being converted to agricultural land and cleared to build dams, reservoirs, roads and railways. Encroachment into protected areas is leading to further reduction of forest cover. Livestock grazing within or near the boundaries of protected areas is leading to a drastic erosion of forested slopes. Timber plantations and secondary growth constitute a major portion of the remaining forests.

A meagre 20% of the original forest cover remains. The rest of the forests are being gradually destroyed or fragmented as a result of a number of anthropogenic threats and land use patterns that include **poaching, logging, extraction of timber wood and non-timber forest produce, mining, quarrying, marijuana cultivation, shifting cultivation and extensive tourism.** Afforestation is predominantly achieved by monocultures which do not match up to natural forests and therefore cannot provide the same goods and services. All these activities have negative connotations for biodiversity, and adversely affect the livelihood of the huge populations that depend on these forests. A serious consequence of such development and interventions is that these forests that are being subjected to various levels of stress are particularly vulnerable to climate change which is exerting its effect on the temperature, river systems and precipitation pattern of the region.

Wetlands

Wetlands are transitions between upland terrestrial systems and deep open water systems. They are an important part of river basins and are distributed all along the course of rivers right from the source to the delta. Aquatic vegetation (hydrophytes) is a typical feature of wetlands.

Wetlands are both a source and sink of greenhouse gases and this equation can be affected by changes in hydrology. The hydrological regime plays a critical role in wetland formation. Changes in temperature and precipitation associated with climate change, influence the hydrological regime and will therefore have an impact on wetlands.

The area, distribution, function and ecological features like the composition and abundance of flora and fauna, are some of the aspects of wetlands that are likely to be influenced by climate change.

The EH has several types of wetlands, many of which are designated as Ramsar sites and wetlands of significance. These wetlands contribute to the flow of mountain streams and river systems, support a rich diversity of mountain flora and fauna, act as carbon sinks, support soil formation and nutrient cycling, purify water and regulate floods, land degradation and disease.

Increased temperatures would lead to a receding snowline and result in a shift in species distribution to higher elevations. The distribution of most species is likely to extend upwards by about 200 m. Exotic invasive species, like potomogaton, have been steadily extending their range upward into the mountains in Bhutan and could spread to higher altitudes where wetland rice has already extended its range.

Wetlands play an important role in regulating floods and droughts. Higher levels of snowmelt from melting snow and glaciers would lead to increased erosion and sediment flow loading. Increased siltation with sediment deposits would negatively impact the ability of lake basins and flood plains to retain floodwater. Flood water retention would also be altered by changes in plant communities. The quality of water would be poor due to increased temperature, lower levels of dissolved oxygen and altered mixing patterns in deep water wetlands. The increased temperature due to climate change would reduce the level of dissolved oxygen and lead to eutrophication of many wetlands and higher Green House Gas emission. This can be disastrous for cold-water species. On the other hand, warmer temperatures will reduce their chances of survival or completely eliminate species that are highly sensitive to changes in temperature and changes in dissolved oxygen levels. Furthermore, in smaller lakes, warmer temperatures will prevail at the surface layer and increase production as most aquatic organisms are cold blooded. Increased production will result in eutrophication, raise the biological oxygen demand and create an anoxic environment in the lower cold layer, which can suffocate fish and kill them. These changes could have a negative impact on the health of wetlands and affect their productivity and the livelihood of people who depend on them.

1. **Wetlands play an important role in regulating floods and droughts. The increased siltation and sediment load from accelerated glacial and snow melt would negatively impact the ability of lake basins and flood plains to retain floodwater.**

2. **The increased temperature due to climate change would increase production and cause eutrophication in the warmer surface layer of smaller lakes and result in an oxygen deficient environment in the lower cold layer which can suffocate fish.**

3. **Flash floods caused by extreme weather events, glacial lake outburst floods and rivers breaking their banks due to increased runoff as a result of prolonged monsoon downpours, are all events expected to occur more frequently, causing grave damage to mountain ecosystems and affecting the livelihoods of communities depending on these resources.**

Larger lakes would probably be able to maintain their temperature gradients in spite of the warming of the surface layer and may see a surge in biodiversity. Biological productivity would increase as a result of warmer temperatures in high altitude lakes and streams, expanding the ranges of cool-water species. At the low altitude boundaries of cool-and cold-water species' ranges, extinctions would be the maximum.

The longer and warmer growing seasons that are projected would be associated with the desiccation of peat and production of carbon dioxide. Melting ice will lead to the production and release of methane from glacial lakes that have accumulated organic matter from littoral vegetation and organic sediment. Flash floods caused by extreme weather events, glacial lake outburst floods and rivers breaking their banks due to increased runoff as a result of prolonged monsoon downpours, are all events expected to occur more frequently, causing grave damage to mountain ecosystems and affecting the livelihoods of communities depending on these resources. Climate change will also probably hasten the deterioration of wetlands and freshwater systems like lakes, marshes and rivers. influence

The changes in temperature and precipitation patterns will influence the seasonal variability in the water levels in wetlands. This would have a direct impact on important aspects of their functioning such as flood protection, carbon storage, water cleansing, and waterfowl/wildlife habitat. **Alterations in wetland ecosystems will influence freshwater supplies, fisheries, biodiversity and tourism.** The wetlands of the EH, especially the lakes have great religious and cultural value and are also important tourist destinations.

Glaciers

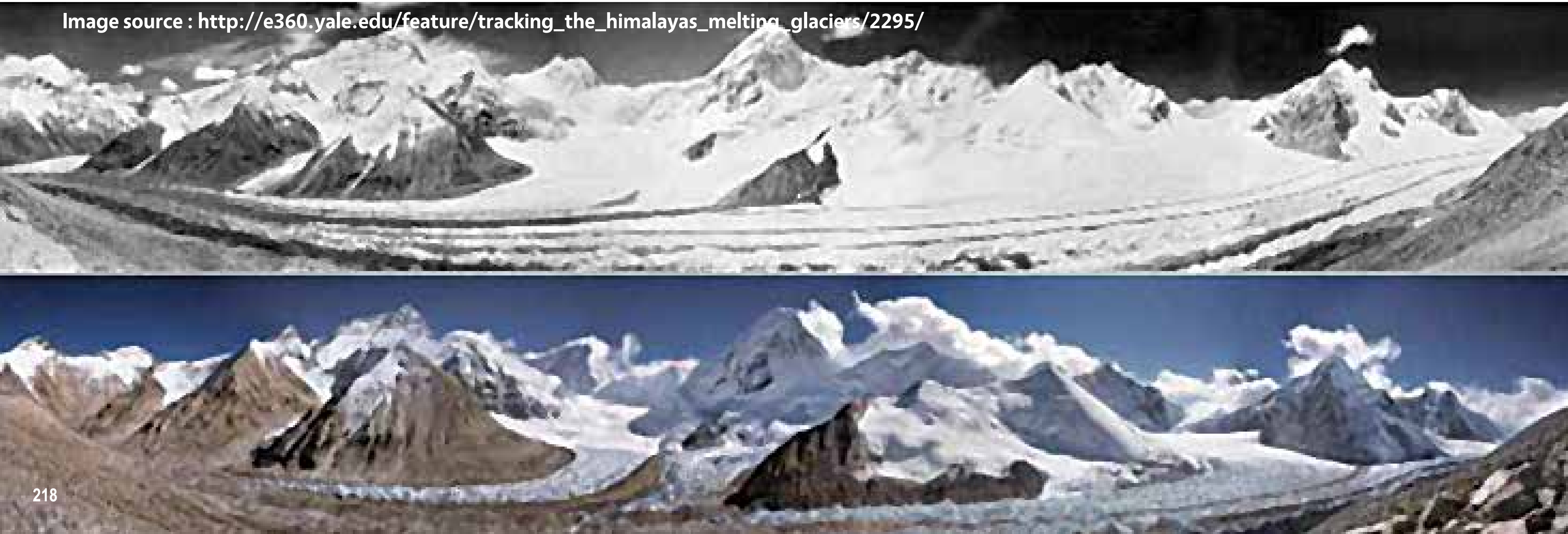
Melting of glaciers and receding snow lines that have been fairly extensive in the 20th century are expected to occur more rapidly through the 21st century and reduce the availability of water and hydropower potential and alter the seasonality of flows in basins that are fed through melting snow and ice. There is increased runoff, and earlier peak spring discharge into many snow-fed and glacier-fed rivers. **Runoff is expected to increase until the 2030s and gradually reduce after that.** Rising temperatures will also influence the physical, chemical and biological properties of wetlands, freshwater lakes and rivers and severely affect their thermal structure, freshwater species, community composition and water quality. Winter precipitation in the form of snowfall has decreased over the years and the area under snow cover is expected to reduce further. Most permafrost regions are expected to experience an **increase in thaw depth**. The number of drought affected areas is expected to increase leading to a substantial increase in the requirement for irrigation water.

In Nepal, for example, the temperature has been rising steadily and the average summer temperature is increasing. Although this is leading to an increase in rainfall of 13 mm per year, the number of rainy days is decreasing which suggests that rainfall is predominantly occurring in bursts. The flow in rivers is increasing at the rate of 1.48 m, which is 1.5 times higher than the increase in precipitation. This increase in summer river flow provides further evidence that glaciers are melting faster due to the higher summer temperatures.

The Gangotri glacier which provides 70% of the water of the Ganges has been receding at the rate of 25 m a year and is expected to disappear completely by 2035. This would drastically affect the availability of water in India, where 500 million people depend on the Ganges for drinking water and for farming. A large part of Bangladesh and the Sundarban mangrove forests rely solely on the Ganges for their water. Its river basin is one of the most fertile in the world and it is home to more than 140 species of fish. According to predictions, the Ganges will eventually become a seasonal river that is fed entirely by rain water primarily from the monsoons.

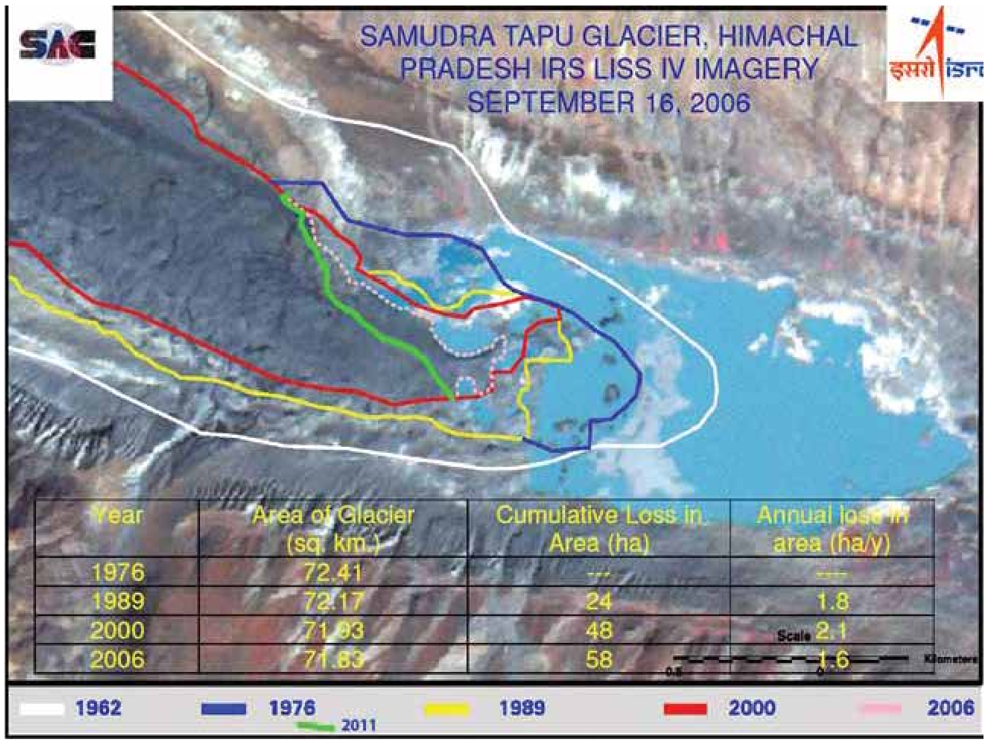
Snow cover with its high albedo plays an important role in insulating glaciers from higher temperatures. Recent research suggests that in addition to greenhouse gases, the warming effect of **soot could be causing the melting of glaciers**. More specifically, black soot which is formed during the combustion of diesel fuel is darker and absorbs more radiation than organic carbon which is produced when wood is burnt. Most industrial processes produce a mixture of organic and black carbon. During the last two decades the concentration of black soot in Tibetan glaciers has increased two- to three-fold relative to its concentration in 1975.

Panoramic view of West Rongbuk Glacier and Mount Everest, taken in 1921 (top) by Major E.O. Wheeler and in 2009 (bottom) by David Breashears. (Photo courtesy of the Royal Geographical Society)



Muir Glacier, located in Glacier Bay, Alaska, photographed by W. Field in Aug. 1941 (left) and B. Molnia in Sept. 1976 (middle) and Aug. 2004 (right). Note how the glacier has retreated to expose rock in 1976 that has since become lush vegetation in 2004. The glacier has retreated so much that it is hardly visible in the 2004 photo. —Courtesy NSIDC Glacier Photo Collection

Image Source: http://nsidc.org/cryosphere/glaciers/gallery/retreating.html



Retreat of the Samudra Tapu Glacier in Himachal
Image Source: http://himachal.gov.in/environment/PDF/Dr%20Kulkarni.pdf

The ice streams flanking the summit have also shrunk. Similarly, Field found that the Jannu Glacier in Nepal, which in photographs looked like a huge tongue of ice filling the valley in 1899, had disappeared by 2009. He claims that the Sherpas who live at the 'roof of the world' or the third pole and climbers who return are definitely aware about how much temperatures have increased at high altitudes in recent years and how extensively the snow and ice on the Himalayan Glaciers has thinned and retreated. The glacier lake formed by the melting of the Rongbuk glacier can be seen in the figure above.

The retreat of the Muir Glacier in Glacier Bay, Alaska traced over 60 years between 1941 and 2004 can also be seen here.

The glaciers of the EH are shrinking at a rapid rate leading to expanding glacial lakes. **Recent observations indicate that the maximum rate of glacial retreat is 41 m/yr in the Indian Himalayas, 74m/yr in Nepal and 160m/yr in Bhutan.**

Glacial lake formed by melting of the Kenai Glacier

Glacial Lakes and Glacial Lake Outburst Floods (GLOF)

A considerable increase in heavy rainfall is projected for the future with increasing flood risk. In Nepal, this is already the case with a steady increase in the number of flood days and consecutive days of flood events increasing. Himalayan glaciers are receding at a rate that is clearly above the world average. A serious consequence of these alarming rates of glacial retreat is the increased occurrence of glacial lake outburst floods (GLOFs) and the disastrous effects they have.

Glacial lakes are often formed when water from melting glaciers accumulates. These lakes are extremely unstable lakes found at high altitudes. They are usually held back by unstable dams consisting of moraine debris, and in many cases there is a danger of the dam being breached. Such breaching is called a Glacial lake Outburst Flood (GLOF) and can cause extensive damage in the valley below. **These events result in enormous amounts of water rushing downstream.** Wild and domestic animals get washed away. The top soil which is very important for mountain farmers is lost and what remains is rocky infertile land.

Such floods can take place when a glacial lake bursts out, due to erosion, build up of water pressure, an avalanche, an earthquake, volcanic eruptions under the ice, or if a large enough portion of a glacier breaks off and causes excessive disturbance at the base of a glacial lake.

Several people can be injured and killed; and forests, cultivated land, houses and valuable infrastructure can be damaged. In some cases, there is a sudden release of a huge amount of water and debris. The intensity of such events depends on the nature of the dam, the size of the lake and its depth, the rapidity of its drainage and the surrounding landscape.

Since the beginning of the 20th century most of the EH glaciers have begun retreating, at an approximate rate of 18 – 20 m /y. According to the Department of Hydrology and Meteorology, close to 20% of the existing glaciated area above an altitude of 5,000 m is expected to become snow and glacier free with a 1˚C rise in temperature. A 3˚ to 4˚C rise in temperature has been predicted to result in a 58 – 70% loss in snow and glaciated areas.

Imja Lake lies at 5,100 m above sea level in the Khumbu Region of Nepal. It was formed and grew very rapidly in the second part of the 20th century due to the rapid retreat (approximately 70 m per year) of the Imja Glacier. There are 12 potentially dangerous lakes in Nepal, 14 in Sikkim and 24 in Bhutan. The most recent GLOF in Bhutan occurred in 1994 when the 140 m deep Luggye Tsho burst releasing 10 million m^3 of flood water.

At least 12 GLOFs have occurred in the Tibetan part of the Himalayas since 1935.

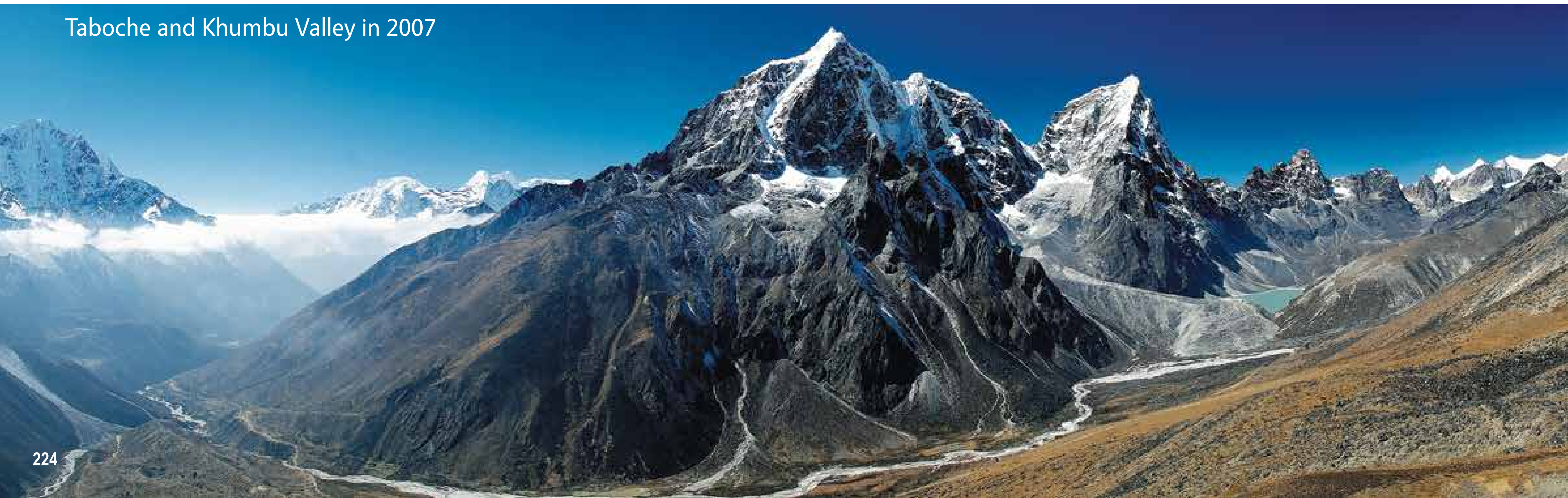
A GLOF which originated from the lake of the **Sangwang Cho glacier** in July 1954, buried the upper valley with a layer of debris that was 3 – 5 m thick and created a 40 m high flood in the Nyang Qu river. Gyangze city 120 km away and Xigaze city 200 km downstream were damaged. The GLOF that originated in the **Zhangzhangbo glacial lake** in Tibet in July 1981 caused damage 50 km downstream, destroyed 3 concrete bridges and a large section of the Nepal-China Highway. The GLOF event of 4, August 1985, originated in the **Dig Tsho glacial** lake in Bhutan and destroyed almost the entire Namche Small Hydropower Plant, 14 bridges, cultivated land, and a lot more. One of the worst GLOFs in China occurred at the **Sangwang lake** in 1954. The **Nianche River Valley** was flash-flooded by more than 300 million cubic metres of debris. The valley was buried in a three to five metre thick layer of debris. About 691 people lost their lives and around 16,000 people lost their land, crops, houses, and livestock.

There have been many GLOFs and other glacier related hazards such as ice avalanches and debris flows in mountain ranges all over the world in the past. The accelerated thinning and retreat of glaciers due to climate change is expected to increase the frequency of these events.

A study carried out in 2005 by Greenpeace on the impact of climate change on the glaciers **at the source of the Yellow River in China, found that 17% of the glaciers in the region had disappeared** and that ice was melting 10 times faster than it was over the last 300 years. As a consequence, they found that lakes had dried up, deserts had advanced, there was subsidence of the ground due to melted permafrost and soil erosion.

A combination of increased temperature and reduced precipitation is driving the retreat of glaciers. According to the IPCC's fourth annual assessment report, several glaciers will retreat over the next few decades and many small ones would have disappeared. According to projections,

a 2°C rise in temperature by 2050 would lead to the disappearance of 35% of the glaciers that currently exist and increase the level of runoff causing it to peak between the 2030s and 2050s.



Taboche and Khumbu Valley in 2007

Surface Water Availability

Intense precipitation causes large scale wasting in the Himalayas. Incessant rainfall affects the water storage capacity of the top layer of loose rock and causes hill slope failures. The frequency and intensity of extreme weather events such as floods, landslides, drought, glacial lake outburst floods and rivers breaking their banks due the excessive runoff caused by heavy monsoon downpours, is expected to increase over the next few decades. There will also be a **decrease in the certainty and predictability of the timing of the monsoon and rainfall**.

One of the main causes for concern related to the impact of climate change in the Himalayan region is the **decrease in snow and ice**, which reflect the water storage capability. Initially there will be a steady increase in the stable base-flow originating from melting ice and snow, particularly in the warm and dry seasons. With time as the reservoirs of snow and ice in the higher reaches of the mountains continue to decrease; there will be an increase in the variability of downstream runoff which would be more a reflection of rainfall runoff. When the snow and glaciers are substantially reduced or have disappeared, water systems may see a severe shortage in a very short span of time of a few decades or even less. Current trends in glacial melt indicate a considerable reduction in slow flow as a consequence of climate change. This would **drastically affect half a billion people in the Himalayan region and a quarter of a billion people in China** who depend on glacial melt for their water supply. Some of the most densely populated areas could face an acute shortage of water in the dry season.

Climate change could also alter the frequency and intensity of fire outbreaks. Extended duration of summer drought can convert areas that are prone to fire outbreaks into regions of sustained fire hazard. Areas that are currently safe will begin to see an incidence of fire outbreaks.

Water supply in the EH is regulated by the renewal processes associated with the hydrological cycle. A rise in temperature would accelerate the cycle, increasing evapotranspiration and causing increased liquid precipitation. **Alterations in the quantity and seasonality of precipitation would influence soil moisture, ground water reserves and the frequency of drought and flood episodes.**

Freshwater systems that are not fed by snow melt will undergo shrinkage and desiccation in the summer when evapotranspiration is more rapid than precipitation and there is a decrease in surface water flow. Contraction of these surface water-fed ponds and wetlands will decrease freshwater habitats. Consequently there would be a **reduction in fresh water biodiversity because of the shrinking of habitats, acidification of lakes and the molecular damage associated with UV exposure**. A decrease in surface water flow will decrease the availability of cations and the buffering capacity of saltwater lakes, increase acidification and severely affect organisms that cannot withstand decreases in pH.

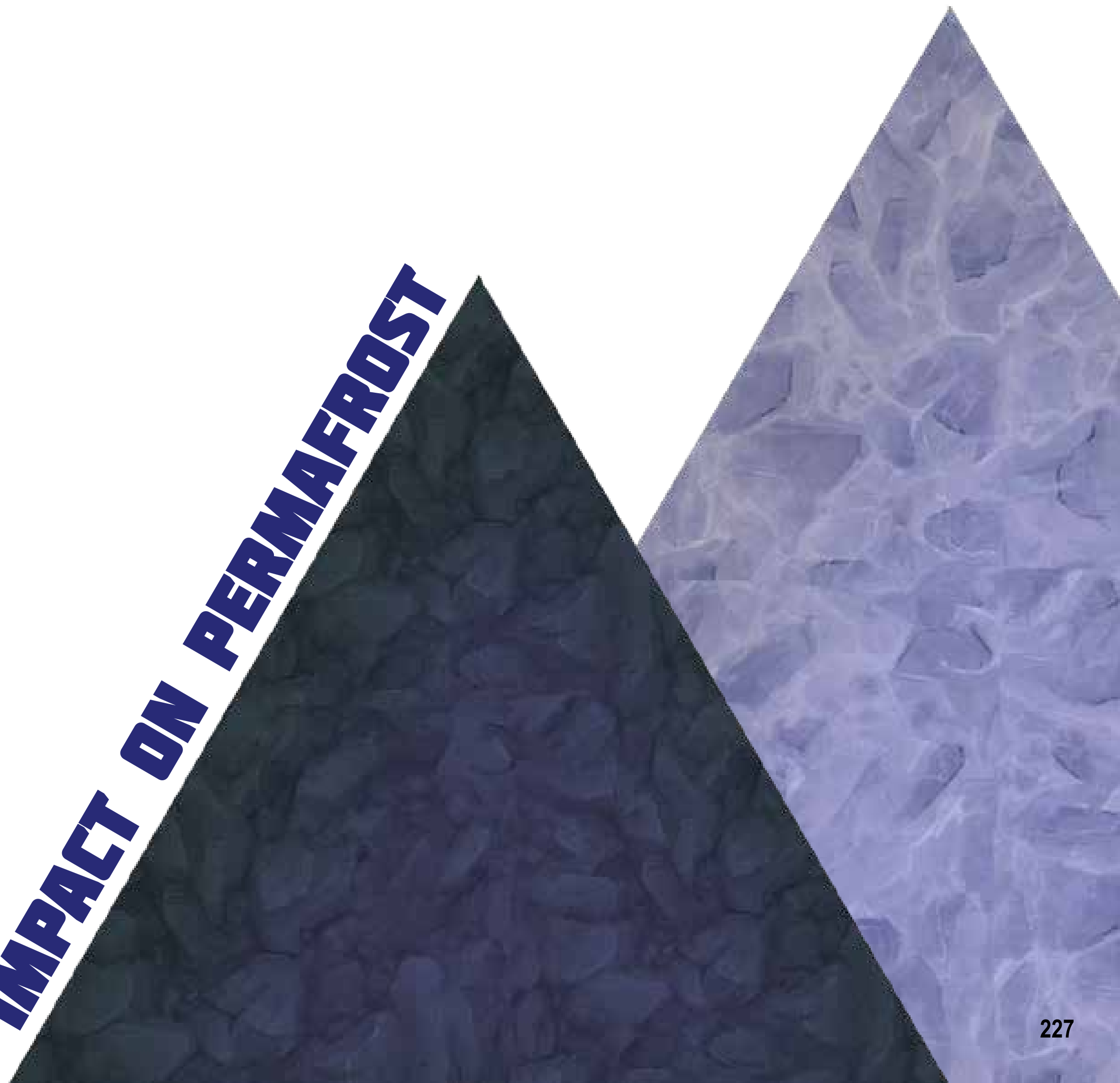
The rate and timing of discharge in rivers that originate in the mountains is modulated by glacier melt. In many EH river basins, the timing of maximum runoff associated with the monsoon is likely to change in the future. Alterations in the timing and intensity of the monsoon and the manner in which the available precipitable water content in the atmosphere is intercepted by the Himalayan range will have a significant influence on the timing and quantity of runoff in river basins like the Ganges, the Brahmaputra and the Irrawaddy. According to estimates, **the snowline will recede by 135 m for every 1˚C rise in temperature.** Changes in snowpack duration and amount as a result of changing climate will affect the availability of water in hydrological basins. As glaciers continue to melt rapidly there will be increased runoff. However, this will decrease once there is a significant reduction in glacier volume. Similarly, the availability of water in snow-fed rivers will increase in the near future but will eventually decrease.

When precipitation exceeds the rate of evapotranspiration, there will be an increase in water flow. Thawing of permafrost and the melting of glaciers will further enhance flow in systems that are fed by glacier melt. An increase in water flow can change the morphology of stream channels by enhancing erosion along the banks and depositing the sediments in other places. Alterations in channel morphology have a direct impact on the lifecycles and habitat requirements of freshwater species (e.g., fish spawning and rearing) and influence the entire population.

IMPACT ON PERMAFROST

Permafrost is a layer of earth that is frozen for at least two years or more and traps water in the uppermost layer of the soil by making it possible for plants to grow at altitudes where climatic conditions are extremely severe. High altitude areas on mountains and plateaus that are not covered in perennial snow and ice are underlain by permafrost, which can be adversely affected by climate change, especially warmer temperatures. Recent studies have shown that **the extent of permafrost is reducing and the thickness of the active layer (the upper portion of the soil which thaws each summer) is increasing.** This has led to changes in the hydrological cycle, vegetation composition and carbon dioxide and methane fluxes that seem to be linked to permafrost degradation. Permafrost has a **major influence on ecology, slope stability and erosion processes and surface water hydrology**.

Climate change is increasing the temperature of permafrost in the Qinghai-Tibetan plateau, more slowly than at the poles but faster than at anywhere else in the world. There has been a decrease in the extent of permafrost, a rise in the altitude of its lower boundary and progressive thinning. For example, over the last three decades, **the lower limit of permafrost has risen by about 71 m and the thickness has reduced by about 20 cm on the Central Tibetan Plateau in the Kekexeli Wildland Area.** This accelerates the process of desertification and could have a serious impact on alpine ecosystems.



IMPACT ON ECOSYSTEMS AND CONSEQUENCES FOR BIODIVERSITY

Climate change has been associated with many of the changes observed in terrestrial biological systems. Spring events such as leaf-unfolding, bird migration, and egg-laying are occurring earlier. The range of plant and animal species is moving upwards both towards higher altitudes as well as pole-ward. This shift of species range towards higher elevations will be more acute in the future. Shifts in plant species will be more gradual and the complex terrain and steep slopes of the EH will be a tough challenge for successful colonization. Satellite observations since the early 1980s suggest an **early greening of vegetation in the spring that has been associated with the longer thermal growing season due to increasing temperatures.**

It has been predicted that climate change will have an impact on the boundaries and areas of different types of forests, primary productivity, species and population migration, incidence of pests and diseases, and forest regeneration. Increased levels of GHGs will influence the species composition and structure of ecosystems which in turn will have an impact on ecosystem function. **Primary productivity is expected to increase by 1 to 10% in the EH.** Warmer temperatures and drier conditions will increase the abundance and extend the range of the pests such as the North American Pinewood Nematode. A substantial decrease in alpine and cryospheric ecosystems has been predicted, while tropical zones are expected to gradually cover most of the middle mountains and inner valleys of the region. There are very limited habitats available for Alpine plants above the tree line; these plants can undergo acute fragmentation, suffer habitat loss or become extinct if they are unable to extend their range upward. In contrast, warmer temperatures may increase the habitats available for water hyacinth.

Species Responses

Species will probably respond to changing climatic conditions by adapting, altering their range, changing their abundance or disappearing completely. While species will vary in the rate with which they shift their geographical range, some species may not be able to reach and colonize new habitats. The rate of decrease in temperature with altitude is about 5 – 10 ˚C/1,000m. As temperatures rise, species will attempt to move to cooler areas where the climate is more suitable. According to estimates, the rate of tree species migration in the past has been in the range of 2 – 200 m per century. Going by these figures **the expected warming of 1 – 3.5 ˚C over the next 100 years in the EH is likely to trigger an altitude shift of 150 to 550 m.**

One of the impacts of climate change on mountain ecosystems would be the elimination of the coolest climatic zones at the peaks of the mountains and an upward shift of all the remaining vegetation zones.

Since mountains get narrower and narrower towards the top, the shifting vegetation belts would have smaller and smaller areas to occupy. This would lead to a decrease in population of various species because of genetic and environmental pressure. However, different species would be affected to varying degrees depending on their climate tolerance, genetic variability and different longevities and survival rates and pressure from invading species.

Climate change is expected to alter the composition of 75% of India's forests by the end of this century. Eighteen percent of the forested grids in the WG and 50% of the forested grids in the Himalayas are vulnerable to climate change and will be affected by 2030. The Nilgiris in the WG are likely to see an increase in evergreen, moist deciduous and dry thorn forests; and a reduction in montane forests and grasslands and dry deciduous forests. The stunted montane forests and grasslands found at higher elevations in the western ghats are likely to be highly sensitive to climate change. The Nilgiri tahr and other montane species would be adversely affected by a reduction in montane grasslands, their principal habitat.

Evolutionary Impacts

Species with short generation time, such as insects and annual plants, may well adapt to such changes by rapid evolution. Long lived species such as trees will be worse off. Eventualities such as **species extinction and ecosystem disruption** are directly influenced by the rate of climate change.

Individuals within a species may vary in their ability to undergo phenological adaptations in response to climate change. These individuals might be selected in preference to others, causing a change in the dynamics within a species and the community, and exerting evolutionary pressure on the species. Sub-populations inhabiting the warmer boundaries of a species range would be extirpated leading to a **loss of species diversity.**

Rising temperatures could also cause pest species to shift north or to higher altitudes and also increase their abundance. Entire ecosystems or a few species may not be able to shift their range if they cannot match the pace with which changes are occurring. The unavailability of appropriate new habitats or the presence of landscape features such as cities could also prove to be an obstruction. Colonization may also be unsuccessful if, the soil in the new habitat is not satisfactory, or if coexistence with the existing inhabitants is not possible or the level of human development is too high. **Invasive species would be at an advantage under these circumstances.**

Lifecycle Changes

Snow cover is of great significance as it protects plants from frost in the winter and supplies water in spring and summer.

Plants that inhabit snow beds and hollows will be the worst affected by climate change as they will be exposed to desiccation in the summer. In general, species will vary in their sensitivity to climate change. This would change the relationships among species, and affect ecosystem functions that rely on interactions between species. Plants, animals and insects will bud, breed, or hatch earlier in the year as temperatures continue to rise. Long living plants that cannot migrate will be exposed to these changes within their life time and their survival would depend on their ability to undergo phenological adaptations.

Such lifecycle changes in the animal world can prove to be detrimental to communities and affect their composition as they can have a negative impact on breeding seasons, predator-prey relationships and competition between species. Migratory species will be especially vulnerable as there would be a time lag between migration and the availability of food. These changes could alter the composition and functioning of ecosystems.

Species will probably respond to changing climatic conditions by adapting, altering their range, changing their abundance or disappearing completely.

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Landscape Level Changes

Climate change can alter both the frequency and the extent of major disturbance events. Droughts can lead to insect epidemics and large-scale wildfires with significant effects. Climate change has the potential to increase both the frequency and the severity of such disturbances. Disturbances, such as fire, are capable of converting entire forest ecosystems to grassland ecosystems. Changes in disturbance regimes can bring about major ecosystem level changes by altering **structure** (dominant vegetation, age class distribution, species composition and so on), **functioning** (productivity, nutrient cycling, decomposition and so on) and **distribution** within and across landscapes.

Alpine Ecosystem

Alpine and sub-alpine ecosystems that are situated between the tree line at 4,000 m and the snow line at 5,500 m are almost as vulnerable to climate change as the polar regions. They are undergoing desertification, there is less snowfall and glaciation events have decreased. All over the world, there is evidence of tree lines advancing and of the extinction of montane plant populations in recent years and these changes have been attributed to the effects of climate change. The changes in temperature and the pattern of snowfall are altering the distribution and phenology of various alpine plant species. As alpine plants move upwards where the temperature is more suitable the competition for resources and space will intensify and the plants will be subjected to additional stress. Some cold-adapted alpine plants have already begun to move upwards along mountains. The species composition is changing and the productivity of the grasslands is on the decline.

For example, **Quercus-betula forests are being transformed into Krummholz-type of vegetation** consisting of species such as Rhododendron, Salix and Syringia.

Most communities residing in the upper reaches of the Himalayas rely on cattle and sheep farming. They are worried about the decrease in the production of grass in the Himalayan grasslands. This is primarily due to the lack of sufficient moisture that has resulted from the decrease in snowfall. Hills, that have in the past been covered in snow all year round, are now barren and dry over the last 20 years. The flow of water in streams and from springs has undergone substantial changes over the last few years and has had a major effect on water supply.

In a study carried out by Kumar, RK and his co workers, in many regions of the Himalayas, wherein repetitive surveys were carried out every 10 years for the last four decades, the following observations were made:

A 200 – 500m upward shift in vegetation to higher elevation

Phenological changes, especially early flowering, observed in most cases

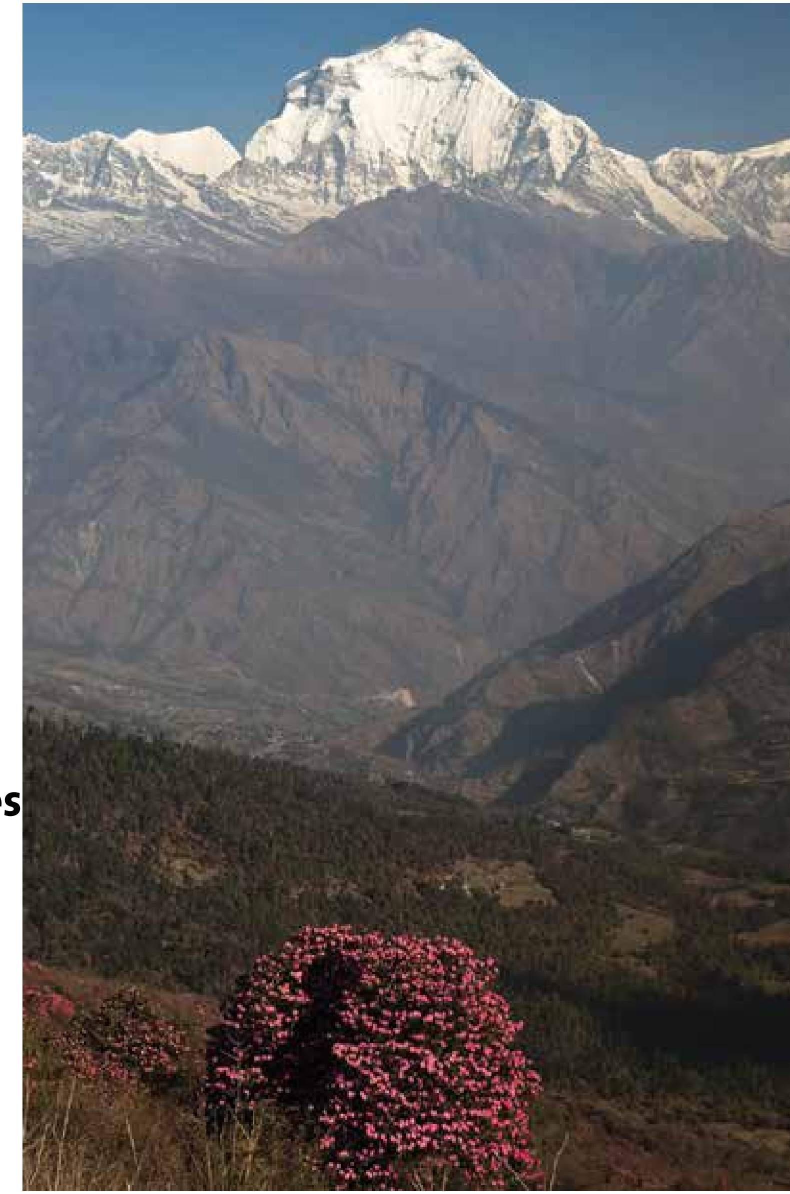
Long period of seed dormancy observed in some high altitude plants

Low rate of seed germination in some high altitude medicinal plants

Spread of invasive species upto the sub-temperate Himalayan region

Erect habit of some plants converted to prostrate habit

Migration of alpine region species to cold deserts



They found that climate change was leading to **phenological shifts in medicinal and aromatic plants and in animals.** These shifts affect community structure as they alter the timing of activities that allow species to coexist. The life cycle of a number of wild plants is strongly influenced by the passing of seasons and climate change can have a drastic effect on the synchronisation between interdependent species.

In general, many invasive species are able to extend their ranges quickly and are also able to tolerate a wide range of climatic conditions and it has been observed that such species tend to be favoured when the climate changes rapidly. The community structure and population dynamics of native flora and fauna of the Himalayas have been altered by the invasion of **alien species of weeds such as Lantana camara, Parthenium and Ageratum.**

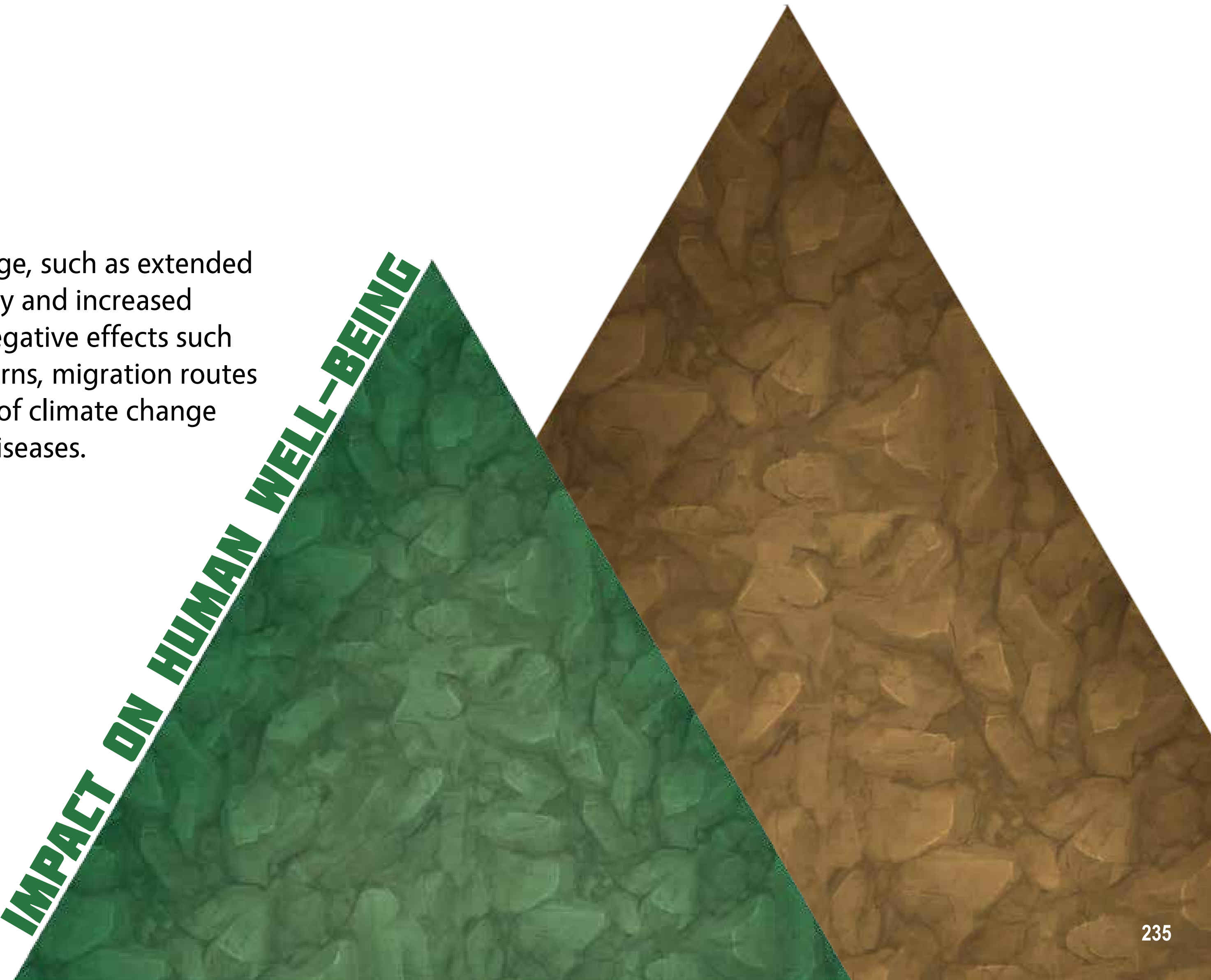
SUMMARY

Alpine and sub-alpine ecosystems are extremely vulnerable to climate change. They are undergoing desertification and a decrease in the production of grass. This is due to insufficient moisture as a result of the reduction in snowfall and decrease in glaciation events.

The changes in temperature and the pattern of snowfall are altering the distribution and phenology of various alpine plant species. As alpine plants move upwards where the temperature is more suitable the competition for resources and space will intensify. Tree lines are advancing along mountains all over the world and montane plant populations that inhabit the alpine zone are facing extinction.

IMPACT ON HUMAN WELL-BEING

While there are beneficial effects of climate change, such as extended growing seasons, reduced natural winter mortality and increased growth rates at higher altitudes, there are also negative effects such as changes in well established reproductive patterns, migration routes and ecosystem interactions. The indirect effects of climate change include disastrous changes in pests, weeds and diseases.



Livelihoods

Climate change will adversely affect the pastoral people and subsistence farmers who constitute a substantial portion of the rural population of the EH. Agriculture is a direct or indirect source of livelihood for 70% of the population of the EH. The impact that climate change will have on agriculture will depend on many variables such as temperature, precipitation, length of growing season, timing of critical events related to crop development and the atmospheric carbon dioxide concentration (which is advantageous for the growth of many kinds of crops).

There has already been a **decrease in the production of rice, corn and wheat** due to increasing water stress caused by increasing temperature, increased frequency of El Nino, and a reduction in the number of rainy days. The 15 major droughts that India has faced over the last 50 years have had a severe impact on the rain-fed crop in drought years. Crop productivity directly affects the livelihood of the vast population that makes a living out of agriculture.

The yield of tea, coffee and cardamom from high latitude plantations in the WG has been decreasing because of changes in the climate of the region, which was earlier characterized by high rainfall and humidity, optimum temperatures and needed little irrigation. The WG is expected to experience a 1.7˚ – 1.8˚C rise in temperature by 2030, with an increase in the amount of rainfall and a reduction in the number of rainy days. Drought, degrading forests, decrease in soil and atmospheric moisture, drying up of forest streams after the rains are problems that this region and the rest of peninsular India are going to be faced with. The annual rainfall in Coorg has already dropped by one third from 106 inches to 70 inches.

Coconut yields are expected to increase by about 30% in most parts of the WG, partly due to an increase of around 10% in rainfall and a lower increase in temperature. However, some parts of south-west Karnataka and parts of Tamil Nadu and Maharashtra are likely to see a decrease in yield of about 24%.

The yield of irrigated **rice** is expected to fall by about 4% throughout the WG.

Parts of southern Karnataka and the northern most districts of Kerala, are expected to see an increase in the yield of rice. These regions have lower maximum and minimum temperatures and are expected to experience lower increases in temperature. The yield of rain-fed rice is likely to fall by about 10% and that of maize and sorghum by about 50%. In the WH region, an increase in temperature of 2˚C is expected to reduce the yield of rice by 0.75 ton/hectare in high yield areas and by 0.06 ton/hectare in low yield coastal areas.

A 0.5˚C rise in winter temperature is expected to reduce the yield of rain-fed **wheat** by 0.45 ton/hectare. The major impact would be on rain-fed or un-irrigated crop which accounts for 60 % of the total crop area. Climate change will thereby adversely affect the livelihood of poor people who depend on rain-fed crops and on regional food security.

Disruptive changes in growing conditions and adverse effects of the environment at critical phenological stages can have a negative impact on food productivity and elevate the level of malnutrition. There will be changes in the phenological events related to flowering and fruiting in many species. Late snowfall could immobilise bees due to the low temperature and thereby affect pollination. Melting of glaciers and snow is expected to increase runoff till the middle of this century after which there will be a **decline in the availability of melt water** as a substantial portion of glaciers and snow cover would be lost.

In a study carried out by the International Rice Research Institute, **rice** production decreased by 10% for every 1˚C rise in temperature. A substantial decrease of 20 – 78% in **wheat** production potential in South Asia, 6 – 38% in production potential of rain-fed **sugar** crops and a decrease of 23% or an increase of 20% for **roots** and **tubers** has been predicted for the coming decades. **The net cereal production is projected to reduce by 4 – 10% by the end of the 21st century.**

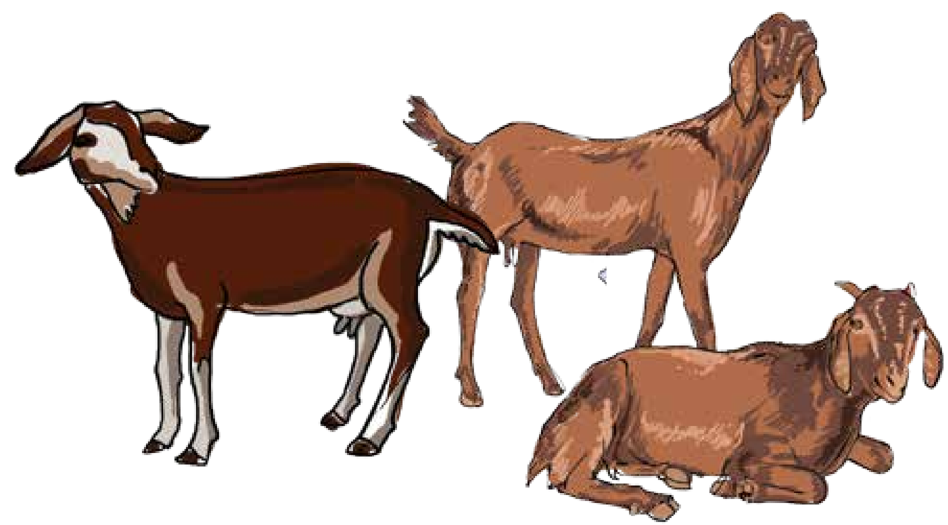
Analysis of weather patterns in **Kullu and Shimla**, showed that in both these regions, rainfall has increased, and there has been a reduction of snowfall in the winter months. Warmer temperatures together with altered precipitation patterns have reduced the total number of annual chilling hours. While Shimla, Kullu and the entire Himachal have seen a **decrease in apple productivity,** and the area under apple cultivation over the last two decades, Lahaul, Spiti and Kinnaur which lie more than 2,500 m above MSL have seen a steady increase in apple productivity over the last decade.

The Thermal Humidity Index (THI) has been used to measure thermal stress due to the combined effect of air temperature and humidity. A THI greater than 75 affects **milk production** in European cross breeds and buffaloes. A THI greater than 80 has a negative impact on the **health and productivity of livestock**.

Most parts of India have a THI greater than 75. While the Himalayan region is likely to remain unaffected, the TSI is expected to increase further by 2030 in the WG and North Eastern states and adversely affect the economic viability of livestock production systems.

Upland crop production which is practised on the edges of established production zones is extremely vulnerable to climatic variations. The upward movement of thermal regimes due to increasing temperature causes **agricultural zones to shift upward to higher altitudes.** A good example is the buckwheat–barley belt that is being increasingly used for rice cultivation in Bumthang Dzongkhag in Bhutan which is located at an altitude greater than 3,000 masl.

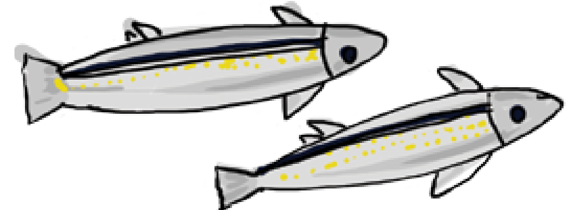
In areas that are going through social change at a fast pace, like many of the EH rangelands, climate change can prove to be an added stress. Rangeland and pastoral production systems will probably be affected by a decrease in the quality and quantity of forage, heat stress and diseases like foot and mouth in livestock.



A 2 – 3 ˚C rise in temperature combined with a decrease in precipitation is expected to reduce the productivity of grasslands by 40 – 90%.

SUMMARY

The major impact would be on rain-fed or un-irrigated crop which accounts for 60% of the total crop area. Climate change will thereby adversely affect the livelihood of poor people who depend on rain-fed crops and on regional food security.
Inland freshwater fisheries at high altitudes will be affected by the decreased availability of oxygen due to an increase in surface temperature
Disruptive changes in growing conditions and adverse effects of the environment at critical phenological stages can have a negative impact on food productivity and elevate the level of malnutrition.



Fisheries and fish production are also sensitive to climatic variations and are already affected by overfishing, shrinking spawning areas and pollution. Inland freshwater fisheries at high altitudes will be affected by the decreased availability of oxygen due to an increase in surface temperature. In the plains, alterations in the timing and quantity of precipitation would have an impact on the migration of fish species from rivers to the floodplains for spawning, dispersal, and growth. Climate change can also bring about major changes in fish breeding habitats, the availability of food for fish, and thereby influence the population of freshwater fish. An increase in the number of alien invasive pests and diseases would have an adverse effect on crops and livestock.

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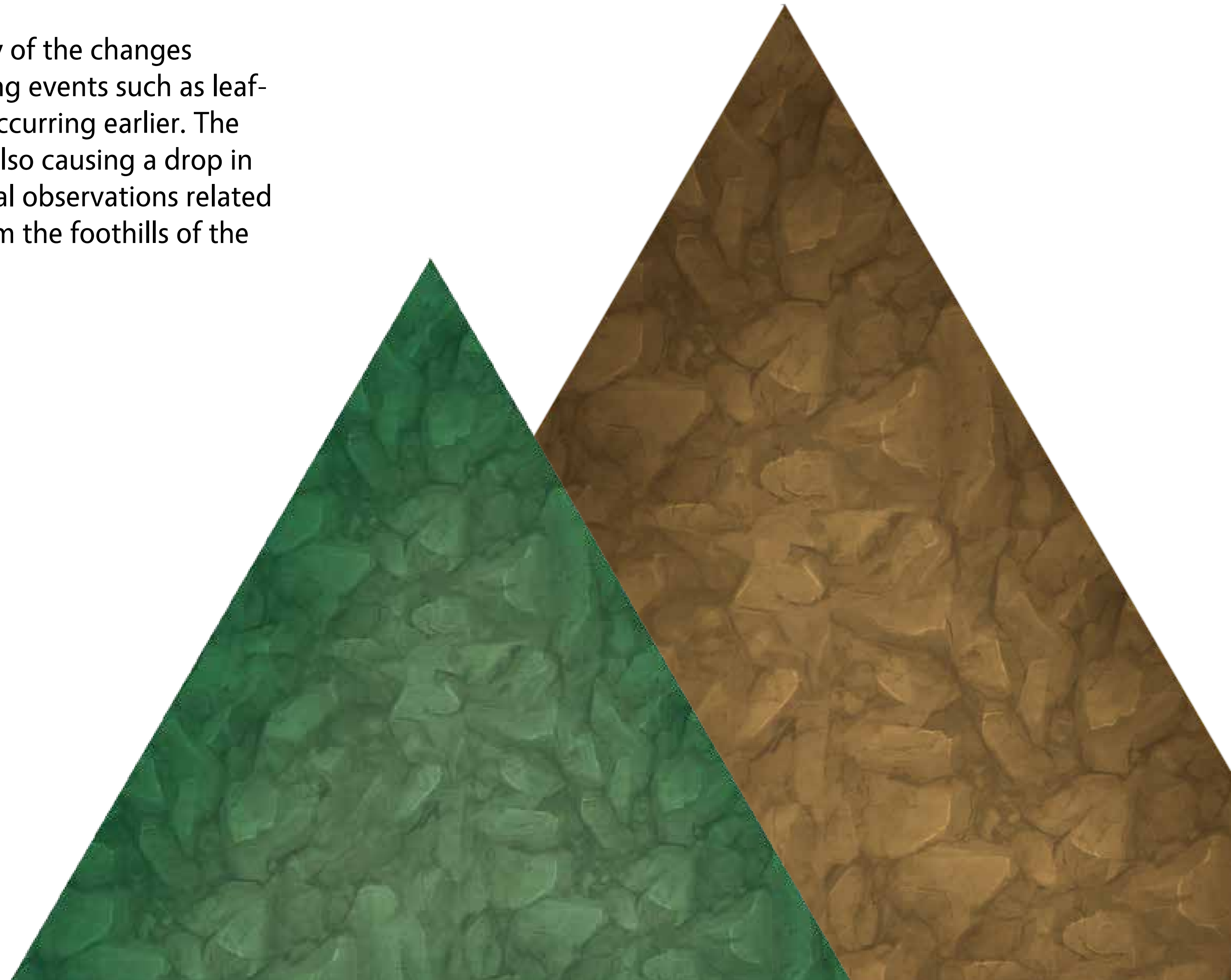
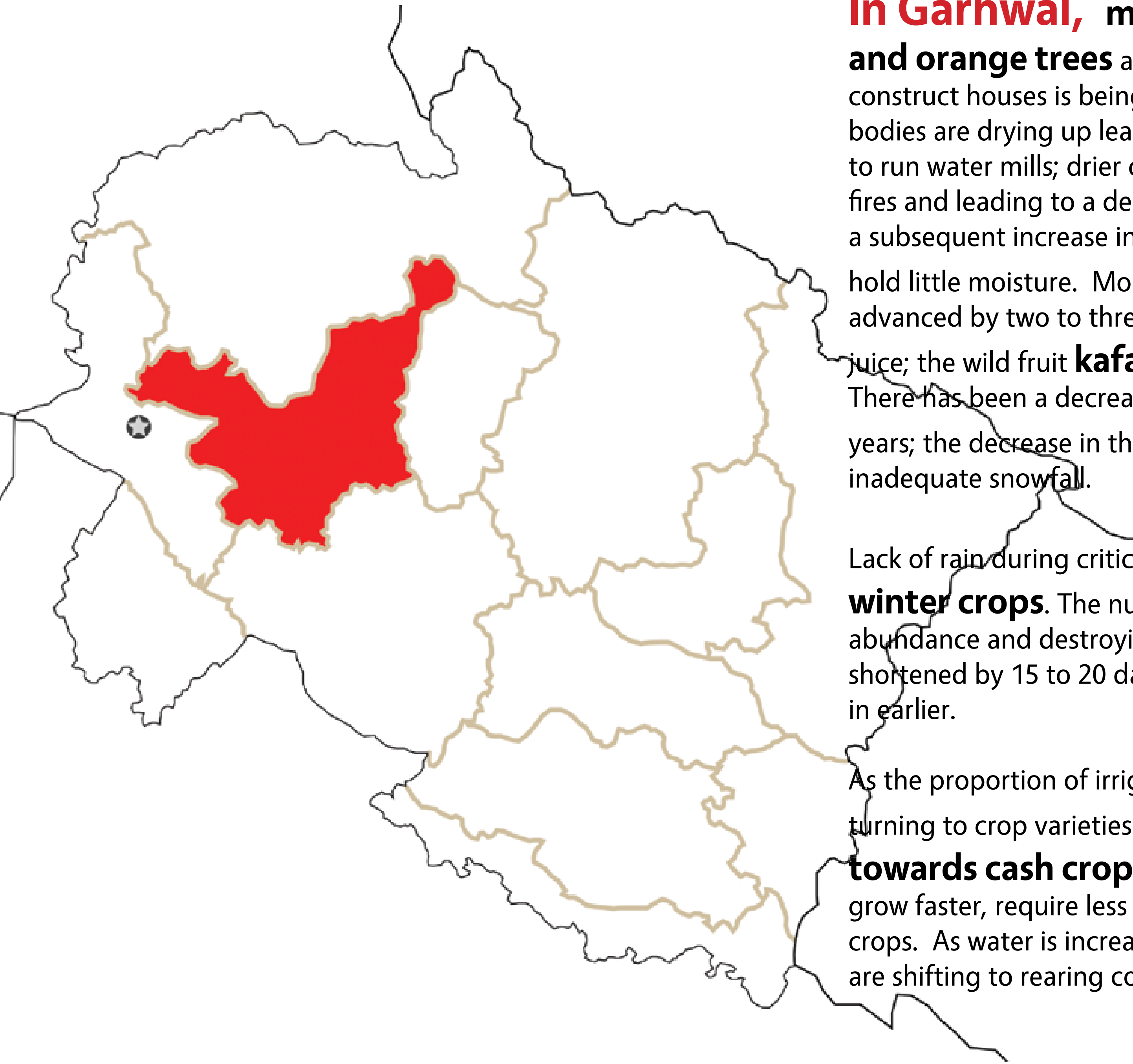
CASE STUDIES AND EXPERIENCES OF PEOPLE LIVING IN DIFFERENT MOUNTAINOUS REGIONS

Climate change has been associated with many of the changes observed in terrestrial biological systems. Spring events such as leaf-unfolding, bird migration and egg-laying are occurring earlier. The changes in temperature and precipitation are also causing a drop in productivity of various species. There are several observations related to climate change that have been reported from the foothills of the Himalayas.





In Garhwal, **mango trees** are beginning to give fruit; **apple and orange trees** are unable to survive; **pinewood** used to construct houses is being attacked by termites; springs and other water bodies are drying up leading to a reduction in irrigated land and inability to run water mills; drier conditions are increasing the frequency of forest fires and leading to a decrease in the population of broad leaf species and a subsequent increase in the number of pine trees which comparatively hold little moisture. Moreover, flowering of **Rhododendron** has advanced by two to three months; flowers are smaller and contain less juice; the wild fruit **kafal** is available two months ahead of its actual time. There has been a decrease in agricultural productivity in the last 10 to 15 years; the decrease in the productivity of **wheat** has been attributed to inadequate snowfall.

Lack of rain during critical winter periods is leading to a **failure of winter crops**. The number of weeds and diseases are increasing in abundance and destroying crops. The cultivation time of wheat has been shortened by 15 to 20 days as conditions suitable for crop ripening now set in earlier.

As the proportion of irrigated land is steadily decreasing, farmers are turning to crop varieties that require less water. There is also a **trend towards cash crops like tomato, onion and potato** that grow faster, require less water and have greater output than traditional crops. As water is increasingly becoming a limiting resource, poorer people are shifting to rearing cows and selling milk.

In Kinnaur in Himachal Pradesh, changes in the climate have led to a **decrease in the production of food grains and traditional millet crops**. Besides, production and quality of **apples** has decreased; regeneration of **chilgoza** and **wild apricot** has been affected; water bodies have been drying up; and there is an increase in soil erosion and in the frequency of rainfall. The reduction in the quantity and intensity of snowfall has reduced the chilling hours available for temperate fruit and led to a decrease in crop yield. The timing of phenological events like flowering, fruiting, and new leaf formation has advanced by one or two months.

In Baunsari, village in Pauri Garhwal district of Uttaranchal, four out of eight water sources (mostly springs) in the village have dried up and the remaining four have very low levels of water. As a result most irrigated land has become rainfed and barren and there has been a substantial decrease in crop production. All the water mills in the village have stopped working due to the low levels of water in the streams.

An increase in the incidence of forest fires has reduced the forest cover around the village. Broadleaf species such as **Oak, Rhododendron, Kafal, Utis and Bhamora** that maintain water recharge in the area, conserve moisture and are more resistant to forest fires, have been replaced by Pine trees that retain very little moisture and are more susceptible to forest fires.

The rapid spread of **Kala Bans** (Upatorium species) in forests and grasslands has reduced the space available for grass and resulted in a shortage of grass for livestock in the village. Women now have to walk 10 to 15 km to find fodder for their livestock.

Rhododendron trees which have medicinal properties and are used to treat heart ailments have also been affected by climate change. For the last few years Rhododendron flowers have begun to blossom two to three months earlier than usual. The flowers are smaller and contain less juice.

The complete absence or reduced levels of snowfall has led to a **decline in wheat production.** There has also been an increased incidence of new diseases and insects attacking the crops and widespread growth of weeds.

Another study included 100 tribals (50 men and 50 women) from 10 villages **in Kalpa** block in Kinnaur district of Himachal Pradesh. More than 80% of the tribal people reported that the temperature was rising, there was **increased frequency of forest fires, more pollution and less snowfall.** A large majority of the people also felt that climate change has led to a decrease in food grain production, production and quality of **apples**, regeneration of **chilgoza** and production of local varieties of **grapes.** They also reported that water bodies have dried up and the frequency of rainfall, deforestation, and the extent of soil erosion have increased and there is inadequate drinking water.

A large number of respondents felt that as there was a decrease in the quantity and intensity of snowfall, the chilling requirements especially for temperate fruit were inadequate and this was leading to a decline in crop yield. Pollination was also proving to be a problem. All these developments were forcing many people to change their cropping pattern; they had begun to prefer cash crops and early maturing varieties that require less water. **Wild apricot** and some local varieties of grapes seemed to be disappearing. Most people in the village have **shifted to broom grass cultivation** which is commercially more viable and less sensitive to climate change.

Forest Fire

Two hundred people living in villages in the **Kunjapuri hills** in the Garhwal Himalayan region were asked how they perceived the impact of climate change in their area. Most of the people were of the opinion that the climate has been changing; temperatures are higher than normal since the last three or four years and there have been changes in the pattern of rainfall and snowfall. They felt that snowfall had reduced over the last 10 – 12 years. Many claimed there had been no snowfall for the last 8 – 12 years. They said that the higher temperatures have forced them to install ceiling fans in their houses and **now there are mosquitoes in the hills**.

The Konyak tribe lives in **Mon** district in Nagaland which is considered one of the most backward districts of the country. When asked about their perception about climate change, the villagers said the **yield of paddy had dropped** over the last few decades, crops were being attacked by pests and the frequency of **flash floods and landslides** due to heavy rainfall had increased in recent years. What was peculiar was that there was an intense cyclone that hit one of the villages in 2003; the people of the village situated 800 m above mean sea level had never experienced a cyclone in the village before. The traditional method of farming which was practiced and depended on an established and predictable pattern of rainfall and weather was being disturbed due to climate change. Diseases like **malaria and tuberculosis** have recently begun to appear. The number of mosquitoes is increasing due to the warmer temperature and new varieties of mosquitoes are being observed.

The impact of climate change is also being felt by the hill communities of **Arunachal Pradesh**. A few village elders from Mechuka in West Siang district claimed that they have observed a **change in the pattern of snowfall and its intensity** over the last 12 – 15 years. Earlier snowfall used to begin late in October and reach their homes but recently it has been starting only in December and rarely reaches their homes. The last snowfall received in Thungri village in Bomdila when about a foot of snow was deposited on the ground was about 10 – 12 years ago. Snowfall now remains restricted to the tops of the mountains. About 15 – 20 years ago the **apples** in Mechuka were sweet but now the fruit tastes sour. Earlier apples used to flower once a year in February. Now they flower in late march as well as in September and the flowers that bloom in September do not produce any fruit. Many species of trees like Rhododendron and Abies which were earlier found in lower altitude areas are now restricted to the higher ridges of the mountains and the lower ridges of the mountains are being gradually occupied by pine species.

A study conducted in **Tangmang village** of East Khasi Hills in Meghalaya revealed that there has been a significant change in temperature, rainfall and in the length of seasons during the last four decades. Since 2000, temperatures have been very high, there has been considerable irregularity in the intensity, frequency and duration of rainfall and there has been no distinct autumn season. The people of the village felt that changes in the rainfall pattern and soil conditions have affected four of their crops. The number and severity of various diseases has increased. Two of the commercially important crops are **betel nut and bay leaf**. They are very sensitive to drought and disease respectively. Due to frequent famines over the last few years, hundreds of betel palm trees have died each year and people said they would have to stop cultivating betel nut. The productivity of bay leaf has dropped from 90 – 100 kg bay leaves per tree to 15 – 30 kg per tree, due to increase in pests and disease. The size of the trees has also reduced. There has been a sharp decline in the cultivation of **orange, papaya and sweet potato** and the yield and size of oranges has reduced. Till a few decades ago orange was one of the major crops cultivated.

Records show that the temperature of **Kashmir** has increased by 1.45 ˚C in the last two decades and the temperature of the southern plains has increased by 2.32 ˚C during this period. The deficit in food production in Kashmir which was 23% in 1980 – 81 has now increased to 40%. The scarcity of water has forced many farmers to **replace paddy with rain fed orchards**. The food grain deficit in Kashmir is expected to reach 60% over the next decade if the current trend continues. Rivers in the region are drying up, glaciers are rapidly retreating and food production is being adversely affected due to climate change.

The summer monsoon has become very unpredictable and there is a lot of unseasonal rain which is adversely affecting both the monsoon and winter crops. Heavy rainfall is causing **excessive leaching of the soil**. The increased run off along steep slopes is causing substantial erosion.

Many of the people living in the hills have noticed **heavy and erratic monsoon rains** in recent years which is very untypical. Monsoon rains in the upper reaches of the hills have conventionally been lower in intensity and quantity and heavy rainfall was experienced only at lower altitudes. The flat roofed houses in these areas are made of mud and stone and have not been designed to withstand such heavy downpours. On the contrary they are built that way to retain winter snowfall which is used to meet domestic water requirements. Heavy rainfall is giving rise to problems like **leaking roofs** and walls are being eroded. People of lower income groups who cannot afford repairs are the worst affected. The decrease in winter snowfall is expected to create a water shortage.

Farmers in the district of **Mustang** are very clear from their experience of the past few years that the climate has changed and has affected their lifestyles. They are able to grow vegetables like cauliflower, cabbage, chilli, tomato and cucumber, which until now required a greenhouse to survive the chill. Local fruits are now larger in size and are tastier. Plants that earlier grew only at lower altitudes are now seen in their district. Apple trees bear large and tasty apples. Earlier it was too cold to cultivate apples. Apple farms and orchards are coming up. The tree line is rising. Many of the residents feel their district is a lot greener than it used to be even a couple of decades ago.

They say the winters are relatively warm, snow-free and less frosty and they have not experienced a long chilly winter since five or six years. The **river valleys are windier** than they used to be. There is increased rain and snowfall after the winter and the summer rainfall is unusually intense. **Flash floods, avalanches, windstorms and hailstorms** are now more frequent. Rainfall has become more erratic and there are long periods of drought and sudden heavy rains. Such incidents of harsh weather are on the rise and are increasing the loss of life and property.

The long periods of drought following the monsoon have made **tourism more profitable** as tourists are able to visit for a longer period. The shortage of water and the variable precipitation patterns have adversely impacted agriculture. People who have traditionally relied on cultivating wheat, potato and other local vegetables are affected.

The shortage of water is also forcing people to abandon some of the old localities. The elderly people are of the opinion that large avalanches, windstorms and hailstorms have been occurring more and more frequently.

In **Jomsom valley** which is located at a height of 2,700m, the warmer climate seems to be the reason why **mosquitoes are becoming a menace.** In the summer of 2003, a herd of 36 yaks were killed near the valley. The meteorological data for the valley substantiates the views of the residents. The rainfall data indicates a decline in winter precipitation and an increase in rainfall after the winter. Snowfall after the winter affects the crops.

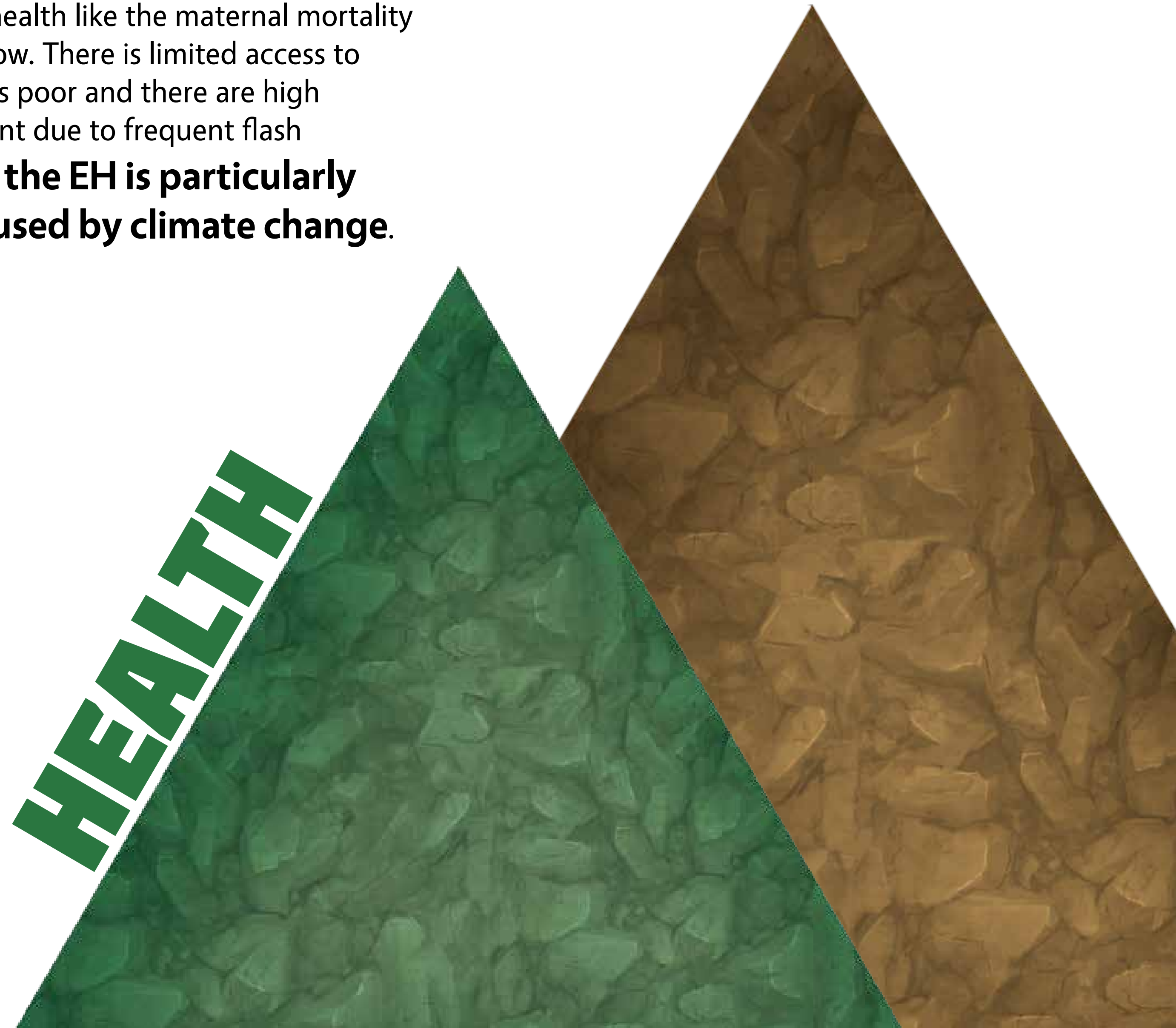
Changes in temperature and rainfall over the last 15 years has made **cardamom,** which is an important cash crop, susceptible to viruses. This has resulted in destruction of large cardamom plantations and a decline in productivity in the Sikkim Himalayas.

Butterflies are very sensitive to local weather, climate, and light levels. Small changes in temperature, wind speed, humidity, and sunshine can alter their behaviour and abundance in areas where they are present in large numbers. Many species of butterflies in the **Western Himalayas** have been moving from warmer to cooler areas and are being seen at higher altitudes.

Traditionally plantation crops have been cultivated in high altitude regions where there is heavy rainfall, high humidity and temperatures are moderate. They did not require irrigation. However, the reduction in rainfall in recent times is making irrigation a necessity. Wells are being dug and this is lowering the water table. Many crops are growing close to the maximum temperature they can tolerate. The yields of plantation crops like **tea, coffee and cardamom** is decreasing due to the changing climate. Even slight shifts in temperature could reduce or completely inhibit flowering.

Nonseasonal showers which are an indicator of climate change have led to a major decline in the production of **honey** in the WG which is a major source of natural as well as cultured honey. Heavy summer showers in 2011 caused many blooming flowers in the Wayanad Wild Life Sanctuary and adjacent areas to drop off plants and trees. Bees were deprived of nectar and many bee colonies collapsed.

The demographic and socioeconomic status, and the condition of poverty in the EH are far below the minimum level required to withstand all the negative impacts that climate change could have. The level of poverty is high; basic infrastructure is poor; a substantial portion of the population relies on subsistence farming and forest products as a means of livelihood. It is very vulnerable to the adverse effects of climate change on these sensitive ecosystems.The main indicators of health like the maternal mortality rate, infant mortality and life expectancy at birth are low. There is limited access to sanitation and safe drinking water; the health system is poor and there are high incidences of water-borne diseases and malnourishment due to frequent flash floods and landslides.Lacking at many different levels, **the EH is particularly vulnerable to the damage that can be caused by climate change**.



Overexploitation, industry and infrastructure development and other anthropogenic causes can lead to a decline in ecosystem services and limit the availability of natural resources. This would result in **conflict and competition** for scarce resources. **Agriculture and hydropower generation** which are the mainstay of livelihood and income in the EH will be severely affected by water scarcity caused by increasing temperature, melting glaciers, reduced snowfall, high evapotranspiration and variable rainfall. Climate change will affect human health through **extreme weather** and indirectly by decreasing water availability and quality and by **poor sanitation,** that are associated with a rise in water-borne diseases. Climate change would make the region susceptible to heat-related and **vector borne infectious diseases** such as malaria, cholera and dengue. People who are malnourished or live in poverty will be the first victims. Accessing basic necessities like food, water and fuel will become more and more difficult and as men migrate in search of better sources of income there will be an **enormous burden on women.**

Climate change would probably increase the level of **malnutrition** by adversely impacting food security. Extreme weather events such as floods, rock avalanches, landslides and droughts which are expected to occur with increasing frequency would elevate the levels of **stress, disease and injury**. The poor quality of water would elevate the incidence of diarrhoeal diseases. Warmer temperatures would cause and upward shift in vector borne diseases such as malaria, dengue and kala azar and also extend the duration of their transmission seasons. There would also be an increase in the incidence of cardio-respiratory diseases due to **elevated levels of air pollutants** such as nitrogen dioxide, a decrease in the level of ozone in the troposphere and at ground level, and increased abundance of air borne particulates in urban areas. While the number of winter-time deaths would decrease, there would be a substantial increase in heat related stress and deaths. Exposure to a combination of higher temperatures and elevated levels of air pollutants seems to be a critical risk factor for health in the summer.

HEALTH DETERMINANTS AND HEALTH OUTCOMES THAT CURRENTLY EXIST IN MOUNTAIN REGIONS OR ARE RELATED TO MOUNTAINS: SYNTHESIS OF COUNTRY REPORTS

Country	Afghanistan	Bangladesh	Bhutan	China	Nepal	India
Heatwaves	+	+	–	+	+	+
Glacial lake floods	M	–	M	M	M	M
Flash floods	M	+	M	M	M	M
Riverine (plain) floods	+	+	–	+	+	+
Malaria	+	+	+	+	M	+
Japanese Encephalitis	–	+	–	+	+	+
Kala-azar	+	–	–	–	+	+
Dengue	–	+	+	+	–	+
Water-borne diseases	M	+	M	M	M	M
Water scarcity, quality	M	+	+	M	M	M
Drought-related food insecurity	M	+	–	M	–	M

An "M" indicates the health determinant or outcome is present in the mountainous region of the country (and also in the non-mountainous areas); a "+" indicates the health determinant or outcome is present elsewhere in the courtry; a "–" indicates the health determinant or outcome is not present.

Source :WHO (World Health Organisation). 2005. Human health impacts from climate variability and climate change in the Hindu Kush –Himalaya region. Report of an interregional workshop, Mukteshwar, India, October 2005. Retrieved from http://whqlibdoc.who.int/publications/2006/9290222697_eng.pdf

previous Table summarizes data pertaining to the presence of climate related diseases in the Himalayan region. In the lowlands, warmer temperature and higher moisture content in the atmosphere would expand the range of heat-related and vector borne infectious diseases and widen their transmission windows. Optimal climatic conditions would cause vector borne diseases like **malaria, schistosomiasis and dengue** to occupy new regions that lie on the border of endemic areas. **Bartonellosis, tick-borne diseases** and infectious diseases that depend on the rate of pathogen multiplication will all be enhanced. The breeding of malarial protozoa is directly influenced by temperature; optimal climatic conditions can increase the invasiveness of mosquitoes. Vectors survive and multiply in specific ecosystems. The malaria mosquito has recently been detected at high altitudes in the EH. In certain situations, climate change can create critical changes in the climate and environment of these ecosystems and cause **epidemics** to occur.

As changes in temperature and precipitation patterns cause vector borne diseases to become more prevalent in affected areas and to extend their range to new areas, more and more people will be affected by these diseases. The extended transmission windows will only make matters worse. Studies carried out in Nepal have shown that the subtropical and warm temperature regions in the country are already vulnerable to malaria and kala-azar. Climate change related disasters have contributed to the incidence of water-borne diseases such as **cholera, diarrhoea, salmonellosis and giardiasis in India, Nepal, Bhutan and Myanmar.** The risk associated with these diseases is expected to increase in the 2030's due to higher temperatures and more frequent flooding.

Future projections for the middle of this century predict that malaria will continue to affect **Odisha, West Bengal and the southern parts of Assam** bordering the northern part of West Bengal. There may also be a shift in the range, from central India to the south western coastal states of **Maharashtra, Karnataka and Kerala.** Malaria may also move to the cooler states in the North including **Himachal Pradesh.** The duration of the transmission window for the parasite is expected to extend in the northern and western states and contract in the southern states.

However, at higher altitudes, warmer temperatures would also have a positive impact on health.

The risk associated with cold and respiratory diseases due to the burning of fuel wood for heating would reduce. Winters would be less severe, livelihood opportunities would increase and agricultural production would increase as the repertoire of crops available for cultivation would be larger.

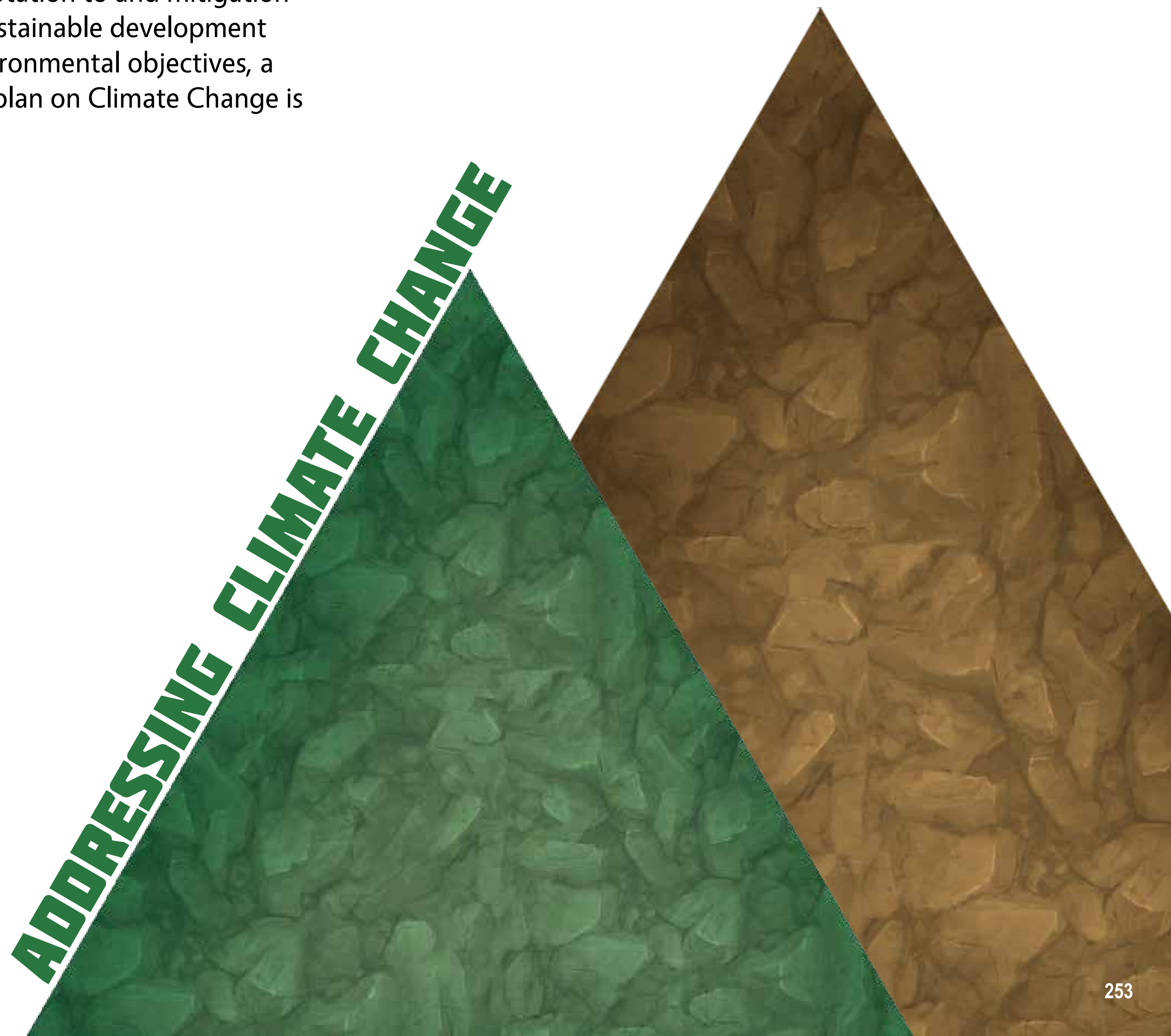
Research carried out by the National Institute of Malaria Research has found incidents of malaria in the hilly regions of Nainital district in Uttarakhand. Dengue which was first seen in the district in 1996 is now being frequently reported. The situation is similar in Nepal and Bhutan where dengue was reported for the first time in 2004.

SUMMARY

Climate change will lead to an increase in the frequency of extreme weather events which will adversely affect human health. Furthermore decreased availability and quality of water, poor sanitation together with the after effects of floods and storms will raise the incidence of water-borne diseases. Warmer temperatures would cause vector borne diseases like malaria, kala-azar and dengue to extend their range to higher altitudes and increase the duration of their transmission windows.

There will be an increase in cardio-respiratory diseases due to elevated levels of air pollutants. Decline in food productivity would increase the level of malnutrition and aggravate food insecurity.

The National Action plan on Climate Change identifies measures that can be taken to promote the country's development objectives while simultaneously addressing adaptation to and mitigation of climate change. To work towards a path of sustainable development that takes into account both economic and environmental objectives, a few of the principles which the National Action plan on Climate Change is based on are as follows



1. Protecting the poor and vulnerable sections of society through an inclusive and sustainable strategy, sensitive to climate change.

2. Achieving national growth objectives by adapting a strategy that enhances ecological sustainability leading to further mitigation of greenhouse gas emissions.

3. Deploying appropriate technologies for both adaptation to and mitigation of greenhouse gas emissions extensively and at a rapid pace.

4. Engineering new and innovative forms of market, regulatory and voluntary mechanisms to promote sustainable development.

5. Effective implementation of programmes through innovative associations with civil society and local government institutions and through public-private partnerships.

With the objective of acting simultaneously on different aspects of the problem of climate change in a focussed manner, using a multipronged approach, the National Action Plan has been designed to have a core of Eight National Missions. The emphasis will be on creating awareness about climate change, adaptation and mitigation, energy efficiency and natural resource conservation. The National Mission for Sustaining the Himalayan ecosystem will be launched to develop management measures for sustaining and safeguarding the Himalayan glacier and mountain ecosystem. Since the Himalayas are the source of very important perennial rivers, the Mission would seek to understand whether and to what extent the Himalayan glaciers are in recession and how the problem could be addressed.

DO WE NEED THIS?

Mountain ecosystems are extremely important sources of water and feed several rivers. As they are characterized by sharp changes in altitude over a relatively small geographical area, they harbour an enormous range of biodiversity. Half the world's population depends on the goods and services provided by mountain ecosystems.

The increase in the levels of green house gases due to excessive use of fossil fuels is causing temperatures to rise all over the world. The effects of climate change are also being felt in mountain ecosystems. Increased temperature and reduced precipitation is causing glaciers to retreat. Glaciers are melting at an accelerated rate leading to the formation of potentially dangerous glacial lakes at high altitudes and increasing the risk of glacial lake outburst floods.

CONCLUSION

The range of plant and animal species is moving both upwards towards higher latitudes as well as poleward. Alpine grasslands are being forced to move to higher altitudes and their habitat is shrinking as they are being replaced by trees from lower altitudes. The production of alpine grasslands is decreasing as reduced snowfall is decreasing the availability of moisture and many alpine species which means important medicinal plants are on the verge of extinction. The yield of apples is also going down and in many parts of the hills people are being forced to shift to cash crops that are now able to grow in the hills and give better returns. The frequency of extreme weather events has been increasing and rainfall has become very unpredictable which is affecting crops.

Various phenological changes are being observed in plants, and animals that are adapting themselves to the changing climate. Such lifecycle changes in the animal world can prove to be detrimental to communities and affect their composition as they can have a negative impact on breeding seasons, predator- prey relationships, and competition between species. By and large the productivity of various crops is declining. **There is less precipitation in the form of snow which is now restricted to higher altitudes.**

There has already been a decrease in the production of rice, corn and wheat in the EH due to increasing water stress caused by increasing temperature, increased frequency of El Nino, and a reduction in the number of rainy days. Climate change is **adversely affecting un-irrigated and rain-fed agriculture** which is putting many subsistence farmers at risk.

Climate change is leading to an **increase in the frequency of extreme weather events** which is adversely affecting human health. Furthermore, decreased availability and quality of water; poor sanitation together with the after effects of floods and storms are predicted to become more frequent. This will raise the incidences of water-borne diseases. Due to higher temperatures, vector borne diseases like malaria; kala-azar and dengue are extending their range to higher altitudes and the duration of their transmission windows is increasing. Incidents of malaria and dengue are already being recorded in the hills.

Decline in food productivity would increase the level of malnutrition and aggravate food insecurity.
A very serious consequence of climate change in the mountains is the depletion of critical water reservoirs in the form of glaciers, snow and forests. If glacier and snow melt continue unabated, we will soon face a situation where there are no glaciers and no snow and where water will be in extremely short supply. Clearly climate change is affecting mountain ecosystems at various levels. Making the appropriate interventions and adopting measures to keep global warming in check, creating awareness and sensitizing people about the effects it can have on mountain ecosystems is of utmost importance if we want to save these remarkable ecosystems from permanent damage.

Towards this end, the **National Mission for Sustaining the Himalayan ecosystem has been launched by the National Action Plan on Climate Change** to develop management measures for sustaining and safeguarding the Himalayan glacier and mountain ecosystem.

Glossary

Albedo is the relative reflectivity of light from a surface and in the context of solar radiation it refers to the percentage of solar energy that is not absorbed or is reflected back.

El Nino Southern Oscillation ENSO is a climatic pattern that recurs periodically across the tropical Pacific Ocean every five years or so. The extremes of this climate pattern's oscillations, the warm oceanic phase brought about by El Nino and the cold phase due to La Nina cause extreme weather events in many parts of the world.

Eutrophication is caused by the accumulation of an excess of nutrients due to untreated sewage effluent, agricultural run-off carrying fertilizers, excess sediment load in rivers and so on. It promotes excessive plant growth and decay, and tends to favour simple algae and plankton over complicated plants and leads to a drastic decline in the quality of water, reduces the availability of oxygen in the water and adversely affects the growth of aquatic organisms.

A glacier is a large persistent body of ice that forms where the accumulation of snow exceeds its rate of ablation by melting and sublimation, over many years, often centuries. Glacial ice is the largest reservoir of freshwater on Earth.

Glacial Lake Outburst Flood (GLOF) is a flood that occurs when the dam containing a glacial lake gives way. The dam is usually made of glacial ice and debris. A GLOF can occur due to erosion, build up of water pressure, an avalanche of rock or heavy snow, an earthquake, a volcanic eruption under the ice or when a large enough portion of a glacier breaks away, displacing a massive amount of water from a glacial lake at its base.

A greenhouse gas is a gas present in the atmosphere which absorbs and emits radiation within the thermal infrared range and thereby increases the temperature. Hydrological regime refers to the rates of flow of rivers and the level and volume of water in rivers, lakes, reservoirs, and marshes.

Incubation period is the time lapse between exposure to a pathogenic organism, a chemical or radiation and the first appearance of the symptoms and signs of an infection.

An invasive species is a species that has evolved as a result of human activities, exceeded its normal accepted distribution and is considered a threat to valuable environmental, agricultural or other social resources because of the damage it can cause.

Permafrost is soil which has been at or below the freezing point of water for two or more years. Permafrost accounts for 0.022% of total water and occurs in 24% of the exposed land in the Northern Hemisphere.

Phenological events are periodic plant and animal lifecycle events that are often influenced by seasonal and inter-annual variations in climate and usually refer to the date of first occurrence of biological events in their annual cycle.

A pathogen or infectious agent is a biological agent such as a bacterium, virus, protozoan or fungus that causes disease in its host which may be an animal, human being, plant or a microorganism.

A vector-borne disease is one in which the pathogenic microorganism is transmitted from an infected individual to another individual by an arthropod or other agent, sometimes with other animals serving as intermediary hosts.

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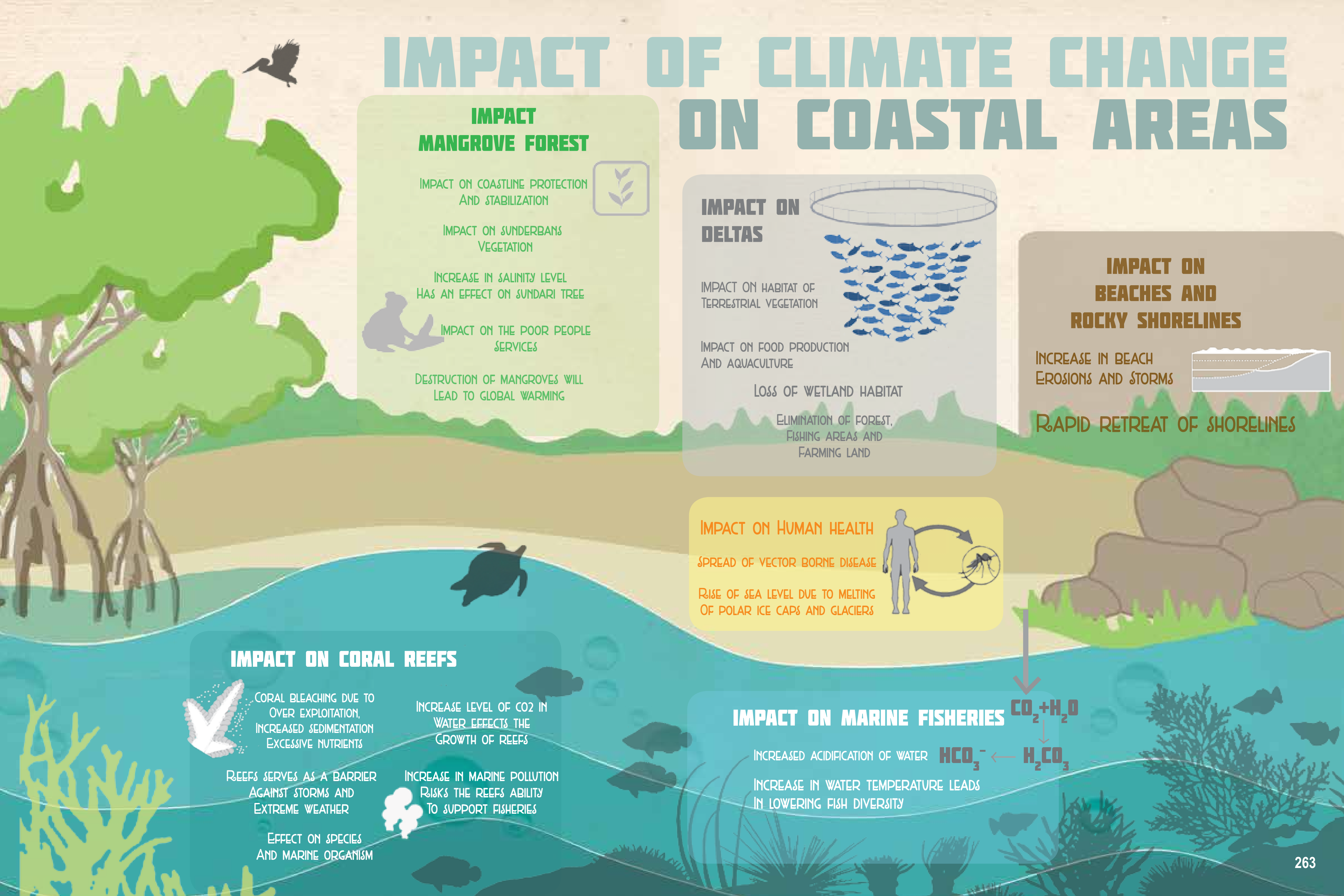


IMPACT OF CLIMATE CHANGE ON COASTAL AREAS
IMPACT MANGROVE FOREST
IMPACT ON COASTLINE PROTECTION AND STABILIZATION
IMPACT ON SUNDERBANS VEGETATION
INCREASE IN SALINITY LEVEL HAS AN EFFECT ON SUNDARI TREE
IMPACT ON THE POOR PEOPLE SERVICES
DESTRUCTION OF MANGROVES WILL LEAD TO GLOBAL WARMING
IMPACT ON DELTAS
IMPACT ON HABITAT OF TERRESTRIAL VEGETATION
IMPACT ON FOOD PRODUCTION AND AQUACULTURE
LOSS OF WETLAND HABITAT
ELIMINATION OF FOREST, FISHING AREAS AND FARMING LAND
IMPACT ON BEACHES AND ROCKY SHORELINES
INCREASE IN BEACH EROSIONS AND STORMS
RAPID RETREAT OF SHORELINES
IMPACT ON HUMAN HEALTH
SPREAD OF VECTOR BORNE DISEASE
RISE OF SEA LEVEL DUE TO MELTING OF POLAR ICE CAPS AND GLACIERS
IMPACT ON CORAL REEFS
CORAL BLEACHING DUE TO OVER EXPLOITATION, INCREASED SEDIMENTATION EXCESSIVE NUTRIENTS
INCREASE LEVEL OF CO2 IN WATER EFFECTS THE GROWTH OF REEFS
REEFS SERVES AS A BARRIER AGAINST STORMS AND EXTREME WEATHER
INCREASE IN MARINE POLLUTION RISKS THE REEFS ABILITY TO SUPPORT FISHERIES
EFFECT ON SPECIES AND MARINE ORGANISM
IMPACT ON MARINE FISHERIES
CO_2+H_2O
INCREASED ACIDIFICATION OF WATER
$HCO_3^- \leftarrow H_2CO_3$
INCREASE IN WATER TEMPERATURE LEADS IN LOWERING FISH DIVERSITY

Coastal areas which are zones where land and sea meet are unique in that they are influenced by the land, the ocean as well as the atmosphere. A variety of landscapes, as well as, colonies of animals and large clusters of plants spread over vast stretches, offer a wide range of habitats. These coastal habitats support several species of plants and animals. Interplay of terrestrial, marine and atmospheric factors makes these habitats very important ecosystems.

INTRODUCTION

COASTAL AREAS SUPPORT MANY ECONOMIES AND PROVIDE A RANGE OF IMPORTANT HABITATS

Coastal areas support several economies and provide many opportunities for **livelihood through fisheries, ports, tourism** and so on. Coastal ecosystems regulate the composition of the atmosphere and cycle nutrients and wastes. They also serve as barriers against storm surges, floods and strong winds, either preventing or reducing the damage caused to coastal areas. They have a rich supply of nutrients which they get from within the ocean due to the action of currents and winds, and from land through rivers, rainwater, sewage and so on. This makes them ideal habitats for a diverse variety of organisms. Some of the habitats typically found in coastal areas are **coral reefs, mangrove forests, sea grass beds and meadows, deltas, estuaries, lagoons, beaches and rocky shorelines.**

COASTAL AREAS ARE INFLUENCED BY A VARIETY OF TERRESTRIAL FACTORS

There are many land-based or terrestrial factors that influence coastal ecosystems. Rivers eventually drain into the sea and bring with them sediment, nutrients, wastes, pollutants and so on. The sediment brought by rivers is a very important component of coastal ecosystems which are very sensitive to changes in the quality and quantity of sediment. Dams and channels which alter the flow of rivers, sand mining, and increased run-off due to melting snow, receding glaciers and heavy rain are some of the factors that influence the sediment carried by rivers. Most of the world's river systems are influenced by human activity. According to estimates, **40% of global river discharge has been intercepted by large reservoirs** which on a global scale retain 26% of the sediment that flows to deltas and the coast.

Dams reduce the flow of water in rivers and reduce sediment transfer. Moreover, many rivers are a source of water for irrigation as well as domestic and industrial use. Use of river water to meet these requirements further reduces the availability of sediment.

Changes in the way land is used in coastal areas is another important factor that has a major impact on these ecosystems. Land is used for cultivation, for the development of ports, and to provide infrastructure to meet the demands of rapid urbanization. Many coastal areas are popular tourist destinations and tend to be overpopulated. They are also undergoing rapid development to keep up with the demands of the growing tourist industry. All these factors are increasing the strain on coastal ecosystems.

COASTAL AREAS ARE ALSO GOVERNED BY MARINE INFLUENCES

In addition to terrestrial factors, coastal ecosystems are affected by a variety of marine factors such as **waves, tides and ocean currents**; these factors also contribute to the changing shape of the coastline which is an ongoing dynamic process. They also play an important role in regulating the temperature of water and in the circulation of nutrients.

Coastal ecosystems are subjected to the routine action of tides, currents and waves of varying intensity and are thereby in a state of dynamic equilibrium. They are capable of accommodating many changes in the environment, provided they occur gradually and there is scope for adjustment. For instance, they **can tolerate a slow rise in sea level** to a certain extent, provided that there is a steady supply of sediment. Similarly, they are able to recover from passing storms or cyclones with the passage of time, as long as these events are not unusually intense or frequent. Depending on their location, the extent of urbanization, the nature and quantity of sediment available, the degree of pollution in the water, the availability of undeveloped land and other such variables, coastal ecosystems differ in their vulnerability and in their ability to withstand changes in the environment.

INCREASING URBANIZATION AND DEVELOPMENT OF COASTAL AREAS

Most coastlines of the world are subjected to varying degrees of **human pressure**. One of the reasons they are preferred (many important cities are located near the coast) is because of their accessibility and the numerous livelihood opportunities they offer. Utilization of the coast is expected to be on the rise through the 21st century. Inhabitation of several of the world's deltas, barrier islands and, estuaries has resulted in large-scale use of coastal landscapes for agriculture, silviculture, aquaculture, industry and residential purposes. Many of these areas are busy ports. As of 2007,

60% of the world's 39 metropolises with populations over 5 million were located within 100 km of the coast.

This included 12 cities with a population over 10 million.

GLOBAL WARMING

AND

CLIMATE CHANGE

All over the globe there have been alterations in climate and weather which have coincided with this sudden increase in global average temperature. Changes have been observed in the pattern of rainfall and in the frequency of floods and droughts; there has been intense rain in some places and the frequency and severity of heat waves has increased. Climate change is associated with a variety of events, ranging from rising sea levels to melting of the polar ice caps and accelerated glacier retreat,which are already exerting their effect and are predicted to have a serious impact by the end of the century.

Sea level rise, however small, can cause a lot of damage to **coastal areas which support about 23% of the world's population –** coastal areas, wetlands and barrier islands will be flooded, shorelines will be eroded, intense storms will cause considerable damage to property, freshwater reservoirs will be contaminated with salt water, and the proportion of salt water in estuaries will increase. Low lying cities and coastal villages can be submerged. A variety of coastal ecosystems such as coral reefs, atolls, and mangroves as well as resources such as beaches, fisheries, and freshwater that are of great significance to coastal communities will be affected.

The polar ice caps are also melting as a result of global warming, since the **temperature at the poles is rising at a rate higher than the global average.** When the amount of snow and ice that is melting is greater than that replenished by snow fall, ice caps, ice sheets, glaciers and sea ice begin to shrink. Huge ice bergs and ice shelves are breaking up. Moreover, the polar ice caps have a **high albedo** or whiteness, which means that they are able to reflect most of the sunlight falling on them. This plays an extremely important role in maintaining the earth's temperature. As more and more ice melts forming water, there is a reduction in albedo and more of the sun's rays are absorbed. This further accelerates the process of warming.

The warmer temperature is also creating **massive moulins** (narrow tubes moulded in the ice by surface water) that carry water from the tops of glaciers to the base. These structures increase glacial motion, cause more ice to melt and accelerate the glacier's flow to the sea where chunks of ice break away as icebergs.

The surface of ice caps melts when it comes into contact with warm air and ponds of melt water are created. While snow melt flows down from the ice-cap, it also trickles into the layers of ice beneath the snow, through cracks and fissures. This erodes the ice and reduces its thickness and results in glacial retreat, melting of sea ice and the collapse of ice shelves. **Since ice has a lower albedo than snow, it absorbs more heat** which leads to further warming.

The ice over the Arctic Ocean is melting at an alarming rate. In the mid-1980s, more than half the ocean was covered with ice throughout the year. At present the perennial ice cover has **reduced to a mere 30%** of the ocean's area.

MELTING POLAR ICE CAPS

The shrinking ice cover of the Arctic is taking its toll on **polar bears** that are marine mammals that spend more time on water than on land. Sea ice serves as a hunting ground for these animals as they venture in search of seals which are their main source of food. The sea ice is moving further away from the land and forcing these bears to swim long distances through rough water and face harsh conditions before they can access ice. In the southern parts of their range, ice is freezing later in the fall and melting earlier in the spring. At Hudson Bay in Canada, the ice–free period has extended by 20 days over the last 20 years. Snow is melting sooner in spring and has shortened the polar bears' time frame for hunting during the critical season when seal pups are born.

The reduction in sea ice in the Arctic has also affected **seals and walruses** which rest on ice while searching for fish and mussels. In some places, the ice is so thin that Caribou are falling through. The population of walruses is decreasing as their prey is moving out of their habitat range. **Killer whales** are also losing their prey to other habitats and are being forced to shift from their preferred prey of sea lions and harbour seals to hunting sea otters. These changes are also affecting the subsistence livelihoods of people who depend on these animals.

When the extent of sea ice decreases, there is **higher potential for wave generation** in areas where the coast is exposed. Furthermore, the relative rise in sea level leads to the rapid retreat of low relief shores that are easily eroded. The melting of permafrost which binds sediments, and warmer ground temperatures also contribute to erosion. Sea ice serves as a natural breakwater and when it melts, larger storm surges develop, causing sedimentation, erosion and coastal inundation. In the Arctic, houses, roads, airports and pipelines, have been damaged by thawing permafrost. Coastal losses due to erosion have been as high as 100 feet in some parts of the Siberian, Alaskan and Canadian Arctic. Walking over thin ice is also a serious hazard.

Shishmaref, a small Inuit village in Alaska is expected to be completely submerged by the advancing sea, over the next few decades. The drinking water supply in this village has already been contaminated by sea water.

According to scientists the entire **Northwest Passage between the Pacific and Atlantic oceans was ice-free** this summer for the first time in recorded history. What is extremely unfortunate about the melting of the ice around the Arctic is that the northern countries, USA, Canada, Russia and Norway are claiming rights over the ice free zones, so that they can commence drilling for oil in this region and tap its resources.

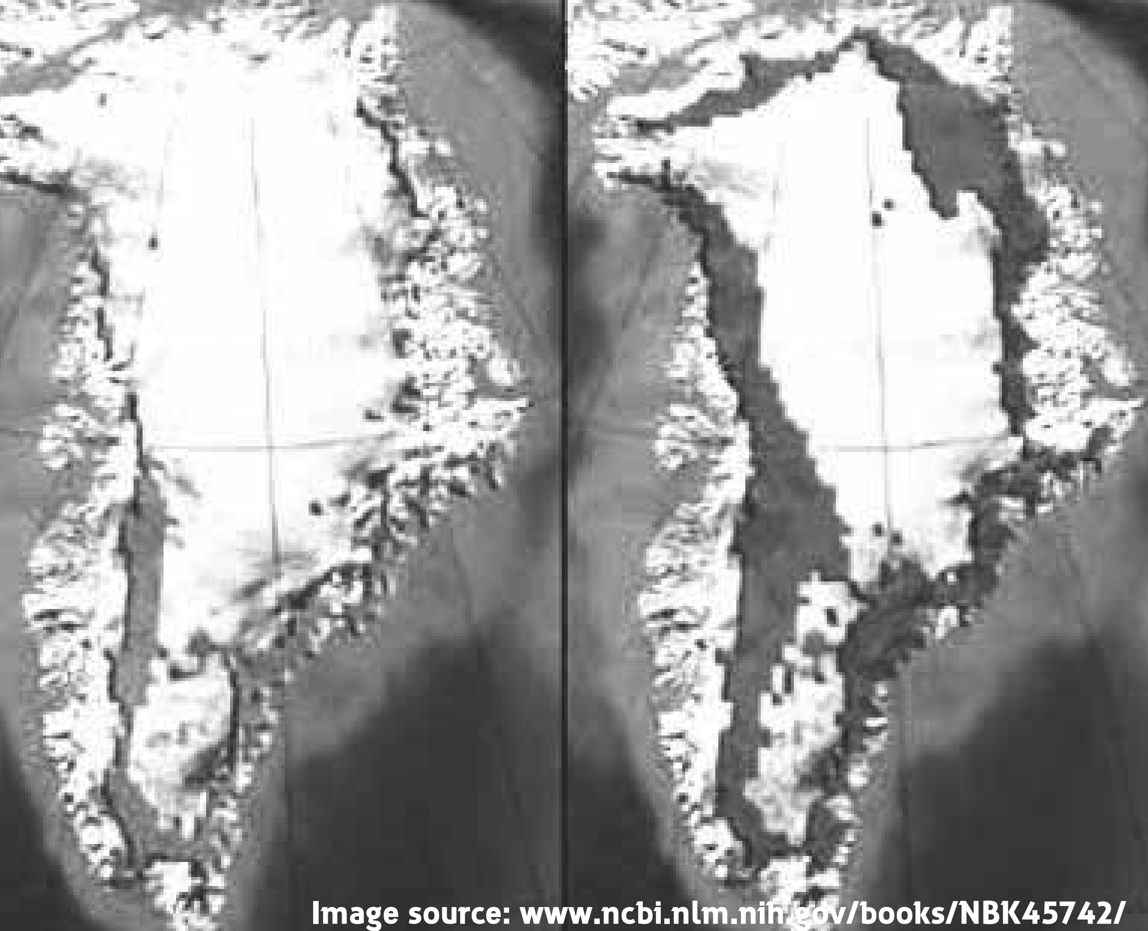


Image source: www.ncbi.nlm.nih.gov/books/NBK45742/

Increase from 1992 (left) to 2002 (right) in the amount of the Greenland ice sheet that melted in the summer.

Ice has been melting at a rapid rate in **Greenland,** where the annual rate of ice loss between 1993 and 2003 was 50 to 100 billion tons and has increased further since then. The extent of seasonal melting of the Greenland ice sheet has been observed since 1979 by satellite. The melt zone (shown in grey in Figure above) where the higher temperature in summer causes snow and ice around the edges of the ice sheet to turn into slush and water, has been expanding further inland and to higher elevations in recent years.

On the 4th of September 2012, the extent of Arctic sea ice fell to 3.41 million sq km, which is 50% lower than the 1979 – 2000 average. Experts feel that the rate of loss of sea ice is accelerating and is beyond what was predicted even 10 years ago.

In 2002, the northern section of the 500 billion tonne **Larsen B ice shelf,** which is a large floating mass of ice on the eastern side of the Antarctic Peninsula, separated from the continent, shattered forming a shower of smaller icebergs and disintegrated within a month. The plume of thousands of small ice bergs formed in the Weddell Sea as the Larsen Ice Shelf broke away from the continent can be seen in Figure below. The **Larsen A ice shelf**, which was two thirds its size collapsed in 1995. In the last five years, the Larsen B ice shelf has lost 5,700 sq. km and is now 40% of its previous minimum stable extent. Over the last 50 years, 80% of the glaciers in the Antarctic have receded like the other glaciers around the world. During the period 2000 – 2005, the glaciers of the Antarctic Peninsula lost an average of 50 metres per year.

The aftermath of the Larsen Iceshelf collapse on 7/3/2002

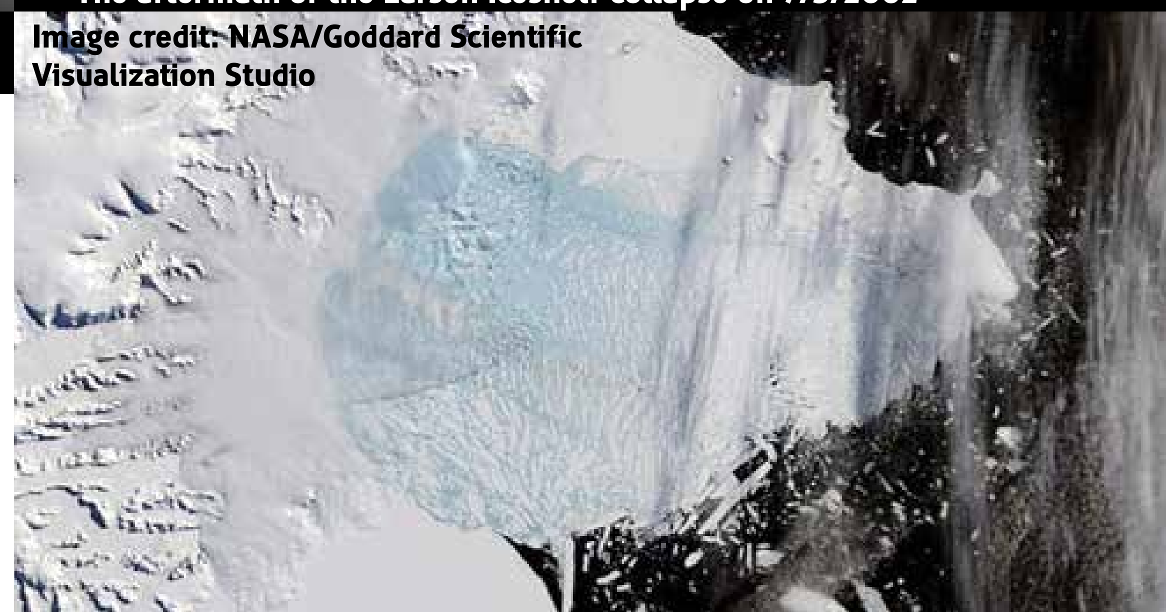
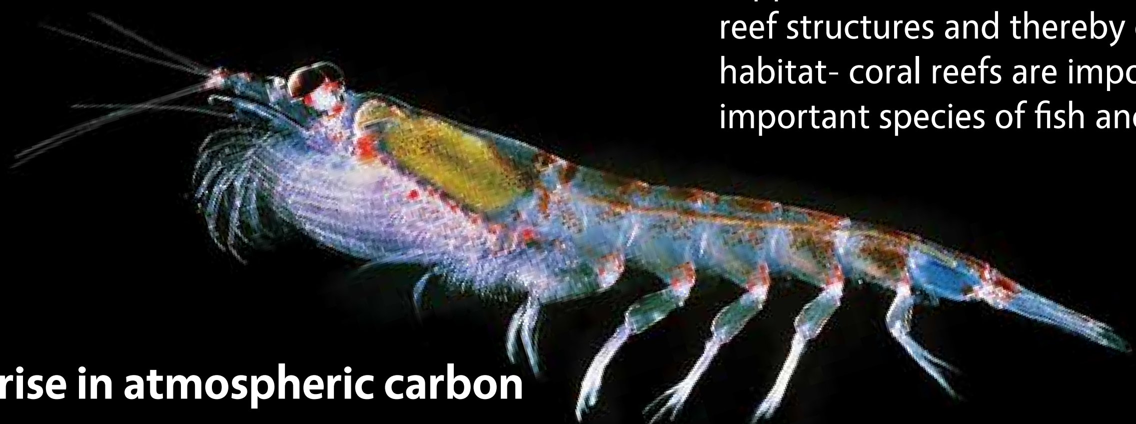


Image credit: NASA/Goddard Scientific Visualization Studio

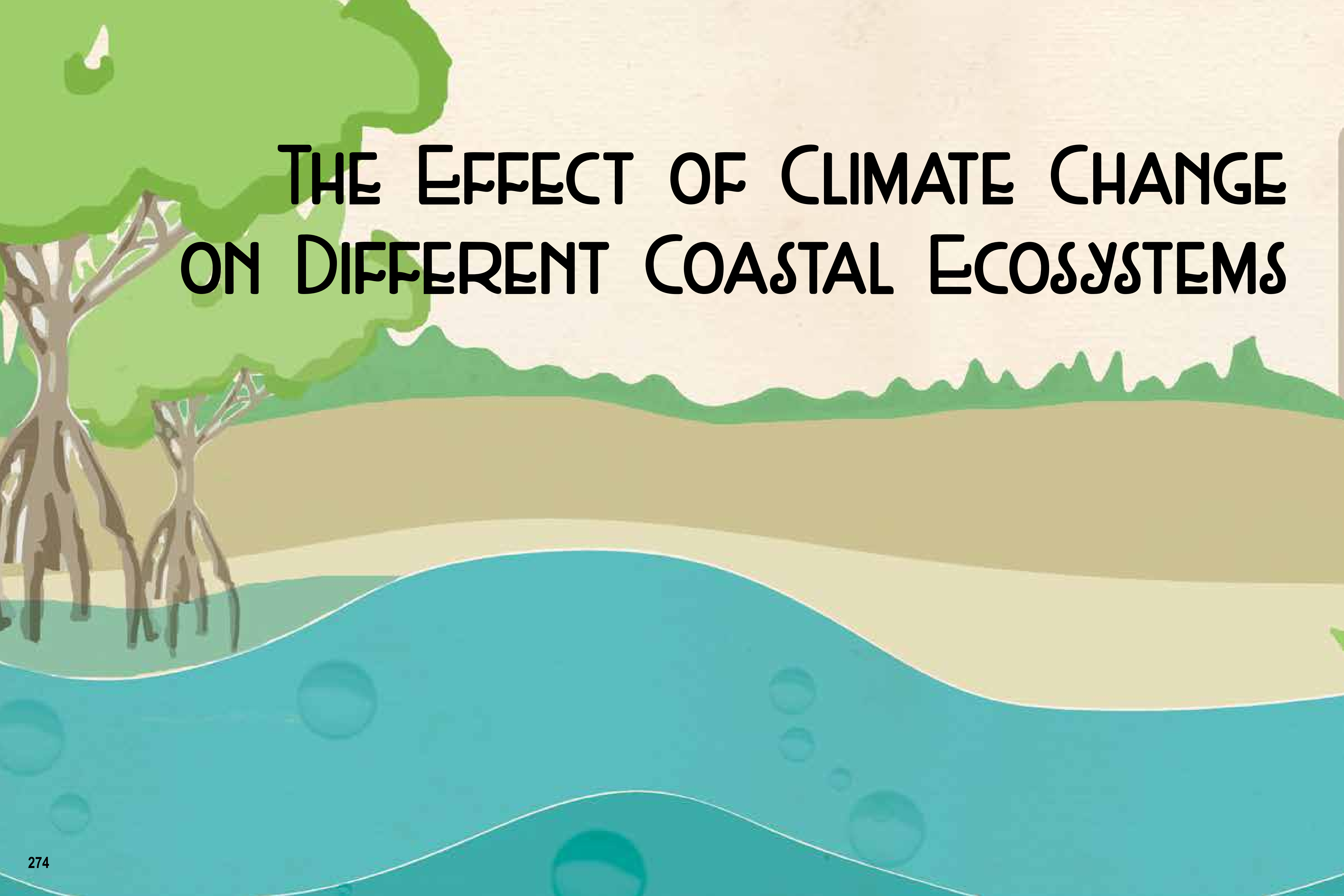
The population of **krill** in Antarctica has dropped by around 80% since the 1970s. The temperature of the region which has increased by 2.5˚C since 1950, could be a factor that has contributed to this decline. Krill are a source of food for several marine organisms, some of which are commercially important, and as a result fisheries have been affected as the Southern Ocean is a valuable resource for fisheries. The numbers of emperor penguins are declining as seas get warmer, the extent of summer ice is reducing and krill, their primary source of food are not available.



There has been a **steep rise in atmospheric carbon dioxide** concentration as a consequence of the exponential increase in the combustion of fossil fuels since the dawn of industrialization. Not only is this leading to warmer temperatures around the world it is also affecting the oceans. Oceans take up about one third of the carbon dioxide in the atmosphere. Once it is absorbed carbon dioxide initiates a set of changes that make the ocean more acidic. According to estimates the ocean has become **30% more acidic** than it was at the beginning of the industrial age. Acidic conditions can cause the carbonate shells of some marine organisms to dissolve. Furthermore, as the ocean becomes more acidic, the concentration of carbonate ions decreases. Many species of marine organisms take up carbonate from sea water and use it to build their carbonate shells and skeletons by a process called calcification. Reduced levels of carbonate affect the ability of these organisms which include clams, oysters and some molluscs to build their shells and exoskeletons. Adverse effects on these organisms could be transmitted to other animals that depend on them as a source of food. Some of these animals are commercially important species and any harm caused to them could impact fisheries and the numerous livelihoods they support. Acidification also affects the ability of **corals** to build reef structures and thereby deprives several marine species of their habitat- coral reefs are important habitats for many commercially important species of fish and harm caused to them affect fisheries.

Researchers have found the shells of **sea snails** in the Southern Ocean to be dissolved to a large extent due to the corrosive property of the ocean that results from ocean acidification due to dissolution of carbon dioxide from the atmosphere. Further, they state that sea water tends to be more corrosive at increasing depths but enhanced mixing of deep and surface water due to stronger winds that are predicted will make the water corrosive even at lower depths. Carbon dioxide is more soluble in cold water and the problem is therefore more acute at the poles and deep down in the ocean.

The Effect of Climate Change on Different Coastal Ecosystems



CORAL REEFS

Coral reefs are colonies of very small animals.
They are formed by the deposition of calcium carbonate, by corals and other organisms like coralline algae and shellfish. They can be ridges or mounds and are found both in warm shallow water and deep cold water at depths exceeding 39 m. They are generally found in tropical and semitropical areas where the temperature of the water is between 16 and 30˚C. The best temperatures for corals are found within 30˚ latitude of the equator. Corals grow best in water that is clear, poor in nutrients, agitated, receives adequate sunlight and has relatively stable temperature and salinity.

Reefs serve as an important barrier against storms and extreme weather events and help prevent the salinization of groundwater. They support many different species of fish and other marine organisms which are the principal source of protein for a sizeable population in many island nations and offer protection from harsh weather and storms. While coral reefs occupy only 0.1% of the ocean's surface they serve as an important habitat for 25% of all marine species which includes fish, molluscs, worms and crustaceans.
Corals feed on plankton and they also get their food through their symbiotic association with algae called zooxanthellae.

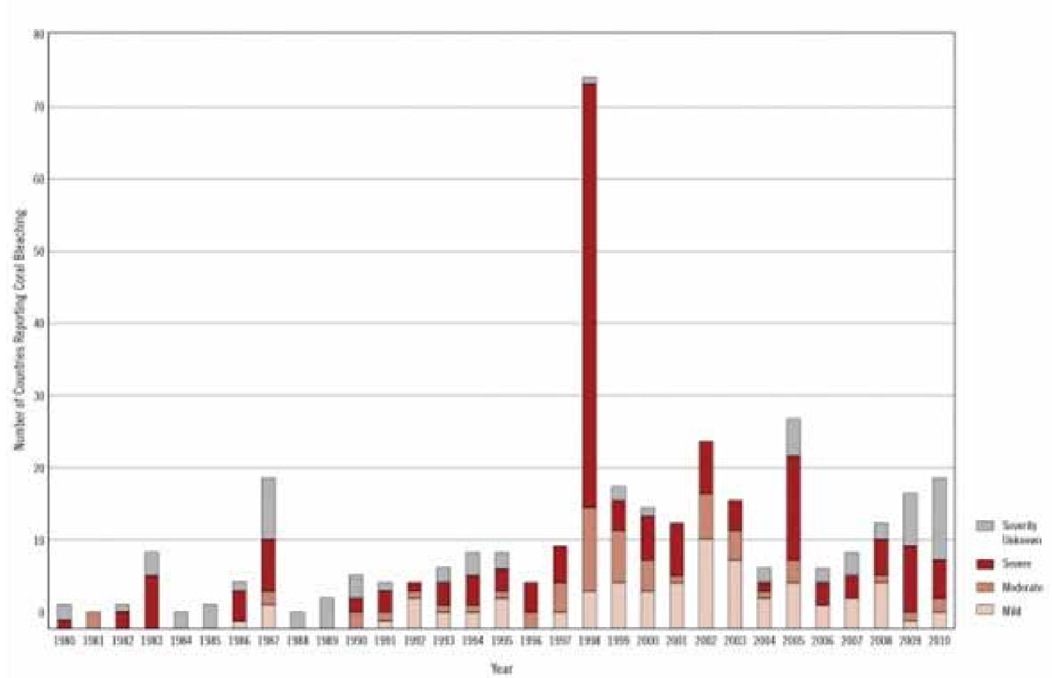
Coral reefs are extremely sensitive to changes in the environment and very little pollution in clear water or an increase in temperature can have a negative impact on them and their ability to support thousands of species of fish and other marine life. A variety of anthropogenic factors as well as natural disturbances can cause coral bleaching. Anthropogenic causes include overexploitation, over fishing, increased sedimentation and excessive nutrients. Natural causes include intense storms, flooding, high and low temperature extremes, El Nino Southern Oscillation (ENSO) events, predatory outbreaks and epizootics.

Coral bleaching occurs when there is a drop in density of zooxanthellae associated with the reef or when the concentration of photosynthetic pigments within the zooxanthellae decrease (Fig. 1). Corals appear bleached when their calcareous skeleton becomes visible through the transparent tissues that are almost devoid of zooxanthellae. Coral tissues are transparent; they appear colored because of the zooxanthellae living in their tissues. The symbiotic association between corals and zooxanthellae is very sensitive to changes in temperature. For example, even a 1˚C rise in sea surface temperature above the average monthly maximum in the hottest months of the year can lead to bleaching.

Climate change is expected to raise the levels of carbon dioxide and the temperature beyond the conditions that corals have been exposed to for the last half million years. At present, **30% of the world's coral reefs are on the decline** and 60% are expected to reach this state by the 2030s. Climate change in combination with other factors like marine pollution may make corals more susceptible to infestation by invasive species, diseases and algal growth, reduce their resilience and affect their ability to support fisheries. The decline of corals has been attributed to many different causes such as **marine pollution, overfishing and dredging, disease outbreaks and hurricanes, sedimentation and El Nino-Southern Oscillation induced bleaching.**

The **El Nino event of 1998** had a severe impact in the zone, 30˚N and 30˚S of the equator. That year was the warmest year recorded all over the world; there were masses of abnormally warm water throughout the Pacific and Indian oceans which led to extensive bleaching of corals all over the world. The western part of the Indian Ocean recorded a 75 to 99% bleaching of its corals and live corals across the inner islands decreased by 90%. It is estimated that 16% of the world's coral reefs were bleached of which 40% will recover and 60% have been damaged beyond possible recovery. Trends in coral bleaching over the last three decades are depicted in Figure 2. The spike in the year 1998 was a result of the El Nino event in that year.

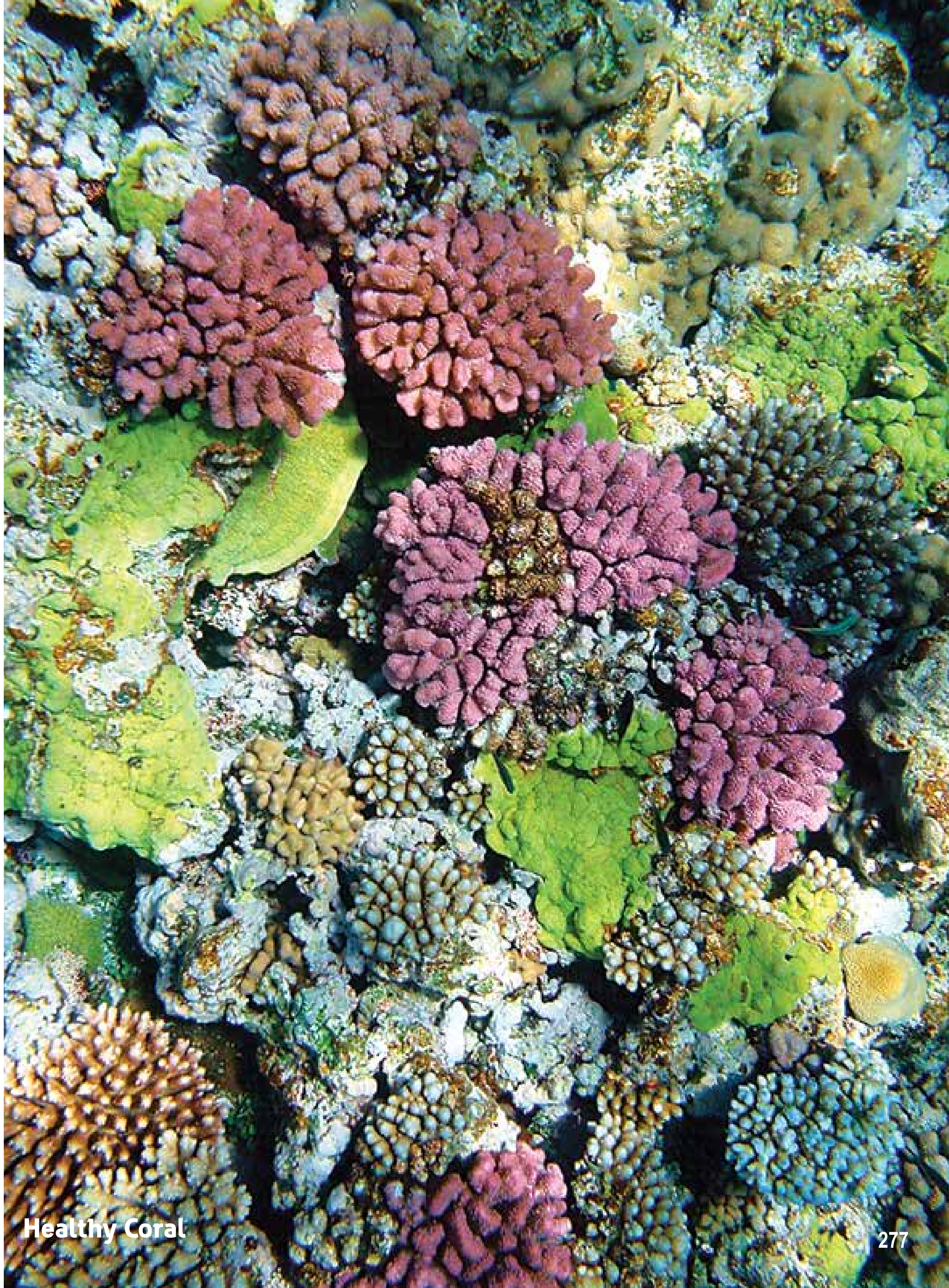
Fig. 2: Trends in Coral Bleaching. Source: http://www.wri.org/resources/charts-graphs/trends-coral-bleaching-1980-2010




A bleached coral

Many of the reefs do **not have enough live coral** cover to be able to grow fast enough to keep up with the recent acceleration in sea level rise. They will eventually be submerged and then disintegrate.

Increasing temperatures lower the solubility of oxygen in water. However, the respiration rates of most microbes, microfauna and algae increase at higher temperatures. This increase in oxygen consumption, in combination with its reduced solubility, increases the number of anoxic zones in the water. In other words, areas with insufficient oxygen will become more numerous. This is especially in areas like coastal regions and deep basins where circulation is poor. Coral reefs in these areas can be killed due to lack of oxygen. When temperatures increased, many enclosed atolls in **French Polynesia** were killed due to anoxia and bacterial infection, and several pearl farms were destroyed. In **Hong Kong**, coral reefs were killed due to anoxia and environmental toxicity due to increased organic pollution in the Pearl River which drains a thickly populated region in China. Thirty percent of the coral reefs in the **Rann of Kutch** have been bleached due to warming of the ocean. With time, the entire range of coral reefs along the south coast of Gujarat may be bleached. As temperatures rise and pollution remains unchecked, the frequency, intensity and duration of coral reef mortality will continue to increase. Bleached corals are also are more susceptible to disease. The rising temperatures associated with climate change are increasing the size of the body of warm surface water which is spreading towards the poles. The tropical area is increasing and with it the potential habitat for corals is expanding. Corals have already expanded their range poleward in the **Sea of Cortez and South Africa**.



Healthy Coral

Rising sea temperatures will also **increase the frequency and intensity of tropical storms**. Intense tropical storms can damage coral skeletons and displace the colonies. Most reefs have nearly lost the ability to recover from damage caused by such intense and frequent storms. Large amounts of sediment are removed from reefs leading to a reduction of soft bottom fauna that feed on filtered material and deposits. Many fish depend on these organisms for their food. All these organisms are displaced after such extreme events. Increased runoff, following storms, can overload the reefs with mud, sand and other wastes carried by rivers and smother them. Soon after a storm, there often is a sharp rise in fish catch but this falls as the habitat takes a long time to recover and its ability to support fish and other organisms is compromised.

Warmer temperatures, in combination with the **increasing turbidity** caused by intense storms and **increasing ocean acidification** are affecting coral reefs which are declining in many parts of the world and may eventually disappear. Shorelines would be exposed and would be more vulnerable to damage by storms, and there would be extensive habitat loss. Fisheries would also be adversely affected.

The increased incidence and intensity of climate change associated events, such as mass bleaching of corals and storms, are affecting the complex ecosystems structured around coral reefs in the islands of **Lakshadweep**. Local communities rely to a great extent on these atolls for their livelihoods and subsistence. The atolls provide a variety of important services such as food resources, construction raw materials and protection from wave action. The reefs also support more than 600 species of reef fish. Climate change and reef fishery are posing a major threat to these atolls.


Bleached Coral

Mangroves comprise many species of shrubs and trees that grow along sheltered intertidal shores in tropical and subtropical regions. Mangroves make a significant contribution to many tropical coastal economies and provide coastal communities with a variety of goods and services. They play an important role in coastline protection and stabilization and serve as nurseries for several species of commercially important shellfish and finfish. They are also a source of a variety of important products such as timber, charcoal, firewood, chemicals and medicines. They also serve as waterways for transport, increase the level of nutrients in coastal waters and provide an environment for aquaculture.

The Sundarbans, located in Bangladesh and partly in West Bengal, are the largest contiguous block of mangrove forests in the world. They are situated in the largest delta in the world that has been formed by sediments deposited by three major rivers: the Ganges, Brahmaputra, and Meghna. The ground covered by these forests is below the level of high tide and is entirely submerged twice a day by tidal water. The rise in sea level that has been predicted is expected to cause considerable damage to these forests.

The Sundarbans are an important source of fish and forestry products that contribute significantly to the economy. They **provide direct employment** to about 5.5 lakh people for half the year; a considerable number of these people harvest the natural resources of this region through fishing, woodcutting, and collecting thatching materials, honey, beeswax and shells. Mangroves also offer **protection from cyclones** and tidal surges. According to some estimates a 10 cm rise in sea level would submerge 15% of the region which would completely disappear if the sea level rises by 60 cm.

Climate change in the form of **increasing salinity and extreme weather** events like tropical cyclones, is already exerting its effect on the Sundarbans. The gradual increase in salinity levels is thought to be a driving force in the spread of the top-drying disease which affects the Sundari tree, a dominant species in these forests. The increasing salinity is also affecting species combination and the established succession patterns; tree species are being replaced by non-woody shrubs and bushes and consequently decreasing forest productivity and the quality of the habitat. Mangroves provide very important ecosystem services to poor people living in coastal areas.

Over the last 15 years, people residing in this area have observed a very **high frequency of thunder and lightning** during storms. They also feel that the frequency of depressions and cyclonic storms has increased. Furthermore, delayed monsoons and untimely rain has destroyed crops, brought down agricultural productivity, and increased pest attacks.

Sea level rise is considered to be the largest climate related threat to mangrove ecosystems and is a major cause of the observed and predicted reduction in the abundance and health of these ecosystems. Mangroves have specific requirements in terms of adequate amount of sediment, and the length of the hydroperiod during which they are submerged, and as long as these conditions are satisfactory they can adapt to rising sea level. Unfortunately, the **construction of dams and channels, sand mining** and so on have caused a substantial reduction in the sediment that is brought by rivers to the sea.

Tiny suspended particles of sediment are carried into mangrove systems from coastal waters during tidal inundation. These particles then form **flocs,** which consist of cohesive clay and fine silt which are trapped by the root system and finally settle down leading to vertical accretion of sediment when the tide recedes. Plant litter on the surface of the soil can also trap mineral sediment and contribute to raising the level of sediment. Storms and extreme high water events can change sediment elevation in mangroves by increasing erosion or deposition.

When the sea level rises, there can be a substantial increase in salinity, root structures become weak and trees begin to fall, and the duration, frequency and depth of inundation may no longer be favourable for the growth of mangroves.

Sand Mining

In response to sea level rise **mangroves try to move inland**, provided there are no obstructions by way of physical barriers, and invasive species and there is adequate salinity, sediment and inundation. When an inland shift is not possible due to changes in land use, physical barriers or coastal infrastructure, habitat loss occurs, leading to coastal squeeze as these ecosystems are confined to limited areas between advancing seas and inland development.

Mangrove ecosystems on islands are vulnerable to sea level rise as they occupy a restricted area as defined by coastal topography, that is, the nature of the landscape and tidal amplitude. Mangroves in these areas may be subjected to considerable stress or disappear completely with moderate to high sea level rise. Mangroves are found along approximately 260 km of the coast of Andaman and Nicobar Islands and very vulnerable to sea level rise. The species composition and extent of these forests **will be drastically affected if the sea level rise exceeds about 10 cm per year.**

Sea level rise seems to have resulted in **landward migration** of mangroves into adjacent wetland communities in the Florida Everglades over the last 50 years. **Sea level rise and salt water intrusion** have also led to the decline of coastal bald cypress forests in Louisiana and death of cabbage palm forests in coastal Florida.

According to the IPCC, **precipitation is likely to decrease in the subtropics** over the next four decades. Decreased precipitation will increase salinity, reduce net primary productivity, growth and survival of seedlings, change the competition between mangrove species and decrease diversity and reduce the area that is suitable for mangroves.

The increase in temperature that has been predicted, will affect mangroves in a number of ways. Species composition will be altered; there will be alterations in the phenological patterns, that is the timing of flowering and fruiting; productivity would increase as long as temperature is within the upper threshold; mangroves would extend their range to higher latitudes provided other conditions are also favorable. The optimum leaf temperature for photosynthesis in mangroves is between 28 and 32˚C and **photosynthesis ceases when leaf temperatures are 38 – 40 ˚C.** Elevated temperatures in well established and productive habitats in lower latitudes can prove to be detrimental to these forests.

Surface water temperature in the Sundarbans has been rising at the rate of 0.5˚C per decade over the last three decades, eight times higher than the increase of 0.06˚C per decade due to global warming. The period **between 1980 and 2007 saw a 1.5˚C rise in temperature**. Consequently, these forests feature among the most climate sensitive regions in the world. Over the last three decades **acidification** has increased. The Mangroves in the Gulf of Kutch are threatened by the rising sea level and drought. Moreover, higher temperatures can lead to a decrease in tree height and leaf size.

A reduction in mangrove area and the health of the plants will make shorelines more vulnerable to **erosion, flooding, storm waves and surges and tsunamis.** The quality of coastal water will deteriorate, biodiversity will decrease and many commercially important species of fish and crustaceans will lose a valuable nursery habitat. Other coastal habitats in the vicinity will be affected and coastal communities would lose a major resource that they rely on for a variety of goods and services and often for their livelihood. The destruction of mangroves will lead to the **release of large quantities of stored carbon** and exacerbate global warming.

BEACHES AND ROCKY SHORELINES

Most of the shorelines around the world retreated over the last century, and sea level rise was one of the major causes. Around half of the Texas and Mississippi shorelines and 90% of the Louisiana shoreline have retreated at average rates of 3.1 to 2.6 m/yr and 12 m/yr respectively since 1970. **Retreat rates as high as 30 m/yr** have been observed in Nigeria. Extensive coastal squeeze and steepening have occurred, for example, along the eastern coast of the United Kingdom where 67% of the coast saw a retreat of the low-water mark over the last century.

Acceleration of sea level rise is expected to increase beach erosion across the globe. However, local responses would differ depending on the availability of sediment.

In response to rising sea levels, estuaries and lagoons would raise their bed elevation primarily with sand from the open coast, in order to maintain equilibrium. This could result in **extensive coastal erosion.** Sea level rise could make the coast unstable in regions where there are tidal inlets.

Beach erosion and storms can together result in erosion or inundation of other coastal systems. In **Louisiana,** for example, sandy barrier island erosion has led to an increase in wave heights on coastal bays resulting in higher erosion rates of bay shorelines, tidal creeks and adjacent wetlands. Gravel beaches are also vulnerable to sea level rise, even when accretion rates are fairly high.

DELTAS

A delta is formed at the mouth of a river where it merges with an ocean, sea, estuary, lake or reservoir. Deltas are characterized by a dynamic and intricate maze of river channels, wetlands and other coastal features and host many unique ecosystems. They are considered to be critically important habitats for threatened terrestrial and marine species. They serve as important filters, reactors and reservoirs for a whole range of terrestrial material including carbon that are on their way to the ocean.

The shape of deltas is defined by the combined effects of river, wave and tide processes. They receive water, nutrients and sediment from rivers as well as the sea. While active deltas are dominated by river processes, abandoned deltas are increasingly influenced by marine processes. They have extremely fertile soil and are therefore very productive. They are of great significance for food production and aquaculture. The network of waterways makes transportation easy and they are very densely populated areas. While they account for 5% of land area, they support over 500 million people.

The construction of dams and channels alter the flow of rivers and reduce the amount of sediment that they bring to deltas. Infrastructure and other developments in coastal areas alter the tidal flow and the influx of sediment. Alterations in surface water runoff and sediment load can reduce the resilience of a delta and decrease its ability to respond to the physical impacts of climate change.

Deltas are extremely sensitive to changes in the environment. A combination of human development, rapidly growing populations, altered river flow and composition, and changes in the climate are making deltas extremely vulnerable. Sea level rise in association with these other factors is expected to destroy many of the world's major deltas during this century. Collapse of a delta could include loss of wetland habitats and the biodiversity they support, flooding of villages and cities, damage to infrastructure, elimination of fishing areas, forests and farming lands and rapid retreat of shorelines. **Already, 33 major deltas covering an area of around 26,000 sq. km are below mean sea level** and a total area of 70,000 sq. km is less than 2 m above mean sea level and at tremendous risk of being submerged.

A good example is the **Mississippi river deltaic plain,** in south-east Louisiana, where sediment starvation and increased salinity and water levels in coastal marshes due to human development occurred very rapidly and resulted in the conversion of 1,565 sq. km of intertidal coastal marshes and adjacent lands to open water between 1978 and 2000.

A further 1,300 sq. km is expected to be lost by 2050 if local, regional and global processes continue at present rates; these losses would be heightened by accelerated sea level rise and an increase in tropical storm intensity. The relative vulnerability of coastal deltas in terms of the population that will potentially be displaced is shown in Figure 3. Sea level rise is expected to displace more than a million people each in the Nile, Mekong and Ganges-Brahmaputra deltas by 2050; between 50,000 and one million people are likely to be displaced in the Godavari, Mississippi, and Changjiang deltas.

Fig 3: Relative vulnerability of coastal deltas as shown by the indicative population potentially displaced by current sea level trends to 2050 (Extreme=> 1 million; High=1million to 50,000; Medium=50,000-5000; Ericson et al., 2006)

Climate change is also expected to hasten the process of erosion in coastal and estuarine zones by **increasing summer flow from glacier and snow melt or by increasing tide penetration as a result of rising sea levels.** Increased erosion and sedimentation in combination with churning action will raise the concentration of suspended solids and increase the turbidity of water. This would affect the growth and survival of phytoplankton, which are small marine microscopic plants that supply three quarters of the world's oxygen. As a consequence, there would be considerable disturbance in the food chain of mangroves which are very important nurseries and breeding grounds for aquatic organisms.

Alterations in the timing of freshwater delivery to estuaries could result in the displacement of the juvenile stages of several estuarine and marine fishery species from their nursery habitat. **Sea level rise could result in the landward transgression of natural estuarine shorelines.** In the Venice Lagoon in Italy, the combined action of sea level rise, altered sediment dynamics and geological land subsidence has lowered the lagoon floor, widened tidal inlets, submerged tidal flats and islands and has resulted in retreat of the shoreline along the margin of the lagoon. For several years now, Venice, which was built on a lagoon 1,300 years ago has been considered the most endangered city in the world.

image Source: Katherine Elaine

SALTMARSHES AND SEAGRASSES

Brackish and freshwater marshes are expected to be particularly vulnerable to climate change because of the changes it would bring about in the quality and quantity of water brought by rivers, and in the nature and variability of the hydro period during which they are inundated and the number and severity of extreme events. Many **salt marshes are able to withstand rises in sea level as they accrete vertically**, that is, they are able to increase their elevation and can maintain their elevation when there is sufficient sediment available. However, there have been instances where these marshes have drowned. The combined action of sea level rise and subsidence effects caused the marshes of the Mississippi River Delta to rapidly subside in spite of sediment inputs from frequently recurring hurricanes.

The salt water marshes and mud flats of the Rann of Kutch in Gujarat are one of the largest breeding areas of the **Greater Flamingo**. Rising sea levels are likely to submerge these salt marshes and mud flats. As a consequence, these birds as well as the **Lesser Florican and the Indian Wild Ass** could lose their habitat.

Sea grasses are flowering plants that live in the shallow waters of oceans and estuaries all over the world. They rank among the most productive plant communities in the world, producing large quantities of organic carbon. They are of great significance to commercially important species like fish and prawns which depend on them for shelter. They also serve as **nurseries for species like shellfish and fin fish.** They are extremely important ecosystems and provide many services. They provide shelter to many marine organisms and are a source of food for some species. Their roots and rhizomes help stabilize sediments and protect the coastline from erosion due to ocean currents and extreme weather. Their leaves act as filters, trapping suspended particulates and nutrients in the water. Sea grass beds are often the sole fishing ground for small subsistence fishing.

Sea grasses around coasts all over the world are declining as a result of human activity and climate change is expected to accelerate this decline. Warmer temperatures will cause shifts in **distribution**, alter the **pattern of sexual reproduction** and change their **growth rates, metabolism and carbon balance.**

Rising temperatures are also likely to result in the burning or die off of sea grasses, especially in areas where they are already close to their critical thresholds for temperature. Increasing temperatures can favour the growth of **competitive algae and epiphytes** which can out number sea grasses and reduce the availability of sunlight which is critical for their survival. The reduction in light as a result of coastal runoff can affect deep sea grasses. Storms which are predicted to increase in intensity in tropical areas can cause massive sediment movements which can uproot or bury sea grass meadows. The increase in turbidity following such sediment movement will also affect the availability of sunlight which is needed by these plants. Increased rainfall and discharges from rivers will elevate sediment load and reduce light. Excessive sediment can also be detrimental to these plants. Nearly **1,000 sq. km of sea grasses were destroyed** due to sediment loading and uprooting in Queensland, Australia when two major floods and one cyclone occurred within a span of three weeks.

The frequency and intensity of floods is expected to rise because of climate change. This would increase turbidity as well as the sedimentation rate and also reduce sunlight which will adversely affect these plants.

In the **Philippines and Thailand**, the species richness and leaf biomass of sea grasses reduced drastically when the silt and clay content in the sediment went beyond 15%.

Sea grasses are particularly **vulnerable to anoxia** or oxygen depletion due to sediments. Although most sediments are anoxic, sea grasses tend to counter this by transferring the oxygen they produce during photosynthesis from the shoots to the extensive root system, which they depend on for anchorage. However, excess sediment load can reduce light and thereby decrease photosynthesis and the supply of oxygen to the roots. When anoxia persists for too long, **sulphides are produced** in the sediment; these are toxic to sea grasses and kill them. Increasing temperature also enhances the rate of respiratory breakdown of organic matter in the sediment and decreases the level of oxygen.

Sea level rise will increase the depth of water above sea grasses and decrease the availability of light. Altered currents will increase turbidity and erosion. These changes can adversely affect sea grasses.

SUMMARY

Rising sea level is likely to submerge the salt marshes and mud flats of the Rann of Kutch and deprive the greater flamingo, the lesser florican and the Indian wild ass of an important habitat.

Sea grasses produce large quantities of organic carbon and rank among the most productive plant communities of the world. They are often the sole fishing ground for subsistence fishing.

Over the last decade, 290,000 ha of sea grasses were lost around the world.

The sea around the beautiful city of Venice built on a lagoon in Italy is rising at the rate of 4 mm a year and will eventually drown it.

Impact on Marine Fisheries

Fisheries are generally available in underdeveloped and rural areas and contribute substantially to economic growth and livelihood in remote areas where other economic activities tend to be limited.

Over the last decade, there has been no increase in the production from marine fishery mainly because of over fishing, unregulated fishing, pollution and habitat destruction. Climate change which will increase the frequency and intensity of storms, floods and droughts would adversely affect fisheries and worsen the situation. Increases in the temperature of water can influence fish diversity, distribution, abundance and phenology or the timing of events like spawning. Calciferous animals would be affected by increased acidification of the water. By lowering fish production, sea level rise would have a major impact on livelihoods. While some tropical fish stocks move north as temperatures become more favorable, others may undergo regional extinction. Most species of fish have a narrow range of optimal temperature which is a function of their basic metabolism and the availability of food organisms. A 1°C rise in temperature can alter their distribution and even threaten their existence.

In response to climate change, there may be a change in the species composition of phytoplankton with an increase in temperature; small pelagics may shift their boundaries to occupy larger areas; and phenological changes might occur—there would be a shift in the timing of events like migration for spawning.

SMALL PELAGICS COULD EXTEND THEIR BOUNDARIES

Small pelagics like the **oil sardine and the Indian mackerel** have generally confined themselves to an extremely restricted area between latitudes 8˚N and 14˚N and longitudes 75˚E and 77˚E. This is called the Malabar upwelling zone along the southwest coast of India, where the annual average sea surface temperature lies between 27 and 29˚C. Until 1985, nearly the entire catch of these fish came from the Malabar upwelling zone and there was hardly any catch from areas north of 14˚N. However, the last two decades have seen an increase in the catch from latitudes 14˚ to 20˚N. The catch from this area accounted for 15% of the all-India oil sardine catch in the year 2006 (Figure 4).

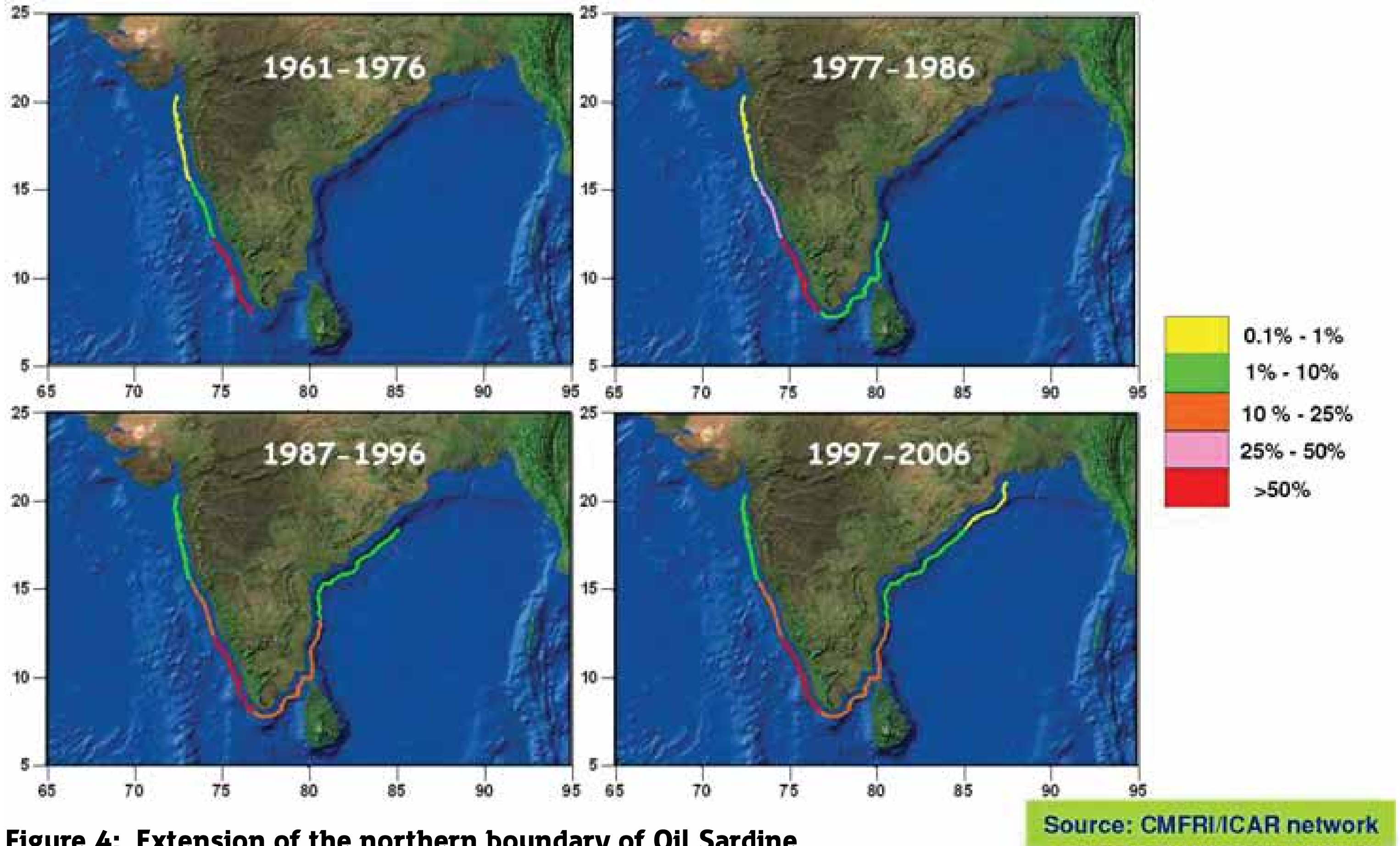


Figure 4: Extension of the northern boundary of Oil Sardine
Source : www.moef.nic.in/downloads/others/Vulnerability_PK%20Aggarwal.pdf

The increase in sea surface temperature has resulted in a warming of the latitudes north of latitude 14˚N making these areas suitable habitats for the oil sardine and Indian mackerel; consequently, these pelagic fish extended their boundaries further northwards. Over the last two decades, the **Indian mackerel has also descended to deeper waters** which are getting warmer as a result of the increasing sea surface temperature.

The spawning season of marine fish found around India is also shifting. **Threadfin breams** which are extremely fecund, fast growing fish with a short lifespan and are found along the entire Indian coast at a depth of 10 – 100 m, have shifted their spawning season from the warmer months between April and September to the cooler months between October and March. Between 1981 and 1985, 35.3% of the spawners of **N.japonicus** occurred in warm months, only 5% of the spawners occurred during the same season between 2000 and 2004. Moreover, between 1981 and 1985, 64.7% of the spawners of **Nemipterus japonicus** occurred between October and March, while 95% of the spawners occurred in the same season in the period, 2000 – 2004. A similar trend was seen in **N. Mesoprion**. The increase in sea surface temperature has made these fish shift their spawning activity to cooler months when the temperature is more suitable. Such instances of smaller, low value fishes with short generation times, being able to withstand climatic changes may lead to a situation where they replace the larger species of higher value whose numbers are already reducing.

The combined effects of climate change and other human activities have increased the frequency of **disease outbreaks in corals and marine mammals** and introduced new diseases. It has been proposed that the increased global transport of species has resulted in species being exposed to pathogens that are different from those found in their normal habitat. The metabolism and physiology of fish are sensitive to small variations in temperature. Temperature, therefore, has an influence on the **growth, fecundity, feeding, behavior, distribution, migration and abundance** of fish. Parasites are also influenced by temperature. Increases in temperature tend to cause rapid growth and maturation of parasites, earlier onset of spring maturation, increased parasite mortality, increased number of generations per year, elevated rates of parasitism and disease, earlier and prolonged transmission and the possibility of continuous year-round transmission. Climate change will extend the geographic range of parasites and pathogens. Furthermore, higher temperatures can cause thermal stress in aquatic animals which can result in decreased growth, sub-optimal behaviors, reduced immunocompetence and alter the abundance and distribution of the hosts of pathogens.

The extreme events and harsh weather conditions associated with climate change will affect the quality, productivity and viability of fish and aquaculture units and thereby the fishing community. The availability, access, stability and use of aquatic food and supplies as well as opportunities for employment would be adversely affected. **Employment would increase in certain tropical and sub-tropical areas.** In certain previously cold regions, production would increase as growth rates improve, growing seasons extend and new farming areas become available due to a warmer temperature that is more suitable for fish.

Consequences for Humanity

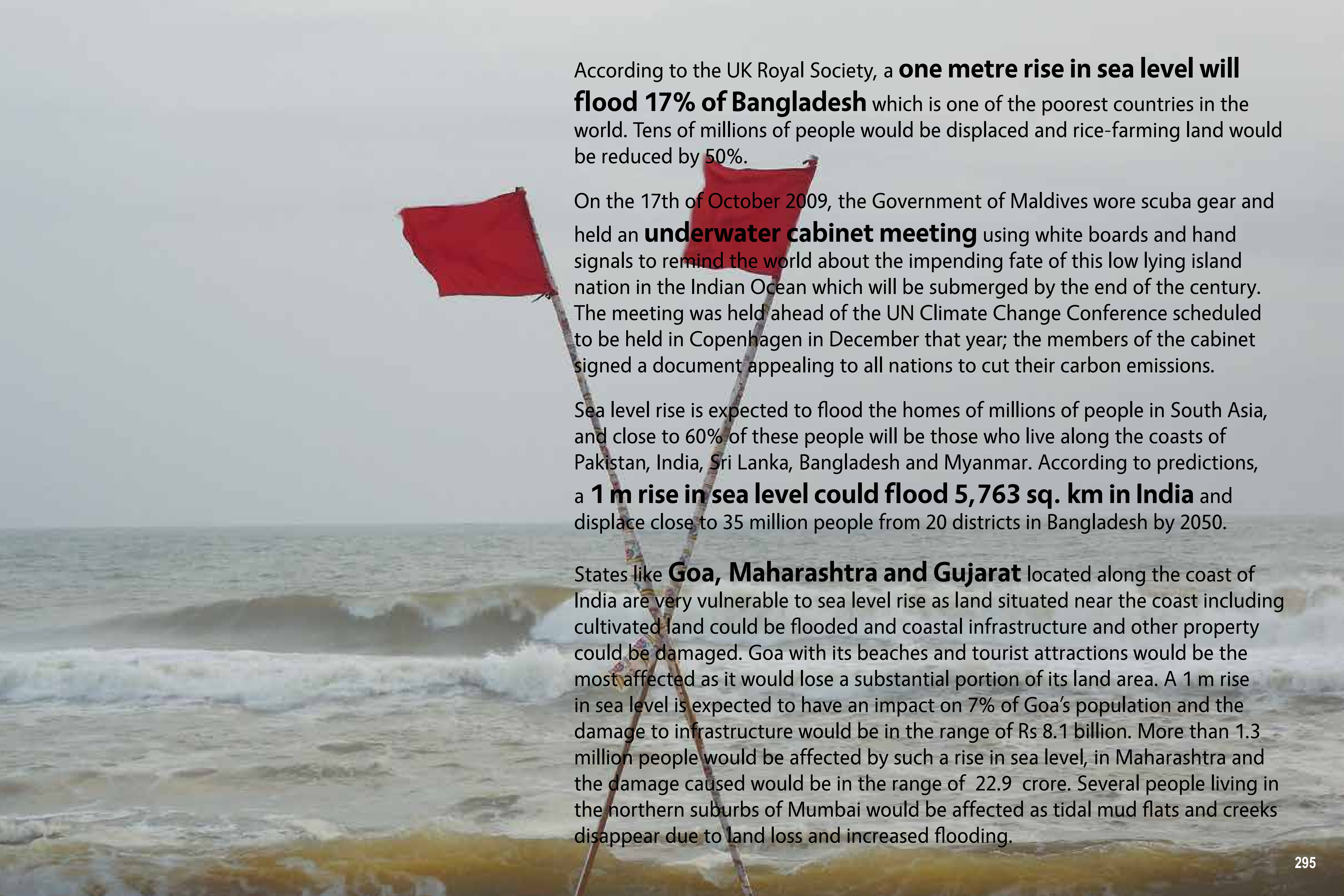
Freshwater Resources

Sea level rise affects fresh water resources mainly because of seawater intrusion into surface waters and coastal aquifers, increased flow of coastal water into estuaries and coastal river systems, enhanced coastal inundation and increased levels of sea flooding, increases in the landward reach of sea waves and storm surges and initiation or enhancement of coastal erosion. While coastal areas account for a major portion of the world's population, they have a much smaller share of the global renewable water supply. **Coastal populations are growing much more rapidly than populations inland and the demand for water is increasing.**

SEA LEVEL RISE

The melting of the polar ice caps, glaciers and snow around the world together with the expansion of the ocean due to higher sea surface temperatures is causing the sea level to rise. **Close to 10% of the world's population inhabits regions that are less than 10 m above sea level;** all these people are particularly vulnerable to the rising sea levels associated with climate change. The sea level rose by an average of 1.7 mm per year for a total rise of 221 mm between 1870 and 2000. Between 1993 and 2009, there has been considerable increase in this rate, approximately 3 mm per year for a total sea level rise of 48 mm. Sea levels rose by 20 cm in the last century and are expected to rise between 18 and 59 cm over the next century.

Several coastal cities, villages and island nations risk being submerged or have already disappeared into the sea. The islands that have submerged include, **Lohachara** in India that had 10,000 residents, **Bedford**, **Kabasgadi and Suparibhanga** islands near India with 6,000 families, 13 islands at **Chesapeake bay** in Maryland, USA, 3 atolls in **Kiribati,** which is a Pacific island nation and half of Bangladesh's **Bhola Island** with 500,000 residents. In the island of **Tuvalu**, there is no fresh drinking water for its 12,000 residents and land where vegetables were being cultivated has been lost to the sea. Two thirds of the **Ghomara** island near India has been submerged and 7,000 of its residents have been relocated. In the neighboring island of **Sagar,** 250,000 people are at risk. Around 50 islands in the **Sundarbans** are at the risk of being submerged. Nearly 30 islands are being submerged in Kiribati which has a population of 107,800. The **Maldives** with 369,000 residents, the **Solomon islands** with a population of 556,800, **Vanautu** with 212,000 and more than 2,000 islands in Indonesia are at risk because of the rising sea level.



According to the UK Royal Society, a **one metre rise in sea level will flood 17% of Bangladesh** which is one of the poorest countries in the world. Tens of millions of people would be displaced and rice-farming land would be reduced by 50%.

On the 17th of October 2009, the Government of Maldives wore scuba gear and held an **underwater cabinet meeting** using white boards and hand signals to remind the world about the impending fate of this low lying island nation in the Indian Ocean which will be submerged by the end of the century. The meeting was held ahead of the UN Climate Change Conference scheduled to be held in Copenhagen in December that year; the members of the cabinet signed a document appealing to all nations to cut their carbon emissions.

Sea level rise is expected to flood the homes of millions of people in South Asia, and close to 60% of these people will be those who live along the coasts of Pakistan, India, Sri Lanka, Bangladesh and Myanmar. According to predictions, a **1 m rise in sea level could flood 5,763 sq. km in India** and displace close to 35 million people from 20 districts in Bangladesh by 2050.

States like **Goa, Maharashtra and Gujarat** located along the coast of India are very vulnerable to sea level rise as land situated near the coast including cultivated land could be flooded and coastal infrastructure and other property could be damaged. Goa with its beaches and tourist attractions would be the most affected as it would lose a substantial portion of its land area. A 1 m rise in sea level is expected to have an impact on 7% of Goa's population and the damage to infrastructure would be in the range of Rs 8.1 billion. More than 1.3 million people would be affected by such a rise in sea level, in Maharashtra and the damage caused would be in the range of 22.9 crore. Several people living in the northern suburbs of Mumbai would be affected as tidal mud flats and creeks disappear due to land loss and increased flooding.

In Mangamari Peta and Pudimadaka, both coastal villages in Andhra Pradesh, the sea has ingressed about half a kilometer inland and is forcing several poor fisher folk to abandon their homes. They are travelling as far as Andaman, Gujarat, and Odisha in search of livelihoods. Over the next five years the inhabitants of between 70 and 80 villages are likely to be displaced.

The **increase in the number of dead zones** (where there are no fish) in the sea in the last few years has been a major obstacle for the fishing community. Fifteen years ago, fish could be caught as close as 1 km from the coast. Now fisher folk have no option but to venture out as far as 30 km to find a good catch. As they use small boats that run on diesel, their costs have been steadily increasing; this is reflected in the price of fish. A large number of fisher folk are migrating to cities.

Many villages in different districts of **Kerala** are also very vulnerable to sea level rise which has already submerged or washed away many houses in these areas. For some places like **Kuttanad,** which is under the sea level and with a distance of a few metres separating the sea from the backwaters in some places, being submerged is inevitable.

Millions of people from coastal areas all over the world have **no choice but to re locate** at a tremendous cost. Whole cities, nations and villages will have to be or are being abandoned and left to their fate. The poor, the sick, the elderly, the women and children are subjected to immense hardship and suffering as families, individuals, and whole communities strive to find shelter, food and resources for a livelihood under conditions of poor sanitation, scarce drinking water, extreme poverty, limited food and poor health. As displaced people are frequently forced to live in extremely poor conditions, quality of health and competition for resources will create major challenges.

In addition to coastal flooding and erosion, and loss of coastal wetlands, sea level rise will cause **salt water intrusion into coastal freshwater aquifers,** adversely affect coral reefs and coastal fisheries, damage coastal infrastructure and property and forcibly displace people. Low-lying coastal and delta regions like coastal **China, Bangladesh and Egypt** as well as low-lying small island nations such as the coral reef atolls all over Polynesia, are particularly vulnerable. Coastal cities like **Mumbai, Shanghai, Miami, New York City and New Orleans** are expected to be the worst hit by surge induced flooding. Cities such as Alexandria in Egypt that have large areas situated below mean sea level are at increased risk.

The pollution of water by the intrusion of sea water has become a major challenge in coastal areas**. Salinity of both water and soil have been increasing** in the coastal districts of Bangladesh particularly in the Southwest region. The **decreased flow of the Gorai River**, a tributary of the Ganges, in the dry season due to withdrawal of water upstream in India, results in increased salinity of water in the Southwest region. The salinity of the soil also increases during the dry period due to seepage of tidal water from the sea and capillary rise of saline water from the underground water table.

In the coastal districts of Tamil Nadu, excessive withdrawal of ground water has lowered the water table and sea water has penetrated into surface aquifers. This has **increased the salinity of ground water.** The pollution of ground water with sea water is also a problem in Gujarat. In the coastal districts of West Bengal and Odisha, the ground water is frequently polluted by sea water during high tides and storm surges.

The predicted rise in sea level in the future due to global warming will intensify the problem of pollution of freshwater with saline water in coastal areas. A 45 cm rise in sea level is expected to result in the inundation of 11% of Bangladesh. In India, a **100 cm rise in sea level is expected to inundate 6,000 sq. km of the coast.**

Increased salinity due to intrusion of coastal water into freshwater aquifers as well as frequent and intense storms and floods will impact **coastal agriculture.** Coastal lowlands which are likely to be affected by climate change constitute approximately one third of the world's croplands. Brackish-water agriculture, including fish and shrimp ponds excavated in former mangrove areas are particularly vulnerable.

The table given below summarizes the climate related impacts such as temperature rise, floods, storms, rising sea level and salt water intrusion on socio-economic sectors in coastal zones. Increased temperature and extreme events will have a strong impact on freshwater resources, agriculture, forestry, fisheries, aquaculture, health, recreation, tourism, biodiversity and infrastructure. The other climate related factors will have a varied effect on these sectors.

CLIMATE-RELATED IMPACTS (AND THEIR CLIMATE DRIVERS)

COASTAL SOCIOECONOMIC SECTOR	TEMPERATURE RISE (AIR AND SEA WATER)	EXTREME EVENTS (STORMS, WAVES)	FLOODS (SEA LEVEL, RUNOFF)	RISING WATER TABLES (SEA LEVEL)	EROSION (SEA LEVEL, STORMS, WAVES)	SALT WATER INTRUSION (SEA LEVEL, RUNOFF)	BIOLOGICAL EFFECTS (ALL CLIMATE DRIVERS)
FRESHWATER RESOURCES	X	X	X	X	-	X	x
AGRICULTURE AND FORESTRY	X	X	X	X	-	X	x
FISHERIES AND AQUACULTURE	X	X	x	-	x	X	X
HEALTH	X	X	X	x	-	X	X
RECREATION AND TOURISM	X	X	x	-	X	-	-
BIODIVERSITY	X	X	X	X	X	X	X
SETTLEMENTS/ INFRASTRUCTURE	X	X	X	X	X	X	-

According to the most conservative estimates, sea level is expected to rise by 40 cm by the end of this century.
This would increase the number of people flooded in coastal populations each year from 13 million to 94 million. South Asia will account for 60% of this increase, along the coasts of Pakistan, India, Sri Lanka, Bangladesh and Myanmar. Twenty percent of this increase will be seen in South East Asia along the coasts of Thailand, Vietnam, Indonesia and the Philippines.

A one metre rise in sea level is expected to inundate 5,763 sq. km in India and 2,339 sq. km in some big cities of Japan.
By 2050, more than a million people will be affected in each of the three major deltas of the world – the Ganges-Brahmaputra-Meghna delta in Bangladesh, the Mekong delta in Vietnam and the Nile delta in Egypt.

Coastal areas throughout Asia are experiencing a range of stresses which are affecting their resilience. Climate change is expected to worsen the situation. The rise in sea level that has been predicted will inundate low lying areas, submerge coastal marshes and wetlands, erode beaches, increase flooding and the salinity of bays and aquifers. There would be increased wind and an increased frequency of intense tropical storms which would cause flood damage due to storm surges. There would be a higher incidence of vector-borne diseases like malaria, dengue and measles.

IMPACT OF RISE IN SEA SURFACE TEMPERATURE ON COASTAL AREAS

Sea surface temperatures (SST) above 26˚C are a prerequisite for hurricane formation. These temperatures occur in the summer months, between 5˚N and 25˚N in the Atlantic ocean and between 5˚N and 20˚N in the North Pacific, Indian and South Pacific Oceans. A rise of just over 2˚C in SST can increase hurricane wind speed by 3 – 7 m/s. SSTs have steadily increased over the last century with a more rapid rise in the last 35 years. The maximum average SST was recorded between 1995 and 2004. In the first half of this period, hurricane activity doubled in the North Atlantic Ocean and increased fivefold in the Caribbean Sea.

Analysis of various factors has shown that the increase in the intensity of hurricanes that has been observed all over the world over the last 35 years is most likely due to the increase in sea surface temperature that has coincided with this period. There is a strong correlation between SST and the intensity and destructiveness of hurricanes. **As SST rises, hurricanes will further intensify in the future.**

The ocean temperatures associated with the **El Nino Southern Oscillation are strongly correlated with the resurgence of major infectious diseases.** Climate variability due to ENSO has been associated with the large epidemics of malaria in the Indian sub-continent and South America. Epidemics of Rift Valley Fever in East Africa have coincided with exceptionally high rainfall associated with ENSO-related Pacific and Indian Ocean SST anomalies. After the ENSO event of 1997 – 98, the Rift Valley recorded a 50 fold increase in rainfall which led to a major epidemic of Rift Valley Fever. Between 1950 and 1988, more than 75% of the outbreaks of Rift valley fever occurred during warm ENSO event periods.

HEALTH

Warm waters have sufficient nitrogen favour blooms or abundant growth of phytoplankton such as dinoflagellates, diatoms and cyanobacteria. These blooms which are known as red tides or harmful algal blooms (HABs), release toxins into marine waters and can **cause amnesiac poisoning** in human beings following consumption of contaminated shellfish and fin fish. They can also kill several fish, shellfish and marine mammals and birds that rely on the marine food-web. The last three decades have seen an increase in the frequency and distribution of toxic algal incidents and algal poisoning of human beings. This period has also experienced an increase in climate change related ecological disturbances. The climate related disturbances may have had some influence on the altered pattern of toxic algal incidents.

During the **El Nino event of 1987,** a bloom of dinoflagellates that thus far had been restricted to the Gulf of Mexico, extended towards the north when warm Gulf Stream water moved up the East Coast. This caused human neurological shellfish poisoning and extensive die off of fish in North Carolina.

In the same year, there was an **outbreak of amnesiac shellfish poisoning in Prince Edward Island** when warm eddies or currents from the Gulf Stream came close to the shore and nutrient rich runoff led to a bloom of toxic diatoms. According to predictions, a combination of water column stratification and a 4˚C rise in summer temperature by 2100 would double the growth rates of several HABs in the North Sea. **Ciguatera fish poisoning** is another toxin-associated human disease which is likely to extend its range to higher latitudes. In India too, where millions of people depend on the sea as a source of income and for their food, algal blooms are affecting prawns, mussels, oysters and other important marine species. Marine fishery is an important source of livelihood for people in coastal areas along the Indian coast. Many of these species, especially **oysters and mussels,** are the principal source of protein for the poor. Sea surface temperature is increasing as a result of global warming and is causing an increase in the incidence of algal blooms, which kill these important marine species, affect livelihoods as well as the economy.

Warm marine waters are also an ideal habitat for Vibrio species. Zooplankton that feed on algae can serve as reservoirs for Vibrio cholerae and other enteric pathogens. In Bangladesh, it has been observed that the increase in the incidence of cholera coincides with periods when there is a massive increase in plankton blooms. The seasonal rises in temperature are generally associated with increased nutrient levels, which favour abundant growth and proliferation of plankton. The frequency of outbreaks is maximum between early April and mid-May and between early September and end November when temperature, salinity and the concentration of nutrients is high—conditions that are optimal for plankton blooms. **The increased occurrence of plankton blooms will have a direct effect on cholera outbreaks.**

During the El Nino event of 1997 – 98, the winter temperature in Lima, Peru was more than 5 °C above normal; the number of daily admissions for **diarrhoea** doubled during this period as compared to a five year average for the same period. Many studies have observed a correlation between the El Nino Southern Oscillation (ENSO), cholera and other diarrhoeal diseases. In recent years, the ENSO has been increasingly responsible for **cholera outbreaks,** possibly due to the effects of climate change. The inter-annual variability in the incidence of cholera in Bangladesh over a seven year period shows a strong correlation with SSTs in the Bay of Bengal, ENSO and the extent of flooding in Bangladesh.

VECTOR BORNE DISEASES

Vector borne diseases like **Plasmodium falciparum and Plasmodium vivax malaria, dengue fever, dengue haemorrhagic fever and schistosomiasis,** are endemic to parts of tropical Asia and are particularly sensitive to changes in climatic conditions. Climate change could influence the transmission of these diseases by altering the geographic range of the vectors and increasing their reproductive and biting rates and reducing the incubation period of the pathogen.

Dengue and dengue haemorrhagic fever (DHF) have a wide distribution in several tropical Asian countries. While the transmission of DHF has been attributed to rapid urbanization, the **disease vector Aedes aegypti** has an extremely widespread distribution. Children are the worst affected in tropical Asia where DHF and dengue are responsible for many cases of hospitalization and deaths. According to the WHO, both these diseases will continue to persist in Indonesia, Myanmar, and Thailand, where they are already endemic. India, Bangladesh, and Sri Lanka have also reported sporadic cases and outbreaks in recent years.

Climate change is expected to affect the distribution, lifecycle and population dynamics of dengue and a 3 – 4 ˚C rise average temperature is expected to double the reproduction rate of the virus.

According to the predictions of a mathematical model, **Indonesia will probably experience a threefold increase in the incidence of dengue** under the best climate change scenario.

Some effects of weather and climate on vector-borne diseases

Vector-borne pathogens spend part of their life cycle in cold-blooded arthropods that are subject to many environmental factors. Changes in weather and climate that can affect transmission of vector-borne diseases include temperature, rainfall and wind.

Examples of temperature effects on vector-borne pathogens

Vector

Survival can decrease or increase depending on the species

Some vectors have higher survival at higher latitudes and altitude with higher temperatures

Changes in the susceptibility of vectors to some pathogens (e.g., higher temperatures reduce the size of some vectors but reduce the activity of others)

Changes in the rate of vector population growth

Changes in feeding rate and host contact (which may alter the survival rate)

Changes in the seasonality of populations

Pathogen

Decreased extrinsic incubation period of pathogen in vector at higher temperatures

Changes in the transmission season

Changes in distribution

Decreased viral replication

SOURCE: Adapted from Gubler et al. (2001).

In Sri Lanka, there is a fourfold increase in the risk of malaria epidemics in an El Nino year, associated with precipitation below normal levels.

A strong **correlation between El Nino and the risk of malaria** epidemics has been observed in southern Asia, Africa and South America. Cases of malaria in South America have shown a significant correlation with the rise in sea surface temperature associated with ENSO. In Southern Africa a similar correlation has been observed with the El Nino Southern Oscillation Index (SOI).

By 2050, as temperatures rise further, malaria is expected to shift from the central Indian region to the south western coastal states of Maharashtra, Karnataka and Kerala. The predicted rise in sea level could reduce or **wipe out the breeding habitat of salt-marsh mosquitoes** that inhabit salt marshes. Mammalian and avian hosts that inhabit these areas may risk extinction, and this could contribute to the elimination of viruses that are endemic to the habitats. However, in some cases, inland intrusion of saltwater can convert freshwater habitats into salt marshes which could serve as a habitat for vector and host species that have been displaced from former salt marshes.

The South American nation **Guyana** has succeeded over the last two decades in bringing down the incidence of malaria from 92,000 cases a year to 10,000 by using treated bed nets, increasing the awareness about malaria drugs and training health personnel. Earlier, in the 1950s and 1960s the use of DDT had eliminated this disease from the densely populated coastal areas. However, recent research has shown that climate change is causing an increase in the incidence of malaria and taking it back to the coast.

The increase in the intensity and frequency of storms, floods and other extreme weather events, the increased vulnerability of coastal areas due to extensive development and rapid urbanization, and the exponentially rising populations of most coastal areas are some of the factors that will heighten the impact of vector borne diseases which are spreading to coastal areas as a consequence of climate change. **Many of these diseases do not have a history in these areas and the people are not equipped to deal with them.** Under these circumstances, such disease can spread rapidly and cause many fatalities in the event of an outbreak. Many coastal areas have shortage of drinking water. **Salt water intrusion into coastal aquifers** due to sea level rise, and during floods, storms and periods of intense rainfall will increase this shortfall of drinking water. Moreover, storms and floods will increase the spread of infectious enteric diseases which cause diarrhoea in young children.

The last three decades saw a rise in frequency and distribution of toxic algal incidents and algal poisoning of human beings by harmful algal blooms or red tides.

A combination of water column stratification and a 4°C rise in temperature by 2100 is expected to double the growth rates of several harmful algal blooms in the North Sea. The incidence of toxic algal blooms is already increasing in the seas around India. Ciguatera fish poisoning is also likely to extend its range to higher latitudes.

Vector borne diseases like malaria, dengue, dengue hemorrhagic fever and schistosomiasis are very sensitive to changes in climatic conditions. Climate change can increase the rate of transmission of these diseases by altering the geographic range of the vectors and increasing their reproductive and biting rates and reducing the incubation period of the pathogen. Climate change is expected to affect the distribution, lifecycle and population dynamics of dengue and a 3–4°C rise in average temperature is expected to double the reproduction rate of the virus.

SUMMARY

According to estimates, 23% of the world's population lives both within 100 km distance of the coast and less than 100 m above sea level. **The population density in coastal areas is three times the global average.**

The sudden increase in the burning of fossil fuels with industrialization which commenced in the 1750's, and deforestation to clear land for agriculture and other purposes has resulted in **a sharp rise of more than 100 ppm (parts per million) in carbon dioxide concentration** which in turn has led to a 0.6 – 0.9 ˚C rise in temperature over the last century. This is causing a change in the climate all over the world.
Polar ice caps, glaciers and snow are melting much more in the summer; the sea level is rising; the incidence of floods, droughts and heat waves is increasing; the intensity and frequency of storms, cyclones and hurricanes is on the rise.

Coastal areas support a wide range of ecosystems which include **coral reefs, mangrove forests, sea grasses, lagoons and estuaries.** These ecosystems provide a wide range of products and services which are of great significance to coastal communities. They also serve as important habitats for several marine species.

Climate change is **affecting the health, resilience and productivity** of these ecosystems. The rising temperatures are bleaching coral reefs; sea level rise is reducing the habitat available for mangroves; many densely populated deltas of the world are on the verge of collapse; sea level rise is increasing the salt water component in estuaries and depriving many species of juvenile fish of a nursery habitat; elevated temperatures and increased sediment due to frequent storms are affecting sea grasses.

The gradual deterioration of coastal habitats that support many commercially important species of fish and other marine organisms is affecting fisheries. As fishes move north towards cooler regions, scores of **fisher folk are losing their means of livelihood**.

Sea level rise is leading to **coastal inundation**; whole islands and many coastal areas have submerged or are most likely to be submerged in the near future. Many deltas and coastal cities are at risk. **Sea water is contaminating fresh water aquifers** and causing a drastic fall in the availability of drinking water. Millions of people have been forced to migrate further inland and have lost their homes. **Vector borne diseases** like malaria and dengue are extending their range to the coast. Toxic algal blooms are occurring more frequently.

Glossary

Albedo is the relative reflectivity of light from a surface and in the context of solar radiation it refers to the percentage of solar energy that is not absorbed or is reflected back.

An aquifer is a layer of water bearing permeable rock, gravel, sand or silt situated underground from which groundwater can be extracted using a water well. Aquifers located near the coast have a layer of freshwater at the surface and denser sea water beneath it. If too much ground water is pumped near the coast or if the sea level rises, sea-water can intrude into freshwater aquifers and contaminate potable freshwater supplies.

An atoll is a ring-shaped reef, island or chain of islands made of coral that nearly or entirely encloses a lagoon.

El Nino Southern Oscillation ENSO is a climatic pattern that recurs periodically across the tropical Pacific Ocean every five years or so. The extremes of this climate pattern's oscillations, the warm oceanic phase brought about by El Nino and the cold phase due to La Nina cause extreme weather events in many parts of the world.

A glacier is a large persistent body of ice that forms where the accumulation of snow exceeds its rate of ablation by melting and sublimation, over many years, often centuries. Glacial ice is the largest reservoir of freshwater on Earth.

Glacial Lake Outburst Flood (GLOF) is a flood that occurs when the dam containing a glacial lake gives way. The dam is usually made of glacial ice and debris. A GLOF can occur due to erosion, build up of water pressure, an avalanche of rock or heavy snow, an earthquake, a volcanic eruption under the ice or when a large enough portion of a glacier breaks away, displacing a massive amount of water from a glacial lake at its base.

A greenhouse gas is a gas present in the atmosphere which absorbs and emits radiation within the thermal infrared range and thereby increases the temperature.

Incubation period is the time lapse between exposure to a pathogenic organism, a chemical or radiation and the first appearance of the symptoms and signs of an infection.

Inundation refers to being flooded or covered in water usually due to a flood.

An invasive species is a species that has evolved as a result of human activities, exceeded its normal accepted distribution and is considered a threat to valuable environmental, agricultural or other social resources because of the damage it can cause.

Permafrost is soil which has been at or below the freezing point of water for two or more years. Permafrost accounts for 0.022% of total water and occurs in 24% of the exposed land in the Northern Hemisphere.

A pathogen or infectious agent is a biological agent such as a bacterium, virus, protozoan or fungus that causes disease in its host which may be an animal, human being, plant or a microorganism.

Phenological events are periodic plant and animal lifecycle events that are often influenced by seasonal and inter-annual variations in climate and usually refer to the date of first occurrence of biological events in their annual cycle.

A vector-borne disease is one in which the pathogenic microorganism is transmitted from an infected individual to another individual by an arthropod or other agent, sometimes with other animals serving as intermediary hosts.

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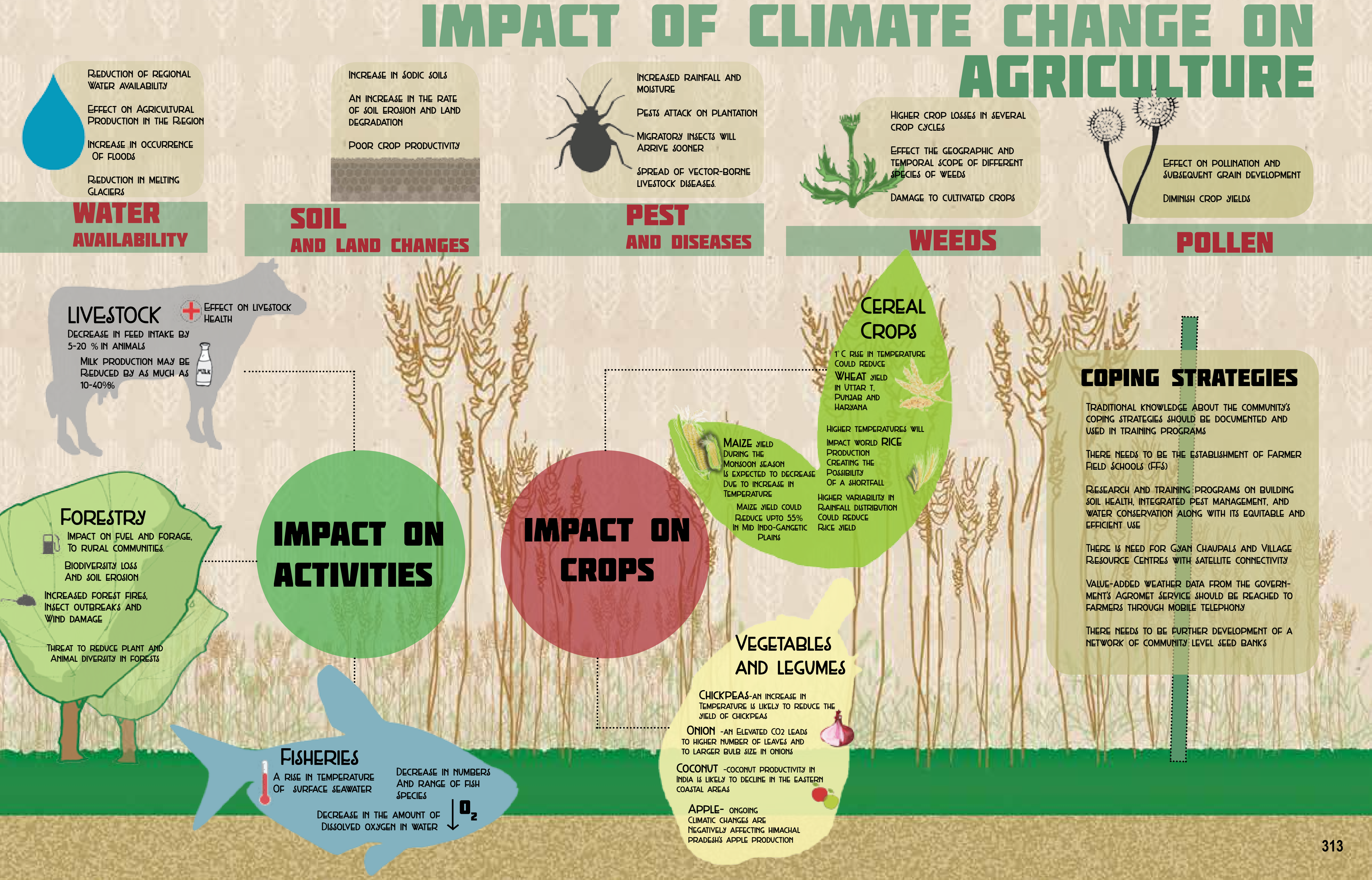

IMPACT OF CLIMATE CHANGE ON AGRICULTURE
Reduction of regional water availability
Effect on agricultural production in the region
Increase in occurrence of floods
Reduction in melting glaciers
WATER AVAILABILITY
Increase in sodic soils
An increase in the rate of soil erosion and land degradation
Poor crop productivity
SOIL AND LAND CHANGES
Increased rainfall and moisture
Pests attack on plantation
Migratory insects will arrive sooner
Spread of vector-borne livestock diseases.
PEST AND DISEASES
Higher crop losses in several crop cycles
Effect the geographic and temporal scope of different species of weeds
Damage to cultivated crops
WEEDS
Effect on pollination and subsequent grain development
Diminish crop yields
POLLEN
LIVESTOCK
Effect on livestock health
Decrease in feed intake by 5-20 % in animals
Milk production may be reduced by as much as 10-40%
MILK
Cereal Crops
1°C rise in temperature could reduce Wheat yield in Uttar T, Punjab and Haryana
Higher temperatures will impact world Rice production creating the possibility of a shortfall
Higher variability in rainfall distribution could reduce Rice yield
Maize yield during the monsoon season is expected to decrease due to increase in temperature
Maize yield could reduce upto 55% in Mid Indo-Gangetic Plains
COPING STRATEGIES
Traditional knowledge about the community's coping strategies should be documented and used in training programs
There needs to be the establishment of Farmer Field Schools (FFS)
Research and training programs on building soil health, integrated pest management, and water conservation along with its equitable and efficient use
There is need for Gyan Chaupals and Village Resource Centres with satellite connectivity
Value-added weather data from the government's Agromet Service should be reached to farmers through mobile telephony
There needs to be further development of a network of community level seed banks
Forestry
Impact on fuel and forage, to rural communities.
Biodiversity loss and soil erosion
Increased forest fires, insect outbreaks and wind damage
Threat to reduce plant and animal diversity in forests
IMPACT ON ACTIVITIES
IMPACT ON CROPS
Vegetables and Legumes
Chickpeas-an increase in temperature is likely to reduce the yield of chickpeas
Onion -an elevated CO2 leads to higher number of leaves and to larger bulb size in onions
Coconut -coconut productivity in India is likely to decline in the eastern coastal areas
Apple- ongoing climatic changes are negatively affecting Himachal Pradesh's apple production
Fisheries
A rise in temperature of surface seawater
Decrease in numbers and range of fish species
Decrease in the amount of dissolved oxygen in water
O2

The Impact of Climate Change on Agriculture

Farmers across the world are deeply connected to weather and climate patterns. The term "farmer" is broad, and includes pastoralists, traditional societies, coastal populations, forest-dependent people, artisanal fisher-folk and indigenous people who rely on natural resources and depend on animal migration patterns for traditional food, fuel and medicines. All these people stand to be drastically affected by climate change. In particular, those living along coasts, in floodplains, mountains, dry lands and the arctic are most vulnerable.

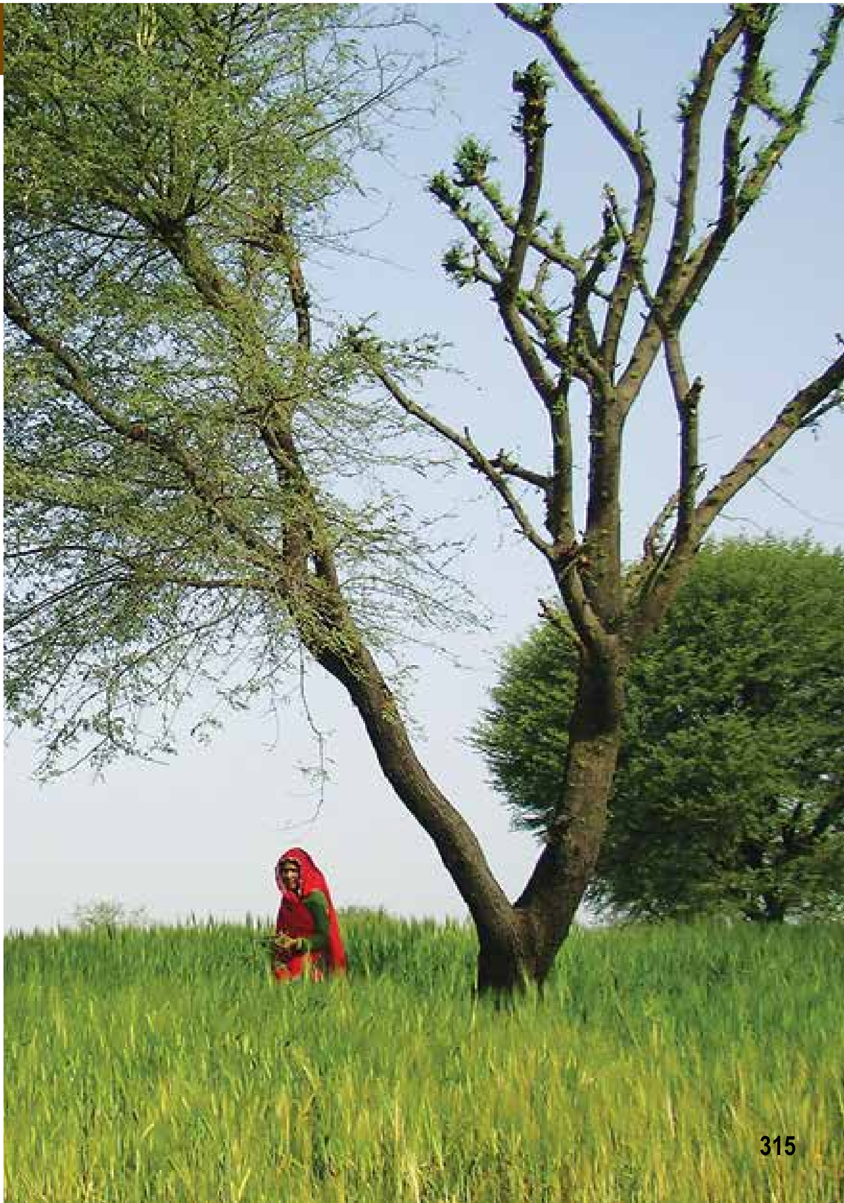
Agriculture plays a particularly important role in India. **Over two thirds of India's population is employed in agriculture** or an agriculture-related field. Of these people, over 60% depend on rain-fed sources of water to grow their crops. This is made possible by the extensive networks of 12 main rivers in India, which spread over a catchment that covers more than 75% of the country's total land area. This also explains why over 44% of the country's land is under agricultural cultivation, while 23% is forested.[1] These numbers show the incredible importance of temperature and rainfall in shaping India's social and environmental landscape. In fact, scientists predict that a 2°C increase in temperature and 10% decrease in rainfall could decrease annual water availability by 5 – 30%. Temperature changes by 2080 to 2100 will probably lead to a 10 – 40% loss in crop production.[2]

CLIMATE CHANGE IMPACT ON DIVERSE ECOSYSTEMS IN INDIA

1.1. Semiarid Agro-ecological Region

Gujarat, the northern plains, the central highlands (Malwa) and the Deccan plateau are the semi arid regions in India. The climate varies among these regions. Some regions are characterized by hot, wet summers and dry winters, while others by dry summers and cool winters. With rising temperatures, semi-arid regions of western India are expected to receive higher rainfall, while central regions are likely to experience a **10% to 20% decrease in winter rainfall by 2050**.[3] In North India, the average mean surface temperature is set to rise between 3.5°C and 5°C by the end of this century. According to the Department of Agricultural Meteorology, Anand Agricultural University, these increasing temperatures and CO_2 concentrations are already having an impact on the yield of wheat and maize in these regions.[4] Furthermore, these semiarid agro-ecological regions are already affected by water shortages, which impact agriculture. Although rice and sugarcane is grown where there are irrigation facilities, in some sectors of the central highlands, like Bundelkhand, less than 25% of the net cropped area is under irrigation.[5]

Another anticipated aspect of climatic change is the **increase in the frequency and intensity of extreme weather events** like cyclones. This will make agricultural (and human) losses higher. Adverse events combined with high population density and environmental degradation makes the **Indo Gangetic plains an especially vulnerable area.**



1.2. Arid Agro-ecological Region

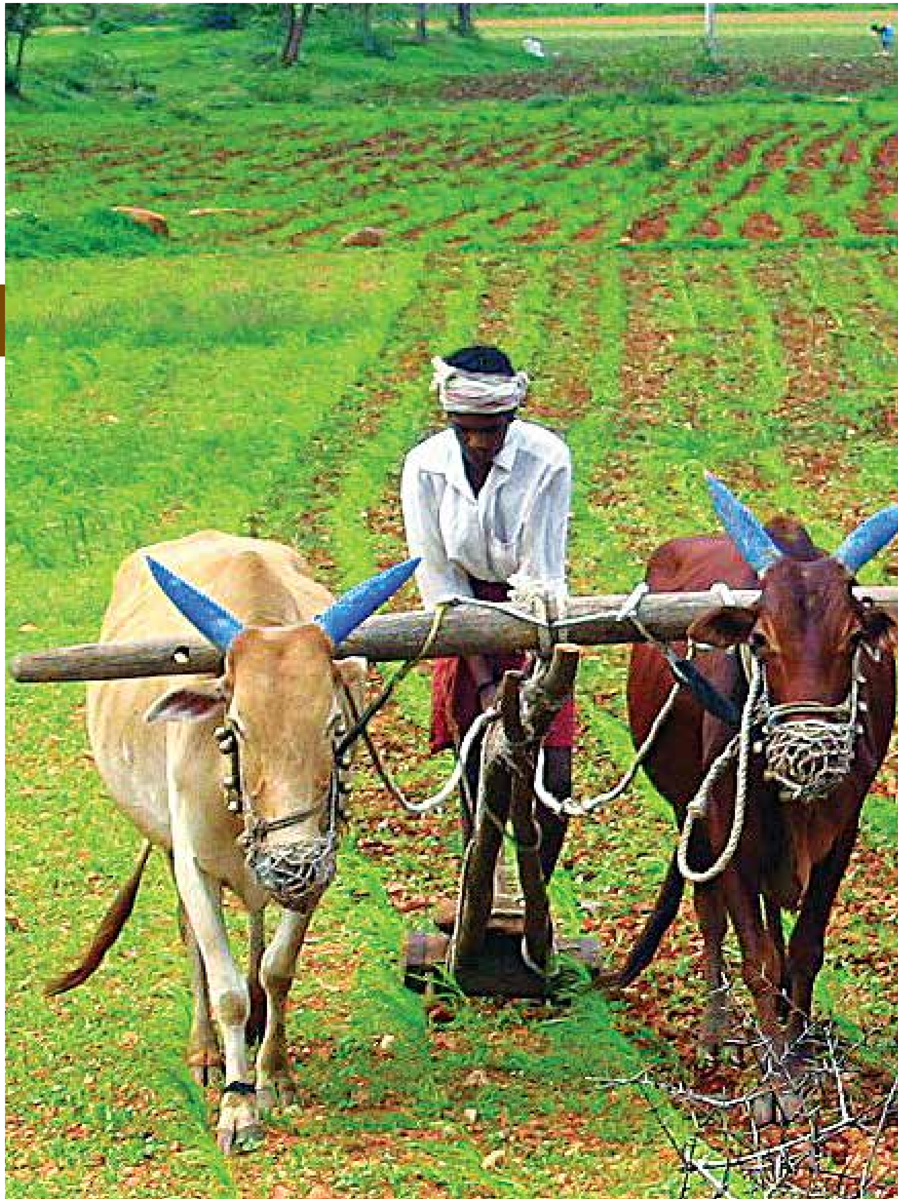
Life in the deserts is made more difficult by the increasing temperatures. Excessive precipitation and floods in desert areas are also harmful because the water washes away the salt present in the sand, thereby making the water gradually becoming more saline and decreasing availability of fresh water. In addition, the **Thar Desert experienced unusual flooding during August 2006**. The unusual flooding of Barmer and other parts of western Rajasthan. The floods have already formed three large lakes covering about seven to eight square km in Kawas, Malwa, and Uttarlai, all in the Barmer district.[6] Which is destructive to the ecosystem and affects livelihoods adapted to live with water scarcity.

1.3. Tropical Wet and Dry Agro-ecological regions

The tropical wet and dry agro-ecological regions comprising the **south-eastern coastal plain from Kanyakumari to the Gangetic Delta** have both rain-fed and irrigated agriculture. **Rice is the predominant crop** cultivated both in kharif and rabi seasons. After the rice is harvested, pulses like black gram and lentil; and oilseeds such as sunflower and groundnut are cultivated using the residual moisture. Besides agriculture, coastal and brackish water fisheries are important economic activities.

Similar to other agro-ecological zones, these areas are also highly vulnerable to changes in climate. For example, in Odisha, seawater incursion has reached 2.5 kilometers inland over the previous two decades. This has negatively impacted more than 600 families and their livelihoods, primarily in the Satabhaya and Kanhupur areas.[7] Along these eastern coastal and inland areas, rainfall is now increasingly unpredictable and has become incompatible with established crop schedules.

Evidence of this can be seen in the fact that **only seven of the past 25 years have had normal rainfall**. The remaining 17 years were characterized by deficient or delayed monsoon, causing an upheaval in rice production.



Furthermore, disasters related with extreme water events have spread to some areas that where earlier characterized by drought conditions. Drought prone districts such as **Balangir, Kalahandi, Koraput, Bargarh and Jharsuguda** have experienced frequent floods in the prior two decades. Extreme heat events are also being seen more often in coastal areas.

1.4. River Deltas, Costal areas and Mangroves

Some of the areas most vulnerable to climate change are the coastlines of tropical countries such as India. The river deltas are already facing the burden of climatic change and these adverse impacts are expected to increase in the coming century. For example, negative effects are already visible in the Sunderbans, the wetlands at the mouth of the Ganga and Brahmaputra river systems. The **Sunderbans** wetlands harbour one of the most globally important wildlife habitats, the **largest mangrove forest.** The Sunderbans wetlands have long been highly susceptible to seasonal ocean currents, tides, waves, winds, and cyclonic storm surges that cause rapid soil erosion on the one hand and salt deposition on the other. This leads to a constantly changing local ecology. Thus, the climatic uncertainty and high anthropogenic pressure resulting from climate change is exacerbating the already high pressures on this region.

One of the most vulnerable aspects of the Sunderban wetlands are its mangroves. **Changes in temperature and CO_2 levels, changed rainfall patterns, frequency of storms and rise in sea level directly threaten** the mangrove ecosystems and diminish their ability to cope with changes. Mangroves will be able to adapt only if sea-level rise is slow and if there is space to expand. Ambient temperatures higher than 35°C will affect mangroves by reducing the rate of leaf formation, ultimately causing the population to weaken. If temperatures rise above 35°C, there will be acute thermal stress affecting the development of roots and seeds.

At temperatures of 38-40°C, photosynthesis will stop, killing the mangrove population.[8] On the other hand, if it gets cooler, which can also happen with climate change, mangroves would be prevented from migrating north.[9]

A decrease in rainfall is likely to cause a decrease in mangrove production, development, and reproduction, as well as affect its geographical distribution and biodiversity. An indirect effect of increasing temperature and CO_2 will be felt because of the **degradation of coral reefs**, which provide shelter to mangroves from wave actions.[10] An increased turbulence in water dynamics will impact mangrove health and composition due to changes in inundation, salinity, and extent of wetland sediments. Ultimately, the combination of extreme water events and sea level rise will lead to a steady destruction of mangrove populations.[11] Another example of an indirect threat is that: a **rise in sea level can increase demand for timber** needed to create structures to protect coastline from seawater inundation.[12] In this instance, mangroves will likely be the first casualty.

The Sunderbans and its mangroves are not the only region that are vulnerable, as negative impacts will be experienced in other parts of the delta regions of peninsular India. **River basins of the Krishna, Cauvery and Narmada** are estimated to be highly vulnerable to climate change. These basins are expected to experience regular water shortage. The river basins of the Mahanadi and Godavari, on the other hand are considered to be only moderately vulnerable.[13]

In the long run, the most pressing threat from anthropogenic climate change in coastal areas will be the rise in sea level and increases in precipitation. There is no steadfast agreement on the extent of anticipated warming, but expectations are of 0.5 – 2°C by the year 2030.[14] This is because a drastic cut in carbon emission is not expected to happen before a threshold is crossed in the next decade. In the worst case scenario, temperature increase would be between **1°C and 7°C by 2070**.[15] This would translate into a 3 to 16 cm rise in sea level in the next two decades, 50 cm by 2070, and a 60 cm increase by 2100.[16]

1.5. Forests

In India, a **shift towards wetter forest types in the north eastern region and drier forest types in the north western region** is predicted.[17] Current climate change scenarios predicting an increase of CO_2 concentrations of approximately 575 parts per million (ppm) to 740 ppm are expected to result in large shifts in Indian forests, affecting up to 80% of the forest by the end of the century. More than half the vegetation is unlikely to adapt to the new conditions and will become susceptible to biotic and abiotic stress.

Climate is an important determinant of vegetation patterns, and has significant influence on the structure and ecology of forests, meaning that specific plant communities are associated with particular climate zones. It is therefore expected that **changing vegetation patterns will alter forest ecosystems significantly**. As biodiversity and species composition in the forest changes, there will be unwelcome consequences for the livelihoods of people who are dependent on what they can collect from the forest. Given the severity of the estimated impacts of climate change on forest ecosystems and the people dependent on forest resources, it is urgently required to incorporate adaptation strategies in both short and long-term planning for the forest.[18]

Climate Change and Agriculture

The uncertainties associated with climate change do not permit a precise estimation of its impact on agriculture and food production. However, what is happening already in terms of changing seasonal patterns and respective increases in temperature, moisture concentrations and CO_2 levels is likely to have diverse largely negative impacts on ecosystems – and therefore on **crops, livestock, pests and pathogens.**

The physiological response of crops to changing climate is expected to be varied. Although some positive outcomes are expected, the new climatic conditions are more likely to have negative impacts such as a **rise in the spread of diseases and pests**, which will reduce yields. A meta-analysis of experiments on crop performance shows that a potential increase of photosynthetic activity of plants under higher CO_2 concentrations is only realistic if linked with optimum temperature and favourable rainfall patterns. But the temperature and rainfall patterns are expected to change in future climate scenarios in unpredictable ways.

The nature of changes may be uncertain but what is certain is that changing environmental parameters are likely to affect ecosystems and the cultivation of crops. Examining these various parameters in turn provides a better picture of the challenges which global agriculture is facing in an era of climate change.

2.1 Water

According to the 2006 Human Development Report of the UNDP, **2.5 billion people in South Asia will be affected by water scarcity by the year 2050**.[19] Rising temperature, changing precipitation patterns, and an increasing frequency of extreme weather events are expected to be the main reasons for reducing regional water availability and impacting hydrological cycles of evaporation and precipitation. This will drastically affect agriculture production in a region where over 60% of the agriculture is rainfed, such as in India. On the other hand, climate change can also increase the occurrence of floods, as was seen in the arid regions of Rajasthan in 2006.

A **decrease in water storage coupled with increased evaporation** would further widen the gap between water supply and water demand. In addition to increased agricultural demand for water, water availability is further exacerbated due to escalating urban, industrial, and environmental demands for water coupled with poor water management.

Already **the global use of water exceeds the renewable supply**, with 15 – 35% of total water withdrawals for agriculture estimated to be unsustainable.[23] Evidence of decreased water availability in India is already apparent. Between 2002 and 2008 ground water levels in northern India fell by 40.5 mm per year and overall more than 109 cubic km of groundwater has disappeared from aquifers.[24] More evidence comes from Uttarakhand where over the previous decade, 34% of 809 perennial water streams have become seasonal or have dried up completely.[25] Further, in Kashmir the average water release from streams has dropped by two thirds.[26]

A majority of farmers in India depend on rainfall to grow their crops, especially those who cultivate arid or semi-arid and marginal soils with low inputs. In years where monsoon rainfalls are low, crop yields show very significant declines. Unfortunately, these losses are not made up by crop gains in years when rainfall levels are above average, and with temperatures rising, rainfall will likely become more unpredictable[20] (Jayaraman, 2011). As aridity and droughts spread in some parts of the country, rainfall is predicted to rise and intensify in others, increasing the risk of floods. In fact, wet years are expected to be wetter, while dry years will be even dryer.

Almost two thirds of India's annual precipitation is delivered in the monsoon months. It is not just the amount of rainfall that is important, but also the timing. Both factors will be unpredictable, and monsoons may often arrive late. It is easy to imagine the widespread impact of inconsistencies in monsoon rainfalls, and these have already been observed. In 2002, for instance, India experienced a mid-summer break in the monsoon. This led to a drought and reduced the national cereal output for that year by a staggering 18%.

Receding glaciers and snow cover in the mountainous regions of the country may lead to more freshwater,and perhaps even floods, in the short-term as snow and ice melt, but lower water levels in rivers in the long-term as water levels are not replenished. Several parts of the country, especially in the northern areas and the Indo-Gangetic plains, rely on these rivers for irrigation. The amount of water that Himalayan glaciers contribute to river systems in India, for example, will be reduced by as much as 70% over the next 50 years.[21]

Changing rainfall and snowmelt patterns also threaten to lead to more floods in some parts of the country and droughts in others. In low-lying areas, such as the rice-producing regions in the east of the country, the risk of floods is particularly severe. If rice crops are submerged for over two weeks, their mortality rate is 100%.[22] Floods also cause immense damage to ecosystems, homes, infrastructure and soils.

WATER AVAILABILITY

2.1.1 Melting Glaciers

Glaciers play an important role in climate and weather regulation. They are important for **maintaining ecosystem integrity and in feeding rivers,** thus providing water for agriculture. Apart from the monsoon rains, India relies heavily on the Himalayan Rivers for its irrigation. The hydrological characteristics of Himalayan watersheds have already undergone significant changes as a result of climate change and anthropogenic activities. This has resulted in increased variability in rainfall and surface water runoff, more frequent hydrological disasters, and the pollution of lakes.

Melting glaciers will impact certain areas more than others and in different ways. The **increase in temperature resulting in more rainfall instead of snow** is a direct consequence of Himalayan glacial melt. More rain and less snow fall increases the availability of fresh water in the short term but **decreases water availability in the long run** since moisture is not stored in frozen form. The retreat of Himalayan glaciers reduces water flow into the rivers. A reduced water flow from the melting glaciers changes the watershed distribution and the ecological parameters of rivers causing the temperature of river waters to rise. This further affects the oxygen dissolved in the water, negatively affecting aquatic flora and fauna which are very sensitive to oxygen concentration.

The India government has plans to combat challenges posed by Himalayan glacier melt. The government has established the National Action Plan on Climate Change (NAPCC) to deal with domestic climate change issues. The NAPCC includes a **National mission for Sustaining the Himalayas**. Research organizations and institutes are making attempts to reduce the threat to the region through mitigation strategies and have put in place a monitoring system.

2.1.2 Disruption of Rainfall Patterns

The disruption of established precipitation patterns negatively impacts Indian agriculture since agriculture systems have developed cropping patterns dependent on regional weather conditions. Across regions, precipitation patterns are changing with **wet years becoming wetter and dry years become drier.** This change could result in a greater number of heavy rainfall events, a decrease in the overall number of rainy days, and longer gaps between rains, as well as increased rate of evapo-transpiration. This would disturb established cropping patterns. Heavy rainfall combined with a decrease in the total number of rainy days is occurring over a major parts of India and a annual rainfall variability is increasing. Estimates show that the rise in mean surface temperature will not only affect the post-monsoon and winter weather, but it is likely to lead to a **70% decline in summer rainfall by 2050**.[27] These changes are altering the seasons and changing the distribution of fauna and flora. They are also affecting the emergence and spread of new pathogens which threaten crop yields.

2.1.3 Flooding

Changes in the rainfall pattern leading to a more frequent occurrence of intense weather events will lead to an **increased risk of flooding.** In tropical areas extreme events will impact agriculture that is already vulnerable to floods and environmental hazards such as drought, cyclones, and storms. For example, in 1962 and 1988 Bangladesh lost about half a million tons of rice due to floods, which amounted to nearly 30% of the country's average annual food grain import.[28] While most rice varieties can withstand submergence for about six days, after this period approximately 50% of the plants will die. When submergence lasts for 14 days or longer, then mortality will reach 100%.[29] Indian agriculture and food production is particularly susceptible to flooding since **one third of the country's flood prone area is used for cultivation.**

2.1.4 Droughts

In certain vulnerable arid and semiarid regions, increased temperatures have already resulted in diminished precipitation. Notably, precipitation in Southern Asia and Western Africa has decreased by 7.5% between 1900 and 2005.[30] Increased temperatures cause an intensification of the water cycle with more extreme variations in weather events and **longer-lasting droughts.** Furthermore, the expected temperature increase is likely to exacerbate drought conditions during sub-normal rainfall years. Large areas in Rajasthan, Andhra Pradesh, Gujarat, and Maharashtra and some areas of Karnataka, Odisha, Madhya Pradesh, Tamil Nadu, Bihar, West Bengal, and Uttar Pradesh are already experiencing recurrent drought with several regions currently experiencing water deficits.

In dry land areas, marginal cropland could convert to range-land, and some crop-land and rangelands could no longer be suitable for food and fodder production. More frequent drought would **necessitate greater multi-year reservoir storage capacity**, in which India is currently deficient. Water conservation and management practices, as well as water storage will need urgent attention.

2.1.5 Monsoon

Monsoons are the lifeline of Indian agriculture so it is not surprising that the changes occurring in monsoon patterns are damaging crop yields. The timely arrival of the monsoon is of crucial importance to food production in the country and changing patterns in the monsoon are a threat to agriculture, food security, and the overall economy. The **onset of the summer monsoon in India is getting delayed** and disturbed. This affects crop cycles and cultivation in rain fed areas. Monsoon delays and failures inevitably lead to a reduction in agricultural output, thereby deepening food insecurity.

Pre-monsoon rainfall disruption can be just as big a problem however. For example, the Chattisgarh region in the past years has received half its usual amount of water during the months of May and June, seriously affecting rice production.

2.2 Soil

While it is natural to expect precipitation patterns to be impacted by climate change, soil processes are also heavily affected. This is because **changes in temperature and precipitation influence water runoff and erosion, affecting soil; organic carbon; nitrogen content and salinity in the soil**. This in turn has a major impact on the biodiversity of soil micro-organisms. These parameters are very relevant to soil fertility.

Higher air temperatures will increase soil temperature and with it, increase the speed of organic matter decomposition and other soil processes that affect fertility. Experiments show that global warming will have the effect of **reducing soil organic carbon by stimulating decomposition rates**.[31] At the same time increasing CO_2 can also have the effect of increasing soil organic carbon through net primary production.[32] According to researchers, a small increase in temperature in low carbon soil results in higher carbon dioxide emissions as compared with medium and high carbon soil.[33] This phenomenon makes low carbon soil more vulnerable to warming.

Another example which looks at the complex and often ambiguous effect climate change has on soil focuses on nitrogen. It has been shown that **soil nitrogen availability is reduced in drier soil conditions**.[34] This is because dry soil affects root growth and the decomposition of organic matter that affect the activity of nitrogen fixing bacteria. Reduced nitrogen fixation in turn reduces soil fertility.

Increasing the use of chemical fertilizers to compensate for soil degradation and fertility loss is commonly thought of as a solution to decreased soil fertility. However, this practice not only **contaminates ground water**, but also **decreases natural soil fertility** in the long run. Excessive, chemical fertilizers destroy the living processes of the soil and make it more vulnerable to climate variability. At the same time, they contribute to emission of nitrous oxide, a potent greenhouse gas.

An increase in the rate of soil erosion and land degradation will lead to desertification and **climate change will contribute to the expansion of arid zones.** The impact of climate change has already resulted in the contraction of several million hectares of fertile growing land. Flooding will cause soil erosion, and in severe instances, landslides which cause extensive damage to livelihoods and habitations. In India, it is likely that intense rainstorms may become more common and lead to more frequent floods, further reducing the amount of arable land, especially in low-lying areas such as fertile river deltas. In order to reduce the expected increase in runoff and soil loss, it is necessary to increase and improve rainwater management as well as take steps for effective soil conservation.

Soil and Land Changes

Over half of India's land is arid or semi-arid. The soils in these areas are very prone to becoming saline or 'sodic', which is already currently occurring in several parts of the country (Pal, in Gene Campaign and Action Aid, 2010). Sodic soils are very unstable, and since they are unable to hold or filter water, it leads to poor plant growth.

Heavy rains and flooding, which are likely going to occur in some parts of the country, will cause soil erosion. Rising sea levels in coastal and delta areas will erode beaches and salinize waters and soils, and which are incredibly fertile. Both processes destroy the soil micro-organisms and biology that keep ecosystems and plants productive.

Less rainfall and droughts in dry areas threaten to expand arid lands that are not suitable for cultivation. This pattern has already been seen: climate change has led to the contraction of fertile growing land by 31–35 million hectares.

2.3 Biodiversity

The fourth IPCC Report (2007) states that by the end of this century climate change will be the main cause of biodiversity loss. If there is an increase in the average global temperature by 1.5 – 2.5°C, then approximately **20% to 30% of known plants and animal species will be threatened by extinction**.[35] Climate change will increase the pressure on land degradation and habitat loss, as well as genetic erosion which is already intensifying because of the growing uniformity in agricultural systems across the world. By mid-century, most species could lose half of their geographical range and size because of habitat fragmentation. According to the Food and Agricultural Organisation (FAO), **three-quarters of the global crop diversity is already lost**.[36] This is particularly problematic as the loss of genetic diversity, both in natural ecosystems and domesticated crops, is exacerbating the impact of climatic change. Only a fraction of the total genetic variability of crop plants is currently stored in gene banks. Diminished genetic diversity, especially if combined with poor human and financial resources, will make adaptation to climate change that much more difficult.

Changes in the climate pattern also favour the diffusion of invasive alien species which are considered to be second only to habitat destruction as threats to global biodiversity and ecosystems. Invasive alien species are able to conquer new territories when changed eco-climatic zones become favorable for their breeding. Future biodiversity scenarios show a **steady rise in the number of invasive alien species** in many regions. Since these species constitute a large majority of the weeds in agriculture, they pose a growing threat to food production. Alien invasive plants often replicate faster by vegetative means (roots, stolons etc) and are usually more responsive to increases in atmospheric CO_2 concentrations.[37]

Biodiversity of plants, both agricultural and uncultivated, as well as of animals around the world has been severely reduced and threatened over the course of the past century. Biodiverse systems are also stronger systems, especially when confronted with change. Approximately 20 – 30% of all species are likely to be at risk of extinction if global average temperatures increase by 1.5 – 2°C (IPCC, 2007; FAO, 2008).

Biodiversity of agricultural systems is equally important in creating strong and adaptable crops and systems. Unfortunately, over 75% of the world's crop diversity was lost in the past century (FAO, 2004). Many of these lost traditional varieties may well have been more adaptable to climate changes, and specific conditions such as drought and flood. Climate change is now going to add significant pressure to existing agricultural systems, exacerbating genetic erosion and the accompanying habitat and species loss.

Warmer temperatures promise to shift habitat ranges of several species, bringing plants and animals that have not interacted in the past into contact with each other. Stronger, invasive species may be able to out compete native ones, reducing biodiversity even further.

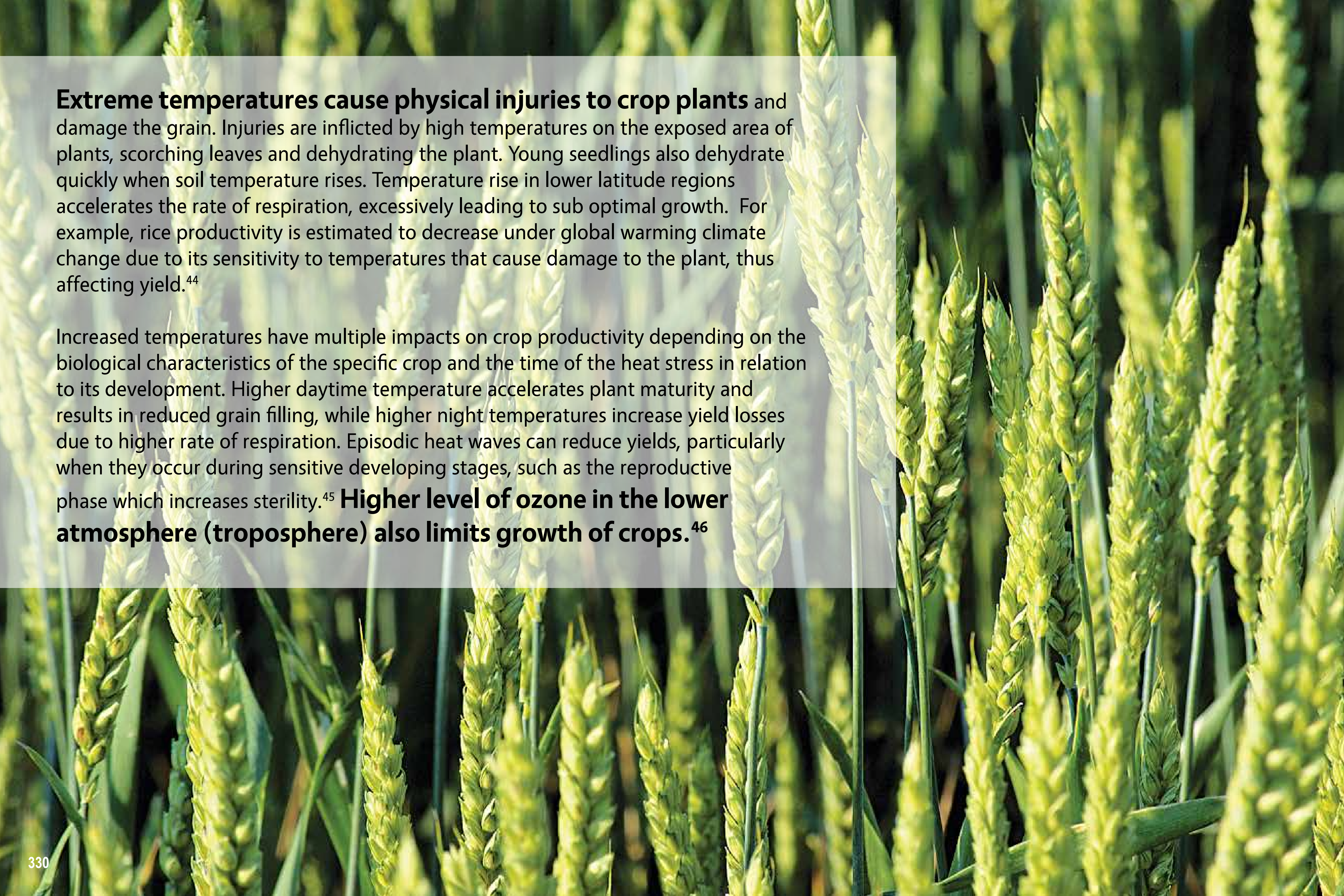
2.4 Crop Productivity

Most studies on the impact of climate change on agriculture come to the same conclusion that **climate change will reduce crop yield in tropical areas.** According to the IPCC, the next few decades of climate change are likely to bring benefits to higher latitudes through longer growing seasons, but in lower latitudes, even small amounts of warming will tend to decrease yields.[38] The regional inequality in food production resulting from climate change will have a very great implication for global food politics. Even without the challenge of climate, food security is already a sensitive issue in the tropical areas considering that almost 800 million people in the developing world are already suffering from hunger.[39] The effects of global warming could leave no room to manoeuvre, since in many parts of India, and other developing countries, **crops are already being cultivated near their maximum temperature tolerance.** This is especially true in the dry land, non-irrigated areas, where vulnerabilities are high. In these regions even moderate warming of 1°C, will reduce yields significantly.[40]

It is known that many agricultural systems are season dependent and, thus, sensitive to climate change. Crop and livestock production need a specific range of weather conditions at particular times, for optimal growth. Changes in the climate can shift these optimal windows. The **most vulnerable agricultural systems are the arid, semiarid and dry sub-humid regions** of the developing world. In these regions high rainfall variability and recurrent drought/flood cycles disrupt food production, particularly where crops are grown in marginal lands with low inputs.

Extreme temperatures cause physical injuries to crop plants and damage the grain. Injuries are inflicted by high temperatures on the exposed area of plants, scorching leaves and dehydrating the plant. Young seedlings also dehydrate quickly when soil temperature rises. Temperature rise in lower latitude regions accelerates the rate of respiration, excessively leading to sub optimal growth. For example, rice productivity is estimated to decrease under global warming climate change due to its sensitivity to temperatures that cause damage to the plant, thus affecting yield.[44]

Increased temperatures have multiple impacts on crop productivity depending on the biological characteristics of the specific crop and the time of the heat stress in relation to its development. Higher daytime temperature accelerates plant maturity and results in reduced grain filling, while higher night temperatures increase yield losses due to higher rate of respiration. Episodic heat waves can reduce yields, particularly when they occur during sensitive developing stages, such as the reproductive phase which increases sterility.[45] **Higher level of ozone in the lower atmosphere (troposphere) also limits growth of crops.**[46]



CROP PRODUCTIVITY

Higher temperatures reduce yield for those crops that are already functioning at the limit of the heat levels that they can tolerate.[41] Most agricultural crops in India come under this category. Hotter weather patterns mean that crops are less durable, have higher respiration and evapotranspiration rates and are less efficient at using the nutrients in fertilizers.

Higher temperatures also force grain crops to mature more rapidly, reducing overall yield. In addition, even small increases in temperature at specific times in plant development can render some grain-crop seeds sterile. Perhaps most significantly, hotter temperatures will mean that certain seasons of the year will be too hot and dry to grow crops, reducing several of the areas that can produce two or even three crops in a year to 'single-crop zones'[42]. The crop loss in these situations is very substantial.

Carbon dioxide is essential for photosynthesis, leading scientists to wonder if plants would be more productive with greater CO_2 concentrations in the atmosphere. This is however not the case. This increase only takes place when optimum growing conditions, such as temperature and rainfall, are also present. Any growth benefits that may have arisen due to increased CO_2 concentrations are negated by negative – and often unpredictable – changes in other weather conditions.[43]

PREDICTED EFFECTS OF CLIMATE CHANGE ON SOME CEREAL CROPS IN INDIA

Wheat (rabi)

Increasing temperatures and shorter winters threaten to reduce wheat yields by as much as 4 – 5 million tonnes for every degree in temperature increase (Aggarwal, 2008). Field observations have been similar. In March 2004, for instance, the Indo-gangetic plains saw 3 – 6°C higher temperatures than usual. The wheat crop in the area matured 10 – 20 days earlier, reducing overall yields by more than 4-million tonnes. A 2°C increase in temperature could reduce wheat yields by anywhere from 28% to 68% (Samra & Sigh, 2004).

Rice (kharif)

Rice yields have been showing a decline in the past 30 years. Between 1979 and 2003, yields declined by 10% with every 1°C increase in temperature. Scientists have calculated that temperatures below 23°C and above 35°C during flowering lead to pollen sterility. Changing patterns of rainfall, droughts and coastal-soil salinity also all pose a threat to rice. A 2°C rise in temperature could reduce overall yields by 0.75 ton/hectare (Sinha & Swaminathan, 1991). Areas where rice can be grown productively may also shift.

Maize (kharif)

Maize productivity is dependent on rainfall patterns, especially in semi-arid areas. As these and temperatures change, average maize yields in South Asia are predicted to drop by 6% by 2050. In Tamil Nadu for instance, maize yields are expected to decline by 3% by 2020, 9% by 2050 and 18% by 2080. Yield changes however vary across the country, with varying rainfall and temperature changes (Geethalakshmi, 2009).

2.5 Diseases and Pests

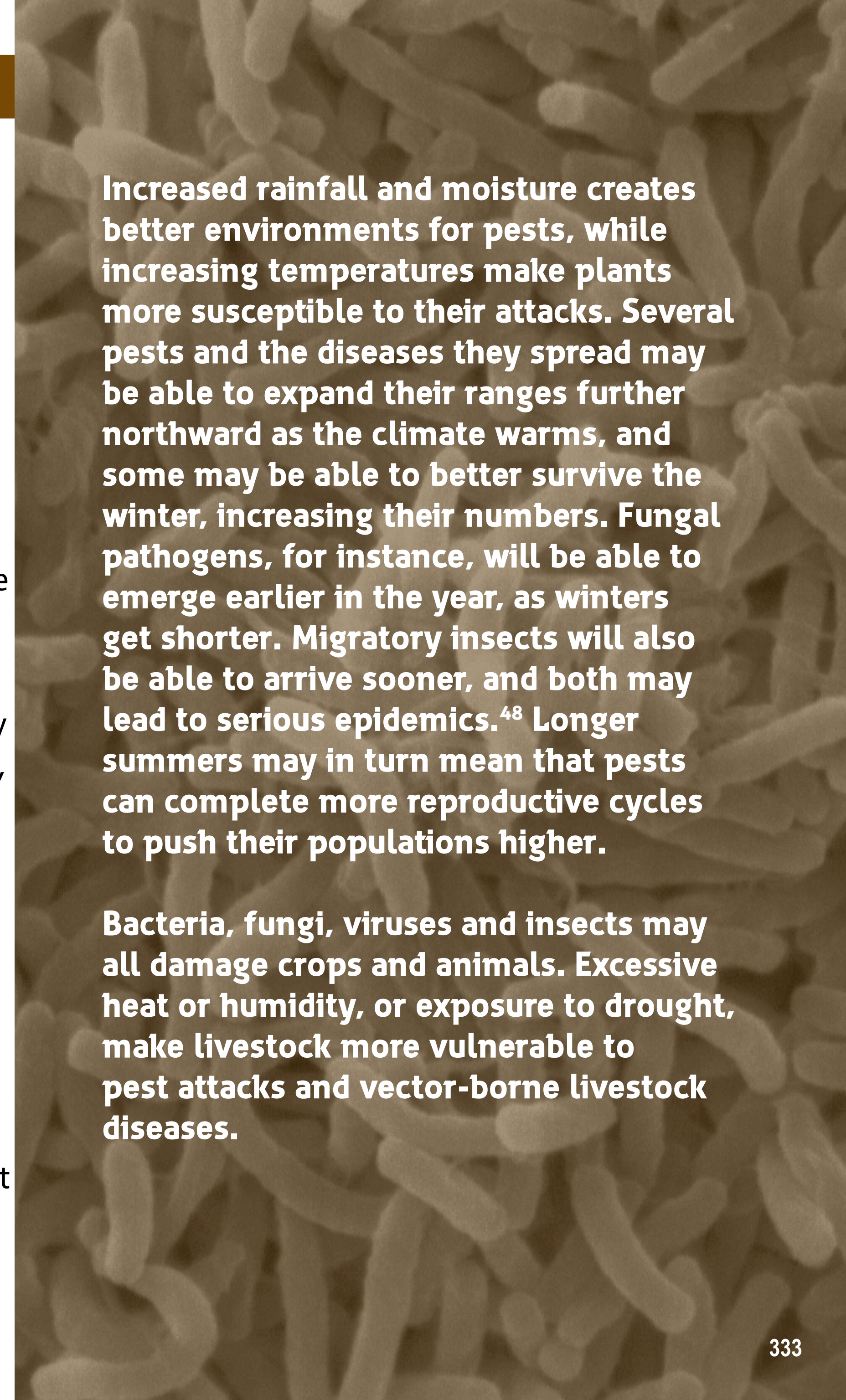
The severity of diseases caused by fungi, bacteria, viruses and insect pests are anticipated to increase with global warming. The spurt in the population of pests and other vectors is related to the interplay of different factors such as increases in temperature, changes in moisture concentration, and a rise in atmospheric CO_2.[47]

2.5.1 Temperature

Changes in environmental conditions are likely to result in the **northward extension of certain diseases and pests**, more generations of pathogens per season, and a better capacity to survive the winter, thus increasing their prevalence and range. As farmers change crops and cropping patterns to adapt to the changing climate, their crops will be exposed to new kinds of diseases and pests.

However, it is also possible that physiological changes in the host (like more acidic sap) results in higher disease resistance.[49] On the other hand, resistance can be quickly overcome by more rapid pathogen life cycles when temperatures are high. Ultimately, rapid life-cycles will lead to a **greater chance of mutations and selected resistant populations.**

Due to the ambiguity in the expected changes, planning and preparing for new and varied pathogen and pest profiles is a complicated and oftentimes impossible task to undertake. For example, the favorable temperature range for the development of the rice gundhi bug is 13 – 35°C.[50] If the temperature exceeds the upper threshold of the favorable range, the development rate and the survival capacity of the bug will be reduced. As the impact of climatic change will likely vary in different agro-climatic zones, the behavior of the rice bug population will also vary making it difficult to forecast its evolution. Strategies for the biological control of pests will have to undergo a change to **adapt to changes in the development patterns, morphology and reproduction of the targeted pests.**



Increased rainfall and moisture creates better environments for pests, while increasing temperatures make plants more susceptible to their attacks. Several pests and the diseases they spread may be able to expand their ranges further northward as the climate warms, and some may be able to better survive the winter, increasing their numbers. Fungal pathogens, for instance, will be able to emerge earlier in the year, as winters get shorter. Migratory insects will also be able to arrive sooner, and both may lead to serious epidemics.[48] Longer summers may in turn mean that pests can complete more reproductive cycles to push their populations higher.

Bacteria, fungi, viruses and insects may all damage crops and animals. Excessive heat or humidity, or exposure to drought, make livestock more vulnerable to pest attacks and vector-borne livestock diseases.

2.5.2 Moisture

Moisture also plays an important role in the activities of the pathogens as optimal **breeding conditions are usually created when moisture is high.** Simultaneous increase in temperature and moisture creates especially favorable conditions and affects both hosts and pathogens in various ways.

2.5.3 Carbon Dioxide

Similar to temperature and moisture levels, increased CO_2 levels can impact both host and pathogen in multiple ways. An increase in **CO_2 stimulates the growth of vegetative parts** like leaves and stems in plants. Increased foliage leads to denser canopies and higher moisture levels that favours pathogen development. When plant matter decomposition is low under higher CO_2 concentrations, the presence of intact plant residue enables organisms to overcome winter. Ability to survive winter means more fungal spores and higher level of infections in the next growing season.

2.5.4 Plant-based contaminants

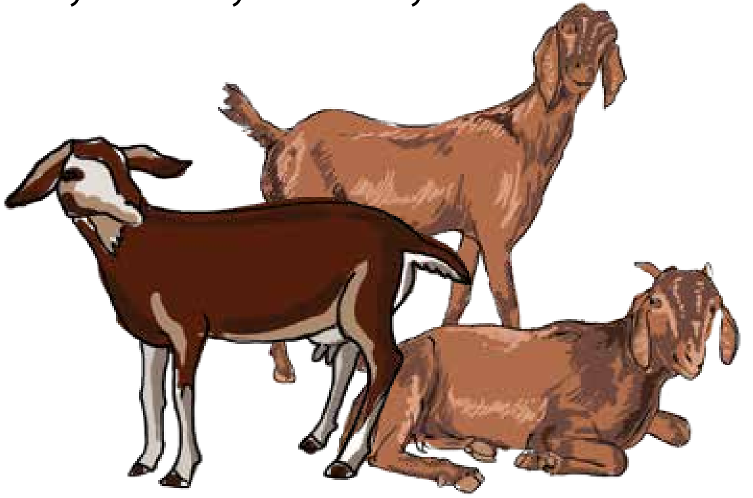
Another aspect is that the **occurrence of plant-based toxic contaminants can be influenced** by changes in climate. For example, aflatoxin a metabolite of the fungal species Aspergillus, is a dangerous contaminant that infects food grains and is harmful for human and animal health. Climatic changes including increased prevalence of drought and unseasonal rains, changes in relative humidity and shift in temperature will affect the population of aflatoxin-producing fungi.

Compounding this problem is the fact that changes in climate may allow the increased population of fungal pathogens to have increased opportunities to attack food grain crops.

For example, dry conditions during grain filling and maturity enhance the probability of cracked grains, which can get more easily infected by this fungal pathogen. Heavy rains during or after the harvest can lead to incompletely dried crops before storage, causing proliferation of the fungus during the storage period.

2.5.5 Livestock

Poultry, livestock and other farm animals will suffer due to climate changes because **higher temperatures will increase the number of new diseases directly or indirectly affecting them.** For instance, exposure to drought and excessive humidity or heat renders cattle more vulnerable to infections. Also, alternating drought and heavy rainfall cycles provide a good environment for **midge and mosquito vectors** that are linked with to outbreaks of vector-borne livestock diseases. Poultry is similarly affected by excessive heat or rainfall.



2.6 Weeds

Weeds are another aspect of agriculture likely to be affected by climate change. This is important since the **dynamics of crop-weed competition ultimately decides crop output.** The higher genetic diversity in weeds gives them flexibility to adapt to new environments through quickly responding to the changes with higher rates of growth and reproduction. Hence, a larger number of weed species are found associated with respective major crops. It is estimated that 410 weeds species are associated with 46 major US crops.[51] Often the **worst weeds of crops are their wild relatives,** for example, red rice is a weed in rice cultivation and Johnson grass, a close relative of sorghum is a weed in sorghum fields. In almost all cases of weed/crop competitions where the plants have similar photosynthetic pathways, weed growth is favoured as CO_2 increases, posing a challenge to the crop.

It is shown that **in a CO_2 enriched environment, weeds transfer significantly more carbon to roots** and rhizomes than to shoots.[52] This improves their root growth and increases their chances of survival. More vigorous roots lead to more viable plants and higher reproduction with more seeds. Weeds with stronger roots are more competitive and more difficult to control with traditional weed management techniques or herbicide which attack the foliage rather than the roots. Adaptable weed systems will lead to higher crop losses in several crop cycles, under adverse climatic conditions.

Similar to changes in insect, pest, and pathogen profiles, changes in the climate can affect the geographic and temporal scope of different species of weeds. **Weeds can migrate to new areas under higher temperatures** where earlier they were unable to prosper because of the cold.

Weeds are very resilient plants. Often able to adapt to changing or stressful conditions faster than the crops they are associated with, weeds are particularly likely to outcompete cultivated crops in stressful conditions, such as rising temperatures and inconsistent rainfall patterns. In these situations they use much of their resource base to strengthen their roots, which allows them to spread faster. This also makes herbicides, which commonly act on foliage and not on root systems, less effective.

Weeds have a very high genetic diversity. In the United States for example, there are approximately 410 weeds that grow and compete with the country's 46 major crops.[53] Often, the weeds that are most damaging to crops are the wild relatives of those cultivated crops. In almost all crop-weed interactions, weeds will be favoured and stronger in the case of high CO_2 levels.

2.7 Pollen

For good grain formation, there needs to be a high percentage of germinated pollen grains followed by vigorous growth of the pollen tube to the ovule. Yet, these factors are all very sensitive to environmental changes. Any fluctuation in temperature during the flowering season can be deleterious to effective pollination and subsequent grain development.

Scientists have shown that **in rice and wheat, changes in normal temperature around lowering had a significant effect on fertility** of the pollen grains.[54] High temperatures lasting just 1 – 2 hours during anthesis induces sterility in rice pollen. While Basmati varieties are particularly susceptible to high temperature, above 32°C , pollen germination decreases dramatically in all rice varieties.[55] In wheat on the other hand, it is low temperature around anthesis that can be detrimental for pollen viability and successful fertilization.[56] Changes in the climate with increasing temperature fluctuations can have serious implications for reproductive mechanisms with the potential to diminish crop yields. Since the extent of damage depends on the particular variety, crop genetic diversity is an indispensable resource which allows farmers to adapt to climate change.[57]

Climate change in various regions in India

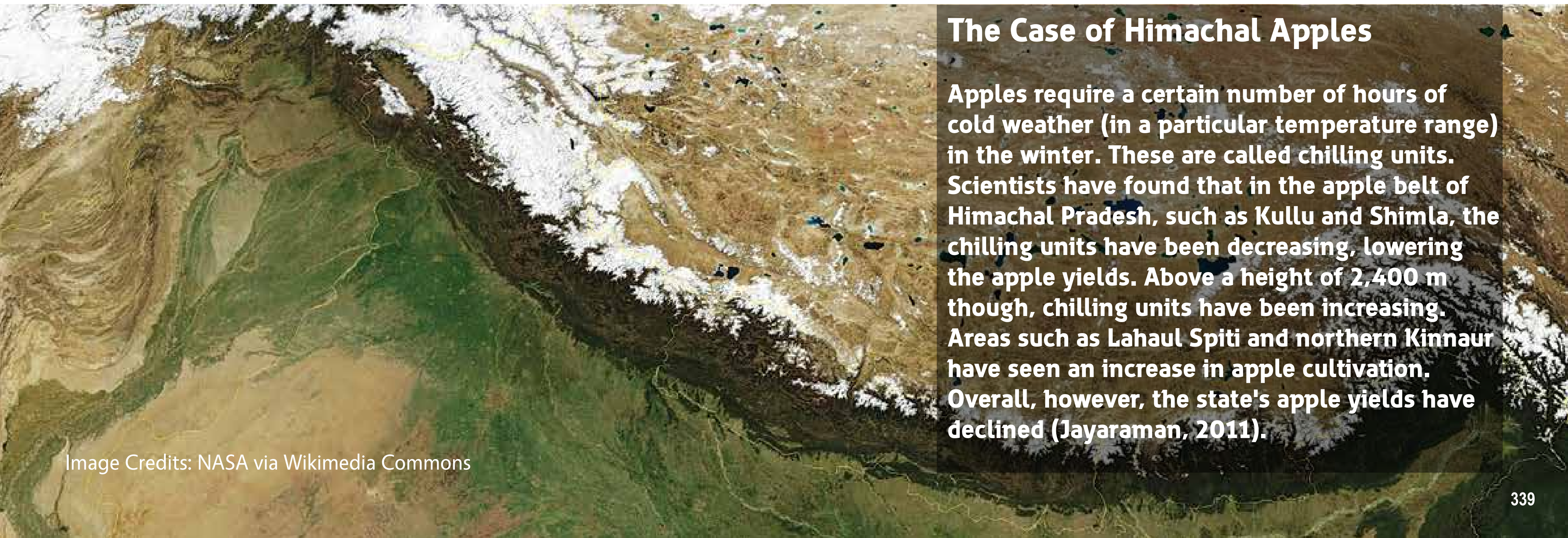
Indo-Gangetic Plains

The **most fertile soils in India are found in its Gangetic plains**. The many rivers and tributaries that drain this region provide valuable irrigation, and the rice, wheat, oilseeds, legumes and vegetables grown in this area provide for a large part of the country's population. Over the past few decades however, **overuse of chemical fertilizers and pesticides has degraded the soil** and irrigation has pushed the groundwater levels to unprecedented lows. Climate change will exacerbate these effects, and lower yields even further. Warmer, drier weather is predicted to reduce grain yields significantly, and shrinking glaciers threaten to reduce vital water flow to the plains. By 2050, approximately half of the highly productive areas of these plains may well be considered heat-stressed and short-season environments.

Image Credits: NASA via Wikimedia Commons

High Altitude Zones

Glaciers in the northern mountain ranges in the country are particularly vulnerable to a rise in temperature. **Kashmir, for instance, has become 1.45°C warmer** in the past two decades. Himalayan glaciers have already shrunk in area from 2077 km^2 in 1962 to 1628 km^2 in 2007. This amounts to an overall "deglaciation" of 21%.[58] While this snowmelt leads to higher water volume (and possibly even flooding) in streams and rivers for a short time period, in the longer term it greatly threatens water supply for irrigation in the plains. Over the next 50 years, the **glacial belt's contribution to water for irrigation is expected to decrease by 70%.** This could drastically reduce crop yields, and increase food insecurity, since melting Himalayan glaciers supply water for the production of 514 million tonnes of cereals a year, which is nearly 25% of world cereal production.[59]



The Case of Himachal Apples

Apples require a certain number of hours of cold weather (in a particular temperature range) in the winter. These are called chilling units. Scientists have found that in the apple belt of Himachal Pradesh, such as Kullu and Shimla, the chilling units have been decreasing, lowering the apple yields. Above a height of 2,400 m though, chilling units have been increasing. Areas such as Lahaul Spiti and northern Kinnaur have seen an increase in apple cultivation. Overall, however, the state's apple yields have declined (Jayaraman, 2011).

Image Credits: NASA via Wikimedia Commons

Hot and Humid Regions

Central regions of the country, such as parts of **Madhya Pradesh, Maharashtra, West Bengal, Odisha and Chhattisgarh** have hot summers and cool winters, and an annual rainfall of 1,000 – 1,600 mm a year. Rainfed cultivation of **rice, pulses and groundnut are common**, while those who have irrigation may also grow cotton and wheat. Rainfall patterns are crucial here. Higher temperatures and droughts severely damage crops, and dry soils makes tilling difficult. When the rains are too heavy, however, inundation will be the biggest threat, with poor germination, standing water and soil erosion following close behind. Climate change may lead to reduced rainfall or drought in some years, and very heavy rainfall and floods in others.

Image Credits: NASA via Wikimedia Commons

Tropical Wet Regions

The southern part of the country, in **Tamil Nadu, Karnataka, Kerala and parts of Maharashtra**, gets hot and humid summers and warm winters. These areas are covered with tropical rainforests, and plantation crops such as **coconut, areca nut, oil palm, spices and tapioca are grown along with rice, oilseeds and pulses**. Marine fisheries are very important. Changing climate poses a significant risk to costal areas, where rising seawater is salinizing both soils and freshwater. This stresses coastal forests and cultivated areas, as well as fisheries. Soil erosion due to changing rainfall patterns and extreme weather events is another risk.

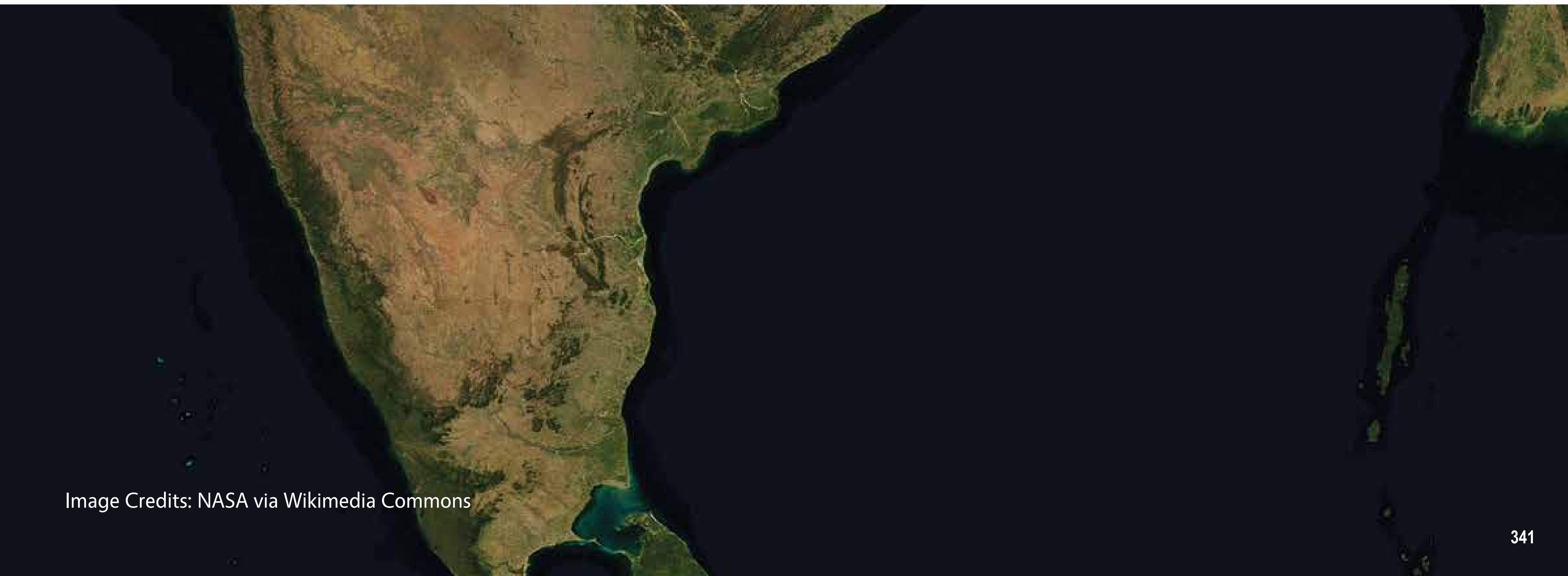


Image Credits: NASA via Wikimedia Commons

Arid and Semi-arid Zones

Parts of the **Deccan Plateau and desert areas in Rajasthan and Gujarat** rely almost exclusively on rain-fed agriculture. Increased temperatures and water shortages have already pushed grain yields down in these areas. Other parts of these zones, such as sections of the Thar Desert however experienced floods in 2006, and again in 2010. The 2006 floods in Barmer district, which were considered to be the worst the region had seen in over 300 years, claimed over 150 lives and left rampant disease and destruction in its wake. **A rising water table in Rajasthan is also leading to salinization.**

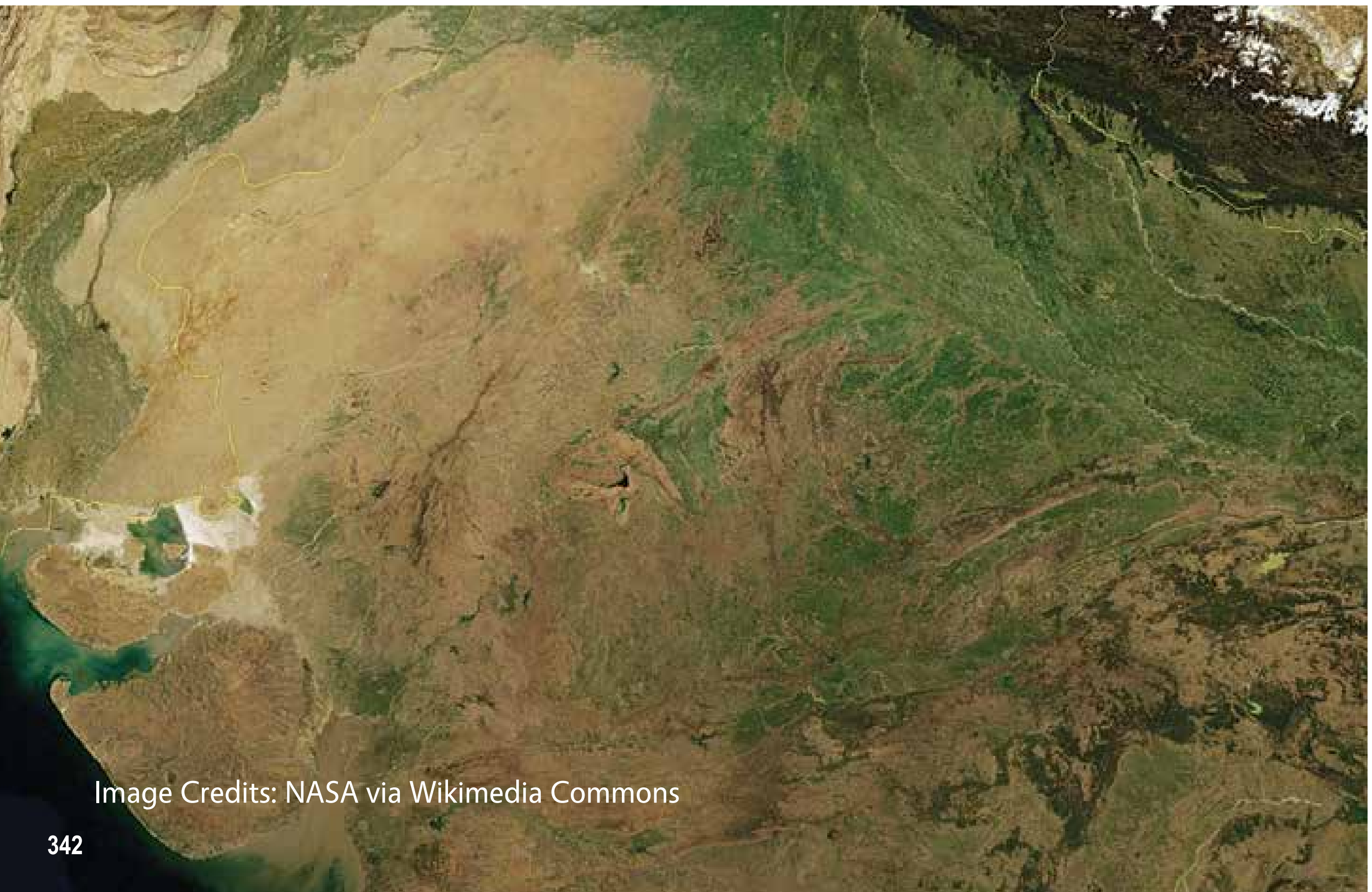
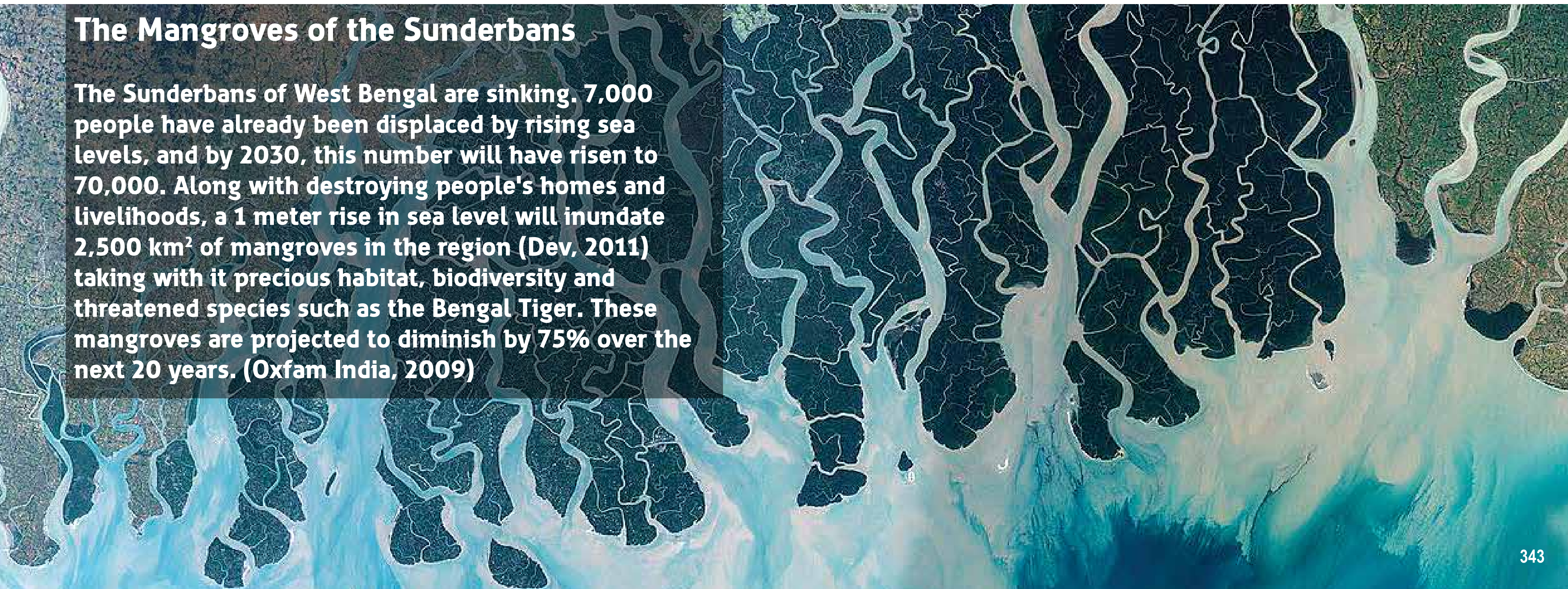


Image Credits: NASA via Wikimedia Commons

Delta and Coastal Areas

Sea level rise is the greatest threat for communities and habitats in coastal and low-lying delta areas in India. As temperatures and sea levels both rise, low-lying areas will be flooded, waters and arable soils will become more saline and unfit for cultivation, the water table will change, and shorelines will retreat. This is already happening in many parts of the world, including Bangladesh and the Sunderbans in India. **Rice is one of the primary crops** in these areas, and **coastal and sea fisheries** another primary activity. Both are highly dependent on rainfall patterns and water availability. Extreme weather events in the region appear to be increasing in both frequency and intensity, as has been seen in the case of multiple cyclones, tidal waves and floods in Odisha in the past few years.



The Mangroves of the Sunderbans

The Sunderbans of West Bengal are sinking. 7,000 people have already been displaced by rising sea levels, and by 2030, this number will have risen to 70,000. Along with destroying people's homes and livelihoods, a 1 meter rise in sea level will inundate 2,500 km^2 of mangroves in the region (Dev, 2011) taking with it precious habitat, biodiversity and threatened species such as the Bengal Tiger. These mangroves are projected to diminish by 75% over the next 20 years. (Oxfam India, 2009)

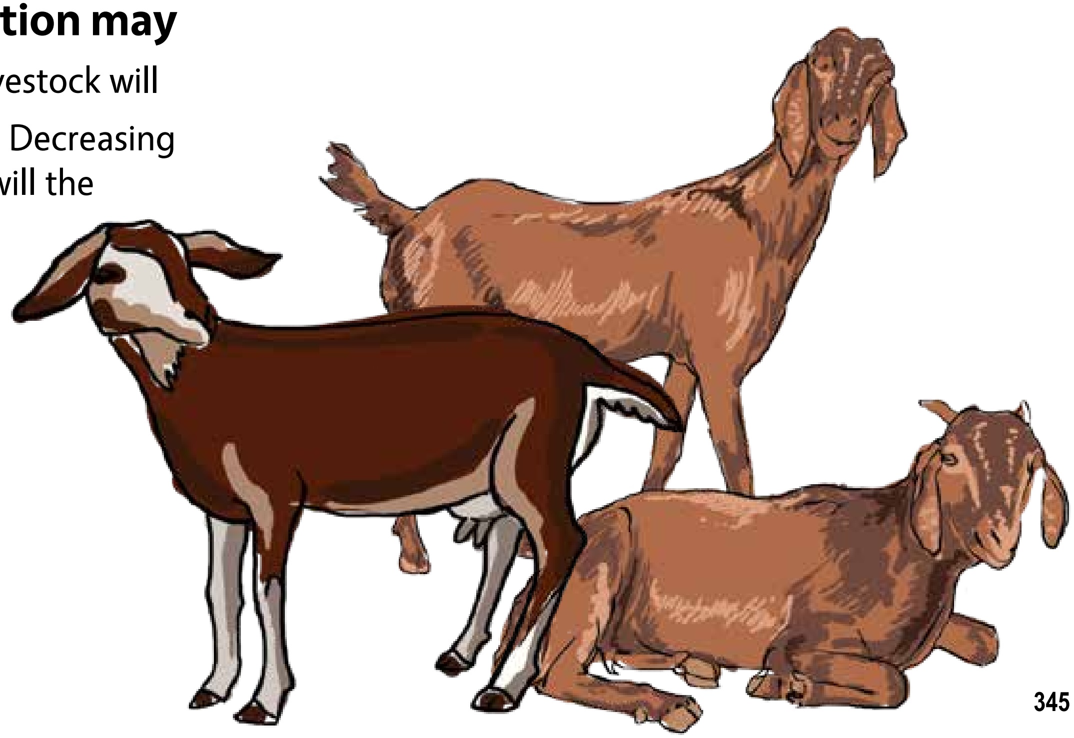
Climate change impacts on other agricultural activities

Livestock

Livestock plays a very important role in Indian agriculture, especially for small-scale farmers. Animals provide **draught power and manure, food products like milk and a very important source of income,** particularly in years when crops fail, for smallholder and poor farmers.

Livestock does, however, **contribute significantly to methane emissions** and hence climate change. India's 485 million livestock (13% of the global population) contribute 17% of India's greenhouse gas emissions.[60] These are created during the digestive tract, as ruminants process cellulose-rich fibrous feed.

Climate change, in turn, will affect livestock in several ways. Scientists predict that rising temperature will lead to higher body temperature and increased respiration rate in animals, a decrease in feed intake by 5 – 20%, decrease in the ability to utilize nutrients and a decrease in reproductive success as well. **Milk production may be reduced by as much as 10 – 40%**. As in the case of crops, livestock will experience **new diseases**, some of which they may not be resilient to. Decreasing land and water availability will, of course, also affect livestock health, as will the availability and quality of feed.[61]

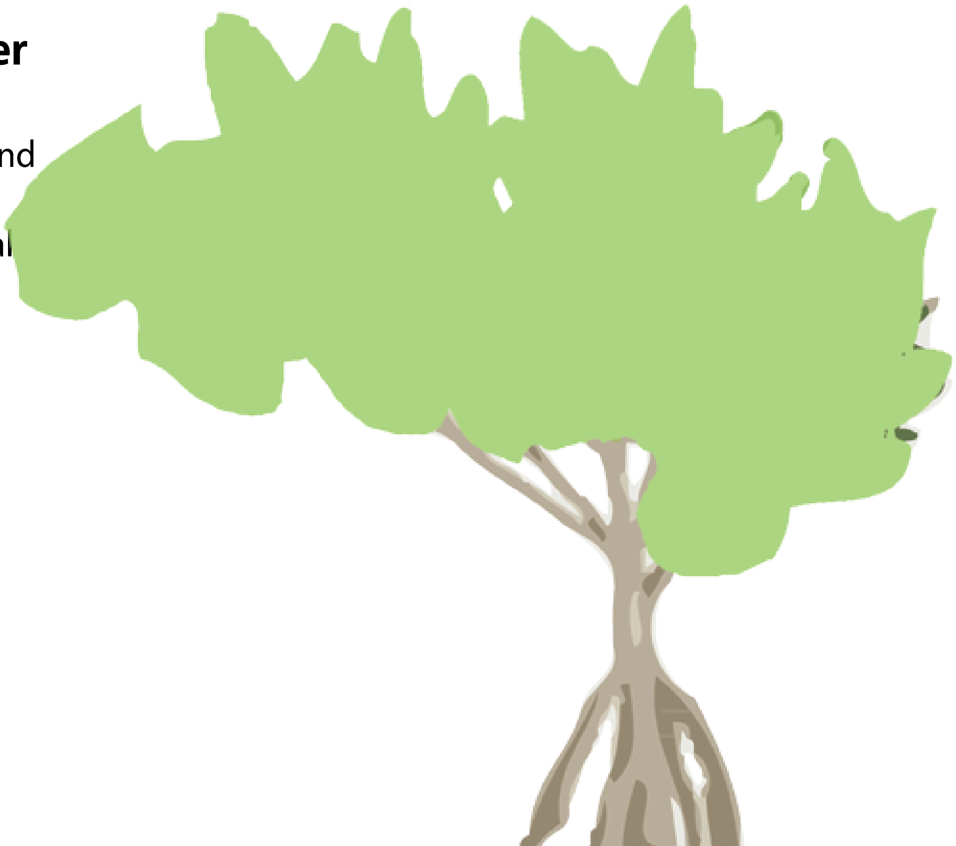


Forestry

Forests the world over will experience several changes due to climate change. These diverse habitats **store greenhouse gases**, such as CO_2, that would otherwise be released to the atmosphere, and are called carbon "sinks." Deforestation is in fact a leading cause of climate change, and contributes 17% of global greenhouse gas emissions.[62]

In India, forests are not only habitat for a wide range of species and biodiversity, but also **provide several essential services, such as fuel and forage**, to rural communities. Deforestation, which in turn leads to biodiversity loss and soil erosion, is a major problem and forest cover in the country shrank by 4,800 km^2 between 1986 and 2003.

Rising temperatures are **pushing several moist forest species to cooler areas**. The Western Ghats, for example, may be heading towards grasslands ecosystems in the future. In other areas, climate change is causing desertification and aridity, invasion by non-native species, increased forest fires, insect outbreaks and wind damage and soil erosion. All these factors threaten to reduce plant and animal diversity in forests.

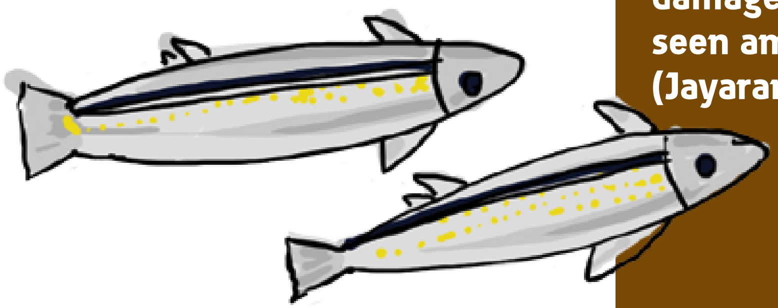


Fisheries

Both marine and inland, freshwater fisheries stand to be significantly affected by climate change. Scientists predict a rise in temperature of surface seawater, and in some cases, even in deep waters. This in turn affects aquatic species, almost all of whose body temperatures are regulated by ambient temperature. In addition, **rising water temperatures also decrease the amount of dissolved oxygen in water, change salinity levels and lead to higher acidity.** In the past years, ranges of fish species have changed, with some species having larger ranges, while others had decreased in numbers and range. Several species' migratory patterns, spawning seasons, and reproductive success have also changed. Warmer temperatures may allow the **spread of diseases, reduced rate of larvae development and overall species and biodiversity loss.**

These trends are already evident:

In the Ganga, fish landings decreased from 85.21 tonnes in 1959 to 62.48 tonnes in 2004. Warm-water fish have moved into ranges in the Ganga pressuring and reducing the numbers of the cool-water fish previously found there. Coral reefs have also been severely affected. Higher temperatures and acidity have led to 29 "bleaching events," and populations of the myriad species that live in reef systems have been severely depleted.



Impacts on certain Indian fish

Oil Sardine: Typically found in a narrow strip off the Malabar Coast, this fish has recently expanded its range north in the Arabian Sea and Bay of Bengal.

Indian Mackerel: Along with extending their range further north, Indian Mackerel also appears to be descending deeper into the ocean. Warmer surface temperatures are almost certainly the cause for this.

False Trevally: One of the most important fish species along the southern coastline, this fish's numbers have significantly declined. Their range has also shifted.

Indian Major Carp: Often grown in tank fisheries, this fish's maturing and spawning period occurs earlier, and their breeding period is longer. Warmer waters will likely damage their populations, as has already been seen amongst wild populations in the Ganga. (Jayaraman, 2011)

Climate Change's impacts on specific states

Several states in the country have done research on what the impacts of climate change on agriculture in their regions has been in the past, and may be in the coming years.

Maharashtra

Rainfall in Maharashtra is predicted to increase. Though this may be variable and unpredictable, negatively affecting several crops and ecosystems, it may also mean that yields of some dry-land crops such as jowar and bajra may actually increase. Irrigated crops such as sugarcane may decline by as much as 30% with climate change, emphasizing the need for a shift to less water-intensive crops such as millets.[68]

Himachal Pradesh

Rainfall has declined across the state, and at higher altitudes snowfall has declined from 10 feet to 1 – 2 feet in the past 40 years. Changes in temperature have shortened the reproductive phase of wheat in some parts of the state. These patterns will likely intensify over the coming years.[63]

Rajasthan

Temperatures in Rajasthan may increase by as much as 4°C by 2020.[66] Rainfall intensity may increase, and flooding patterns, as have been seen in the past decade, may continue or even worsen. This will definitely affect the rain-fed crops of the region; pearl millet yields, for example, could reduce by 10-15% with a 2°C rise in temperature.[67]

Uttar Pradesh

Eastern parts of the state have experienced severe flooding and soil erosion in the past two decades. At the same time, the Bundelkhand district suffered severe drought from 2004 to 2007. Both affected public health, biodiversity and food security, and caused drastic crop losses. Extreme weather events are predicted to intensify in UP, which may well create similar situations of flooding and famine in the future. [64]

Orissa

Both floods and droughts are expected to increase in Odisha. Given that the two main rivers in the state, the Mahanadi and Brahmani, are both overused for irrigation, rainfall patterns are very important for crop yields. Studies predict that 66% of the state's agricultural land will suffer severe erosion and declining fertility, and a predicted increase in floods could reduce rice yields by as much as 12%. [65]

Andhra Pradesh

Much of Andhra Pradesh's land is semiarid. A rise in temperature of 2 to 4°C could reduce small farm income by as much as 20%. Traditional varieties of crops that do relatively well on marginal soils, such as millets, may do better in these conditions than other input-heavy crops.[69]

Vulnerability of Indian Agriculture to Climate Change

Indian agriculture today is faced with the challenge of having to adapt to the projected vagaries of climate change. It must develop mechanisms to reduce its vulnerability. The Indian Council of Agricultural Research (ICAR) has already begun research to assess the likely impact of climate change on various crops, fisheries, and livestock. A sector wise analysis is given below.

3.1. Cereal Crops

The **Asia-Pacific region is likely to face the worst impacts** on cereal crop yields. Loss in yields of wheat, rice and maize are estimated in the vicinity of 50%, 17%, and 6% respectively by 2050.[70] This yield loss will threaten the food security of at least 1.6 billion people in South Asia. The projected rise in temperature of 0.5°C to 1.2°C will be the major cause of grain yield reduction in most areas of South Asia.[71]

3.1.1. Wheat

India is considered to be the second largest producer of wheat and the national productivity of wheat is about 2,708 kg/ha. The Northern Indian states such as **Uttar Pradesh, Punjab, Haryana, Uttaranchal and Himachal Pradesh** are some of the major wheat producing states. Here the impact of climate change would be profound, and only a 1°C rise in temperature could reduce wheat yield in Uttar Pradesh, Punjab and Haryana. In Haryana, night temperatures during February and March in 2003 – 04 were recorded 3°C above normal, and subsequently wheat production declined from 4,106 kg/ha to 3,937 kg/ha in this period.[72]

An assessment of the impact of climate change on wheat production states that the country's **annual wheat output could plunge by 6 million tonnes with every 1°C rise** in temperature.[73] However, utilizing adaptation strategies such as changing the planting dates and using different varieties, it is possible to moderate the losses. By adapting certain agronomic strategies it was estimated that at a 1°C rise, 3 million tonnes could be restored.[74] The assessment also found that the impact of climate change on wheat production varies significantly by region. North India and other areas with higher potential productivity were less impacted by a rise in temperature than the low-productivity regions. If there is no mechanism or strategy to cope with rainfall variability, then rainfed crops will be more heavily impacted than irrigated ones.[75]

3.1.2. Rice

Research conducted by Indian Agricultural Research Institute (IARI) has shown that the grain yield of rice is **not impacted by a temperature increase less than 1°C.** However from an increase of 1 – 4°C the grain yield reduced on average by 10% for each degree the temperature increased.[76] Thus, higher temperatures accompanying climate change will impact world rice production creating the possibility of a shortfall. We have seen already that basmati varieties of rice are particularly **vulnerable to temperature induced pollen sterility,** and thus to lower grain formation.

Rainfall pattern is a very important limiting factor for rain-fed rice production. Higher variability in distribution and a likely decrease in precipitation will adversely impact rice production and complete crop failure is possible if severe drought takes place during the reproductive stages. In upland fields, if the rice crop receives up to 200 mm of precipitation in 1 day and then receives no rainfall for the next 20 days, the moisture stress will severely damage final yields.[77] Assessments predict a **decrease in the rice production in tropical regions, but an increase of rice production outside tropical regions**.[78] This shift is of particular concern to India because lower rice production will immediately create a hunger situation on a large scale.

Studies on the impact of night time temperature rise on rice yields indicates that the warmer nights have an extensive impact on the yield of rice, "Every 1°C increase in night time temperature led to a 10% reduction in yield."[79]

The eastern region of India has diverse physiographic and agro-climatic land which supports genetic resources. According to a study done by the Indian Agriculture Research Institute, the impact of climate change with increased temperature and decreased radiation will lead to decrease productivity in rice in the North Eastern region.[80]

3.1.3. Maize

Maize (Zea mays L.) is the **third most important cereal crop in India** and has a major role to play in food security especially in mountain and desert regions. Maize production in arid and semi arid tropical regions is particularly sensitive to weather conditions, especially rainfall. Therefore, variation in the rainfall as well as maximum and minimum temperature during the south-west and north-east monsoon period will negatively impact maize crops. In Tamil Nadu, assessments indicate a reduction in yield by 3.0%, 9.3%, and 18.3%, in 2020, 2050 and 2080 from current yields.[81]

In terms of maize production, two important shifts are predicted to occur. First, **maize yield during the monsoon season is expected to decrease** as a consequence of increase in temperature; though this can be partly offset by increase in rainfall. Secondly, **maize yield during the winter season can decrease in the mid Indo-Gangetic Plains and Southern Plateau** as a consequence of increased temperature. On the other hand, in the Upper Indo-Gangetic Plain characterized by low winter temperature, the maize yield can increase up to a 2.7°C rise in temperature.[82] High temperatures plays a greater role in affecting maize yield as compared to rainfall, which may not have a major impact on winter yields as the crops in the Gangetic belt are well irrigated. Maize yield during monsoon could be reduced by up to 35% in most of the Southern Plateau regions and up to 55% in Mid Indo-Gangetic Plains, whereas the Upper Indo-Gangetic Plain is expected to be relatively unaffected.[83]

3.2. Vegetables and Legumes

Most vegetables are sensitive to environmental extremes, thus periodic high temperature and soil moisture stress conditions are likely to reduce yield, on average. But research also shows that higher CO_2 concentration could offset the negative effect of higher temperature especially in the case of **leafy vegetables that would benefit from increased rates of photosynthesis**.[84]

3.2.1. Chickpeas

Short duration vegetables and legumes could **perform better under higher concentration of CO_2,** especially crops such as chickpeas which have a well developed carbon sink capacity, due to their ability to utilise additional photo-assimilates more effectively.[85] Chickpeas grown under elevated concentration of CO_2 (up to 550 ppm) showed better performance compared to plants grown under current CO_2 concentrations of 370 ppm.[86] There was greater shoot elongation and leaf expansion under elevated CO_2 and an 18% increase in the number of seed in some varieties. Nevertheless, an increase in temperature is likely to reduce the beneficial effect of increasing CO_2.[87]

3.2.2. Onion

Elevated CO_2 (550 ppm) leads to **higher number of leaves and to larger bulb size** in onions. The pseudo stem length, number of leaves and leaf area are higher at bulb initiation and bulb development stages than at ambient CO_2 levels (370 ppm).[88] The enhanced accumulation of dry matter translates into big size bulbs with an average diameter of 75.02 mm under elevated CO_2 levels compared to 65.67 mm under ambient levels.[89]

3.2.3. Tomato

Tomatoes are **positively influenced by elevated CO_2 levels** (550 ppm). Plant length, number of secondary branches and leaf area increase at elevated levels of CO_2, as compared to ambient levels. At elevated concentrations of CO_2 the fruit yield is higher. The yield increase is mainly due to increase in the number of fruits per plant with a mean of 74 fruits per plant, compared to 56 fruits per plant under current ambient conditions.[90]

3.2.4 Castor

Elevated CO_2 resulted in an **increase in the dry matter production** and the total yield of castor.[91]

3.2.5. Coconut

Coconuts, like other plantation crops, have to deal with the impact of climatic variability even within a single generation. Coconuts require an average temperature of 29°C with a diurnal variation not exceeding 7°C.[92] They further require annual rainfall of at least 1,800 mm evenly distributed throughout the year for optimum production.

Research shows that **coconut productivity in India is likely to decline in the eastern coastal areas** of Andhra Pradesh, Odisha, Gujarat, and parts of Tamil Nadu and Karnataka as a result of climate change. Conversely, yields are likely to increase up to 4% by 2020, up to 10% by 2050, and up to 20% by 2080 due to a positive impact of climate change in the western coastal areas of Kerala, Maharashtra, Tamil Nadu, and Karnataka.[93] Nevertheless, the yield projections can vary depending on availability of water, even when climate conditions are favorable.

3.2.6. Apples

The National Network Project of ICAR suggests that, changing climate is thought to be the main reason for the current decline in apple production in Himachal Pradesh. Apple trees develop their vegetative and fruit buds in summer and as winter approaches, the buds become dormant in response to shorter day lengths and cooler temperatures. Once buds have entered dormancy, they become tolerant to sub-zero temperatures and will not grow in response to mid-winter warm spells. These buds remain dormant until they accumulate sufficient chilling units (CU) of cold weather. Only when they have accumulated enough chilling, the flower and the leaf buds are ready to grow in response to warm temperatures. Hence, if the buds do not receive sufficient chilling temperatures during winter then **trees will express delayed foliation, reduced fruit set and increased buttoning**.[94]

This is problematic since data collected over two decades shows that minimum temperatures in Himachal Pradesh increased from November to April; and maximum temperatures increased from April to November. **Decreased snow fall during winter months led to low chilling hours in the region.** Data on cumulative chill units for the coldest months show a decline of more than 17.4 chill units every year due to increase in surface air temperature at Bajura and Shimla in Himachal Pradesh.[95] These ongoing climatic changes are negatively affecting the state's apple production, an important livelihood activity and contribution to the state GDP.

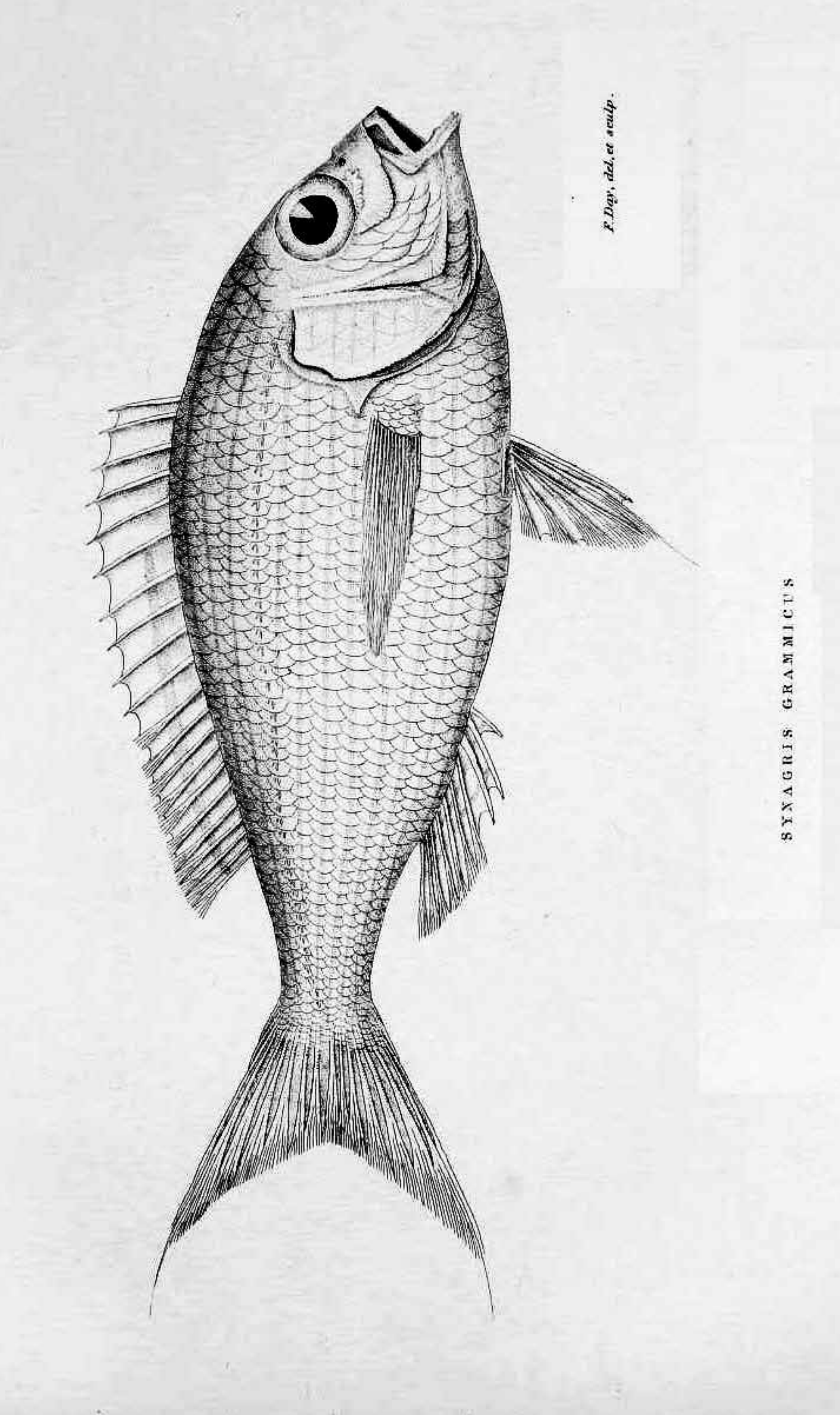
3.3 Fisheries

3.3.1 Marine fish

Climatic changes are likely to impact the geographic distribution and mortality of marine organisms. Depending on the mobility of the species, the area they occupy might expand or shrink. Any distributional changes will directly affect the nature and abundance of fishes. **Fish spawning is especially sensitive to temperature,** and several species of marine fish are known to spawn only at a particular water temperature. Climatic changes are already affecting the availability, behavior and distribution of some commercial fish.

One good example is the changes seen in the **spawning timing of the threadfin breams Nemipterus japonicus and N. mesoprion**.[96] These threadfin breams are found at depths ranging from 10 to 100 m along the entire Indian coast. They have a lifespan of about three years, are fast growing and highly fertile. They are an economically important species as the annual threadfin bream catch along the Indian coast was 1,11,345 tonnes during 2006, comprising 4.7% of the total fish catch.[97]

It has been observed that there is a **positive relationship between the sea surface temperature and spawning activity of threadfin breams**.[98] Data shows that the April to September sea surface temperature in Chennai increased from 29.07°C in 1981 – 85 to 29.38°C in 2001 – 04 (+0.31°C). Between October and March of the same period the temperature increased from 27.86°C to 28.01°C (+0.15°C). The frequency of spawning, of threadfin breams was found to decrease with increasing temperature from April to September, however, it increased from October to March when there is a slight increase in sea surface temperature.[99] The fish were shifting their reproductive activities to a period where the temperature is closer to their optimum. The changes in reproduction patterns will play an important role in the availability of these fish and the livelihoods and incomes of fisher folk.



Changes in behavior directly linked with climatic changes are also visible in **oil sardines**, a coastal, schooling fish with a high reproductive rate.[100] Its distribution is restricted to the Malabar region along the southwest coast; however, it **plays a crucial ecological role in the ecosystem both as a plankton feeder and as food for large predators**. It has economic importance in that the annual average production is 3.8 lakh tonnes which comprises 15% of India's total catch. It is also important in terms of food and nutritional security as it is a good source of protein, serving as a staple food for millions of coastal people.[101]

Due to the current warming of the Indian Ocean, **the oil sardine has already spread to the northern and eastern boundaries of its original distribution** in the Indian ocean.[102] From 1950 – 05 the surface temperature of the Indian ocean has increased on an average of 0.03°C to 0.18°C per decade. Further, the predicted increase in the surface temperature is expected to rise to approximately 3.0°C in the 2000 – 10 decade.[103] While the oil sardine and threadfin breams are two important examples, changes in the temperature of the seas will have an overall impact on many of the types of fish available, affecting not only the value of Indian commercial fishing but the food and livelihood security of many coastal communities.

3.3.2. Fresh Water Fish

Changes in the quality and quantity of water in inland water bodies will affect fresh water fish. Many fish in the Ganges breed during the monsoon because of their dependence on seasonal floods. These floods inundate the Gangetic flood plains and are essential for the feeding and reproduction of many fish types. Changes in the rainfall pattern, especially decreases in precipitation, can **alter the necessary flow and turbidity of the water thereby affecting the breeding patterns of various species of fish.**

One example is the **Indian Major Carps**, which are the most important fish found in both rivers and confined water bodies. Monthly rainfall data records show that the percentage of the total rainfall in the peak fish breeding period between May and August has declined by 5% whereas it has increased by 7% in the post-breeding period.[104] This shift is a major factor responsible for disturbances in breeding and the drastic reduction in the critical numbers of young fish, necessary to maintain the population.

Changes in rainfall pattern and higher temperature have also led to a **shift in distribution of fish in the Ganges.**[105] Warm water fish species that were earlier available only in mid-river are now available in the more upper, colder regions near to Haridwar. On the other hand, phytoplankton population which predominantly inhabit the cold waters near the mountains have become insignificant.[106] Because all species are interlinked with each other, variation in the distribution of one set of organisms can affect the functioning of the entire ecosystem with large economic and environmental consequences.

3.4 Livestock

The livestock sector has already been impacted by climate variability. This is a major concern considering the potential of livestock in poverty reduction efforts, especially for landless farmers. **Disruptions in the seasonal patterns affect the biological rhythms of organisms** and the regulation of their biological-cycles.[107] Examples of factors that regulate the biological rhythm are temperature, the light and dark cycle, noise and interaction with members of the same species. For many livestock species, the most important factor is the 24 hour cycle of light and darkness.[108]

In livestock, their biological clock enables them to synchronize their reproductive behavior with the most favorable environmental conditions for raising their young ones. Ambient temperature plays a major role whereas increased temperatures and humidity levels cause the animals to have increased body temperatures, which **results in declined feed intake, disturbed reproductive functions and low milk yield**. High temperature and increased thermal stress also negatively impact ovarian activity, especially in buffalo, and crossbred cows that are known to have a poor capacity to dissipate heat from the skin. Limited availability of water could further impact reproductive functions and also milk production.[109]

Currently the impact of climate stress on milk production of dairy animals is estimated to be 1.8 million tonnes.[110] Models based on different climatic scenarios suggest that **milk production will decrease by 1.6 million tonnes by 2020** and by more than 15 million tonnes by 2050.[111] North India is likely to experience greater climate related reduction in milk production of both cows and buffaloes compared to other areas.[112]

Therefore, adaptation strategies need to be developed to maintain the viability of the dairy sector. One possible solution is to **promote the use of indigenous cattle breeds** which are more tolerant to thermal and moisture stress, and thus better able to cope with anticipated changes in the climate.

Adapting to Climate Change

Adaptation strategies to climate change will have to be based on sustainable agriculture practices. Such practices are better suited for local climatic variability. To develop sustainable agricultural systems it is crucial to include the knowledge of farmers at every level. A knowledge intensive, as opposed to input intensive, approach needs to be adopted to develop sustainable adaptation strategies. Strategies used by farming communities to cope with climate crises in the past will be instrumental in finding solutions to address the future uncertainties of climate change.[113]

Given that climate change will have far reaching effects on Indian agriculture and food security, it is important that the country prepares itself to adapt to these changes and does so quickly.

Coping with the impact of climate change on agriculture will require **careful management of resources like soil, water and biodiversity.** Making agriculture sustainable is key, and is possible only through production systems that make the most efficient use of environmental goods and services without damaging these assets. If climate change impacts can be incorporated in the design and implementation of development programs right away, it will **help to reduce vulnerability, stabilize food production and better secure livelihoods**. A large scale climate literacy program is necessary to prepare farmers, who are today bewildered by the rapid fluctuations in weather conditions that affect their agriculture. Their traditional knowledge does not help them to manage these recent anthropogenic changes.

Developing countries face a **substantial decrease in cereal production** potential. In India, rice production is slated to decrease by almost a tonne / hectare if the temperature goes up to 20°C. By 2050, about half of India's prime wheat production area could get heat-stressed, with the cultivation window getting shorter, affecting productivity. For each 10°C rise in mean temperature, wheat yield losses in India are likely to be around 7 million tonnes per year, or around $1.5 billion at current prices.[114] To cope with the impact of climate change on agriculture and food production **India will need to act at global, regional, national and local levels.**

Specific Recommendations

Apart from the obvious focus on soil health, water conservation and management, and pest management; there are some specific action areas which will be crucial to making agriculture and food production more sustainable and ecologically sound so as to better adapt to climate change turbulence.

A **special package for adaptation should be developed for rain fed areas based on minimizing risk**. The production model should be diversified to include crops, livestock, fisheries, poultry and agro forestry; homestead gardens supported by nurseries should be promoted to make up deficits in food and nutrition from climate related yield losses. **Farm ponds, fertilizer trees and biogas plants must be promoted** in all semi-arid rainfed areas which constitute 60% of our cultivated area.

A **knowledge-intensive, rather than input-intensive approach** should be adopted to develop adaptation strategies. Traditional knowledge about the community's coping strategies should be documented and used in training programs to help find solutions to address the uncertainties of climate change, build resilience, adapt agriculture and reduce emissions while ensuring food and livelihood security. Therefore conserving the genetic diversity of crops and animal breeds, and their associated knowledge, in partnership with local communities must receive the highest priority.

Breed improvement of indigenous cattle must be undertaken to improve their performance since they are much better adapted to adverse weather than high performance hybrids. Balancing feed mixtures, which research shows has the potential to increase milk yield and reduce methane emissions, must be promoted widely.

An **early warning system** should be put in place to monitor changes in pest and disease profiles and **predict new pest and disease outbreaks**. The overall pest control strategy should be based on Integrated Pest Management because it takes care of multiple pests in a given climatic scenario.

A **national grid of grain storages**, ranging from Pusa Bins and Grain Golas at the household and community level to ultra-modern silos at the district level, must be established to ensure local food security and stabilize prices.

The **agriculture credit and insurance systems must be made more comprehensive** and responsive to the needs of small farmers. For instance, pigs are not covered by livestock insurance despite their potential for income enhancement of poor households. A special climate risk insurance should be launched for farmers.

In each of the 128 agro-ecological zones of the country, various support structures needs to be established. Firstly, there needs to be a **Centre for Climate Risk Research, Management and Extension.** The Centre should prepare computer simulation models of different weather probabilities, and develop and promote farming system approaches which can help to minimize the adverse impact of unfavorable weather, while maximizing the benefits of a good monsoon.

Secondly, there needs to be the **establishment of Farmer Field Schools** (FFS) to house dynamic research and training programs on building soil health, integrated pest management, and water conservation along with its equitable and efficient use. The FFS should engage in participatory plant and animal breeding. Similarly, there should be a focused research program to identify valuable genetic traits, such as pest resistance, disease resistance, and drought, heat, or salinity tolerance, that are available in the region's agro biodiversity.

Thirdly, there is a need for **Gyan Chaupals and Village Resource Centres with satellite connectivity** from where value-added weather data from the government's Agromet Service should be reached to farmers through mobile telephony. This will give them valuable information on rainfall and weather in real time.

Finally, there needs to be **further development of a network of community level seed banks**. These should have the capacity to implement contingency plans and alternative cropping strategies depending on the behavior of the monsoon. Based out of the seed bank network, there must be the establishment of decentralised seed production programs involving local communities to address the crisis of seed availability. Seeds of the main crops and contingency crops (for delayed/failed monsoons or floods), along with the seeds of fodder and green manure plants suitable for the agro-ecological unit, must be both produced and stocked.

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CLIMATE CHANGE NEGOTIATIONS

The Kyoto Protocol

At the Earth Summit in 1992, all countries pledged to halve global warming through the buildup of greenhouse gases. All industrialized countries except for the United States accepted binding restrictions on their greenhouse gas emissions under the Kyoto Protocol, which was concluded in Japan in 1997.
The duration of the Protocol was from 2008 to 2012. It required major industrialized nations to reduce emissions but imposed no mandatory reductions on emerging economic powers like China, India, Brazil and South Africa. In 2010, governments agreed that emissions need to be reduced so that global temperature increases are limited to below 2 degrees Celsius.

Positions on the Climate Treaty

US: The United States signed the climate treaty, but did not ratify it. This was because of vehement opposition in the US Senate since the treaty required no steps to be taken by China or other fast-growing developing countries to reduce their emissions.

Europe: The G8 industrial countries agreed in 2009 to reducing global emissions by 50% by 2050. This would require the richest countries to lead the way by cutting their emissions by 80%. But since they did not set a baseline from which to measure the reduction, firm interim targets have not been defined and there is little progress on emission reduction.

Emerging economies like China and India have opposed taking on mandatory obligations to curb their emissions. They say they will do what they can to stop any rise in emissions — as long as their economies do not suffer.

Carbon dioxide emissions range from less than two tonnes per person per year in India, (where 400 million people do not have access to electricity and therefore do not consume it). In the United States, on the other hand, per person annual emission is ten times as high, at 20 tonnes. Wealthy countries can use their resources including the newest technologies to protect themselves from climate hazards, while the poorest, who have contributed the least to create global warming, are the most vulnerable and suffer the most.

2011 U.N. Climate Conference in Durban

Delegates from about 200 nations gathered at the 2011 climate conference held in Durban, South Africa. One of the major the issues left unresolved was the future of the Kyoto Protocol whose term was coming to an end in 2012.

The United States in any case is not a signatory to the protocol, and Canada, Japan and Russia, have said they will not agree to an extension of the Kyoto protocol unless emerging economies too reduce their emissions. This position in effect throws out the agreed principle of **"Polluter Pays"** which says that since the industrialized countries caused global warming, they should take the major responsibility for taking remedial steps.

The Durban climate conference renewed the Kyoto Protocol but also began a discussion for a new protocol that will treat all countries — including the developing countries like China, India and Brazil, equally. This future treaty was opposed by India and China who said that although their emissions have risen, their per capita emissions are still very low compared to countries like the US.

The delegates at the earlier meeting in Cancun had decided to create a **Green Climate Fund** to help poor countries adapt to climate change. This fund should mobilize $100 billion a year from public and private sources by 2020 to assist developing countries to switch to clean energy and reduce their emissions. Despite many debates and decisions, the Green Climate Fund has not materialized.

Some Recent Developments

The United States has been consistently criticized at the climate talks not only because of its rejection of the Kyoto Protocol but also because it has not adopted a comprehensive domestic program for reducing its own greenhouse gas emissions. US emissions have reduced by about 6% over the past five years largely because of the recession resulting in a slow down in industrial activity, rather than any structured program to reduce emissions.

EU: In December 2011, the EU decided to charge the world's biggest airlines for their greenhouse gas emissions from Jan. 1, 2012. This step would mean an extra charge of Euro 12 to 16 on long distance flights.

This has been challenged by US airlines who say that forcing them to participate in an emissions-trading system infringed on national sovereignty and existing international aviation treaties. Consistent with its position in other treaties, the US refused to participate in the EU program putting its industrial interests above the global interest of having a clean and healthy environment. The EU initiative is likely to set the stage for a potential trade war with the United States, China and other countries. The EU says its proposal to tax large airlines for emissions is to hasten the adoption of greener technologies in the sector.

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