8th BATCH

CLIMATE SMART AGRICULTURE FOR ADAPTATION AND MITIGATION

TRAINING MANUAL 2025

Course Director: Dr. Md. Baktear Hossain, *Member-Director (NRM), BARC*
Course Coordinator: Dr. Md. Saifullah, *MD (A&F) and CSO (Forestry) (Add. Charge), BARC*

Compiled and Edited by:

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Dr. M. Golam Mahboob
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Date: 18-20 February 2025

Forestry Unit
Natural Resources Management Division
Bangladesh Agricultural Research Council
Farmgate, Dhaka-1215, Bangladesh

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Training on

"Climate Smart Agriculture for Adaptation and Mitigation"

Date: 18-20 February 2025

Venue: Conference Room, SAARC Agriculture Center (SAC), AIC Building, BARC

Course Director: Dr. Md. Baktear Hossain, Member-Director (NRM), BARC, Dhaka.
Course Coordinator: Dr. Md. Saifullah, Member-Director (A&F) & CSO (Forestry), BARC, Dhaka

Time Events

09: 00 Registrations
09: 45 Guests take their seats
10: 00 Recitations from the Holy Quran
10: 05 Welcome Addresses by Dr. Md. Saifullah, MD (A&F), BARC
10: 15 Address by Chief Guest, Dr. Dr. Nazmun Nahar Karim, Executive Chairman, BARC
10: 25 Addresses by Chairperson, Dr. Md. Baktear Hossain, Member-Director (NRM), BARC
10: 30 Tea Break

Date & Time		Course Title	Resource Person
1st Day (18/02/2025) Tuesday			
10:50-11:00	:	Pre-evaluation	Course coordinator
11:00-11:45	:	Climate Smart Agriculture (CSA): Concepts, evolution, and significance	Dr. Md. Saifullah MD (A&F) and CSO (Forestry), BARC
11:45-12:30	:	Climate change, its causes and scientific evidence	Prof. Dr. A.K.M. Saiful Islam Dept. of IWFM-BUET
12:30-13.15	:	Impacts of climate change on agriculture and food security	
13:15-14:30	:	**Break for Lunch and Prayer**	•
14.30-15:15	:	Promising CSA technologies for non-rice crops	Dr. Faruque Ahmed CSO & Head, Plant Physiol. Div., BARI, Gazipur
15:15-15:30	:	**Tea Break**	•
15:15-16:00	:	An Introduction to Carbon Pricing: Examples of CSA Projects in Bangladesh in the Light of Carbon Markets	Engr. Shafiqul Alam Lead Energy Analyst, BIEEFA
16:00-16:45		Role of early warning systems for adaptation to climate change in agriculture	Prof. Dr. Moin Us Salam HRD Consultant, PARTNER, BARC-APCU
	:		
2nd Day (19/02/2025) Wednesday			
09:00-10:45	:	Irrigation and water management technologies for CSA	Dr. M.G. Mostofa Amin Professor, IWM, BAU, Mymensingh
09:45-10:30		Accounting carbon and water footprint in CSA	
10:30-10:45	:	**Tea Break**	•
10:45-11:30	:	Introduction to IoT, Big Data, AI and Cloud Computing	Dr. AKM Muzahidul Islam Professor, Deptt. of CSE, & Director, CIAC, UIU
11:30-12:15		Application of IoT, Big Data, AI and Cloud Computing in CSA	
12:15-01:30	:	CSA in BRAC Adaptation Clinics	Kbd. Tausif Ahmed Qurashi SPM, Climate Change Programme, BRAC
01:30-14:30	:	**Break for Lunch and Prayer**	•
14:30-15:15	:	The Soil-climate change connection: Adaptation and mitigation options in Bangladesh	Dr. Habib Mohammad Naser CSO & Head, SSD, BARI, Gazipur
15:15-15:30	:	**Tea Break**	
15:30-16:15	:	Agroforestry for Climate Smart Agriculture	Dr. Md. Robiul Alam PSO, OFRD, Gazipur
3rd Day (20/02/2025) Thursday			
09:15-10:00	:	NDC of Bangladesh: Implication in Crop Agricultural Sub-sector	Kbd. Md. Ziaul Haque Director (AQM), DoE
10:00-10:15	:	**Tea Break**	•
10:15-11:00	:	Farm mechanization for CSA	Dr. Chayan Kumer Saha Professor, FPM, BAU, Mymensingh
11:00-11:45	:	CSA for circular bioeconomy	
11:45-12:30	:	Climate smart rice production technologies in Bangladesh	Dr. Aminul Islam CSO & Head, SSD, BRRI
12:30-13:15	:	Ecosystem services valuation in CSA	Dr. Naeema Jihan Zinia Director, Environmental Management Solution (EnvSol)
13:15-13:30	:	Post-evaluation	Course Coordinator
13:30-14:40	:	**Break for Lunch and Prayer**	•

Closing Session:
Chairperson: Dr. Md. Baktear Hossain, MD (NRM), BARC, Dhaka

14:40 Address by Course Coordinator: Dr. Md. Saifullah, MD (A&F) & CSO (Forestry), BARC
14:55 Remarks by Two Participants
15:15 Certificate Awarding
15:30 Address by the Chief Guest, Dr. Nazmun Nahar Karim, Executive Chairman, BARC
15:50 Closing remark by the Chairperson, Dr. Md. Baktear Hossain, Member-Director (NRM), BARC
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Climate Smart Agriculture (CSA): Concepts, evolution, and significance

Dr. Md. Saifullah
MD (A&F) and CSO (Forestry) (Add. Charge),
BARC, Dhaka
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- **Weather** is the continuously changing condition of the atmosphere usually considered on a time scale that extends from minutes to weeks
- **Climate** is the average state of the lower atmosphere, and the associated characteristics of the underlying land or water, in a particular region, usually spanning at least several years.
- **Climate Change** refers to any change in climate over time, whether due to natural variability or as a result of human activity (IPCC).

Evidence of Global warming and Climate change

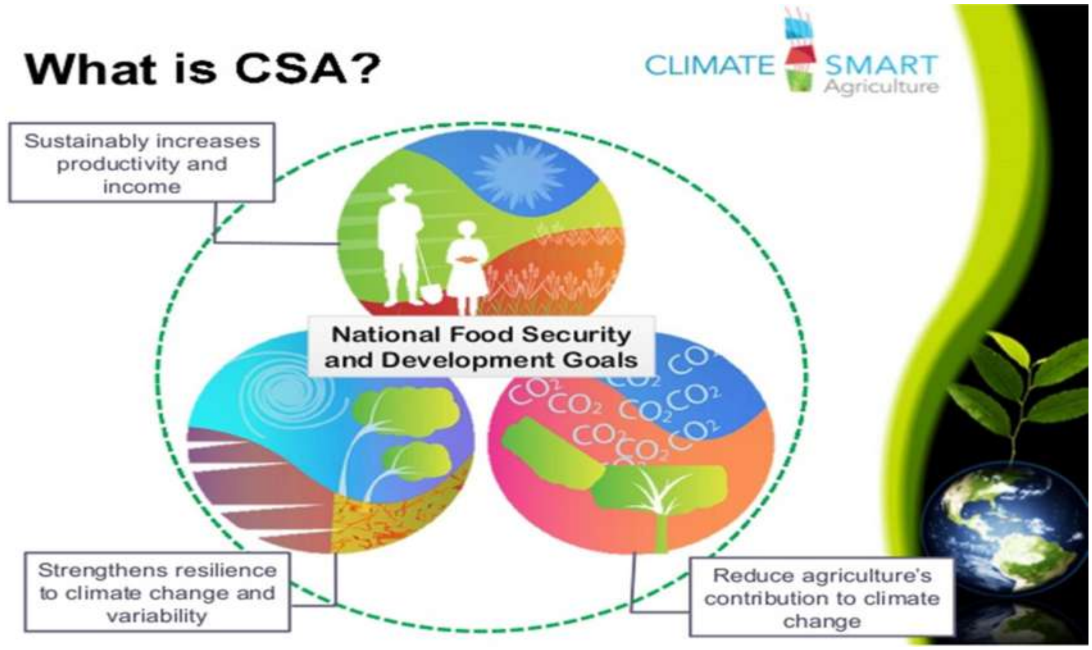
- More warm days
- Melting of snow and ice
- Record number of icebergs
- Sea level rise (*high confidence*)
- Changes in precipitation patterns
- Coral reef damage from algae
- Graph of historical trend of warming temperature
- Carbon dioxide increasing in atmosphere
- More frequent extreme weather
- Disappearing Glaciers

SMART is a mnemonic acronym, giving criteria to guide in the setting of objectives, for example in project management, employee-performance management and personal development. The letters S and M usually mean **specific** and **measurable**. SMART may be S-Specific , M-Measurable, A-Achievable, R-Realistic, T-Time-bound

Climate-Smart Agriculture

FAO coined the term CSA in the background document prepared for the 2010 Hague Conference on Food Security, Agriculture and Climate Change. The CSA concept was developed with a strong focus on food security, for now and the future, including adaptation to climate change. The CSA concept now has wide ownership among, governments, regional and international agencies, civil society and private sector. Emerging global and regional (Africa) Alliances on Climate-Smart Agriculture (ACSA) provide a platform for shared learning and collaboration among all interested parties.

Climate-smart agriculture (CSA) may be defined as an approach for transforming and reorienting agricultural development under the new realities of climate change. The most commonly used definition is provided by the Food and Agricultural Organisation of the United Nations (FAO), which defines CSA as "agriculture that sustainably increases productivity, enhances resilience (adaptation), reduces/removes GHGs (mitigation) where possible, and enhances achievement of national food security and development goals". In this definition, the principal goal of CSA is identified as food security and development; while productivity, adaptation, and mitigation are identified as the three interlinked pillars necessary for achieving this goal.



CSA is not a set of practices that can be universally applied, but rather an approach that involves different elements embedded in local contexts. CSA relates to actions both on-farm and beyond the farm, and incorporates technologies, policies, institutions and investment.

Climate-smart agriculture (CSA) is an integrated approach to managing landscapes—cropland, livestock, forests and fisheries--that address the interlinked challenges of food security and climate change. CSA aims to simultaneously achieve three outcomes:

1. **Increased productivity:** Produce more food to improve food and nutrition security and boost the incomes of 75 percent of the world's poor, many of whom rely on agriculture for their livelihoods.

2. **Enhanced resilience:** Reduce vulnerability to drought, pests, disease and other shocks; and improve capacity to adapt and grow in the face of longer-term stresses like shortened seasons and erratic weather patterns.

3. **Reduced emissions:** Pursue lower emissions for each calorie or kilo of food produced, avoid deforestation from agriculture and identify ways to suck carbon out of the atmosphere.

While built on existing knowledge, technologies, and principles of sustainable agriculture, CSA is distinct in several ways. First, it has an explicit focus on addressing climate change. Second, CSA systematically considers the synergies and tradeoffs that exist between productivity, adaptation and mitigation, in order to capitalize on the benefits of integrated and interrelated results. Finally, CSA aims to capture new funding opportunities to close the deficit in the investment required to achieve food security.

The three pillars of CSA

- **Productivity:** CSA aims to sustainably increase agricultural productivity and incomes from crops, livestock and fish, without having a negative impact on the environment. This, in turn, will raise food and nutritional security. A key concept related to raising productivity is sustainable intensification
- **Adaptation:** CSA aims to reduce the exposure of farmers to short-term risks, while also strengthening their resilience by building their capacity to adapt and prosper in the face of shocks and longer-term stresses. Particular attention is given to protecting the ecosystem services which ecosystems provide to farmers and others. These services are essential for maintaining productivity and our ability to adapt to climate changes.
- **Mitigation:** Wherever and whenever possible, CSA should help to reduce and/or remove greenhouse gas (GHG) emissions. This implies that we reduce emissions for each calorie or kilo of food, fibre and fuel that we produce. That we avoid deforestation from agriculture. And that we manage soils and trees in ways that maximizes their potential to acts as carbon sinks and absorb CO_2 from the atmosphere.

Key characteristics of CSA

- **CSA addresses climate change:** Contrary to conventional agricultural development, CSA systematically integrates climate change into the planning and development of sustainable agricultural systems.
- **CSA integrates multiple goals and manages trade-offs:** Ideally, CSA produces triple-win outcomes: increased productivity, enhanced resilience and reduced emissions. But often it is not possible to achieve all three. Frequently, when it comes time to implement CSA, trade-offs must be made. This requires us to identify synergies and weigh the costs and benefits of different options based on stakeholder objectives identified through participatory approaches.
- **CSA maintains ecosystems services:** Ecosystems provide farmers with essential services, including clean air, water, food and materials. It is imperative that CSA interventions do not contribute to their degradation. Thus, CSA adopts a landscape approach that builds upon the principles of sustainable agriculture but goes beyond the narrow sectoral approaches that result in uncoordinated and competing land uses, to integrated planning and management.
- **CSA has multiple entry points at different levels:** CSA should not be perceived as a set of practices and technologies. It has multiple entry points, ranging from the development of technologies and practices to the elaboration of climate change models and scenarios, information technologies, insurance schemes, value chains and the strengthening of institutional and political enabling environments. As such, it goes beyond single

technologies at the farm level and includes the integration of multiple interventions at the food system, landscape, value chain or policy level.

- **CSA is context specific:** What is climate-smart in one-place may not be climate-smart in another, and no interventions are climate-smart everywhere or every time. Interventions must take into account how different elements interact at the landscape level, within or among ecosystems and as a part of different institutional arrangements and political realities. The fact that CSA often strives to reach multiple objectives at the system level makes it particularly difficult to transfer experiences from one context to another.
- **CSA engages women and marginalised groups:**To achieve food security goals and enhance resilience, CSA approaches must involve the poorest and most vulnerable groups. These groups often live on marginal lands which are most vulnerable to climate events like drought and floods. They are, thus, most likely to be affected by climate change. Gender is another central aspect of CSA. Women typically have less access and legal right to the land which they farm, or to other productive and economic resources which could help build their adaptive capacity to cope with events like droughts and floods. CSA strives to involve all local, regional and national stakeholders in decision-making. Only by doing so, is it possible to identify the most appropriate interventions and form the partnerships and alliances needed to enable sustainable development.

What actions are needed to implement climate-smart agriculture?
Governments and partners seeking to facilitate the implementation of CSA can undertake a range of actions to provide the foundation for effective CSA across agricultural systems, landscapes and food systems. CSA approaches include the following four types of actions:

1. Expanding the evidence base and assessment tools to identify agricultural growth strategies for food security that integrate necessary adaptation and potential mitigation
2. Building policy frameworks and consensus to support implementation at scale
3. Strengthening national and local institutions to enable farmer management of climate risks and adoption of context-suitable agricultural practices, technologies and systems
4. Enhancing financing options to support implementation, linking climate and agricultural finance.

Climate Change and Agriculture

Agriculture is also a major part of the climate problem. It currently generates 19–29% of total GHG emissions. Without action, that percentage could rise substantially as other sectors reduce their emissions.

Gas molecules that absorb thermal infrared radiation, and are in significant enough quantity, can force the climate system. These type of gas molecules are called greenhouse gases. Carbon dioxide (CO_2) and other greenhouse gases act like a blanket, absorbing IR radiation and preventing it from escaping into outer space. The net effect is the gradual heating of Earth's atmosphere and surface, a process known as global warming.

The "greenhouse effect" is the effect of atmospheric gases like carbon dioxide absorbing energy from the sun and earth and "trapping" it near the Earth's surface, warming the Earth to a temperature range that is hospitable for life.

Atmospheric CO_2 levels have increased by more than 40 percent since the beginning of the Industrial Revolution, from about 280 parts per million (ppm) in the 1800s to 400 ppm today. The last time Earth's atmospheric levels of CO_2 reached 400 ppm was during the Pliocene Epoch, between 5 million and 3 million years ago. The greenhouse effect, combined with increasing levels of greenhouse gases and the resulting global warming, is expected to have profound implications. If global warming continues unchecked, it will cause significant climate change, a rise in sea levels, increasing ocean acidification, extreme weather events and other severe natural and societal impacts.

These greenhouse gases include water vapor, CO_2, methane, nitrous oxide (N_2O) and other gases. Since the dawn of the Industrial Revolution in the early 1800s, the burning of fossil fuels like coal, oil and gasoline have greatly increased the concentration of greenhouse gases in the atmosphere, especially CO_2. Deforestation is the second largest anthropogenic source of carbon dioxide to the atmosphere ranging between 6 percent and 17 percent.

The "greenhouse effect" is not the same as global warming. "Global warming" refers to the increase in global average temperature due to excessive amounts of greenhouse gases. The greenhouse effect describes a critical function of our atmosphere: to keep the earth warm enough to sustain life.

The greenhouse gases in the atmosphere allow the sun’s short wavelength radiation in, and because of the chemical properties of the gases, they do not interact with sunlight. But they do absorb the longwave radiation from the earth and emit it back into the atmosphere, different from a greenhouse which does not allow the longwave radiation to escape through the glass. The increase in trapped energy leads to higher temperatures at the earth's surface. This has caused some people to rename the process ‘the atmospheric greenhouse effect’ or just ‘the greenhouse effect’. If the Earth's greenhouse gases increased in concentration and nothing else in the atmosphere changed, then the surface temperature would be expected to rise. The amount of radiation directed back down to Earth would increase and that would heat up the surface as the world's energy balance adjusted to the new conditions. However, the Earth has a very complicated climate system and if this increase in energy occurred, other things like increased evaporation and cloud formation as well as melting of polar ice would be likely to occur and interact in unexpected ways that would further change regional as well as global temperature and climate.

Conservation farming refers to farming practices using conservation tillage methods to establish crops and growing of legume crops in rotation for improving soil fertility. Thus, conservation farming is synonymous to conservation agriculture.

Conservation agriculture (CA) is a system designed to achieve agricultural sustainability by improving the biological functions of the agro-ecosystem with limited mechanical practices and judicious use of chemical inputs. CA system comprise three core principles (i) direct sowing/planting with minimum soil disturbance using zero, strip or reduced tillage, (ii) permanent vegetative residue for soil cover, and (iii) rotation of primary crops in conjunction with other good practices of crop management.

CA has been practiced on about 257 million hectares (M ha) globally in large farming system while there is an increasing trend of its adoption in small hold farming in Asian countries as it conserves and enhance natural resources and environment. CA not only reduces the impact of climate change on crop production but also alleviates the factors that cause climate change by reducing emission and contribute in carbon sequestration in soils. CA increases system diversity by stimulating biological processes in the soil, reduces soil erosion and leaching, reduces production energy inputs by saving time, fuel and cultivation costs as well as reduces labour requirement by about 50%.

Soil under conventional tillage is prone to erosion and loss of quality. Soil organic matter depletion has been reported by 16 to 77% due to tillage in conventional agriculture while organic matter buildup in conservation agriculture after four cropping cycle has been reported by Alam et al. (2014). CA always maintains permanent soil cover, crop residue retention and mulching that protects soil against deleterious effects of exposure to rain and sun, provides constant supply of food to the micro and macro organisms in the soil and alter the micro-climate in the soil leading shift in microbial population towards more beneficial to crop growth and improves soil aggregates, soil biological activity and biodiversity and carbon sequestration. The crop yields can be similar for conventional and conservation agriculture systems if weeds are controlled and crop stands are uniform. Crop yield losses in CA due to weeds may vary, depending on weed community and intensity. Weed species shifts and losses in crop yield as a result of increased weed density have been cited as major hurdles to the widespread adoption of CA.

Maximum operational flexibility and choice of weed control methods are provided with conventional tillage. In contrast, the no-tillage system approaches the lower limit of operational options. The tillage provided by the no-tillage coulter is sufficient to place the seed in the soil, but there is no full width cutting or stirring of the soil. No weed control benefits are derived from this limited amount of tillage. At planting time the soil is covered with residues from the previous season along with weed seeds and any crop seeds missed during harvesting. The soil is farm rather than fluffed, and weeds usually are growing.

The presence of residues affect the micro environment at the soil surface. The plant residues shade the soil reduced the evaporative losses of water, leaving the soil cooler and more moist. This firm moist soil provides an ideal conditions for the germination of small seeded weeds. The plant residue also can interfere with the amount of herbicide that penetrates to the soil surface or to germinating weeds. An undisturbed soil surface can have indirect effects on weed control when fertilizers and limes are applied. Nitrogen can lower the pH in the top inch of soil whereas lime can increase it. The efficacy or persistence of herbicides that are affected by soil pH thus be altered.

Significance of CSA:

- By 2050, the world's population is expected to have risen from 6.7 billion to 9 billion. FAO estimates that, to feed this growing world population (whose consumption habits will also change as household incomes rise), a 70 percent increase in total agricultural production is necessary While innovation and improvements in food production systems have doubled food production over the past six decades such positive developments cannot be taken for granted if the challenges posed by climate change are not addressed.

- Climate change not only threatens the stability and productivity of our agricultural systems – agriculture itself is in fact responsible for over 10 percent of global greenhouse gas emissions However, the agricultural sector also offers great potential to be part of the solution to tackling climate change. It is therefore essential to tackle matters of food security and the challenges posed by climate change *together*. To this end, the Climate-Smart Agriculture (CSA) approach has been developed by FAO in collaboration with other organizations.
- Global warming is turning the lives of farmers upside-down. Drastically different weather patterns, shorter growing seasons, droughts, and pests pose daunting problems for smallholder farmers around the world—especially in the tropics—and could eventually lead to the disappearance of some of our favorite foods. Since those who depend on the land for their livelihoods are often the most vulnerable to the effects of global warming, working with farmers to build climate resilience is critically important for global food security.
- The Rainforest Alliance works with farmers around the world to advance agricultural methods that boost the productivity of arable land, thereby reducing encroachment on standing forests, while decreasing greenhouse gas emissions. These "climate-smart" techniques improve productivity, increase resilience against droughts, torrential rains and changing growing seasons and lower greenhouse gas emissions.
- FAO has decades of experience in promoting agricultural practices and policies that also safeguard the natural resource base for future generations. Agriculture policies are the cornerstones for achieving food security and improving livelihoods. Effective agriculture and climate change policies can also boost green growth, protect the environment and contribute to the eradication of poverty. FAO works closely with many of the world's most vulnerable populations to help them increase their agricultural productivity, while ensuring that the natural resources they depend on are not exploited or depleted.

Actions needed to implement CSA

Governments and partners seeking to facilitate the implementation of CSA can undertake a range of actions to provide the foundation for effective CSA across agricultural systems, landscapes and food systems. CSA promotes coordinated actions by farmers, researchers, private sector, civil society and policymakers towards climate-resilient pathways through four main action areas:

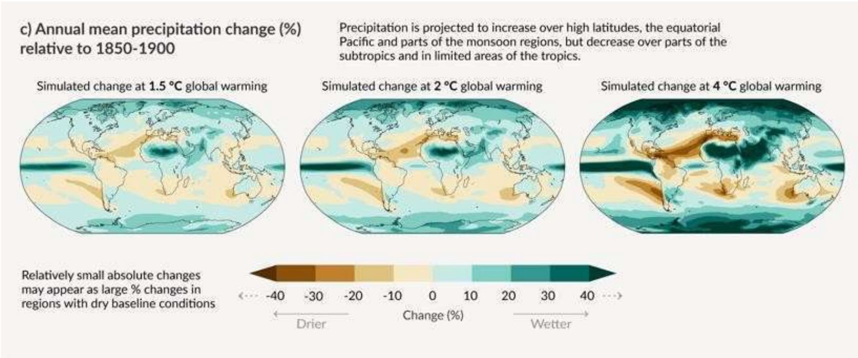
(1) Building evidence: Expanding the evidence base and assessment tools to identify agricultural growth strategies for food security that integrate necessary adaptation and potential mitigation

(2) Increasing local institutional effectiveness: Building policy frameworks and consensus to support implementation at scale
(3) Fostering coherence between climate and agricultural policies: Strengthening national and local institutions to enable farmer management of climate risks and adoption of context-suitable agricultural practices, technologies and systems and
(4) Linking climate and agricultural financing: Enhancing financing options to support implementation, linking climate and agricultural finance.

18 February 2025, BARC, Dhaka

Training Workshop on "Climate Smart Agriculture for Adaptation and Mitigation"

Climate change, its causes, and scientific evidence



Professor A.K.M. Saiful Islam

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Contributing Author: IPCC AR6, WGI- Chapter 9, 10, TS

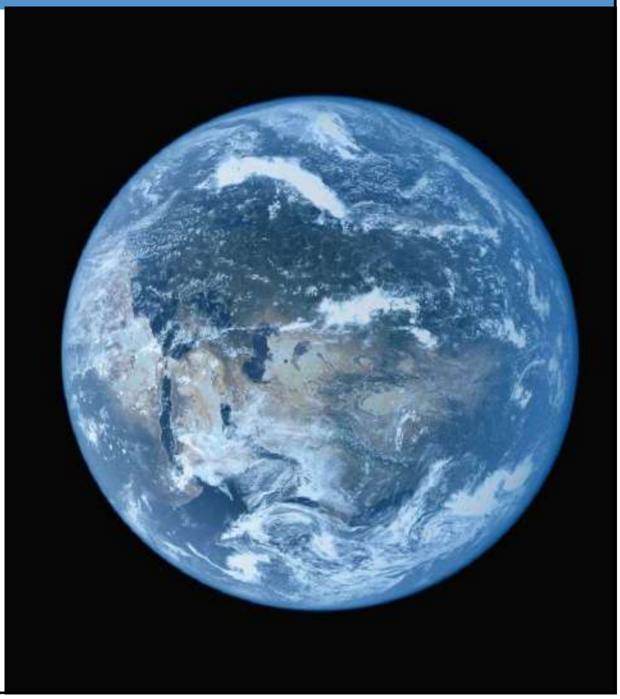
1

SIXTH ASSESSMENT REPORT
Working Group I – The Physical Science Basis

INTERGOVERNMENTAL PANEL ON climate change

Lecture outline

- Climate variability and climate change
- Global warming and greenhouse gases
- Evidence of climate change
- Changes in climate extremes
- Projected changes in extremes
- Changes in Climatic Impact Drivers
- Who is responsible?
- Paris Climate Agreements



2

Understanding Global Warming and Climate Change

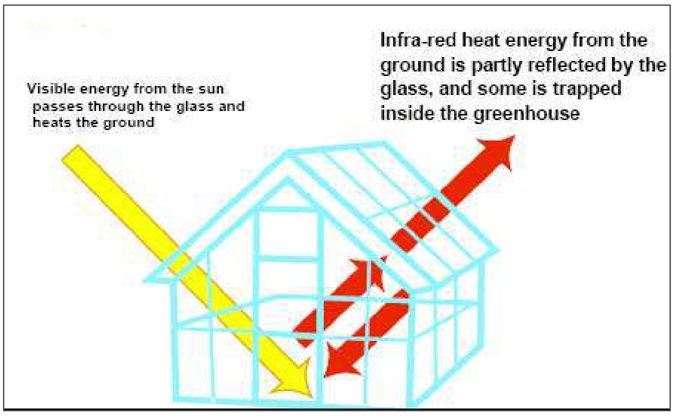
3

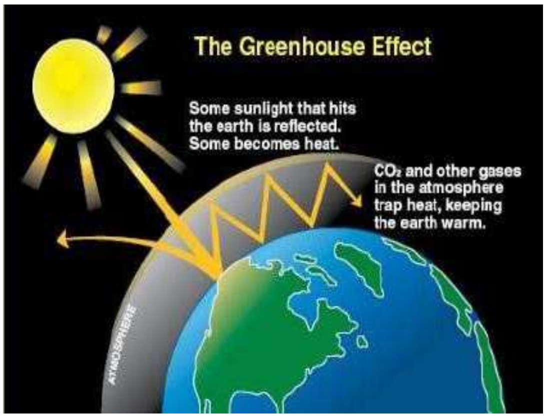
SIXTH ASSESSMENT REPORT
Working Group I – The Physical Science Basis

INTERGOVERNMENTAL PANEL ON climate change

Climate Change, Global Warming and Greenhouse effect

CO2 and some minor radioactively active gases (water vapor, carbon dioxide, methane, nitrous oxide, and ozone) are known as greenhouse gases which acted as a partial blanket for the thermal radiation from the surface which enables it to be substantially warmer than it would otherwise be, analogous to the effect of a greenhouse



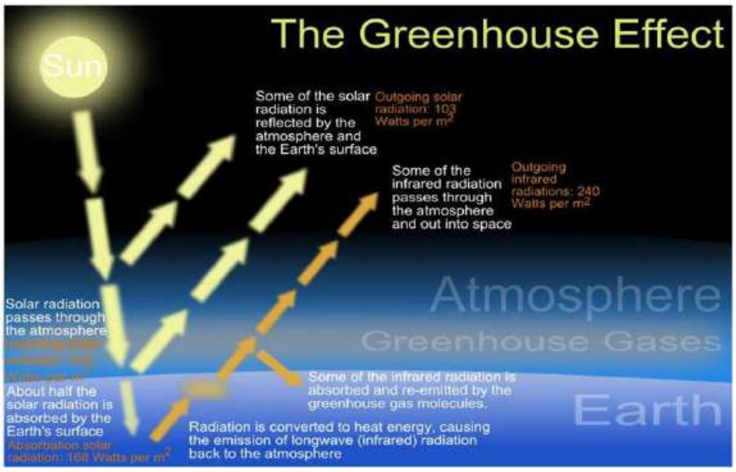


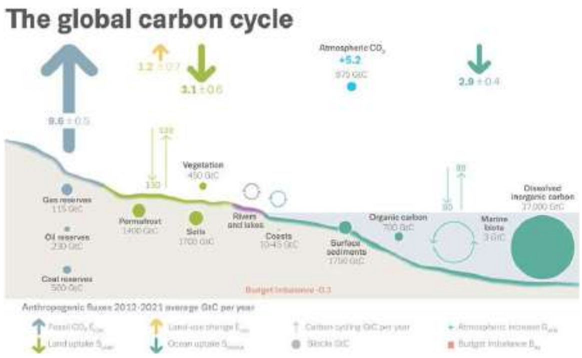
4

SIXTH ASSESSMENT REPORT
Working Group I – The Physical Science Basis

INTERGOVERNMENTAL PANEL ON climate change

Greenhouse gas effect





5

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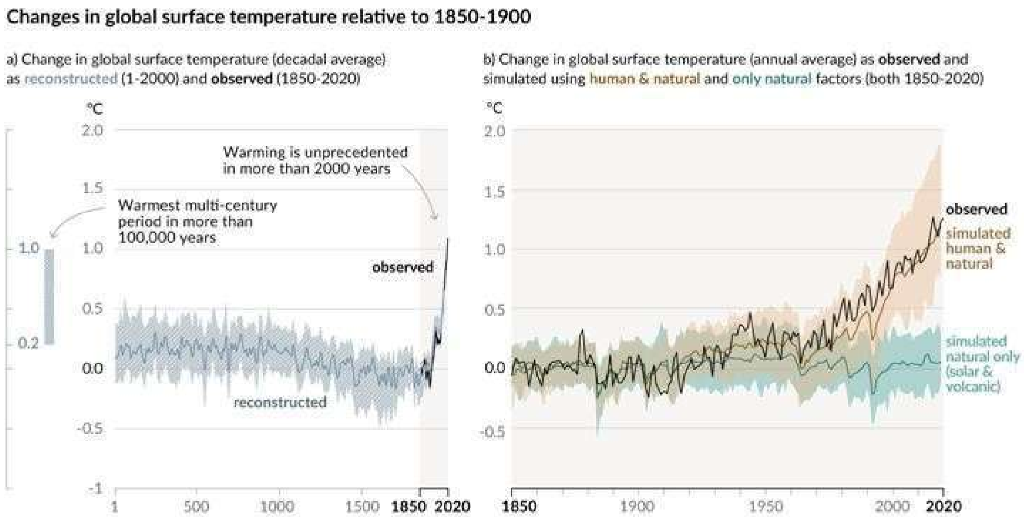
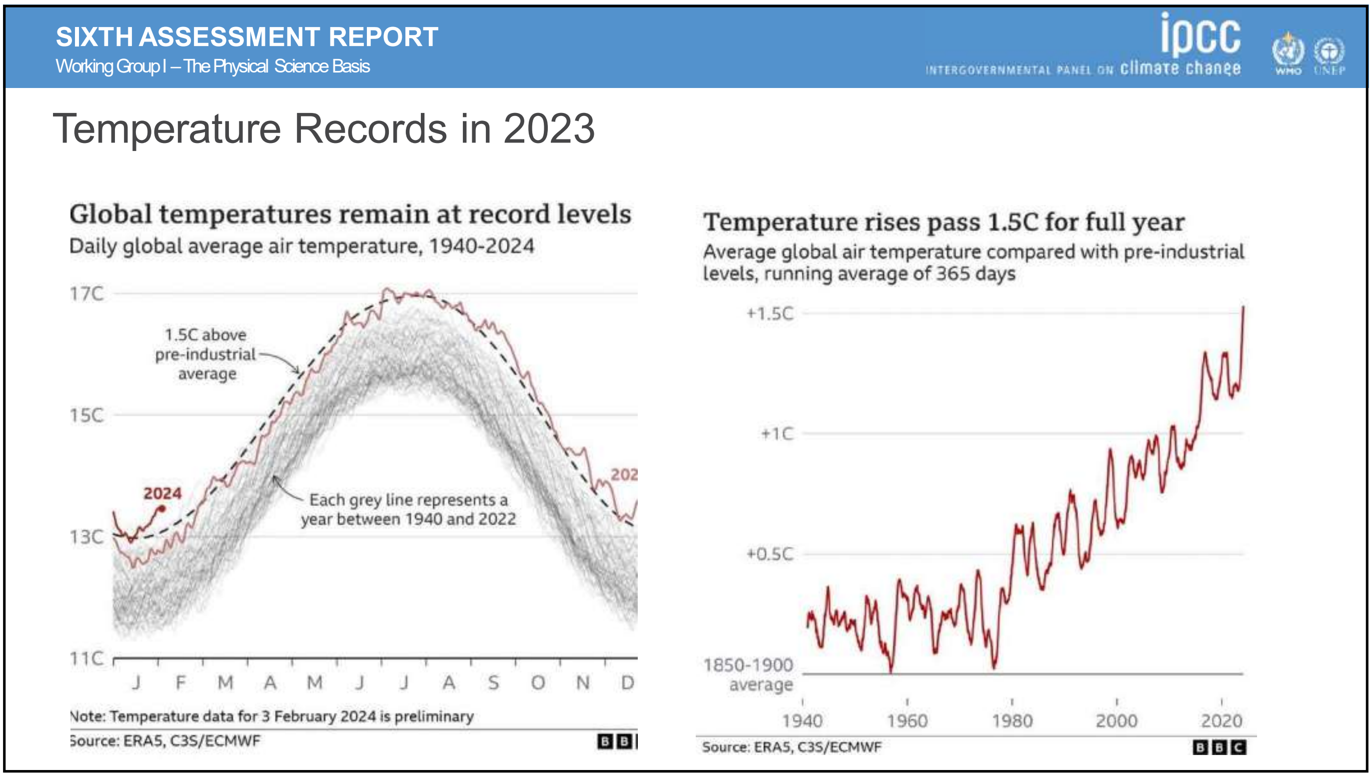
INTERGOVERNMENTAL PANEL ON climate change

Human influence has warmed the climate at a rate that is unprecedented in at least the last 2000 years

Figure SPM.1



6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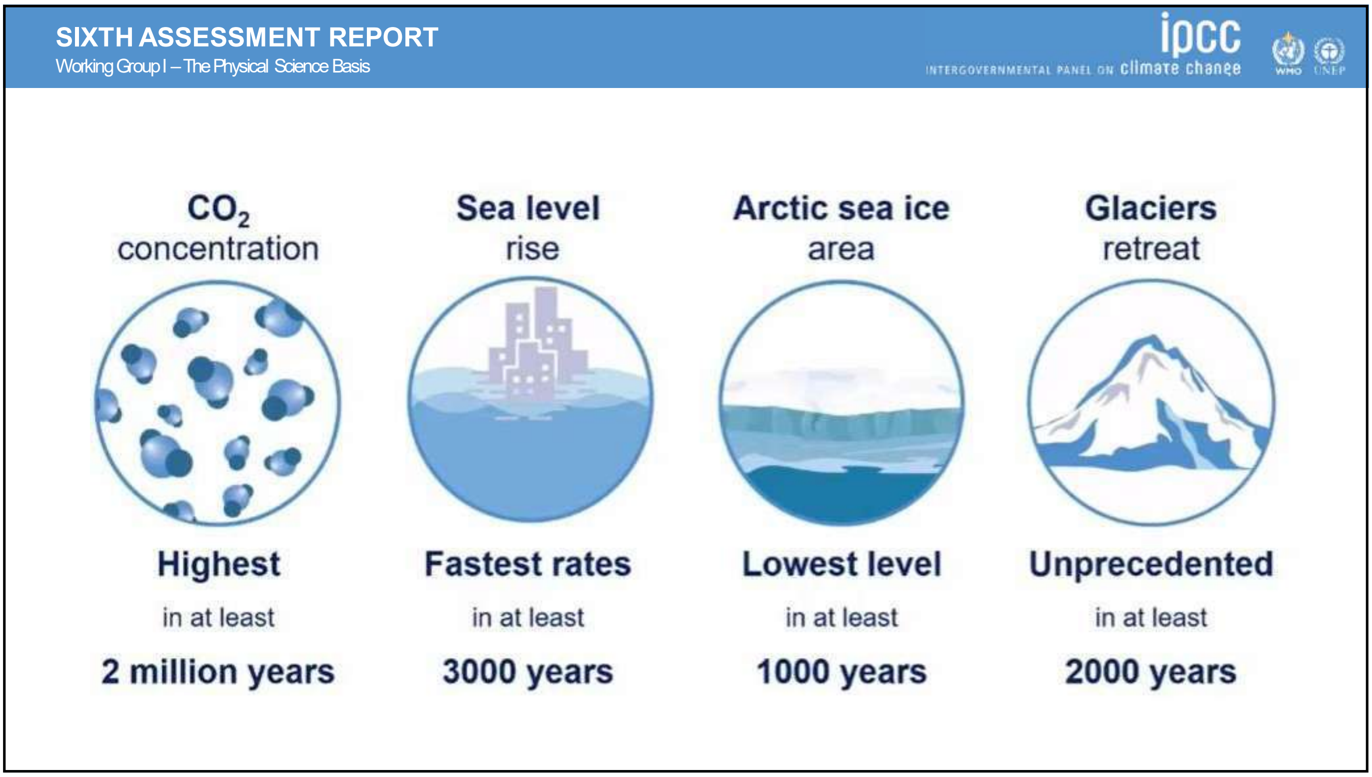
INTERGOVERNMENTAL PANEL ON climate change
WHO
UNEP
Temperature Records in 2023
Global temperatures remain at record levels
Daily global average air temperature, 1940-2024
17C
15C
13C
11C
1.5C above pre-industrial average
2024
202
Each grey line represents a year between 1940 and 2022
J F M A M J J A S O N D
Note: Temperature data for 3 February 2024 is preliminary
Source: ERA5, C3S/ECMWF
Temperature rises pass 1.5C for full year
Average global air temperature compared with pre-industrial levels, running average of 365 days
+1.5C
+1C
+0.5C
1850-1900 average
1940
1960
1980
2000
2020
Source: ERA5, C3S/ECMWF
BBC

7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WHO
UNEP
CO_2 concentration
Sea level rise
Arctic sea ice area
Glaciers retreat
Highest
in at least
2 million years
Fastest rates
in at least
3000 years
Lowest level
in at least
1000 years
Unprecedented
in at least
2000 years

8

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Extreme heat
More frequent
More intense

Heavy rainfall
More frequent
More intense

Drought
Increase in some regions

Fire weather
More frequent

Ocean
Warming
Acidifying
Losing oxygen

9

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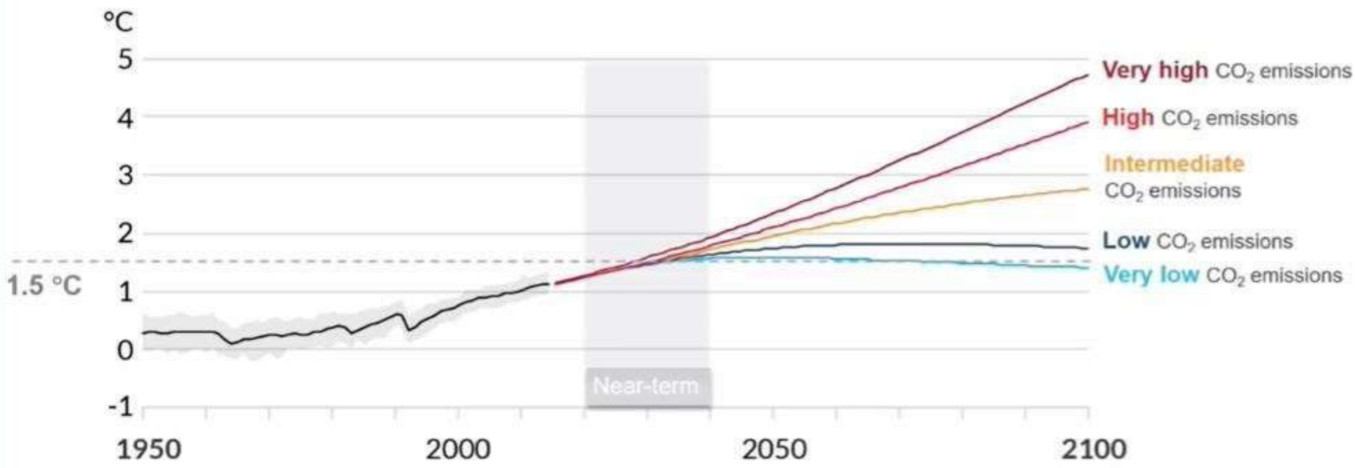
Response of climate system relative to 1850-1900

10

ভবিষ্যতের বিনহাউস গ্যাস বনিঃসরণ অবেবরক্ত উষ্ণো স্বৃি করতি। ম াট বিবিক উষ্ণায়ন
তৌী ে ত্রিং ভবিষ্যতে র কাি্ব- ডাই- অক্সাইড বনিঃসরণ উপরই প্রধানে কভের করতি।

Future emissions cause future additional warming



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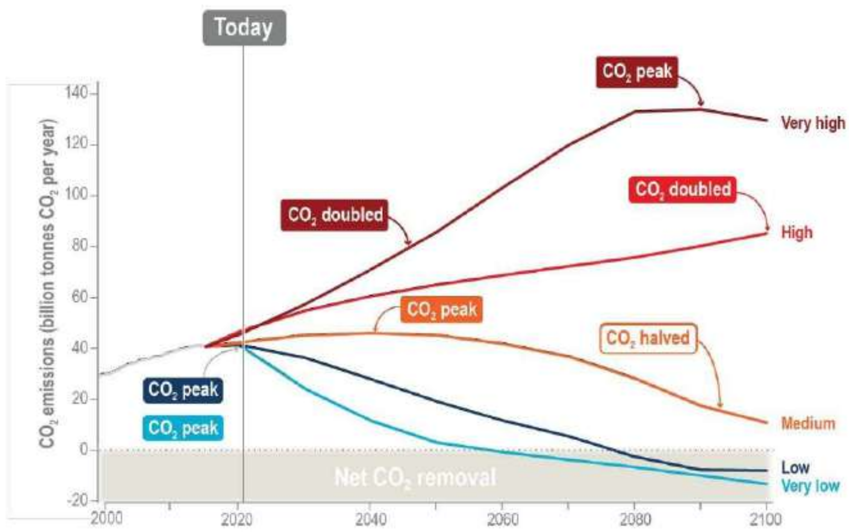
Emission pathways



12

[Credit: Peter John Maridable | Unsplash]

> Unless there are immediate, rapid, and large-scale reductions in greenhouse gas emissions, limiting warming to 1.5°C will be beyond reach.

গ্রিনহাউস গ্যাস গ্রনিঃসরণহ্রাস অগ্রিলম্বে, দ্রুত গ্রিং
িযাপক আকাম্বরনা করা পর্শ্তয , উষ্ণতা িৃদ্ধিম্বক
১.৫ গ্রিগ্রিস্সলগ্রসযাঙ্কসসী মা ি ি করা নাগ্ াম্বলর
িিইম্বর
থাকম্বি।

INTERGOVERNMENTAL PANEL ON climate change

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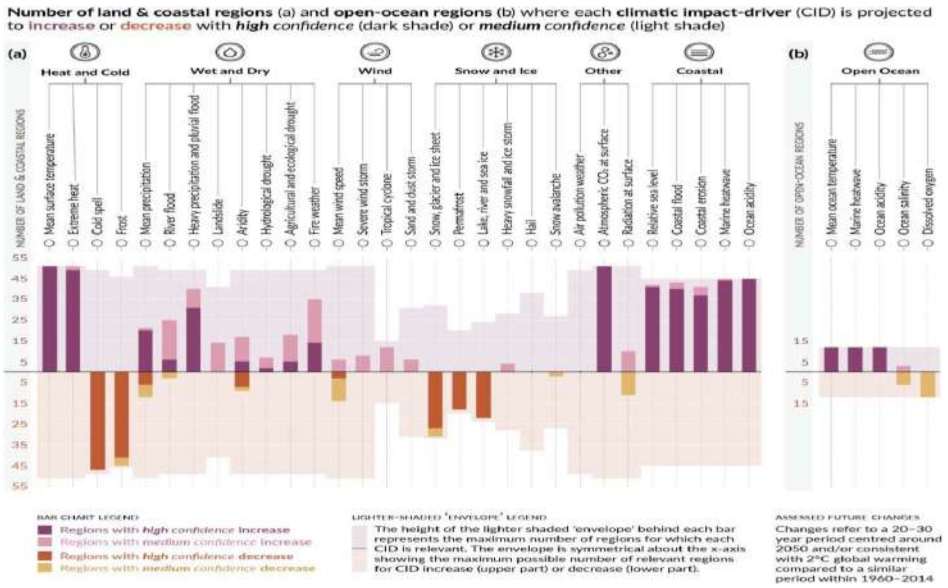
INTERGOVERNMENTAL PANEL ON climate change

Projected changes of CIDs for all regions



SPM.9, WGI, AR6

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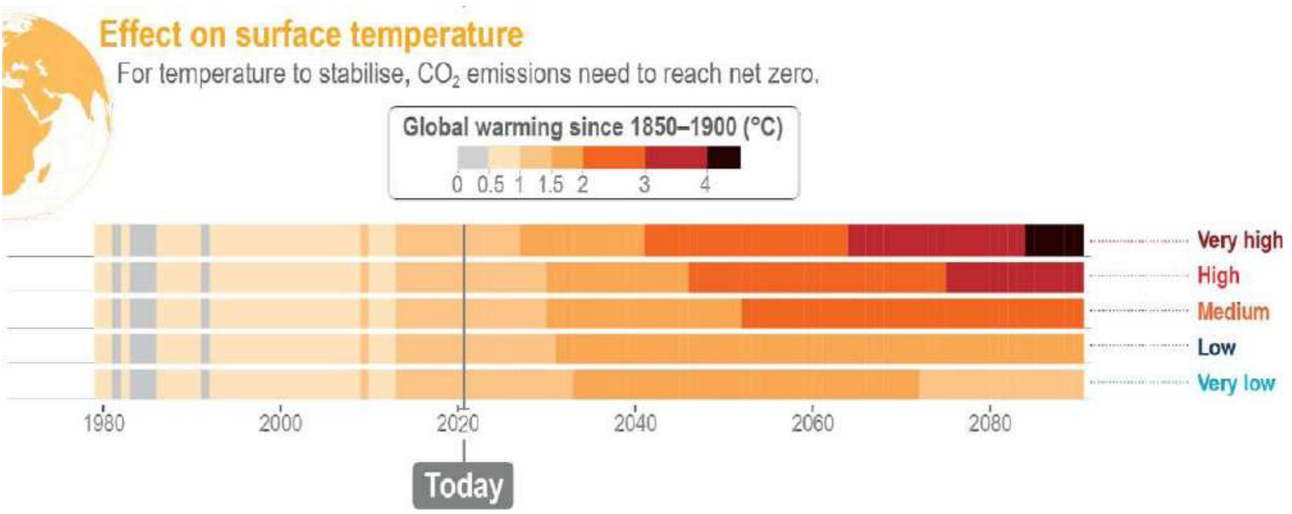
Effect on Surface Temperature



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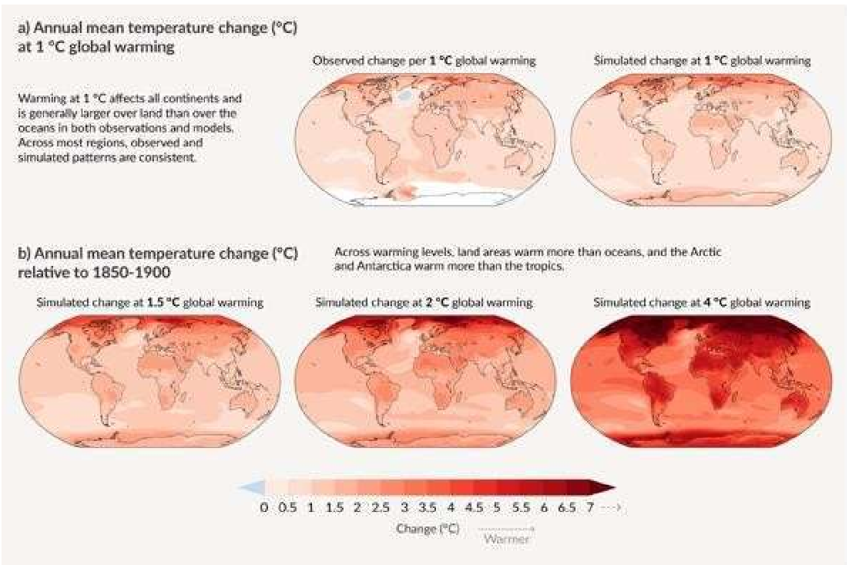
With every increment of global warming, changes get larger in regional mean temperature, precipitation and soil moisture

Figure SPM.5



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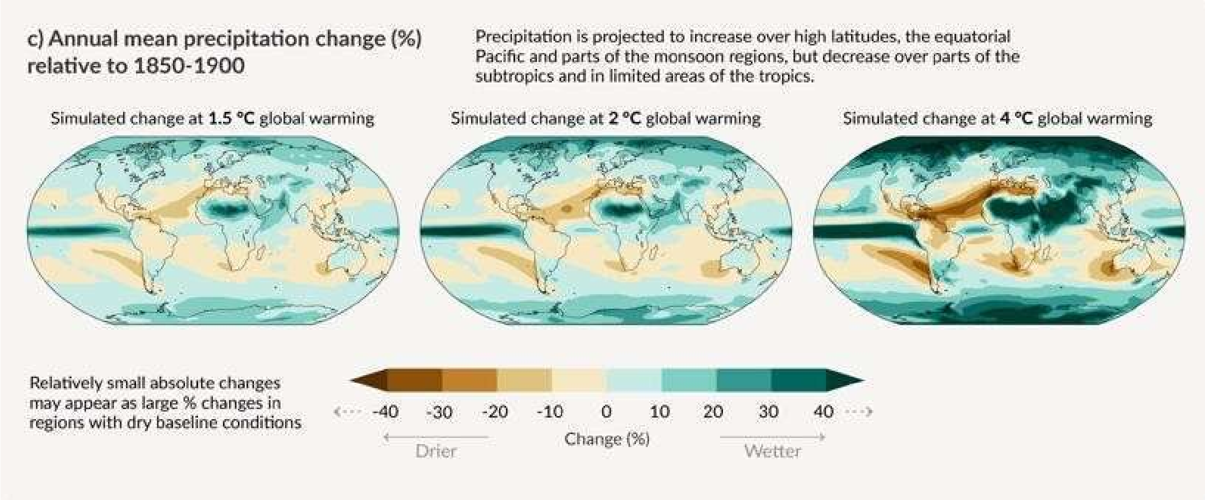
With every increment of global warming, changes get larger in regional mean temperature, precipitation and soil moisture

Figure SPM.5



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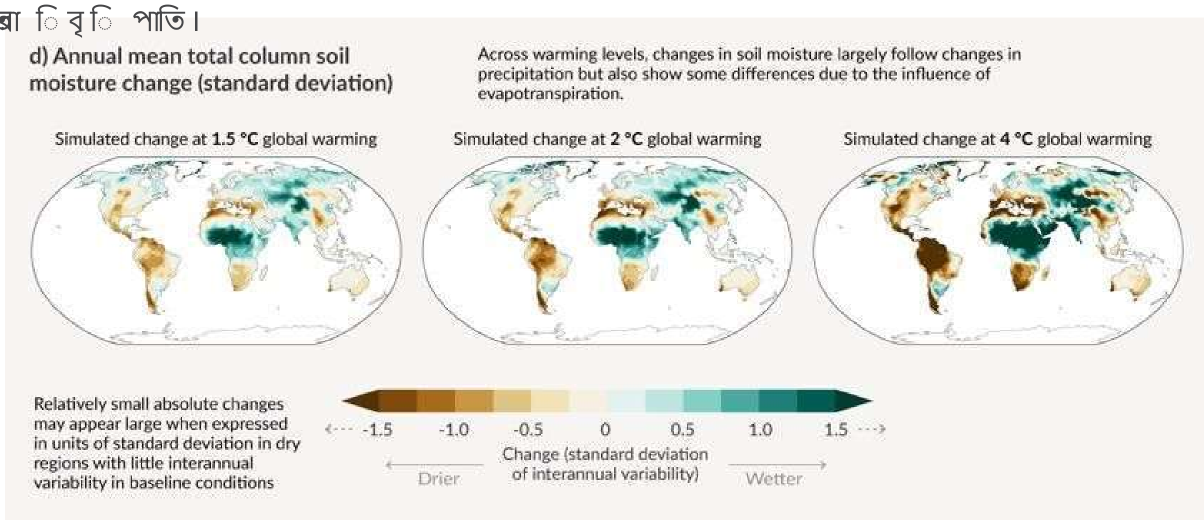
With every increment of global warming, changes get larger in regional mean temperature, precipitation and soil moisture

Figure SPM.5

বিবিক উষ্ণো প্রবেবডবি িৃবির সাতে সাতে আঞ্চবিক গড় েোপ োত্রা, িৃবিপাতে এিং াটির আর্দ্র
েোর পবরিেবন
আরো িবৃি পাতি।



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Response of climate system relative to 1850-1900

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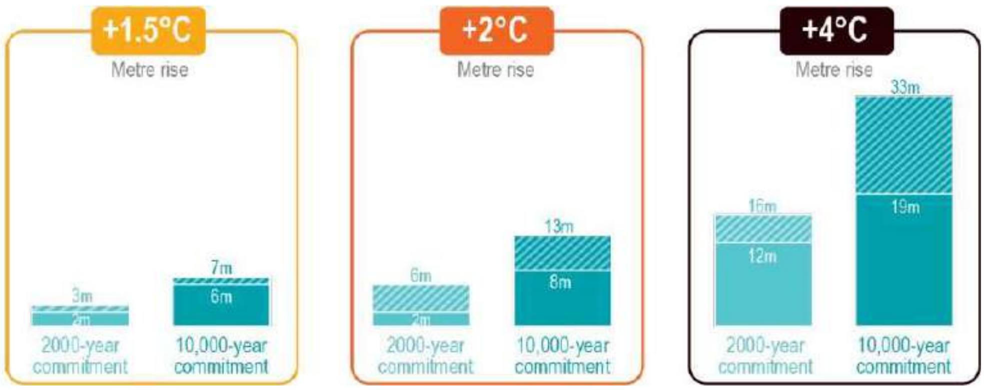
Long-term consequences : Sea level rise

Today, sea level has already increased by 20 cm and will increase an additional 30 cm to 1 m or more by 2100, depending on future emissions.

Sea level reacts very slowly to global warming so, once started, the rise continues for thousands of years.



20

[Credit: Yoda Adaman | Unsplash]

"It is indisputable that human activities are causing climate change, making extreme climate events, including heat waves, heavy rainfall, and droughts, more frequent and severe.

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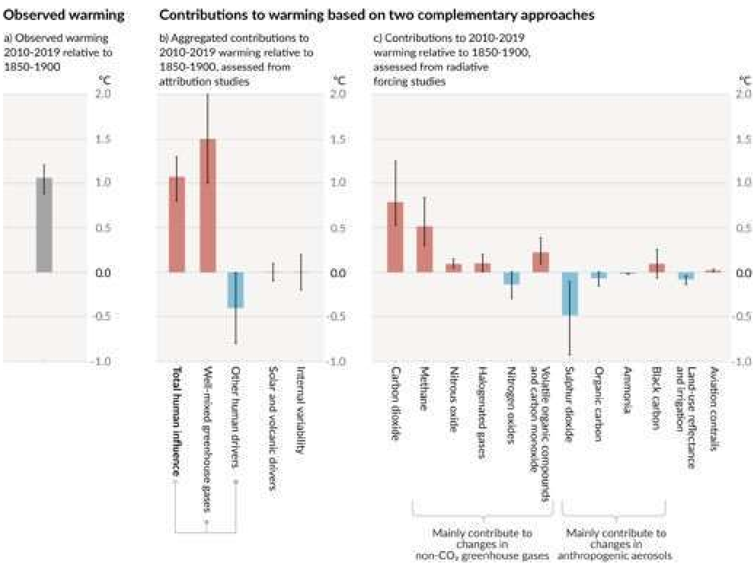
WMO UNEP

Observed warming is driven by emissions from human activities, with greenhouse gas warming partly masked by aerosol cooling

Figure SPM.2



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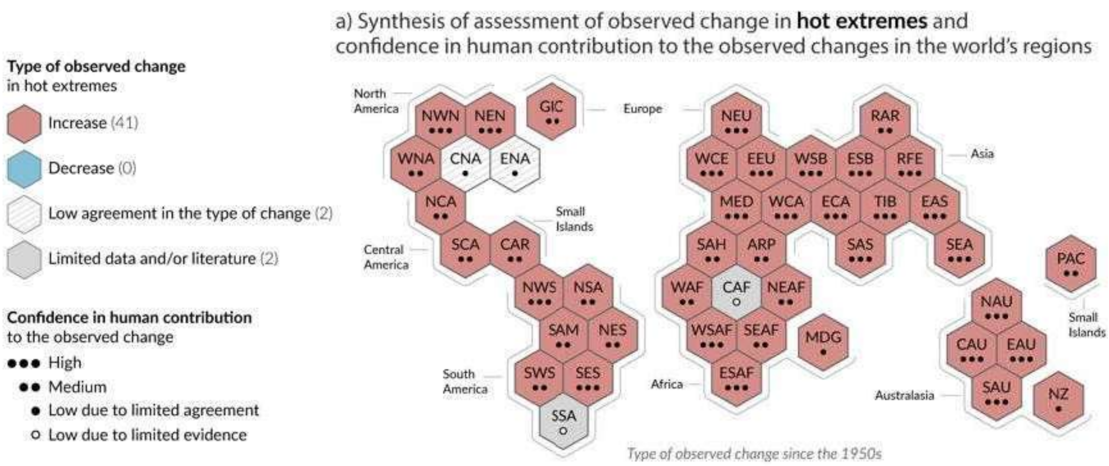
Climate change is already affecting every inhabited region across the globe, with human influence contributing to many observed changes in weather and climate extremes

Figure SPM.3



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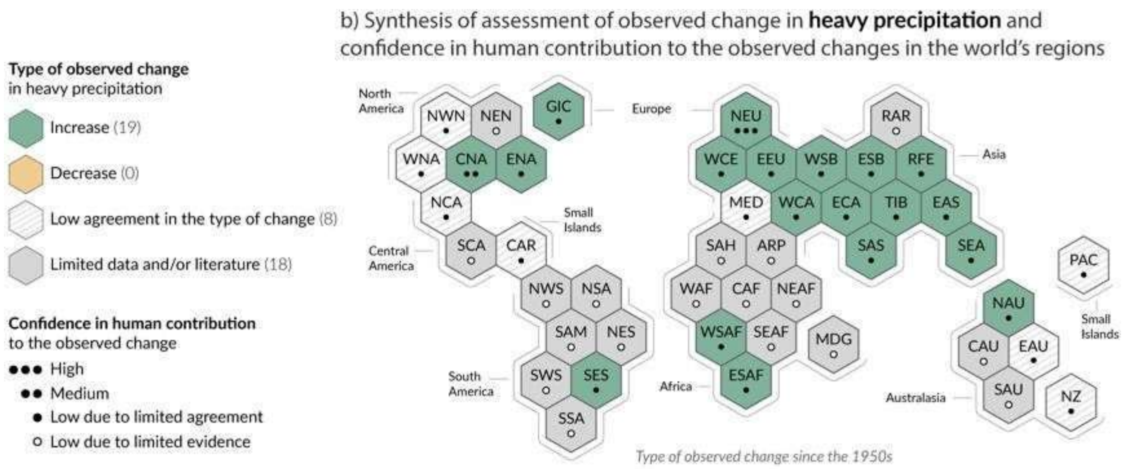
Climate change is already affecting every inhabited region across the globe, with human influence contributing to many observed changes in weather and climate extremes

Figure SPM.3



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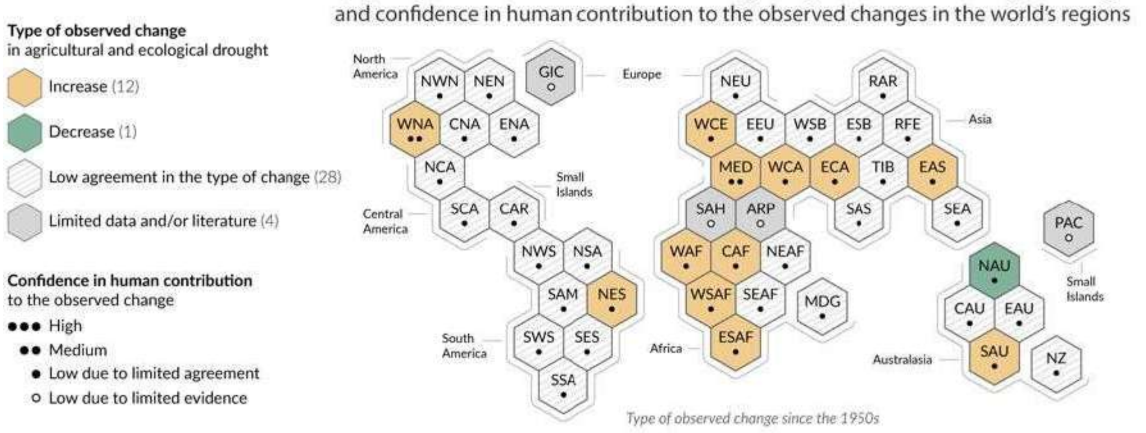
Climate change is already affecting every inhabited region across the globe, with human influence contributing to many observed changes in weather and climate extremes

Figure SPM.3

c) Synthesis of assessment of observed change in **agricultural and ecological drought** and confidence in human contribution to the observed changes in the world's regions



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Climatic impact-drivers

Heat & cold | Rain & drought | Snow & ice | Wind | Coastal & oceanic | Other | Open ocean

A **climatic impact-driver** could go over **thresholds** known to lead to **severe** consequences for people, agriculture, or wildlife

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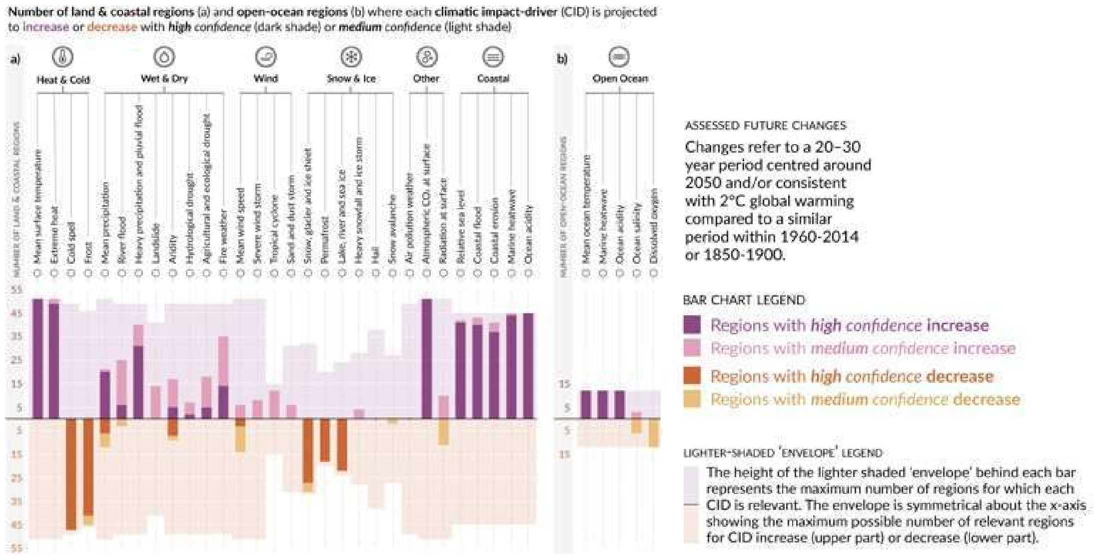
Multiple climatic impact-drivers are projected to change in all regions of the world

Figure SPM.9

একাধক জিিায়ু প্রভািকি এর পবরিেবন বিতির স স্তঅঞ্চত্তিপবরিবিে হতে পাত্র।



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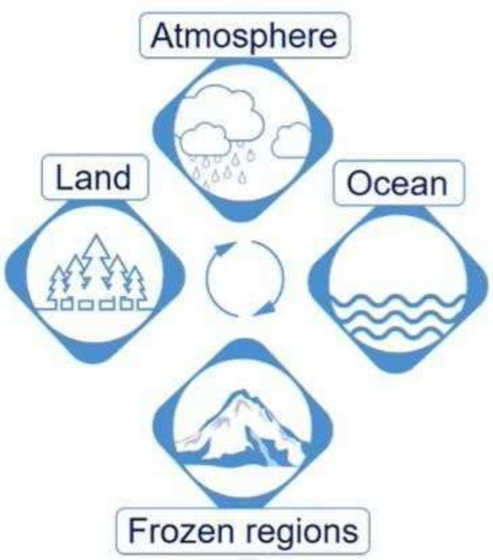
Changes to the Water cycle



With warmer temperature

- Atmosphere can hold more water
- More and faster evaporation
- Heavier precipitation
- Intensifying dry seasons and droughts

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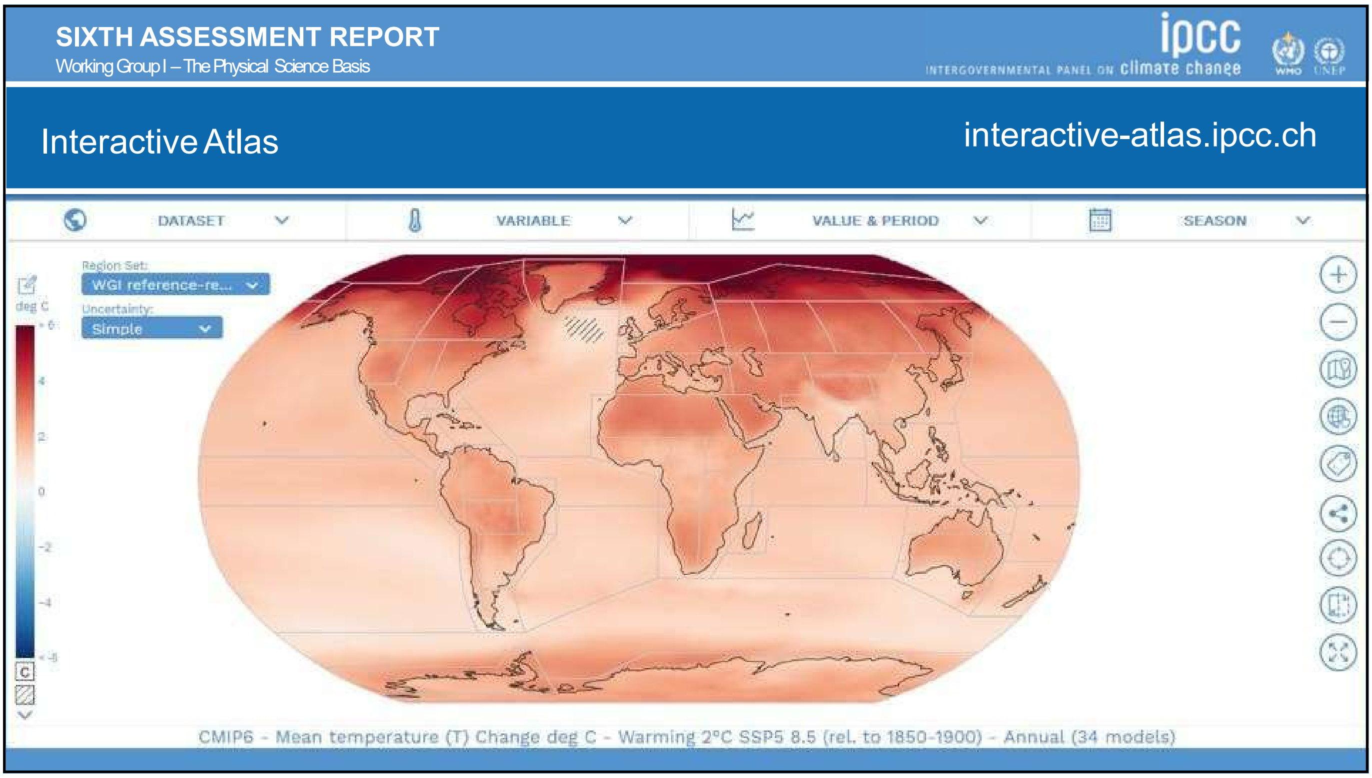
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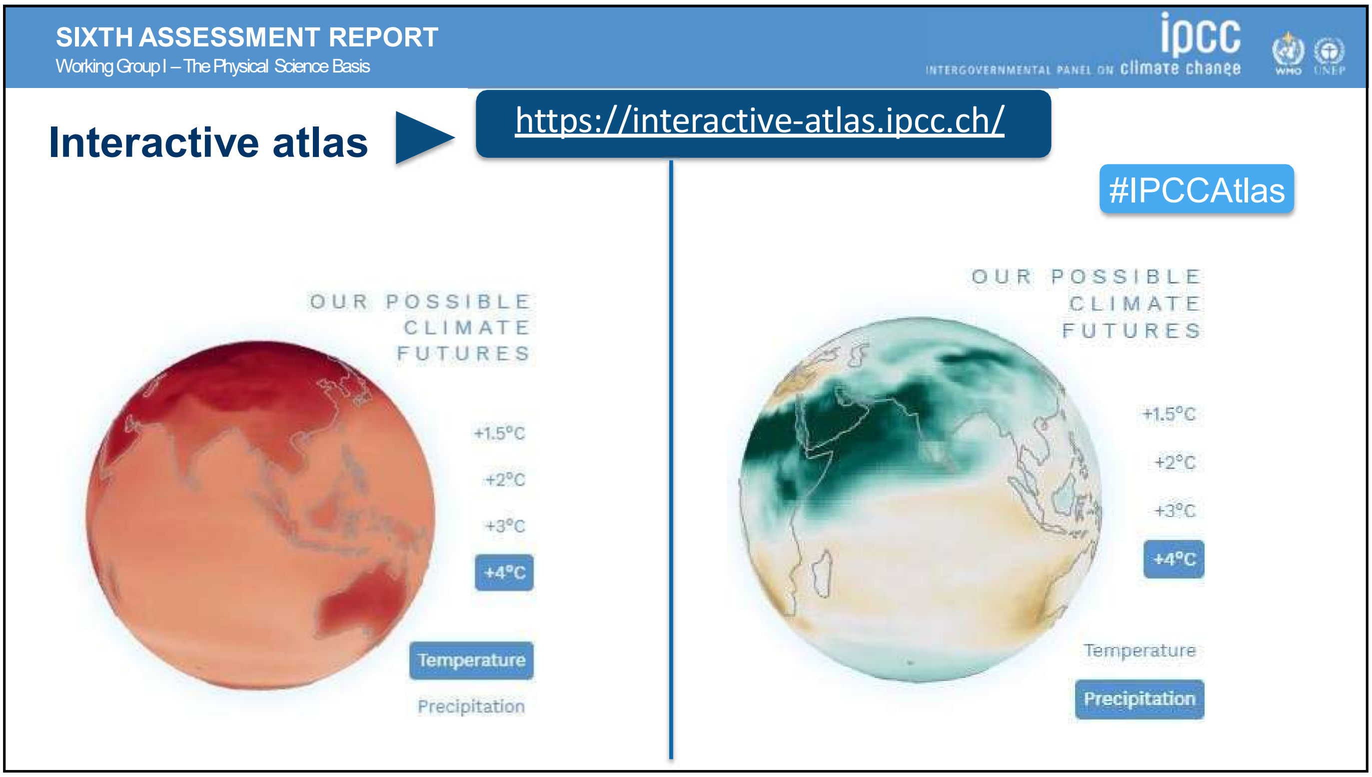
Interactive Atlas
interactive-atlas.ipcc.ch
DATASET
VARIABLE
VALUE & PERIOD
SEASON
Region Set:
WGI reference-re...
Uncertainty:
Simple
deg C
CMIP6 - Mean temperature (T) Change deg C - Warming 2°C SSP5 8.5 (rel. to 1850-1900) - Annual (34 models)

29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Interactive atlas
https://interactive-atlas.ipcc.ch/
#IPCCAtlas
OUR POSSIBLE CLIMATE FUTURES
+1.5°C
+2°C
+3°C
+4°C
Temperature
Precipitation
OUR POSSIBLE CLIMATE FUTURES
+1.5°C
+2°C
+3°C
+4°C
Temperature
Precipitation

30

[Credit: Hong Nguyen | Unsplash]

Climate change is already affecting every region on Earth, in multiple ways.

The changes we experience will increase with further warming.

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[Credit: Jenn Caselle | UCSB]

There's no going back from some changes in the climate system…

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Ocean and ice sheets

Ocean temperature

Increasing

Greenland Ice Sheet

Melting

Sea level

Rising

33

[Credit: Andy Mahoney | NSIDC]

“…However, some changes could be slowed and others could be stopped by limiting warming.

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“There’s no going back from some changes in the climate system. However, some changes could be slowed and others could be stopped by limiting warming.

[Credit: Shari Gearheard | NSIDC]

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“To limit global warming, strong, rapid, and sustained reductions in CO2, methane, and other greenhouse gases are necessary.

This would not only reduce the consequences of climate change but also improve air quality.

[Credit: Evgeny Nelmin | Unsplash]

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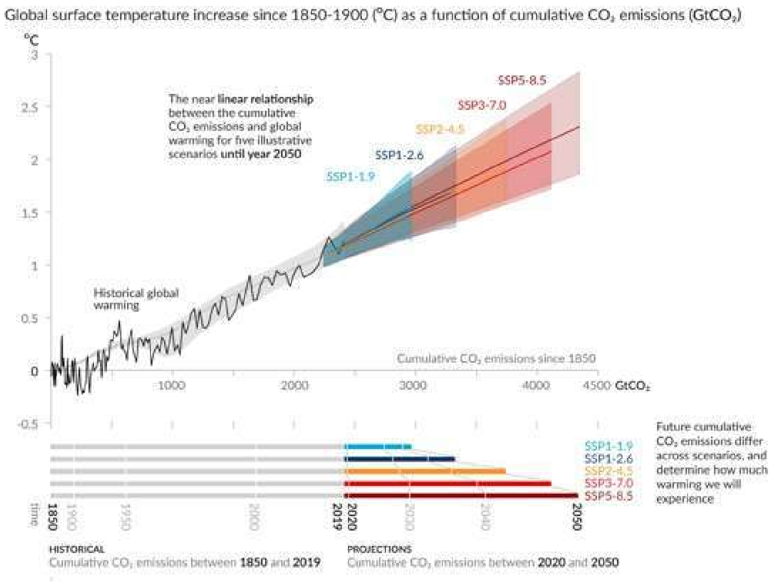
Every tonne of CO_2 emissions adds to global warming

Figure SPM.10



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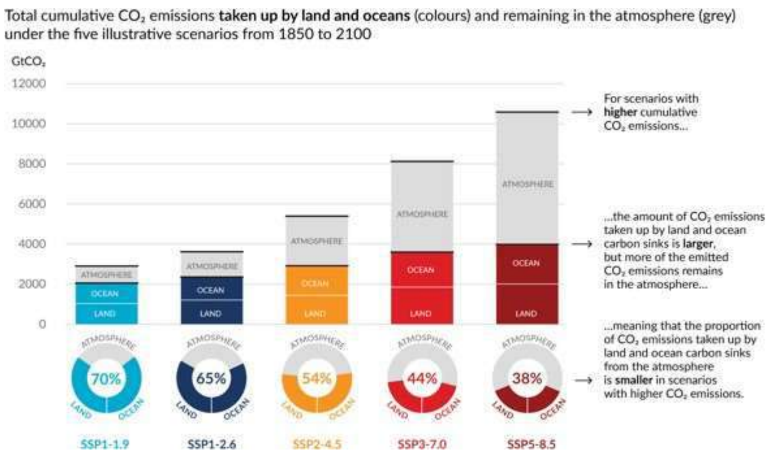
The proportion of CO_2 emissions taken up by land and ocean carbon sinks is smaller in scenarios with higher cumulative CO_2 emissions

Figure SPM.7



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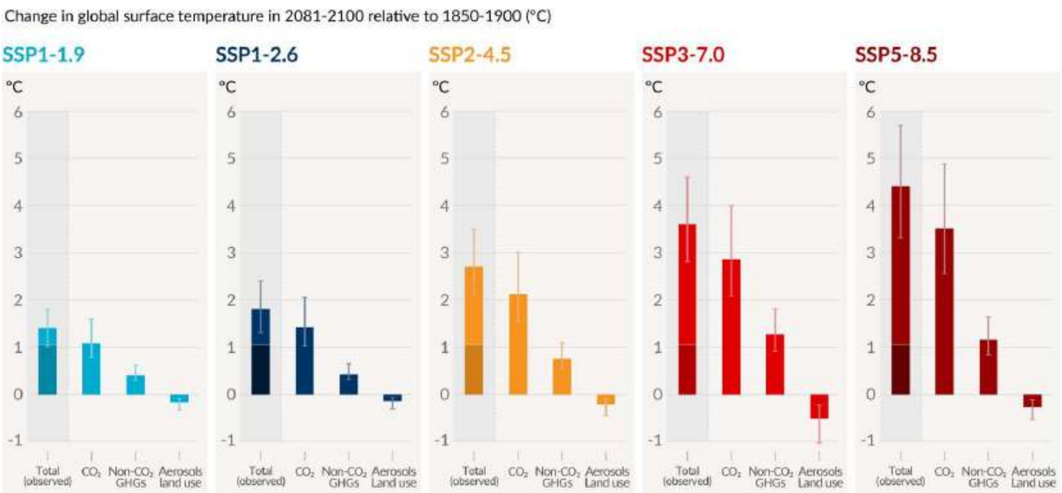
Future emissions cause future additional warming, with total warming dominated by past and future CO_2 emissions

Figure SPM.4



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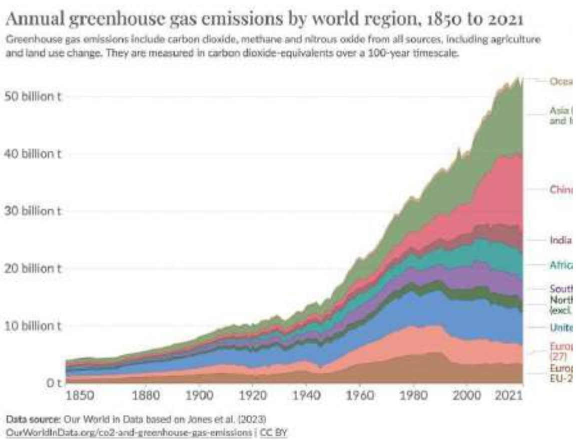
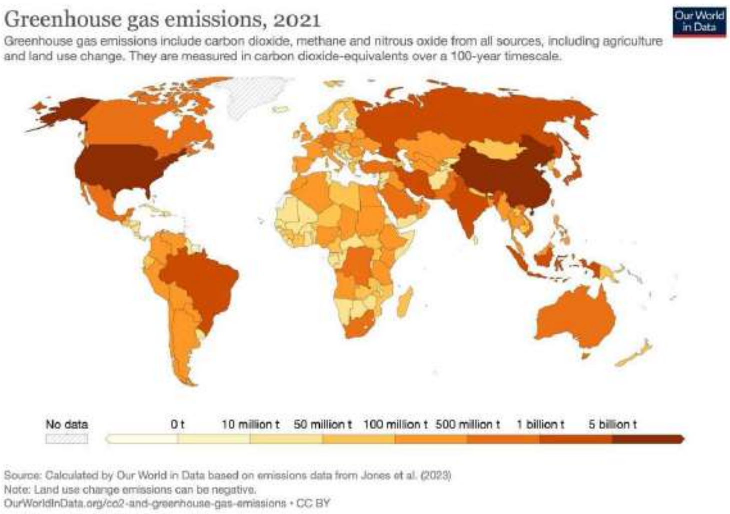
Annual green house gas emissions 2021





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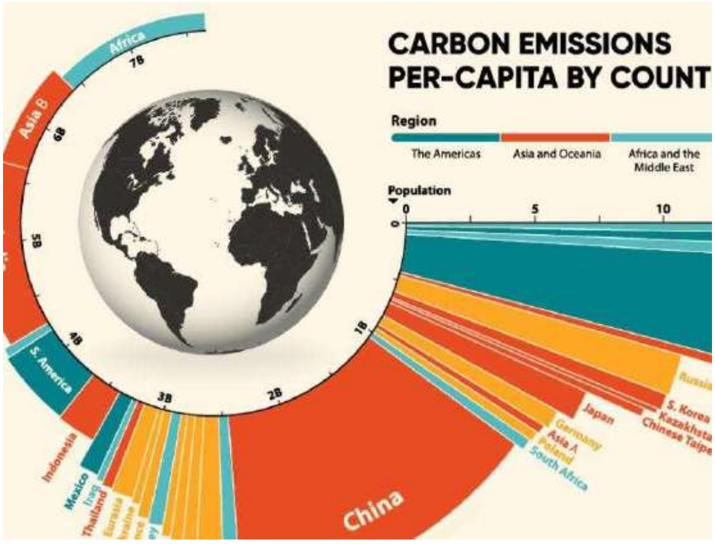
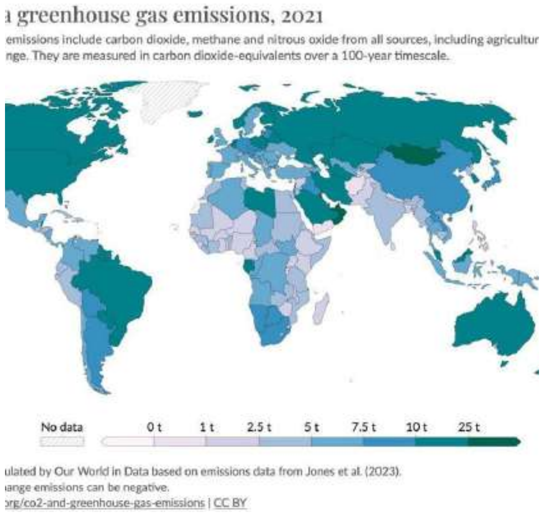
Annual green house gas emissions per capita 2021





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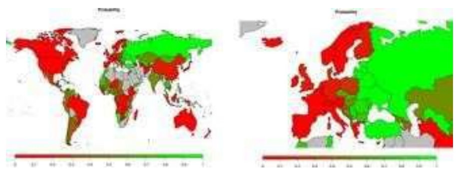
Paris Climate Agreement

- Adopted in 2015, the agreement covers climate change mitigation, adaptation, and finance.
- As of February 2023, 195 members of the United Nations Framework Convention on Climate Change (UNFCCC) are parties to the agreement. Of the three UNFCCC member states which have not ratified the agreement, the only major emitter is Iran. The United States withdrew from the agreement in 2020, but rejoined in 2021.
  - (a) Holding the increase in the **global average temperature to well below 2 °C** above pre-industrial levels and pursuing **efforts** to limit the temperature **increase to 1.5 °C** above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change;
  - (b) Increasing the ability to **adapt to the adverse impacts of climate change** and foster climate resilience and low greenhouse gas emissions development in a manner that does not threaten food production;
  - (c) Making finance flows consistent with a **pathway towards low greenhouse gas** emissions and **climate-resilient development.**
- Under the agreement, each country must determine, plan, and regularly report on its contributions. No mechanism forces a country to set specific emissions targets, but each target should go beyond previous targets

Probability that countries achieve their Paris Agreement Goals according to their nationally determined contributions (NDCs)



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9 August 2021
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IPCC Press Office: ipcc-media@wmo.int
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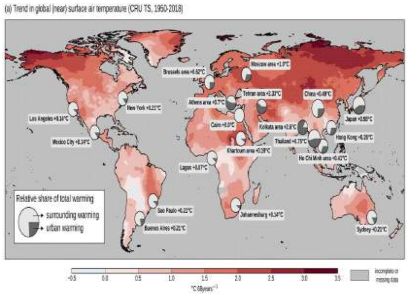
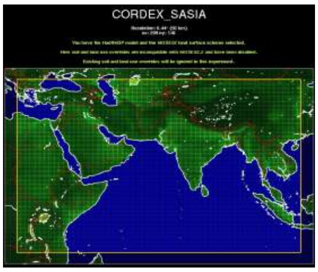
Training Workshop on "Climate Smart Agriculture for Adaptation and Mitigation" Organized by BARC

Impacts of Climate Change on Agriculture and food security





Professor A.K.M. Saiful Islam

Institute of Water and Flood Management (IWFM)
Bangladesh University of Engineering and Technology (BUET)

1

Lecture outline

- Regional Climate Predictions and Modeling (RCM)
- Multi-model Ensemble Regional Climate Projections for Impact studies using CORDEX simulations
- Future Changes in Temperature and Rainfall Extremes
- Future Changes in Metrological Droughts
- Future Changes Flows in GBM River Systems
- Future Changes in cyclones and storm surges
- Future Changes in Permanent Inundation Due to Sea Level Rise
- Future Changes in Water Salinity
- Future Changes in the Boro and Aman Rice yields
- Future Changes in Coastal Erosion

2

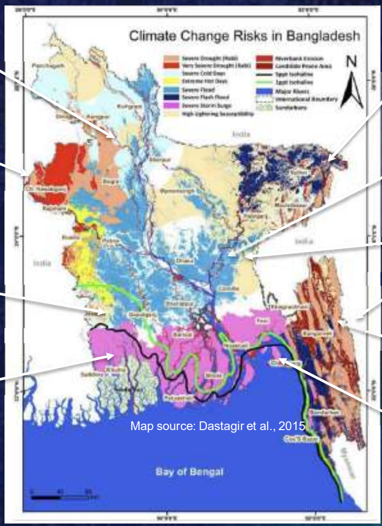
Natural Hazards Expected to Change under Global Warming

Riverine Flood
More intense & frequent

Drought
More frequent & Severe

Salinity
Continue to Increase

Sea level Rise
Continue to Rise



Flash Flood
More severe & frequent

Urban flood
More frequent & intense

Heatwave
Prolonged

Flash flood
More intense

Landslides
Frequent

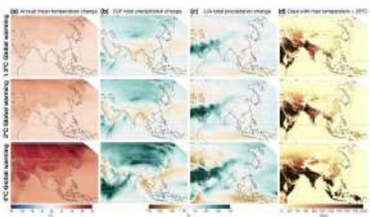
Cyclone, storm surge, tidal flood
Cyclone more intense
Increased Surge

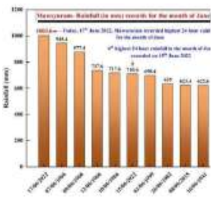
3

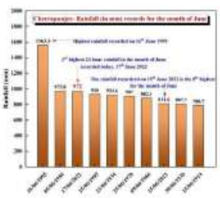
Extreme Events: Floods

Flood in Sylhet in June 2022

- Between 22%-30% of Bangladesh's territory is inundated yearly 45. In 2022, Bangladesh suffered one of th most devastating floods in its history, impacting 7.2 million people. We have seen major floods in 2016, 2017, 2019, 2020, 2022.
- According to IPCC, Precipitation and rivers floods will increase over much of Asia (high to medium confidence).



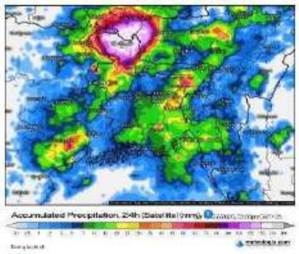


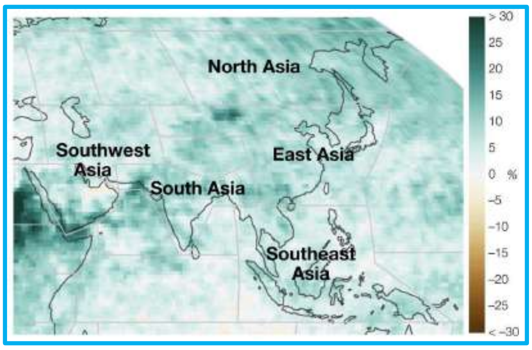


4

Extreme Events: Urban Floods

- According to IPCC, Projected changes in maximum 1-day precipitation at 2ºC global warming under SSP5-8.5
  Scenario relative to the 1995-2014 baseline (From Interactive Atlas).





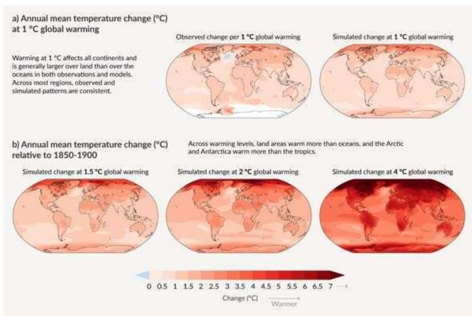
- Highest ever rainfall in 60 years: Rangpur city under knee-deep water on 27 September 2020 of 433mm rainfall is recorded by BMD in 12 hours.

5

Extreme Events: Heatwave

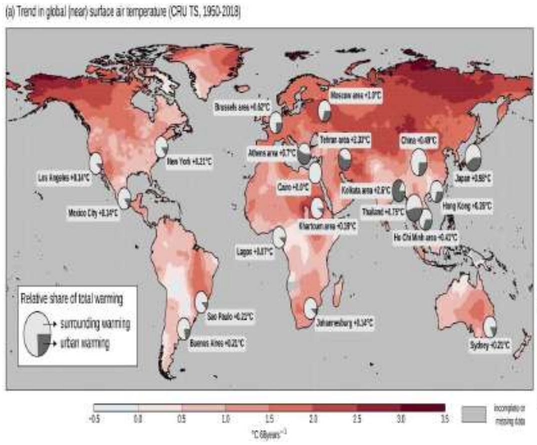
- The number of days per year where temperature exceeds 35°C would increase by more than 150 days in many tropical areas by end of century for SSP5-8.5 scenario, such as the Amazon basin and South East Asia under SSP5- 8.5, while it is expected to increase by less than 60 days in these areas under SSP1-2.6 (except 19 for the Amazon Basin) (high confidence).
- By the end of the 21st century, dangerous humid heat thresholds, such as the NOAA Heat Index (HI) of 41°C, will be exceeded much more frequently under the SSP5-8.5 scenario than under SSP1-2.6 and will affect many regions (high confidence).
- In many tropical regions, the number of days per year where a HI of 41°C is exceeded would increase by more than 100 days relative to the recent past under SSP5-8.5, while this increase will be limited to less than 50 days under SSP1-2.6 (high confidence)

With every increment of global warming, changes get larger in regional mean temperature, precipitation and soil moisture



6

Observed trend in global surface air temperature



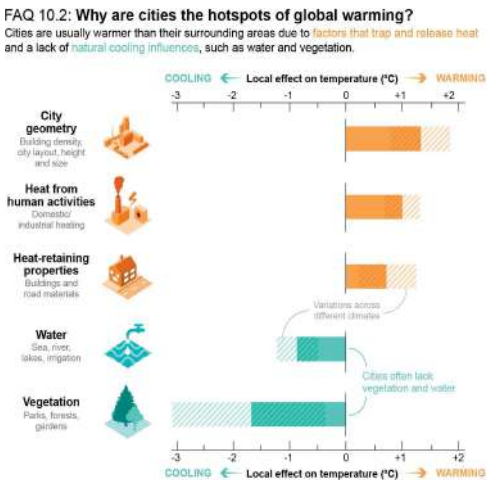
•Despite having a negligible impact on global annual mean surface-air warming (very high confidence), urbanization has exacerbated the effects of global warming in cities (very high confidence).

ipcc

7

Cities under global warming

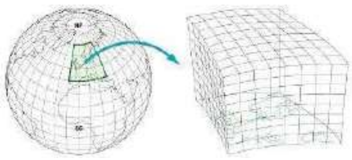
- Urban areas are home to more than fifty percent of the world's population and are the site of most of its built assets and economic activity.
- By 2050, the population in urban areas is expected to increase by 2.5 to 3 billion and comprise two-thirds of the world population.
- For the next three decades, nearly seventy million residents will move to urban areas every year. The majority of these new residents will live in small- to medium-sized cities in the developing world.
- Urban centers and cities are warmer than the surrounding rural areas due to what is known as the *urban heat island effect*.
- This urban heat island effect results from several factors, including reduced ventilation and heat trapping due to the close proximity of tall buildings, heat generated directly from human activities, the heat-absorbing properties of concrete and other urban building materials, and the limited amount of vegetation.
- The difference in observed warming trends between cities and their surroundings can partly be attributed to urbanization.

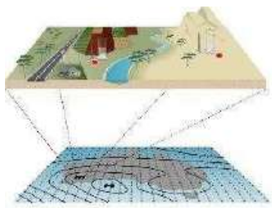


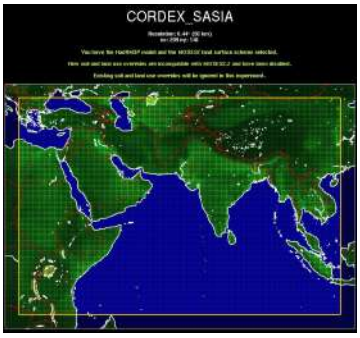
ipcc

8

Regional Climate Modeling (RCM) for Bangladesh over CORDEX: South Asia







- GCM provides output more than 150km resolution which is not enough to capture mesoscale processes.
- RCM daily output with horizontal resolution 50km are available for South Asia CORDEX domain.
- Predictions are considered for extreme emission scenarios, RCP 8.5
- Climate output data have been bias corrected.

Fahad et al. (2016)

9

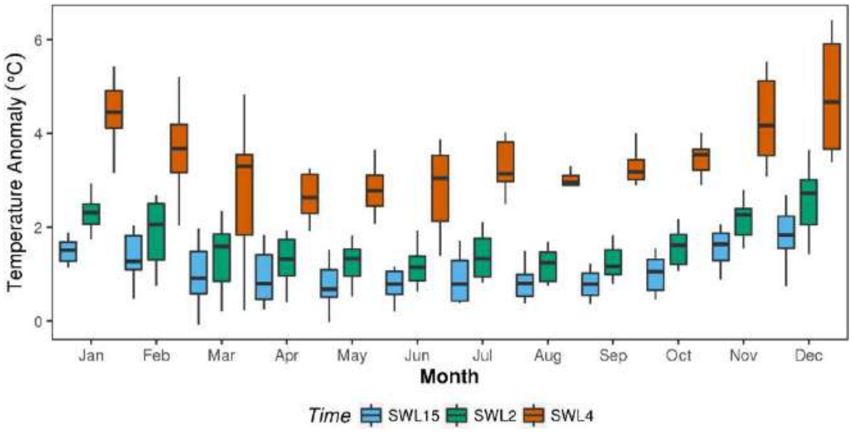
RCM Projections using CIMP5 data

GCM	Ensemble	RCM	RCP8.5 (Year of Crossing)		
			SWL 1.5	SWL 2	SWL 4
ACCESS1-0	r1i1p1	CSIRO-CCAM-1391M	2034	2046	2085
CCSM4	r1i1p1	CSIRO-CCAM-1391M	2016	2031	2079
CNRM-CM5	r1i1p1	SMHI-RCA4	2032	2046	2088
CNRM-CM5	r1i1p1	CSIRO-CCAM-1391M	2032	2046	2088
EC-EARTH	r12i1p1	SMHI-RCA4	2019	2035	2083
CM5A-MR	r1i1p1	SMHI-RCA4	2020	2034	2069
MIROC5	r1i1p1	SMHI-RCA4	2038	2052	-
MPI-ESM-LR	r1i1p1	CSIRO-CCAM-1391M	2021	2040	2083
MPI-ESM-LR	r1i1p1	MPI-CSC-REMO2009	2021	2040	2083
MPI-ESM-LR	r1i1p1	SMHI-RCA4	2021	2040	2083
GFDL-ESM2M	r1i1p1	SMHI-RCA4	2040	2055	-

Specific Warming Levels (SWLs)
It is the mean annual global temperature increase by the end of the century related to preindustrial period (1880). Paris Agreement in 2015 emphasis on reducing GHGs to keep the increase of global mean temperature below 2C and effort should be made to reduce further to 1.5C with respect to pre-industrial period.

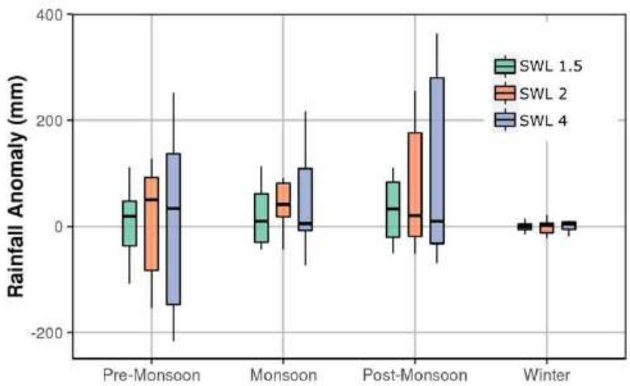
10

Changes of mean monthly temperature over Bangladesh at SWLs



11

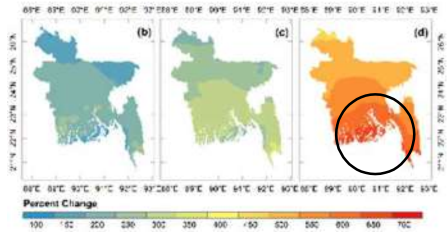
Changes of mean seasonal rainfall over Bangladesh at SWLs



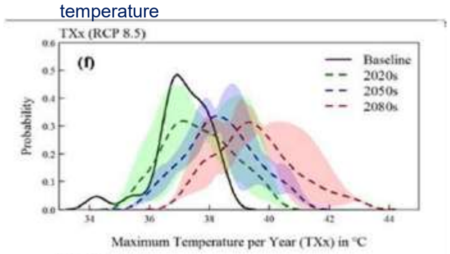
12

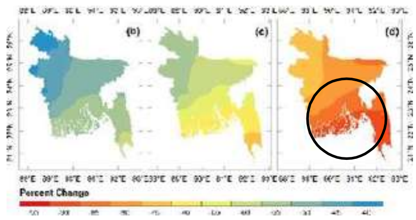
Temperature extremes are increasing – heatwave and health stress will be more intense and frequent

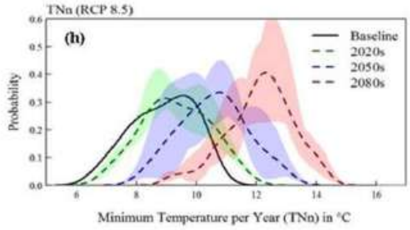
TX90P – Percentage of days when maximum temperature is higher than 90th percentile value.



TXx- maximum of daily maximum temperature







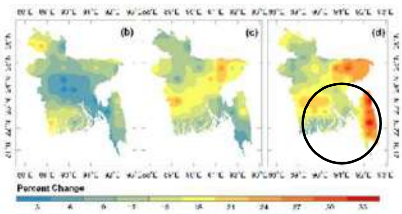
TX10P- Percentage of days when maximum temperature is lower than 10th percentile value

TNn- minimum of daily minimum temperature

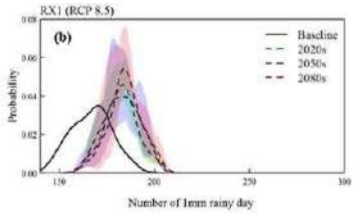
13

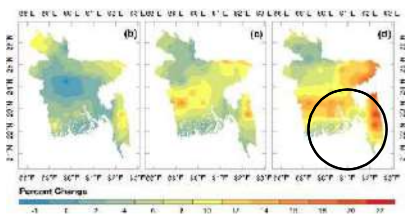
Changes of Extreme Rainfall - more flash floods and landslides are expected

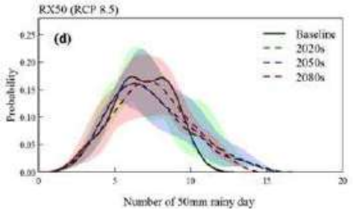
Rx1- maximum 1-day rainfall



Rx1- maximum 1-day rainfall







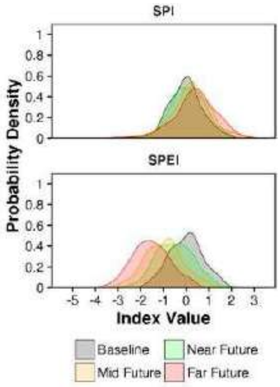
Rx50- number of days when rainfall > 50mm

Rx50- number of days when rainfall > 50mm

14

Changes of Meteorological Droughts

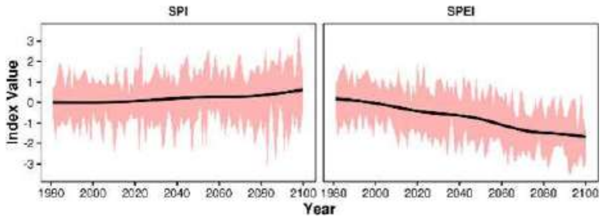
Standard Precipitation Index (SPI) and Standard Precipitation and Evapotranspiration Index (SPEI)



Density distribution of SPI and SPEI values at 3 Month time-scale.

Both SPI and SPEI are calculated relative to a baseline period of 1981 to 2010.

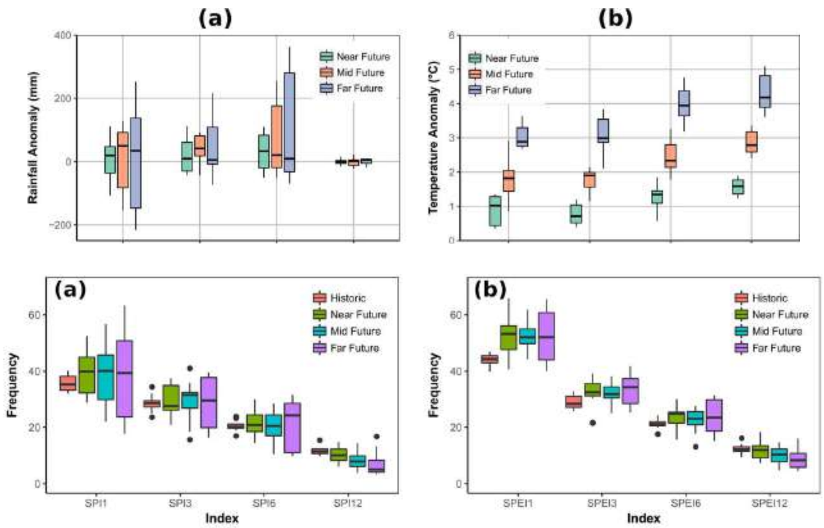
Drought Category	SPI/SPEI Values
No drought	0 ≤ Index
Near normal/Mild drought	-1.0 < Index < 0
Moderate drought	-1.5 < Index ≤ -1.0
Severe drought	-2.0 < Index ≤ -1.5
Extreme drought	Index ≤ -2.0



Ensemble time series of SPI (left panel) and SPEI Throntwhie (right panel) at 12-month timescale averaged over the country. The red patch is the ensemble spread of the index values.

15

Changes of droughts for different SWL

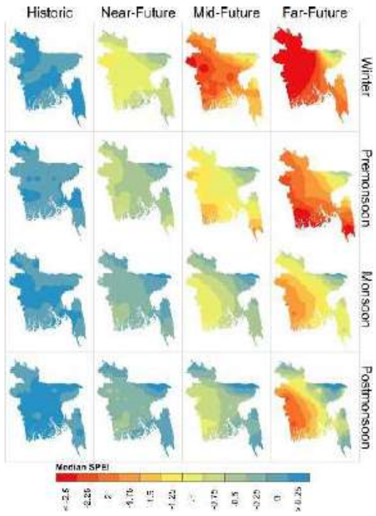


Projected future median SPEI values over Bangladesh from 11 ensemble of Regional Climate Model (RCM).

16

Spatial Changes of Meteorological Droughts

- Inclusion of evapotranspiration in the evaluation of drought is important in the context of global warming.
- The country is expected see more and more deviation from the climatic mean condition.
- At the end of the century, the climate of the country may settle to a condition which may be considered “moderate drought” compared to current climate.
- Long meteorological drought will impact the agriculture and socio-economic condition.

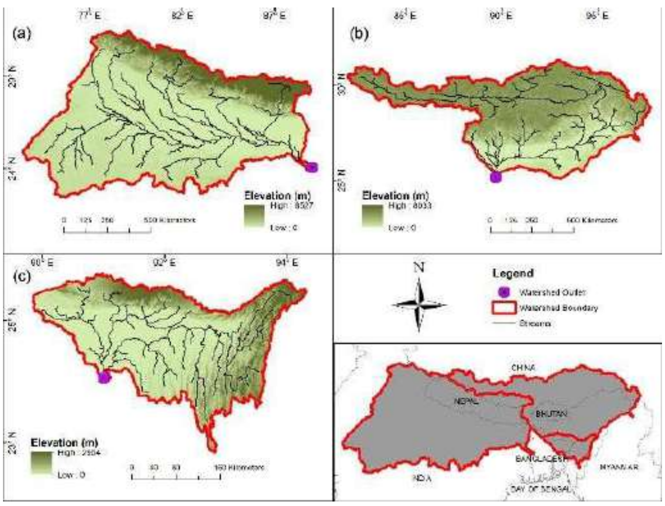


Percentage of area affected with

17

Ganges-Brahmaputra-Megha Basins

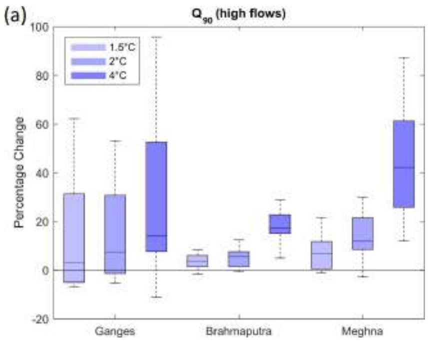
The GBM basins are located over India (64%), China (18%), Nepal (9%), Bangladesh (7%) and Bhutan (3%), and the elevation of the basins range from about 0 to above 8000 m above mean sea level (amsl).



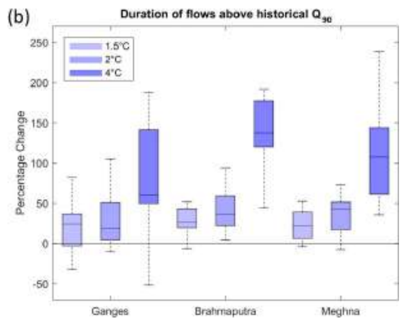
18

High flows and flood duration will be more increasing in the future

Q90 Flow



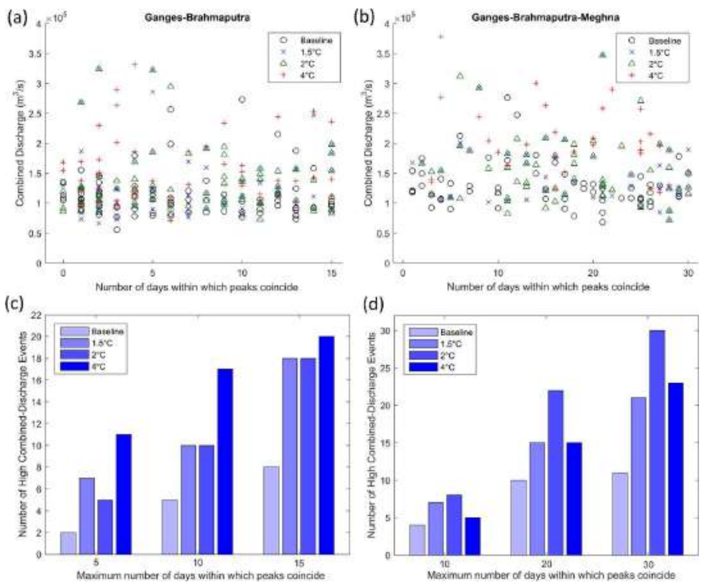
Duration of Q90



The ensemble-median values of the changes of Q90 flow at 1.5°C, 2°C, and 4°C are about 3%, 7%, and 14% for the Ganges; 4%, 5%, and 22% for the Brahmaputra; and 9%, 12%, and 42% for the Meghna, respectively

19

Peak synchronization of GBM Rivers

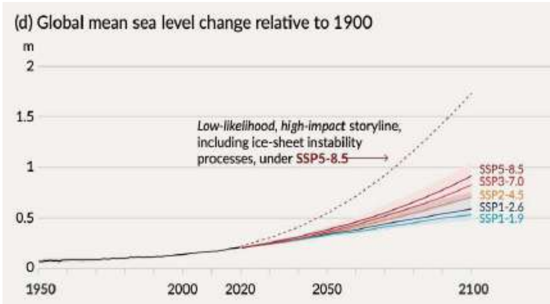


20

Extreme Events: Sea Level Rise

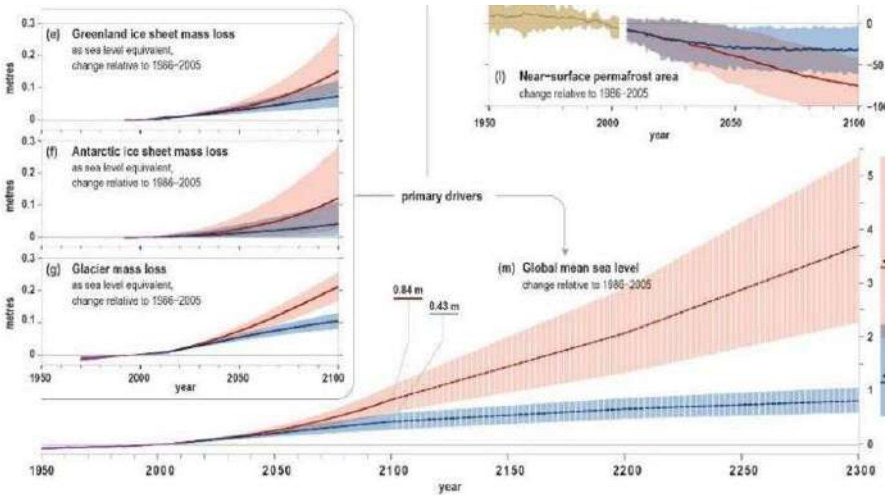
- Over the 21st century, the majority of coastal locations have a median projected regional sea level rise within ± 20% of the projected GMSL change (*medium confidence*).
- Relative sea level rise is very likely to virtually certain (depending on the region) to continue during the 21st century, contributing to increased coastal flooding in low-lying areas (high confidence) and coastal erosion along most sandy coasts (high confidence).
- Sea level will continue to rise beyond 2100 (high confidence)

It is virtually certain that the Global Mean Sea Level (GMSL) will continue to rise over the 21st century in response to continued warming of the climate system, and GMSL will continue to rise for centuries to millennia due to continuing deep ocean heat uptake and mass loss from ice sheets (high confidence).



21

Projected Ice loss and SLR

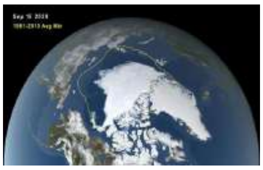


22

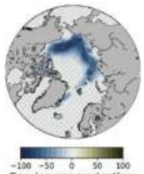
Sea Level Rise

- Bangladesh has been experiencing a rising trend in sea level because of its geographic location and the nature of the delta. Recent estimation of sea-level rise by DoE (2020) indicated the rising trends at different locations of the coastal zone of Bangladesh.
- Between 1901 and 2010 sea level has risen at a rate of 1.7mm/year. From 1993 to 2010, tidal variation indicates a rise of 2.8±0.8mm/year, and it is further validated by satellite altimetry data with a rise of 3.2±0.4mm/year.
- Ocean warming is a global phenomenon due to climate change. The Bay of Bengal is also experiencing increasing sea surface temperature and subsequent changes in pH (Sridevi et al., 2021).

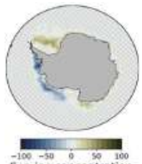
Sea ice in the Arctic

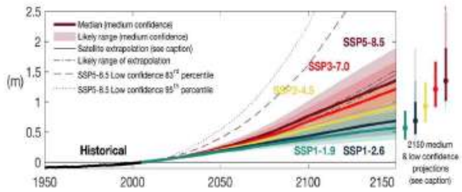


Lowest level in at least 1000 years



Sea ice in the Antartic



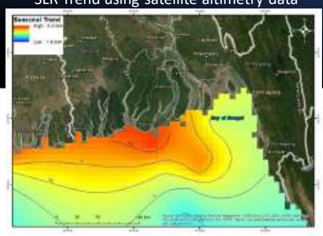


23

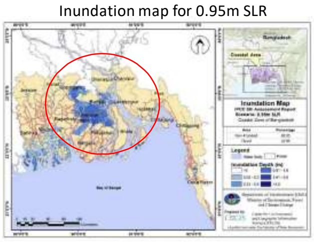
Permanent Inundation due to SLR

- A recent study of DOE (2022) using coastal model simulations for the four sea level rise scenarios (0.50m SLR, 0.62m SLR and 0.95m SLR) have been analysed for potential inundation in the coastal areas of Bangladesh.
- From the analysis, it can be seen that, sea level rise induced flooding will cover 12.3%, 15.5%, and 18% areas of the coastal zone for SLR scenarios of 0.50m SLR, 0.62m SLR and 0.95m SLR, respectively.
- Figure shows inundation map for 0.95m SLR. But the major part of inundation will be in the districts of Barisal, Jhalokati, Pirojpur, Gopalganj and Patuakhali. These districts are affected from the SLR as they do not have comprehensive flood protection system.
- The areas flooded are mostly inner coastal areas that are not protected by polders. So, the flood protection for these areas should be considered as a priority for the future climate change scenario.

SLR Trend using satellite altimetry data



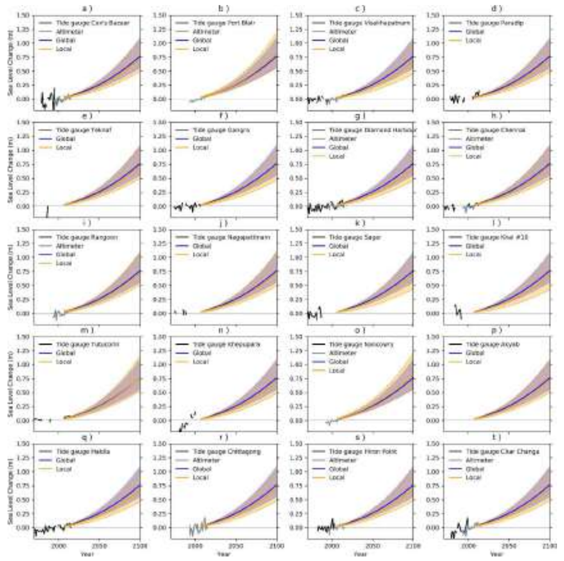
Inundation map for 0.95m SLR



24

21st century sea level projections for RCP8.5 at tide gauge locations in the Bay of Bengal (ARRCC, 2020)

21st century sea level projections for RCP8.5 at tide gauge locations in the Bay of Bengal (ARRCC, 2020)

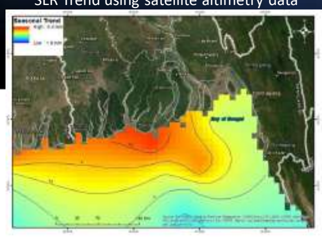


2081-2100	RCP2.6	RCP4.5	RCP8.5
Coxs Bazaar	0.17-0.62	0.3-0.68	0.4-0.86
Port Blair	0.24-0.66	0.34-0.73	0.45-0.92
Visakhapatnam	0.16-0.6	0.27-0.68	0.39-0.84
Paradip	0.16-0.6	0.28-0.67	0.39-0.84
Teknaf	0.17-0.62	0.29-0.68	0.4-0.85
Gangra	0.15-0.6	0.28-0.66	0.38-0.83
Dmnd Harbour	0.14-0.58	0.26-0.64	0.37-0.81
Chennai	0.19-0.62	0.29-0.71	0.43-0.89
Rangoon	0.19-0.62	0.29-0.69	0.41-0.86
Nagapattinam	0.2-0.61	0.3-0.71	0.42-0.89
Sagar	0.16-0.57	0.24-0.68	0.33-0.89
Khal Ten	0.2-0.55	0.25-0.66	0.34-0.89
Tuticorin	0.24-0.6	0.31-0.71	0.45-0.93
Khepupara	0.16-0.61	0.28-0.67	0.39-0.84
Nancowry	0.24-0.66	0.34-0.73	0.46-0.92
Akyab	0.18-0.62	0.29-0.68	0.41-0.85
Haldia	0.14-0.58	0.26-0.64	0.37-0.81
Chittagong	0.17-0.62	0.29-0.68	0.41-0.86
Hiron Point	0.15-0.61	0.28-0.67	0.39-0.84
Moulmein Two	0.22-0.59	0.28-0.7	0.37-0.92
Charchanga	0.16-0.6	0.28-0.67	0.39-0.84
Ko Taphao Noi	0.22-0.65	0.33-0.73	0.44-0.91

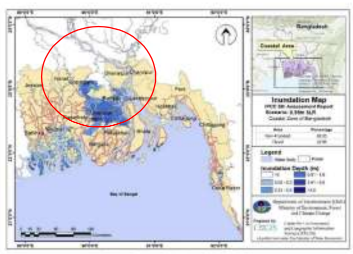
25

Permanent Inundation due to SLR

SLR Trend using satellite altimetry data



Inundation map for 0.95m SLR



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26

Ocean and ice sheets

Ocean temperature

Increasing

Greenland Ice Sheet

Melting

Sea level

Rising

27

Beyond 2050, sea level projections are increasingly sensitive to emissions

NASA Operation IceBridge / October 2012
Thwaites Ice Shelf, Antarctica

AR6 WGI SPM, Box TS.4. Ch9

•**The *likely* global mean sea level rise is**

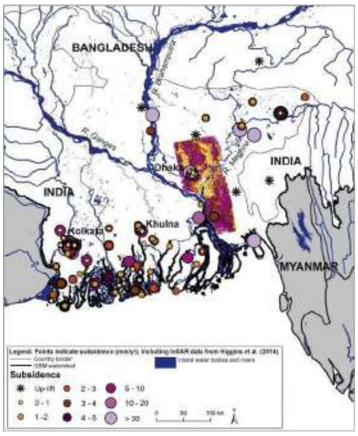
•**by 2100:**
- about 0.6-0.9 m under a high emissions scenario (SSP3-7.0)
- about 0.3-0.6 m under a low emissions scenario (SSP1-2.6)

•**by 2150:**
- about 1.0-1.9 m under a high emissions scenario (SSP3-7.0)
- about 0.5-1.0 m under a low emissions scenario (SSP1-2.6)

28

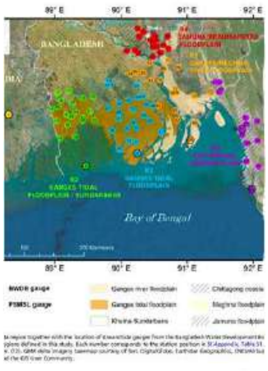
Rates of subsidence recorded from the literature for the GBM delta

- Subsidence reported in this recent time, has a higher rate (8.8 mm/yr) than measurements over much longer time periods (as little as 1.2 mm/yr).
- However, the standard deviation of the results increases in more recent time, compared with long-term records, indicating a greater variability and spread in results.



Brown et al., 2015

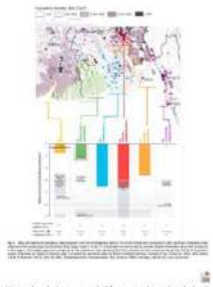
29



neters per year) of regional relative water level (RWL) an

	RWL Trend 1968–2012, mm/y	SD σ, cm	Trend 1993–20 mm/y
	2.1 ± 0.8***	8	2.7 ± 1.4***
in/Sundarbans	2.7 ± 1.3***	9	2.1 ± 1.4*
in	3.6 ± 1.8***	16	3.2 ± 1.6***
floodplain	3.1 ± 2.3*	28	3.1 ± 1.5***
dplain	3.0† ± 2.6*	16	3.4 ± 1.6***
ain	1.3 ± 1.4	17	3.4 ± 1.7***

es are obtained from a robust regression model with the bisquare
se method to maintain the autocorrelation structure of RWL and
defined as the 10% lower bound in the VLM rates distribution (sub
h P ≤ 0.1, P ≤ 0.01, and P ≤ 0.001, respectively.
ated up to 2005 (see *Materials and Methods* for details)



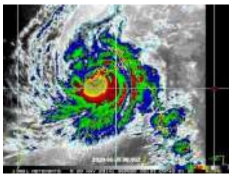
Water level changes, subsidence, and sea level rise i
the Ganges–Brahmaputra–Meghna delta

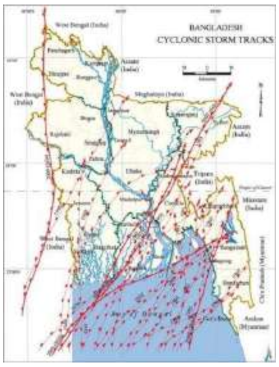
Trends in Water Level and Subsidence

30

Extreme Events: Cyclone

- The Indian Ocean has warmed faster than the global average (*very high confidence*).
- The proportion of intense tropical cyclones (TC), average peak TCs wind speeds, and peak wind speeds of the most intense TCs will increase on the global scale with increasing global warming (*high confidence*).
- Intensification of tropical cyclones and/or extratropical storms in projected in more regions from 2⁰C GWL and above (*medium confidence*)





31

Recent Cyclones in the Bay of Bengal

Cyclone Amphan (2020) Date: 16-21 May 3-min wind: 240 km/hr 1-min wind: 260 km/hr Surge: 3-4 m **Damage: USD 1.5 billion** **Fatalities: 26**	**Cyclone Bulbul (2019)** Date: 5-11 November 3-min wind: 140 km/hr 1-min wind: 195 km/hr Surge: < 2 m **Damage: USD 33 million** **Fatalities: 128**	**Cyclone Fani (2019)** Date: 26 April -05 May 3-min wind: 215 km/hr 1-min wind: 250 km/hr Surge: < 2 m **Damage: USD 63.6 million** **Fatalities: 17**
Cyclone Mora (2017) Date: 28-31 May 3-min wind: 110 km/hr 1-min wind: 150 km/hr Surge: < 2 m **Damage: USD 6 million** **Fatalities: 0**	**Cyclone Roanu (2016)** Date: 16-21 May 3-min wind: 85 km/hr 1-min wind: 110 km/hr Surge: 2 m **Damage: USD 31.8 million** **Fatalities: 30**	**Cyclone Aila (2009)** Date: 17-27 May 3-min wind: 110km/hr 1-min wind: 120km/hr Surge: 3 m **Damage: USD 1 billion** **Fatalities: 190**
Cyclone Sidr (2007) Date: 11-15 November 3-min wind: 215 km/hr 1-min wind: 260 km/hr Surge: 5.5 m **Damage: USD 2.31 billion** **Fatalities: 3,447**	**1991 Cyclone (1991)** Date: 24-30 April 3-min wind: 235 km/hr 1-min wind: 260 km/hr Surge: 6.1 m Damage: USD 1.5 billion Fatalities: 138,000	**Bhola Cyclone (1970)** Date: 3-13 November 3-min wind: 185 km/hr 1-min wind: 240 km/hr Surge: 10.6 m **Damage: USD 86.4 million** **Fatalities: 500,000**

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Changes of inundation patterns or cyclone Sidr (2007), Aila (2009) and Roanu (2016)

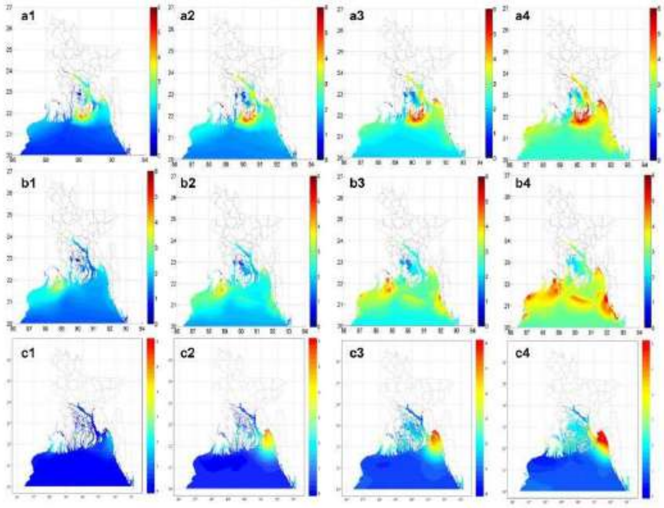

Figure 4. Maximum water level for cyclones under different SLR conditions. Suffix (a) for Sidr, (b) for Aila and (c) for Roanu. Suffix 1 for cyclone with the current sea level, 2 for cyclone plus 0.5-m SLR, 3 for cyclone plus 1.0-m SLR and 4 for cyclone plus 1.5-m SLR.

Rahman et al. (2016)

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Changes of inundation patterns or cyclone Sidr (2007), Aila (2009) and Roanu (2016)

	Sidr			Aila			Roanu		
	Area	%	p	Area	%	P	Area	%	P
Only cyclone	1484	1.2	1.9	1999	1.5	2.3	676	0.46	0.52
0.5m SLR	3380	2.6	4.1	4226	3.3	5.1	2912	1.97	2.24
1m SLR	5777	4.4	7.0	6216	4.8	7.5	7832	5.31	6.02
1.5m SLR	7588	5.8	9.1	7497	5.8	9.0	12550	8.5	9.65

*Inundation Area in Km², % of area w.r.t. country and Affected population in Million

Shaha et al. (2016)

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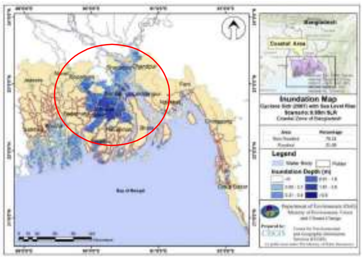
Storm surge Inundation considering sea level rise

For 1991 cyclone under 0.62m SLR and 0.95m SLR Scenario reveals that total 13.05% and 15.37% area will be flooded across the coast. Districts are facing more inundation with the increase of sea level rise are Barishal, Jhalokathi and Pirojpur will be flooded about 65%, 91% and 61% of their total area.

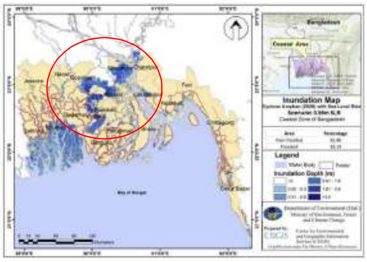
For cyclone Sidr under 0.62m SLR and 0.95m SLR Scenario reveals that total 19.17% and 21.69% area will be flooded across the coast.

For cyclone Amphan under 0.62m SLR and 0.95m SLR Scenario reveals that total 17.5% and 18.1% area will be flooded across the coast.

Cyclone Sidr (2007)



Cyclone Amphan (2020)



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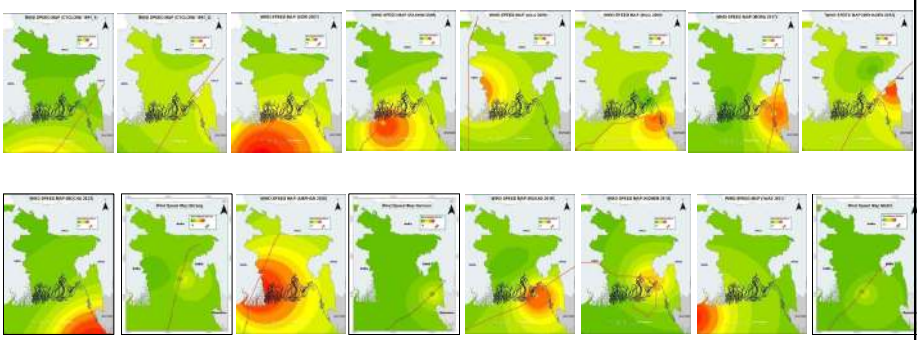
CHAPTER TWELVE

Wind Track for 16 Extreme Events



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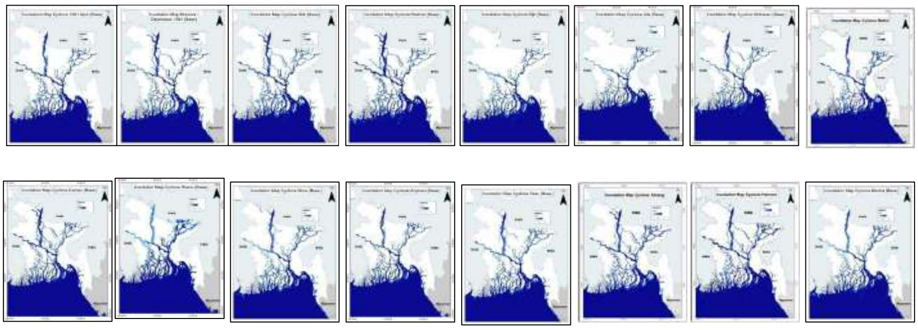
CHAPTER TWELVE

Inundation Map for Base Condition (16 Extreme Events)



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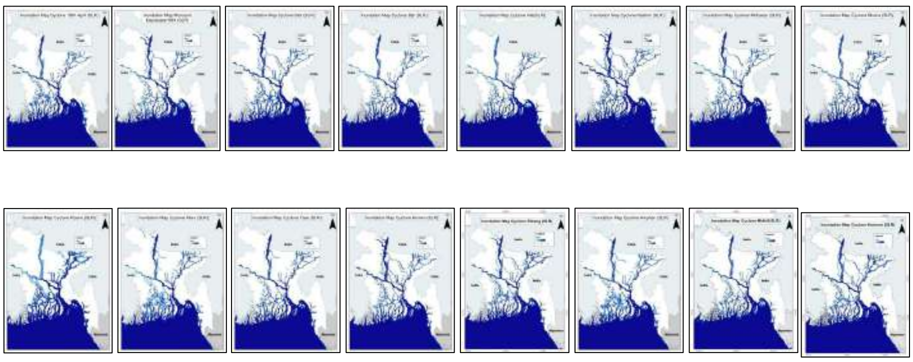
CHAPTER TWELVE

Inundation Map foí 0.7m SLR Condition (16 Extíeme Events)



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Hazard Ranking for Cyclonic Storms and SLR

Pourashava	Hazard Rank		Maximum Surge Depth (m)		Maximum Inundation Area (sqkm)		Maximum Wind Speed (km/hr)	
	Base	SLR	Base	SLR	Base	SLR	Base	SLR
Kuakata	1	3	6.6	6.9	20	20	200	200
Patharghata	2	1	10.9	11.7	138	162	189	189
Chalna	3	4	12.6	12.9	35	47	99	99
Betagi	4	2	9.7	10.1	24	24	113	113
Mehendiganj	5	5	0.0	0.0	0.0	0.0	68	68
Muladi	6	7	0.0	0.0	0.0	0.0	66	66
Nalchity	7	6	7.6	7.8	95	99	86	86
Banari Para	8	10	10.8	11.5	29	39	76	76
Morrelganj	9	11	10.7	10.8	10	10	111	111
Lalmohan	10	12	9.2	9.8	8	12	89	89
Burhanuddin	11	13	0.0	0.0	0.0	0.0	80	80
Gournadi	12	15	4.9	5.8	27	31	66	66
Bakerganj	13	16	0.0	0.0	0.0	0.0	60	60
Zanjira	14	17	11.6	12.3	111	199	59	59
Paikgachha	15	8	12.6	13.1	31	31	105	105
Kalaroa	16	20	7.5	7.9	135	143	111	111
Bagerhat	17	9	8.7	9.4	31	39	76	76
Nesarabad	18	14	12.6	12.9	43	51	73	73
Charfassion	19	21	7.2	7.4	27	27	91	91
Jhalkathi	20	18	10.9	11.7	111	131	81	81
Patuakhali	21	19	0.5	0.8	4	4	85	85
Bhedarganj	22	22	0.0	0.0	0.0	0.0	79	79

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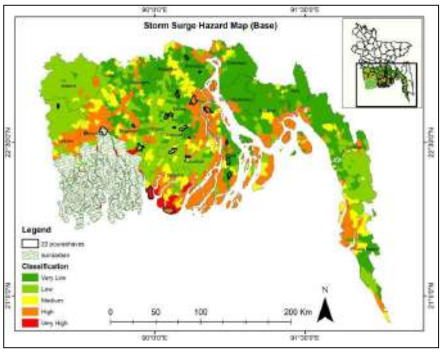
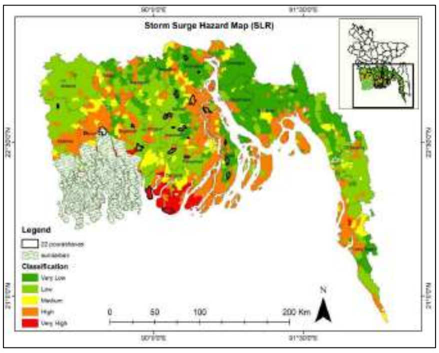
CHAPTER TWELVE

Storm Surge Hazard Map (Base line & SLR Conditions)



Stoím suíge Hazaíd map (Baseline conditions)



Stoím suíge Hazaíd map (0.7m SLR conditions)

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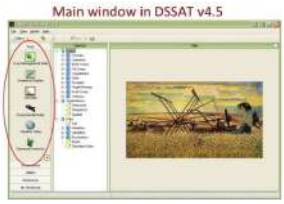
Crop Modeling using DSSAT (Decision Support System for Agro-technology Transfer)

- Extreme climate change will pose threat on various dimensions and Agriculture is one of them.
- About 75% of our agricultural land is rice and it covers 28% of GDP.



Hasan et al. (2016)

Real Name	Brridhan29
Height	95 cm
Duration of growth	160 days
Grain quality	Medium
Yield (Kg/hectares)	7500
Developed on	1994
Developed by	Bangladesh Rice Research Institute (BRRI)

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Crop management data for simulations of BR29 in DSSAT

Parameter	Input Data
Planting Method	Transplant
Transplantation Date	November 21
Planting distribution	Hill
Plant population at seedling	40 plants/ m^2
Plant population at emergence	35 plants/ m^2
Row spacing	20 cm
Planting Depth	5 cm
Transplant age	15-20 days
Fertilizer Application	90 kg/ha applied equally in 3 phases after 15, 35 and 55 days of transplant respectively
Irrigation	1000 mm applied in 15 applications with 7 days interval in 1st month and 10 days interval later
Harvest	May 1

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Default values of the genetic coefficients of Boro rice

Coefficient ID	Name of coefficient	Default Value
P1	Basic vegetative phase coefficient	650
P20	Critical photoperiod at maximum growth rate	90
P2R	Extent in delay of panicle initiation	400
P5	Time from emergence to maturity	13
G1	Potential spikelet number coefficient)	0.65
G2	Single grain weight in gm in ideal condition	0.25
G3	Tillering coefficient	1.0
G4	Temperature tolerance coefficient	1.0

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Values of the genetic coefficients in some important locations (divisions)

Region	P1	P2R	P5	P20	G1	G2	G3	G4	RMSE (Calibration)	RMSE (Validation)
Dhaka	647	93	415	12.9	67	0.26	1.0	1.0	260	125
Chittagong	645	87	395	12.9	62	0.25	1.0	1.0	312	213
Rajshahi	647	93	415	12.9	67	0.26	1.0	1.0	317	106
Barisal	648	90	400	13	67	0.25	1.0	1.0	192	141
Khulna	648	90	400	13	67	0.25	1.0	1.0	211	139
Sylhet	650	90	400	13	67	0.25	1.0	1.0	169	140

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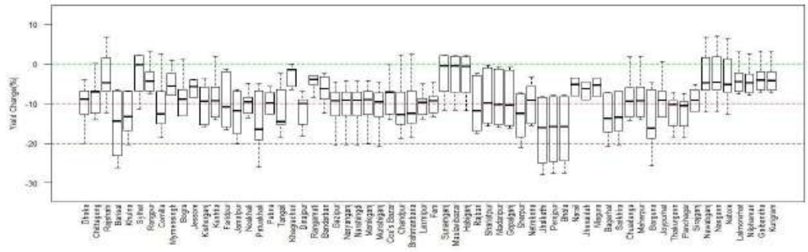
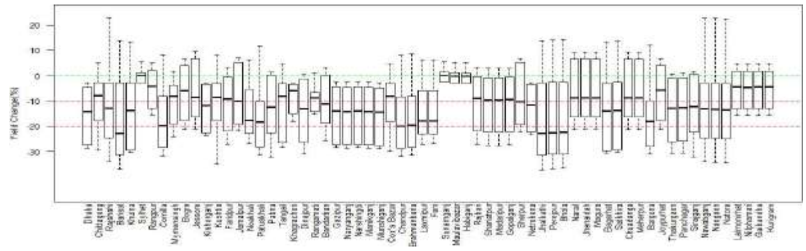
Changes of Boro rice yield at 2C and 4C SWL

2 C



4 C



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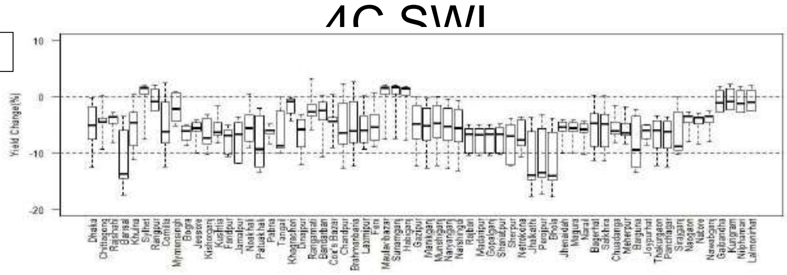
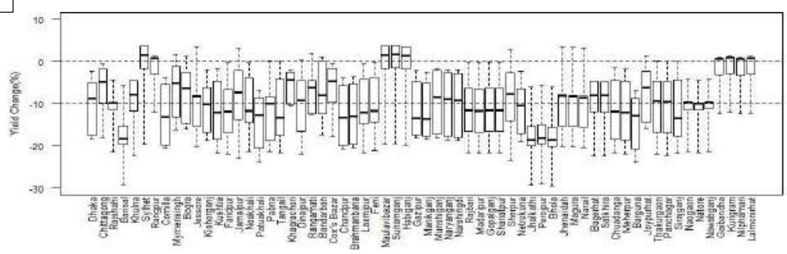
Changes of Aman rice yield at 2C and 4C SWL

2 C



4 C



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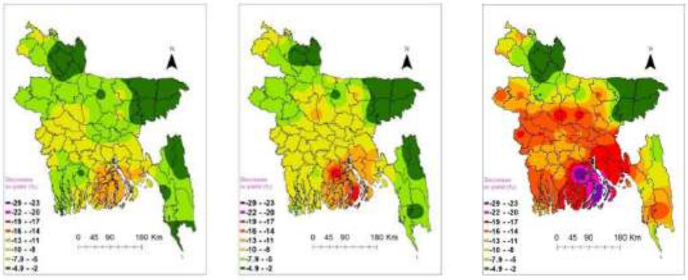
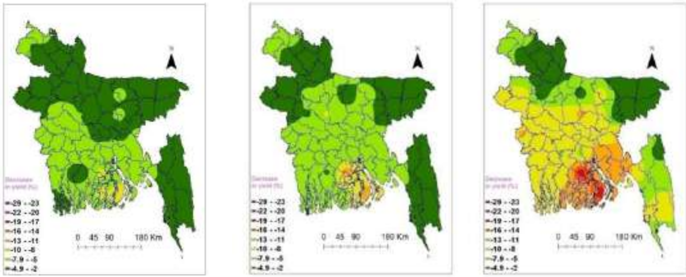
Changes of Boro yield at 1.5C, 2C, 4C SWLs



Changes of Aman yield at 1.5C, 2C, 4C SWLs



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Change in Salinity

- Water and soil salinity is a common hazards in many parts of the coastal zone. Seventy percent of 2.35 million hectares within the Khulna and Barisal Divisions are affected by different degrees of soil salinity. This reduces the crop area.
- It restricts the cultivation of aus (summer rice), boro (dry season rice), and other rabi (dry season) crops.
- There is a seasonal salinity interface in the estuaries, with the threshold limit for agriculture moving further inward from the coast in May in the southern part of the coastal zone.
- In the southwest region, surface water salinity has been accentuated by the reduction in the dry season upland flows entering the Gorai distributaries. Coastal polders were designed to prevent salt-water intrusion.
- Many polders have lost their function because of both undesired breachings causing crop damage and "desired to breach" facilitating shrimp farming. Land-use conflicts exist in the area. Salinity intrusion inhibits industrialization.

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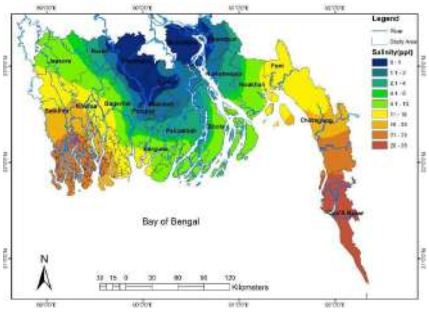
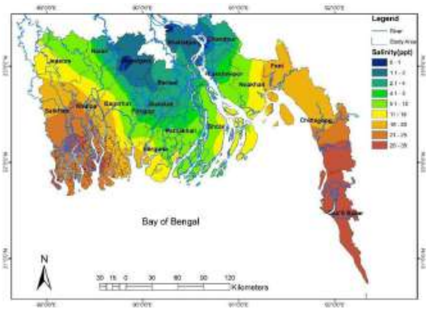
CHAPTER THIRTEEN

Surface water salinity in Coastal Bangladesh

Baseline



Mid-century



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CHAPTER THIRTEEN

Changes in Salinity (baseline & mid-century)

District	Pourashavas	Baseline Salinity (ppt)	Projected mid-century salinity (ppt)
Patuakhali	Patuakhali	2.1 - 4	4.1 - 5
	Kalapara	5.1 - 10	11 - 15
Bagethat	Bagerhat	5.1 - 10	11 - 15
	Morrelganj	2.1 - 4.0	5.1 - 10
Barisal	Mehendiganj	1.1 - 2	4.1 - 5
	Gaoronadi	1.1 - 2	2.1 - 4
	Muladi	1.1 - 2	2.1 - 4
	Banaripara	0 - 1	2.1 - 4
	Bakerganj	1.1 - 2	2.1 - 4
Khulna	Paikgacha	11 - 15	16 - 20
	Chalna (Dacope)	11 - 15	16 - 20
Sathkhira	Kolaroya	11 - 15	16 - 20
Borguna	Patharghata	16 - 20	16 - 20
	Betagi	1.1 - 2	5.1 - 10
Bhola	Charfashion	5.1 - 10	11 - 15
	Borhanuddin	4.1 - 5	5 – 10
	Lalmohon	4.1 - 5	5 – 10
Jhalokathi	Jhalokathi	0 - 1	2.1 – 4
	Nalchity	1.1 - 2	2.1 – 4
Shoriotpur	Bhedarganj	0 - 1	1.1 – 2
	Zanjira (Zajira)	0	0 - 1
Pirojpur	Swarupkathi	0-1	1.1-2

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Salinity in coastal Bangladesh

Annual maximum salinities for 103 selected points under the four future scenarios

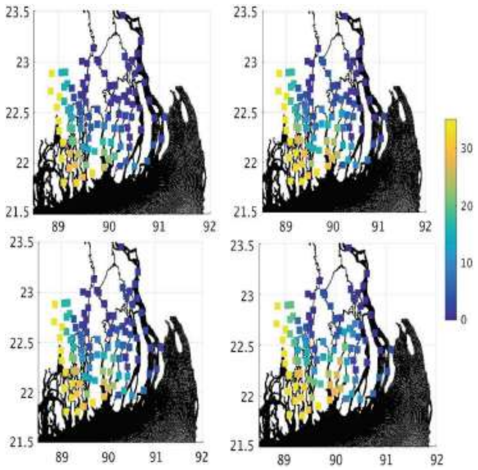

Table 17.1
Summary of scenario runs with annual river discharge over time discussed in this chapter

Scenario	Description	Climate and management	MSLR (cm)	Year	Annual river discharge (m^3)	'Wet' or 'dry'
1	Baseline	Q0+business as usual	0.0	2000–2001	9,928,407	
2	Mid-century	Q0+business as usual	31.96	2047–2048	13,979,424	Wet
3	Mid-century	Q8+less sustainable	27.06	2050–2051	10,011,085	Dry
4	End century	Q8+more sustainable	58.77	2082–2083	16,517,208	Wet
5	End century	Q0+business as usual	59.01	2097–2098	10,978,254	Dry

Bricheno et al., 2018

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Coastal Erosion

■Land erosion is a common natural phenomenon in the coastal zone. Massive changes have occurred in the coastline over the last two centuries due to land erosion, coupled with land accretion. Boundaries of islands undergo major changes due to land erosion and simultaneous accretion.

■Historical satellite images of Landsat TM and Landsat 8 are analys[...] n. It has been found that major accretion is observed in the Rangabali [...] the Patharghata, Taltali, Kalapara, Galachipa, Amtali and Barguna Sadar.

1989-2021

2009-2021

1999-2009

1989-1999

Erosion in Sonar Char

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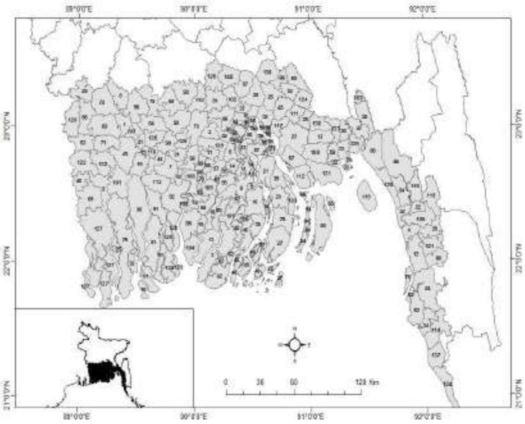
Socioeconomic vulnerability assessment using indicators based multivariate analysis

- Coastal areas of Bangladesh is very much prone to various natural disasters such as cyclone, storm surge, river erosion, flood, salinity intrusion, erratic weather condition, etc.
- 19 coastal districts were selected for the analysis where 140 Upazilas are included



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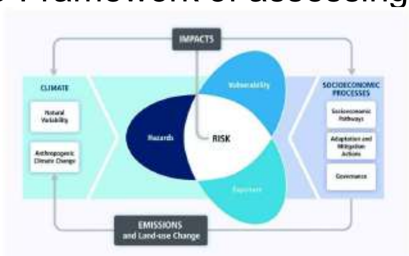
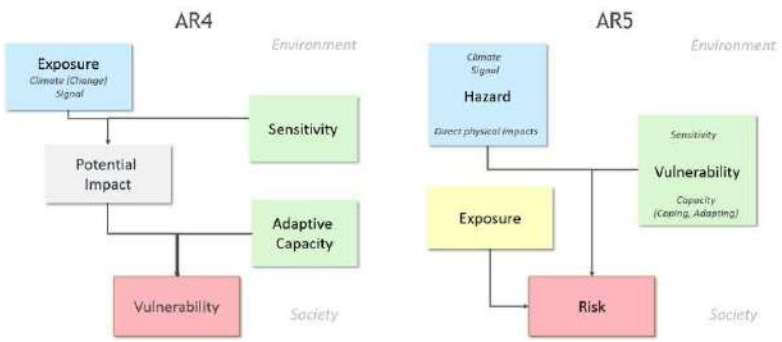
Coastal vulnerability due to climate change following IPCC Framework of assessing vulnerability





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Principle component analysis conducted to determine weight of the indices

5 SENSITIVITY INDICATORS

7 EXPOSURE INDICATORS

19 ADAPTIVE CAPACITY INDICATORS

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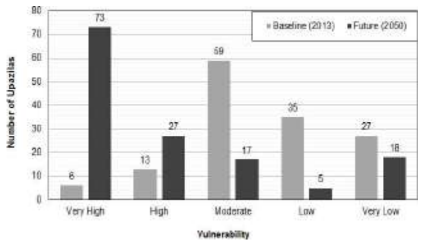
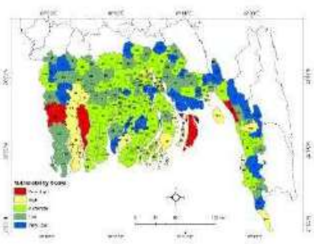
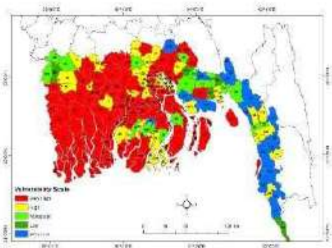
Coastal Vulnerability in preset and in the future (2050)

A total of 140 upazilas (administrative unit) under 19 coastal districts of Bangladesh has been selected as study At present, 6 upazilas come under very high, 13 upazilas under high, 59 upazilas under moderate, 35 upazilas under low and 27 upazilas under very low category of vulnerability





Present (2013)



Future (2050s)

In future, 73 upazilas are mapped as very high, 27 upazilas as high, 17 upazilas as moderate, 5 upazilas as low and 18 upazilas as very low scale of vulnerability

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Key Messages

- Extreme Rainfall over Bangladesh will be increased in the future. Chances of flash flood and land slides will be increased.
- Projected changes in mean annual precipitation and temperature over the basins are larger in 4°C than in 1.5°C or 2°C. Changes are greater over Meghna basin than Brahmaputra basin.
- Annual discharges of the Meghna basin change almost linearly with changes in the annual basin-averaged precipitation, while changes in discharges of the Brahmaputra basin are less sensitive to changes in precipitation.
- Mean monthly flows are projected to increase the most in July (for Brahmaputra and Ganges) and in June (for Meghna).
- Floods are likely to increase in both rivers as well as flood durations.
- However, Hydrological droughts are likely to decrease in both rivers along with drought durations.
- SLR rise will also cause permanent inundations in some parts of the coastal areas of Bangladesh.
- Under high emission RCP 8.5 scenarios the mean yield of Boro rice will decrease about 10% during 2030’s and about 20% by 2100.

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Thank you

58

Publications on floods and climate change

- Attributing the 2017 Bangladesh floods from meteorological and hydrological perspectives. Hydrology and Earth System Sciences, 23, 1409-1429, doi:10.5194/hess-23-1409-2019
- Attributing the 2017 Bangladesh floods from meteorological and hydrological perspectives. Hydrology and Earth System Sciences, 23, 1409-1429, doi:10.5194/hess-23-1409-2019
- Determining Flash Flood Danger Level at Gauge Stations of the North East Haor Regions of Bangladesh. Journal of Hydrological Engineering, 24(4), 05019004.
- Observed Trends in Climate Extremes over Bangladesh from 1981 to 2010. Climate Research , 77(1), 45-61.
- Future floods in Bangladesh under 1.5°C, 2°C and 4°C global warming scenarios. Journal of Hydrological Engineering, 23(12), 04018050.
- Challenges for flood risk management in flood prone Sirajganj region of Bangladesh. Journal of Flood Risk Management, e12450.
- A global network for operational flood risk reduction. Environmental Science & Policy, 84, 149-158.
- Regional changes of precipitation and temperature over Bangladesh using bias corrected multi-model ensemble projections considering high emission pathways. International Journal of Climatology, 38(4), 1634-1648. doi: 10.1002/joc.5284.
- Assessing High-End Climate Change Impacts on Floods in Major Rivers of Bangladesh Using Multi-Model Simulations. Global Science and Technology Journal, 6(2), 1-14.
- Impact of High-End Climate Change on Floods and Low Flows of the Brahmaputra River. Journal of Hydrologic Engineering, 22 (10), doi: 10.1061/%28ASCE%29HE.1943-5584.0001567.
- Extreme flows and water availability of the Brahmaputra River under 1.5°C and 2°C global warming scenarios, Climatic Change, pp 1-17, doi: 10.1007/s10584-017-2073-2.
- Hydrological response to climate change of the Brahmaputra basin using CMIP5 General Circulation Model ensemble. Journal of Water and Climate. doi:10.2166/wcc.2017.076.
- Assessing extreme rainfall trends over the northeast regions of Bangladesh, Theoretical and Applied Climatology, 1-12, doi: 10.1007/s00704-017-2285-4.

59

Publications on cyclone and storm surges

- Projected changes of inundation of cyclonic storms in the Ganges–Brahmaputra–Meghna delta of Bangladesh due to SLR by 2100. Journal of Earth System Science, 23, 1409-1429.
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PROMISING CSA TECHNOLOGIES FOR NON-RICE CROPS

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Climate-smart Agriculture (CSA) is a set of agricultural practices and technologies which simultaneously boost productivity, enhance resilience and reduce GHG emissions. Climate smart technologies (CSTs) and practices contribute to the adaptation of farmers to the effects of climate change.

The three pillars of CSA

- **Productivity:** CSA aims to sustainably increase agricultural productivity and incomes from crops, livestock and fish, without having a negative impact on the environment. This, in turn, will raise food and nutritional security. A key concept related to raising productivity is sustainable intensification
- **Adaptation and building resilience:** CSA aims to reduce the exposure of farmers to short-term risks, while also strengthening their resilience by building their capacity to adapt and prosper in the face of shocks and longer-term stresses. Particular attention is given to protecting the ecosystem services which ecosystems provide to farmers and others. These services are essential for maintaining productivity and our ability to adapt to climate changes.
- **Mitigation:** Wherever and whenever possible, CSA should help to reduce and/or remove greenhouse gas (GHG) emissions. This implies that we reduce emissions for each calorie or kilo of food, fiber and fuel that we produce. That we avoid deforestation from agriculture. And that we manage soils and trees in ways that maximizes their potential to acts as carbon sinks and absorb CO_2 from the atmosphere.

Many agricultural practices and technologies such as minimum tillage, different methods of crop establishment, nutrient and irrigation management and residue incorporation can improve crop yields, water and nutrient use efficiency and reduce Greenhouse Gas (GHG) emissions from agricultural activities (Branca et al., 2011; Jat et al., 2014; Sapkota et al., 2015). Similarly, rainwater harvesting, use of improved seeds and ICT based agro-advisories can also help farmers to reduce the impact of climate change and variability (Mittal, 2012; Altieri and Nicholls, 2013).

In general, the CSA options integrate traditional and innovative practices, technologies and services that are relevant for particular locations to adopt climate change and variability (CIAT, 2014). In this study, we consider a technology or practice as climate smart if it can help to achieve at least one pillar of CSA (either increases productivity or increases resilience or reduces GHG emission).

Climate smart technologies (non-cereal crops) which are uses in Bangladesh to address the climate change are discussed below:

Climate Resilient crop varieties:

Crop varieties	Characteristics	Impact on CSA Pillars
Short duration varieties		
BARI Barley-5	Short duration (95-98 days) Yield: 2.5-3.0 t/ha	**Productivity** Promotes high yields per unit area hence an increase in income and profit due to reduced production costs. **Adaptation** Optimizes the use of available soil moisture contributing to avoid crop loss. Increases water use efficiency. **Mitigation** Provides moderate reduction in GHG emissions per unit of food produced.
BARI Sarisha-14	Short duration (75-80 days) Yield: 1.4-1.6 t/ha	
BARI Masur-9	Short duration (85-90 days) Yield: 1.19-1.52 t/ha	
BARI-mung-6	Short duration (55-60 days) Yield: 1.5-1.6 t/ha	
BARI-mung-7	Short duration (55-60 days) Yield: 1.7-1.9 t/ha	
Salt tolerant varieties		
BARI Barley 7 & 8	Salt tolerant (up to 8 dS/m) Yield: 2.0-2.5 t/ha	**Productivity** Increases in productivity stability due to increased resilience to stress caused by salinity. **Adaptation** Increases farmers' capacity to limit the crop exposure to climate risks like salinity. **Mitigation** Provides moderate reduction GHG emissions per unit of food produced. Promotes carbon sinks through increased below-ground accumulation of biomass.
BARI Sarisha-19 BARI Sarisha-16	Salt tolerant (8-10 dS/m) Yield: 2.0-2.5 t/ha	**Productivity** Increases in productivity stability due to increased resilience to stress caused by salinity. **Adaptation** Increases farmers' capacity to limit the crop exposure to climate risks like salinity. **Mitigation** Provides moderate reduction GHG emissions per unit of food produced. Promotes carbon sinks through increased below-ground accumulation of biomass.
BARI Til-4	Salt tolerant (6-8 dS/m) Yield: 1.4-1.5 t/ha	
Tisi (Nila)	Salt tolerant (10-12 dS/m) Yield: 1.4-1.6 t/ha	
BARI-Alu-72	Salt tolerant (8-10dS/m) Yield: 25-30 t/ha	
BARI-Alu- 78	Salt tolerant (8-10dS/m) Yield: 30-35 t/ha	
Drought tolerant		
BARI Barley-5 & 9	Duration 95-99 days Yield 2.50-3.00 t/ha	**Productivity** Potential increases in profits due to

Crop varieties	Characteristics	Impact on CSA Pillars
BARI China Badam-10	Duration 120-130 days Yield: 2.0-2.2 t/ha	increased crop yield and reduced production costs. **Adaptation** Optimizes the use of available soil moisture contributing to avoid crop loss. Increases water use efficiency. **Mitigation** Reduces fossil fuel requirements for irrigation.
BARI Chola-10	Duration 112-121 days Yield 1.80-2.03 ton/ha	
BARI Chola-11	Short duration (100-106 days) Yield 1.2-1.5 t/ha	
BARI Misty Alu-7 & 8	Duration: 130-150 days Yield: 40-45 t/ha	
Heat tolerant		
BARI Hybrid Maize 13 & 16	Suitable for Rabi & Summer season. Duration: 100-145 Yield: 8-12 t/ha	**Productivity** Potential increases in profits due to increased crop yield and reduced production costs. **Adaptation** Avoid heat shock injury. Increases farmers' capacity to limit the crop exposure to climate risks. Increases water use efficiency. **Mitigation** Provides moderate reduction in GHG emissions per unit of produce. Promotes carbon sinks through increased accumulation of below-ground biomass.
BARI Piaj 2, 3, 5	Suitable for Summer season Duration: 95-110 Yield: 17-22 t/ha	**Productivity** Potential increases in profits due to increased crop yield and reduced production costs. **Adaptation** Avoid heat shock injury. Increases farmers' capacity to limit the crop exposure to climate risks. Increases water use efficiency. **Mitigation** Provides moderate reduction in GHG emissions per unit of produce. Promotes carbon sinks through increased accumulation of below-ground biomass.
BARI Begun-8, 10	Suitable for Summer season Yield: 25-30 t/ha	
BARI Sheem 3,7	Suitable for Summer season Yield: 12-15 t/ha	
BARI Lau-4	Suitable for Summer season Duration: 130-150 days Yield: 80-85 t/ha	
BARI-Alu-73	Suitable for winter season Duration: 85-90 days Yield: 25-30 t/ha	
BARI Tomato-4, 5	Suitable for Summer season Duration: 90-100 Yield: 20-22 t/ha	
BARI Tomato- 6	Suitable for Summer season Duration: 85-90 days Yield: 45-50 t/ha	
BARI Tomato- 10	Suitable for Summer season Duration: 90-100 days Yield: 45-55 t/ha	

Crop varieties	Characteristics	Impact on CSA Pillars
BARI Tomato- 13	Suitable for Summer season Duration: 120-130 days Yield: 40-45 t/ha	
BARI Hybrid tomato-3, 4	Suitable for Summer season Duration: 120-130 days Yield: 40-50 t/ha	
BARI Hybrid tomato- 8, 10	Suitable for Summer season Duration: 80-90 days Yield: 40-42 t/ha	
Disease resistant		
BARI Bt Begun 1,2,3,4	Resistant against brinjal shoot and fruit borer. Yield: 50-55 t/ha	**Productivity** Reduces production costs. Enhance crop production and quality, hence potential increases in income. **Adaptation** Increases farmers' capacity to limit the crop exposure to crop damage caused by diseases and pests. Reduces the need for external inputs for crop protection. **Mitigation** Reduces GHG emissions by reducing the use of synthetic pesticides (fungicides) therefore the carbon footprint reduction per unit of food produced.
BARI Alu-53	Late blight resistance Yield: 30-35 t/ha	

Other CSA technologies:

Technologies	Description	Impact on CSA Pillars
Water-smart		Interventions that improve water use efficiency
Rainwater Harvesting	Rainwater harvesting is the accumulation and storage of rainwater for reuse on-site, rather than allowing it to run off. Rainwater can be collected from rivers or roofs, and in many places, the water collected is redirected to a deep pit.	**Productivity** Increased crop yield and reduced production costs. **Adaptation** Optimizes the use of rainwater for supplemental irrigation. Increases water use efficiency. **Mitigation** Reduces fossil fuel requirements for irrigation.
Drip Irrigation	Drip irrigation is involves dripping water onto the soil at very low rates from a system of small diameter plastic pipes fitted with outlets called emitters or drippers. Water is applied close to plants so that only part of the soil in which the roots grow is wetted. This provides a very favorable high moisture level in the soil in which plants can flourish.	**Productivity** Increased crop yield and reduced production costs. **Adaptation** Application of water directly to the root zone of crops and minimize water loss and increase water use efficiency. **Mitigation** Reduces fossil fuel requirements for irrigation.

Technologies	Description	Impact on CSA Pillars
Alternate furrow irrigation	Alternate furrow irrigation is based on the novel partial root drying technique for vegetables which consists of: Irrigating only one side of the plant, i.e., half of the root system, at each irrigation event, while the other side receives water on the next irrigation.	**Productivity** Increased crop yield and reduced production costs. **Adaptation** Minimize water loss and increase water use efficiency. **Mitigation** Reduces fossil fuel requirements for irrigation.
Seed priming	Seed priming is a pre-sowing treatment which leads to a physiological state that enables seed to germinate more efficiently.	**Productivity** Increased crop yield and reduced production costs. **Adaptation** Plants adapted in drought environment **Mitigation** Reduces fossil fuel requirements for irrigation.
Mini pods	Mini ponds are bodies of water created by constructing by excavating a pit or dugout. Generally, a pond serves irrigating one or more field crops for times of critical need.	**Productivity** Increased crop yield and reduced production costs. **Adaptation** Plants adapted in drought environment with supplemental irrigation **Mitigation** Reduces fossil fuel requirements for irrigation.
Sandbar cropping	When the water subsided, silted sand plains are left behind called 'char lands' i.e. Sandbars.'Sandbar cropping' is an innovative, cost-effective technology that transforms silted barren sandy lands created by flooding into arable farmland. The sandbar cropping technique is a pit cultivation approach, adapted to the sandbars of char lands to grow pumpkin, squash and watermelon. Pits are dug in the sandbars and are lined with manure and compost. Seeds are placed in the pits and are carefully monitored for the next few months with periodic irrigation and nursing as required. Sandbar cropping was first introduced in Gaibandha district by some farmers in 2005.	**Productivity** Increased crop yield and reduced production costs. **Adaptation** Plants adapted in drought environments with supplemental irrigation. Increase water use efficiency **Mitigation** Reduces fossil fuel requirements for irrigation.
Waterlog/ flooding smart		
Floating bed cultivation	In some parts of Bangladesh, where water remains for a prolonged period of time, farmers are using	**Productivity** Increases in income due to harvesting of multiple crops in one season. Generates additional income

Technologies	Description	Impact on CSA Pillars
	their submerged lands for crop production by adopting scientific methods which are similar to hydroponic agriculture practices, i.e. floating agriculture, whereby plants can be grown on the water in a floating bed of water hyacinth, algae or other plant residues. According to their needs, people in different parts of Bangladesh have adopted, modified and named this practice differently (*baira*, *boor*, *dhap*, *gathua*, *gatoni*, *geto*, *kandi*and *vasomanchash*and floating agriculture).	from the sale of seedlings produced. **Adaptation** Reduce risk of complete crop failure. Allows optimum use of natural and local available resources. Creates additional cropping area. **Mitigation** Protects soil structure and organic carbon reserves. Promotes fuel and energy savings due to reduced tillage.
Sorjan	Sorjan, an indigenous technology of Indonesia, is a series of sinks or canals alternating with raised beds. Rice is usually planted in the sinks and a wide variety of upland crops is grown in the raised beds. The use of Sorjanas one component of an integrated rice farming system results in higher and more regular income for the farmer	**Productivity** Increase vegetable production throughout the year. Increases economic return from fallow land. **Adaptation** Increases farmers' capacity to limit the crop exposure to tidal water submergence. **Mitigation** Reduces GHG emission
Pyramid cropping	This practice enables farmers to grow rabi and kharif-I vegetables in relatively lowlands that remain under few cm of flood water at the time of harvest of the transplanted aman rice. Soils are heaped up like a pyramid just after harvest of the aman rice at a spacing required for the next desired crop. The height of the pyramid to be determined such that the rooting zone of the next rabi or kharif-I crops remains above the waterlogged zone.	**Productivity** Increased crop yield and reduced production costs. Enhance food security. **Adaptation** Plants adapted in waterlog environment **Mitigation** Reduces GHG emission
Salinity smart		
Sowing date adjustment	By adjusting sowing dates adverse effect of salinity can be avoided	**Productivity** Increased crop yield and reduced production costs. Enhance food security. **Adaptation** Increases farmers' capacity to limit the crop exposure to climate risks. **Mitigation** Reduces GHG emission. Promotes carbon sinks through increased accumulation of biomass.

Technologies	Description	Impact on CSA Pillars
Mulching	Mulching is referred to a mixture of wet straw, leaves and loosen earth evenly spread on the ground to conserve soil moisture and reduced weed growth	**Productivity** Increased crop yield and reduced production costs. Enhance food security. **Adaptation** Plants adapted in salinity and drought environment **Mitigation** Reduces GHG emission
Energy-smart		**Interventions that improve energy use efficiency.**
Zero Tillage/ Minimum Tillage	No-till farming (also called zero tillage or direct drilling) is a way of growing crops without disturbing the soil through tillage. No-till is an agricultural technique that increases the amount of water that infiltrates into the soil, the soil's retention of organic matter and its cycling of nutrients.	**Productivity** Increased crop yield and reduced production costs. Enhance food security. **Adaptation** Reduces soil degradation and erosion. Increases water availability. Frees up time for decision-making. **Mitigation** Reduces GHG emission. Reduces the amount of energy used in land preparation.
Nutrient-smart		**Interventions that improve nutrient use efficiency**
Site Specific Integrated Nutrient Management	Site specific nutrient management is a set of nutrient management principles combined with good crop management practices that help farmers to attain high yield and achieve high profitability. It provides an approach for the timely application of fertilizers at optimal rates to fill the deficit between the nutrient needs of a high yielding crops and the nutrient supply from naturally occurring indigenous sources, including soil, crop residues, manures and irrigation water.	**Productivity** Increased crop yield and reduced production costs. Enhance food security. **Adaptation** Plants adapted with judicious fertilizer. Reduce indiscriminate use of fertilizers. **Mitigation** Reduce GHG emission and fertilizer cost Reduce environmental pollution.

Technologies	Description	Impact on CSA Pillars
Green Manuring	Green manuring is defined as the growing of green manure crops & then turning off these crops directly in the field by ploughing the field so as to make the field richer in nitrogen which is the most deficient nutrient of the soil. Green manuring crops help in improving the structure of soil & also increases its physical properties. One of the main objectives of the green manuring is to increase the content of nitrogen in the soil to increase crop production.	**Productivity** Increased crop yield and reduced production costs. Enhance food security. **Adaptation** This practice improves nitrogen supply and soil quality. **Mitigation** Reduce GHG emission and fertilizer cost
Vermicompost use	Vermicomposting is the process by which worms are used to convert organic materials (usually wastes) into a humus-like material known as vermin-compost. It provides nutrients to the soil.	**Productivity** Increased crop yield and reduced production costs. Enhance food security. **Adaptation** This practice improves nutrient supply and soil quality. **Mitigation** Reduce GHG emission and fertilizer cost
Intercropping with Legumes	Intercropping is growing two or more crops, simultaneously in the same land.	**Productivity** Increased crop yield and reduced production costs. Enhance food security. **Adaptation** Improves soil health by increasing organic matter content and microbial activities. Increases the possibility of farming in degraded soils. **Mitigation** Reduces requirements of synthetic fertilizers use, thereby related GHG emission during its production and use. Increases above- and below-ground biomass.
Carbon-smart		**Interventions that reduce GHG emissions**

Technologies	Description	Impact on CSA Pillars
AgroForestry	Agroforestry is a collective name for land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately used on the same land-management units as agricultural crops in some form of spatial arrangement or temporal sequence. In particular, agroforestry is crucial to smallholder farmers and other rural people because it can enhance their food supply, income and health. Agroforestry systems are multifunctional systems that can provide a wide range of economic, sociocultural, and environmental benefits.	**Productivity** Increased crop yield and reduced production costs. Enhance food security. **Adaptation** Enhance sustainable land use management. **Mitigation** Reduce GHG emission and Promote carbon sequestration
Integrated Pest Management (IPM)	IPM is an ecosystem-based strategy that focuses on long-term prevention of pests or their damage through a combination of techniques such as biological control, modification of cultural practices, and use of resistant varieties. Pesticides are used only after monitoring indicates they are needed according to established guidelines.	**Productivity** Reduces production costs. Enhance crop production and quality, hence potential increases in income. **Adaptation** Increases farmers' capacity to limit the crop exposure to crop damage caused by diseases. Reduces the need for external inputs for crop protection. **Mitigation** Reduces GHG emissions by reducing the use of synthetic pesticides (fungicides) therefore the carbon footprint reduction per unit of food produced.
Solar powered irrigation	Solar-powered irrigation pumps are a low-cost and reliable irrigation alternative for farmers as solar technology is well suited to the country's flat terrain and abundant sunshine.	**Productivity** Increases yield per unit area, especially during the dry season. Ensures income diversification. **Adaptation** Minimizes water use per unit of product, increasing water use efficiency and resilience to climate shocks. **Mitigation** Reduces GHG emissions due to reduced fuel/energy required for pumping and/or carrying water for irrigation.
Weather-smart		**Interventions that provide services related to income security and weather advisories to farmers.**

Technologies	Description	Impact on CSA Pillars
Weather based Crop Agro-advisory	Climate information based value added agro-advisories to the farmers. The internet, mobile phones, television and radio are providing opportunities to connect the people to obtain and disseminate information and to bring in a new revolution in agriculture.	**Productivity** Increased crop yield and reduced production costs. Enhance food security. **Adaptation** Farmers can adopt different management practices based on information gathered **Mitigation** Reduce GHG emission and Reduce environmental pollution Reduce the risk of crop failure

These technologies, practices and services directly or indirectly contribute to improve productivity, enhance resilience and reduce GHG emission. Technologies/practices that help to improve at least one component can be considered as CSA. Some technologies can help to improve all three elements of CSA.

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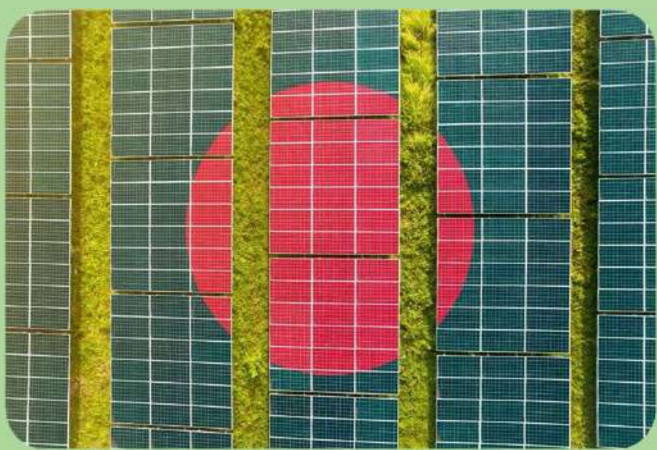
1

Agenda

1. Snapshot of IEEFA
2. What is carbon pricing
3. Carbon Tax vs Carbon Trading
4. Carbon Pricing and Carbin Markets
5. Analysis of CDM
6. New Carbon Market Regime (Article 6)
7. Bangladesh's Readiness for Article 6
8. Examples of Climate Smart Agriculture
9. Concluding Remarks



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Snapshot of IEEFA

The Institute for Energy Economics and Financial Analysis (IEEFA) is a non-profit global impact think tank that produces a significant volume of original independent public interest research and analyses on issues related to sustainable energy markets, trends, regulations, and policies.

Intellectual leadership
We produce cutting-edge, solutions-focused analyses. We don't just highlight the problems – we offer ways to resolve the issues and roadblocks that stand in the way of a zero-emissions future.

Independence
We are an independent non-profit think tank. Our analyses are thoroughly researched, fact-based, and data driven. Our work is free from political influence, corporate and sectoral interests.

Nimble
We act on signals across the energy and finance spectrums in South Asia and worldwide. Our analyses are timely and relevant. We can learn, adapt, and move quickly.

Trust
IEEFA is a trusted voice on issues related to sustainable energy markets, trends, regulations, and policies.

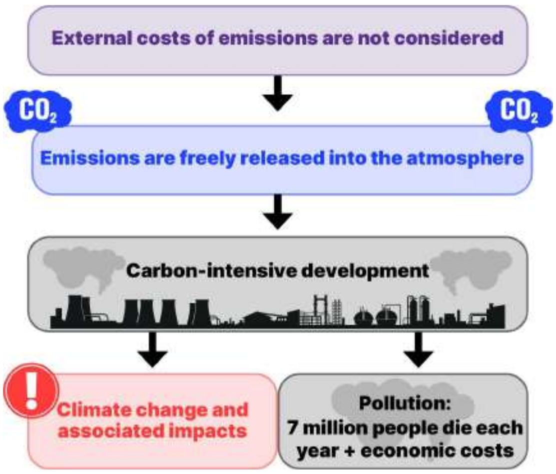
Impact
Our work makes a positive impact in the world. We aim to accelerate the energy transition to help achieve a cleaner future for humankind and the planet.

3

Carbon Pricing?

- ✓ Putting a price on carbon emissions to reduce emissions and the associated external costs is called carbon pricing;
- ✓ Without a carbon price, the costs are borne by everyone in society due to the impacts of climate change and air pollution;
- ✓ Carbon pricing is recognised as one of the cost-effective tools for decarbonisation;
- ✓ Among other things, carbon pricing has the potential to catalyse private investment;

Probable Scenario without Carbon Pricing



Sources: Adapted from UNFCCC; WHO data;

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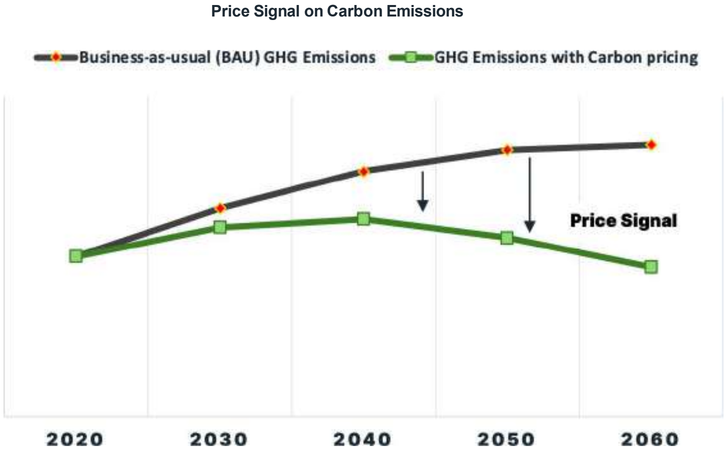
Carbon Pricing to Price Signal



Source: Adapted from UNFCCC;

Expressed in US$/tonne of CO_2 emission or EUR/tonne of CO_2 emission;

Emission equivalence is used based on Global Warming Potential of different GHGs;

Carbon is about taxing "bads" [pollution]

5

Carbon Pricing Instruments

Instrument Type	Characteristics
Carbon Tax	Price is Fixed – A fixed price per unit of emission is levied upon entities; The level of emission reduction is uncertain;
Emissions Trading Scheme (**ETS**)	Price is determined by the supply/demand; The Government sets emission reduction targets for different entities; Some entities will achieve more than their targets while some entities will only be able to reduce a fraction of their targets. Therefore, trading of emissions will likely take place between different entities; The level of emission reduction is certain.

6

Carbon Tax vs ETS

- ✓ Government's regulation is necessary for both Carbon Tax and ETS;
- ✓ Both instruments can influence changes in consumption patterns and help adopt cleaner alternatives;
- ✓ Both can generate revenue (via tax and auctions of allowances), which a government can utilise in clean energy and climate change mitigation and resilience projects;
- ✓ A Carbon Tax is easier to implement – less administrative requirements, monitoring is simple;
- ✓ ETS is more flexible;
- ✓ Hybrid schemes (a combination of Tax and ETS) are implemented too;

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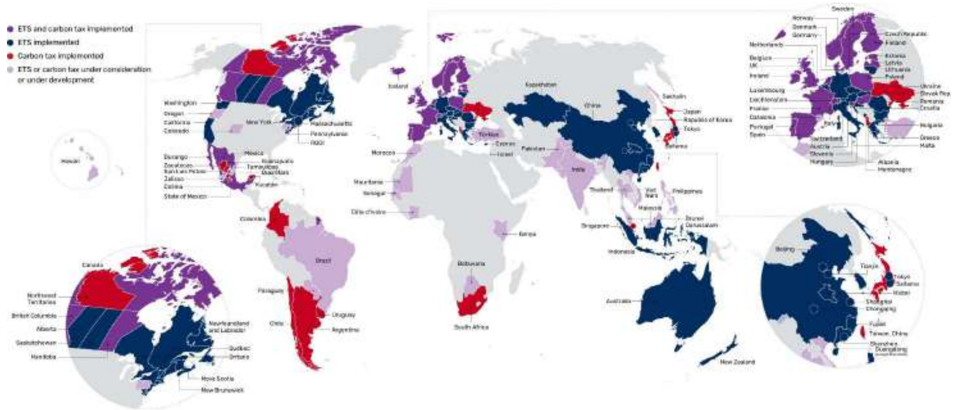
Coverage of Carbon Pricing Tools

Carbon Pricing Instruments around the World



75 carbon pricing instruments are operational;

Carbon pricing instruments cover around 24% of global carbon emissions.

Sources: World Bank, 2024;

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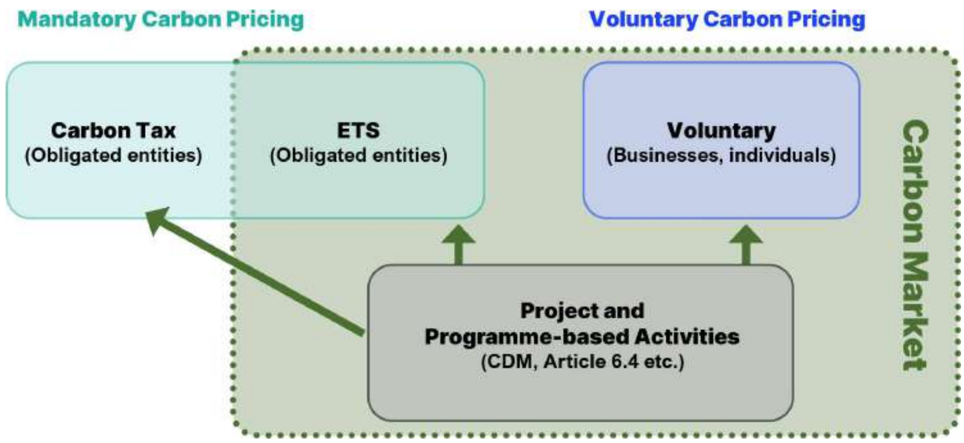
Carbon Pricing and Carbon Markets



Source: Adapted from UNFCCC;

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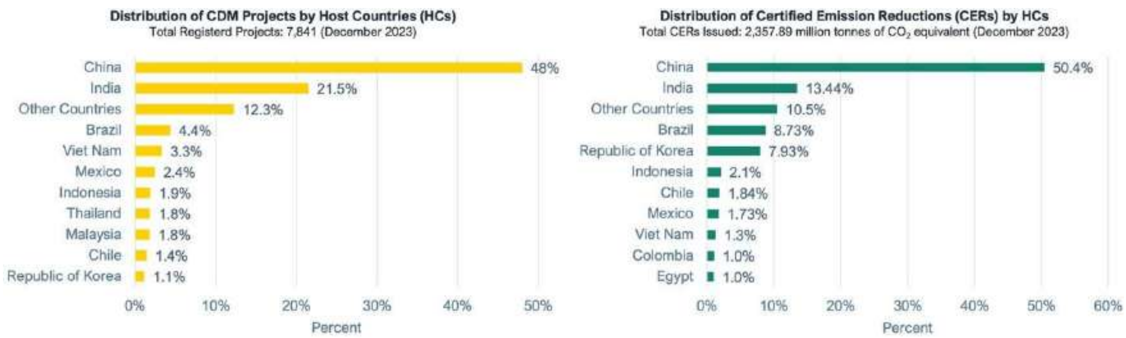
Analysis of CDM, Largest Project-based Carbon Crediting Programme

Geographical Distribution of CDM Projects and Emission Reductions, December 2023



Source: UNFCCC; IEEFA's Analysis

10

Bangladesh’s Experience with CDM

Examples of Projects

- Brick Kiln Efficiency;
- Solar Homes Systems;
- Improved Cookstoves;
- Waste Management;
- Minimising Losses in Gas Distribution Networks etc.

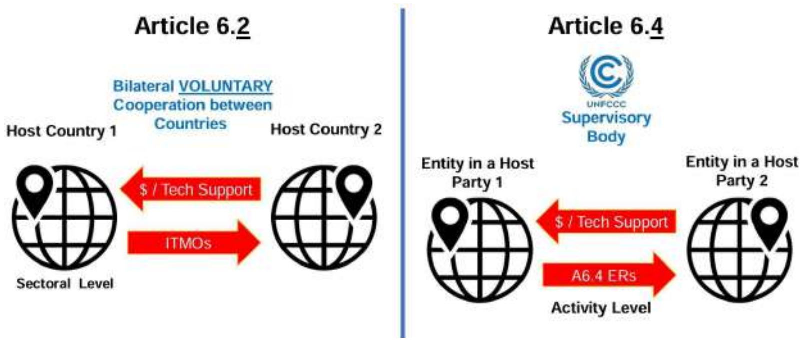
* Bangladesh registered only 10 Projects and 11 Programme of Activities with the UNFCCC;

** A lack of capacity to design projects and prepare documents following UNFCCC’s methodologies is one of the key reasons behind such limited success.

11

New Carbon Market Regime under the Article 6

Article 6.2 vs Article 6.4



- Projects under Article 6.4 will be more stringent;

* Article 6.4 will allow private sector participation;

Source: UNFCCC;

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Bangladesh's Readiness Plan for Article 6

Bangladesh's Roadmap for Article 6 Readiness

Building Blocks	Sub-elements
Policies and Strategies	• Carbon Market Strategy • Risk Management Strategy for NDC Alignment • Guiding Principles and safeguards • Eligibility Criteria for participating mitigation activities • Capacity Building Plan
Legal Foundations and Governance	• Legal Mandate and regulatory Framework • Governance Structure • Co-operation Agreements • Financial Procedures and Budget
Institutional Arrangements	• Establishment of Article 6 Focal Point Designated National Authority • Institutional arrangements to participate in Article 6.2 • Private Sector and third-party entity engagement
Operational procedure	• Guidance and support in mitigation activity cycle • Sourcing mitigation activity • Activity Approval • Validation • Issuance and Authorization • Corresponding Adjustment • Reporting • Tracking • Accreditation of Auditors • Participation in Paris Agreement Crediting Mechanism
Infrastructure	• Registry • MRV tools

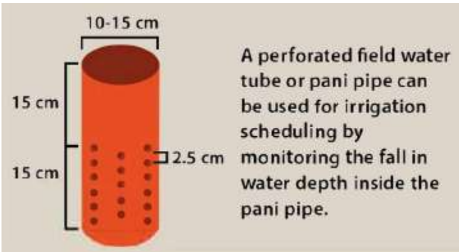
Source: MOEFCC, Bangladesh;

Opportunities for Climate Smart Agriculture Projects under Article 6 – Probable Areas

Alternate Wetting and Drying (AWD)

- ✓ It is a water-saving technology that helps farmers reduce irrigation water consumption; This may also help minimise methane (CH_4) emissions related to rice cultivation;
- ✓ Notably, CH_4 is 27 times more potent than Carbon dioxide over a 100-year lifecycle according to IPCC's sixth assessment (non-fossil emission);
- ✓ A water tube is used to monitor the water level after irrigation; Once the water level falls beyond a certain level, farmers irrigate their fields again.

Water Tube for AWD



Source: Climate & Clean Air Coalition

Opportunities for Climate Smart Agriculture Projects under Article 6 – Probable Areas

Solar-powered Irrigation

- ✓ It can help during the dry months; With support from the government, it can be an income source when irrigation is not required;
- ✓ It can reduce emissions associated with diesel or grid electricity.

Solar-driven Irrigation

Source: IDCOL;

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Opportunities for Climate Smart Agriculture Projects under Article 6 – Probable Areas

- ✓ **Commercial Livestock Fattening** – Alternative feed sources can lead to reduced methane emissions;
- ✓ **Rice-fish Culture** – Profit increases; It may improve soil carbon stock;
- ✓ **Compost and Biogas Production** – Increases land productivity; Organic fertiliser reduces nitrogen-based fertiliser; It further reduces methane emissions from manure, and helps generate energy;
- ✓ Salinity resilient and high yielding crop production etc.

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Concluding Remarks

- ✓ Building on the limited success of CDM, Bangladesh should follow a clearsighted approach to benefit from Carbon Markets;
- ✓ While Bangladesh has already prepared a roadmap for Article 6 readiness, it should first assess the potential role of carbon markets in Bangladesh;
- ✓ Bangladesh should then prepare strategies and institutional arrangements;
- ✓ Ministry of Environment, Forest and Climate Change, as the DNA to the UNFCCC, should design capacity development programmes for key stakeholders on conceptualising projects, writing project design documents, monitoring emission reductions etc. as per the relevant methodologies;

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Thank you

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Ecosystem Valuation in Climate Smart Agriculture

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Environmental Management Solutions (EnvSoL)

February 18, 2025, Dhaka

Outline

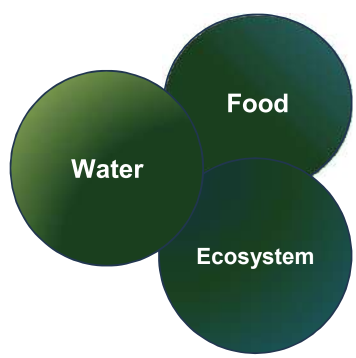
- Challenges & Concepts
- Importance of Valuation
- Methods
- Key Messages

Challenges & Concepts

Food Security Challenges

- Poverty and landlessness
- Population growth and displacement
- Sustainable food supply chain
- Global/regional conflicts and price fluctuations
- Changes in temperature and precipitation patterns
- Increased frequency and severity of extreme events
- Sea level rise and salinity intrusion
- Ecosystem degradation and loss of biodiversity
- Uncertainty in climate change information and knowledge
- Lack of long-term data availability and access to data
- Lack of monitoring and poor enforcement of regulatory frameworks

Interconnected Crisis



Concepts: Ecosystem

"A dynamic complex of plant, animal, and microorganism communities and the nonliving environment interacting as a functional unit" of which humans are an integral part (Millennium Ecosystem Assessment, 2003).

Concepts: Ecosystem Services

The direct or indirect goods and services, i.e., benefits derived from ecosystem functions, which contribute to human well-being (Costanza et al., 1997; Daily, 1997; de Groot, Wilson, & Boumans, 2002; MA, 2005; TEEB, 2010).

Source: Millennium Ecosystem Assessment

Concepts: Ecosystem Services

Importance of Valuation

Ecosystem Services Assessment

❑ **Three** assessment approaches are widely practiced:

1. Impact analysis
2. Partial valuation
3. Total valuation

❑ Total economic value (TEV): "The sum of the values of all service flows that natural capital generates both now and in the future – appropriately discounted" (TEEB, 2010).

$$TEV = DUV + IUV + OV + NUV$$

DUV- Direct Use Value
IUV- Indirect Use Value
OV- Option Value
NUV- Non-use Value

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Why?

- Monetary standard
- Policy instrument
- Impact evaluation

Applications

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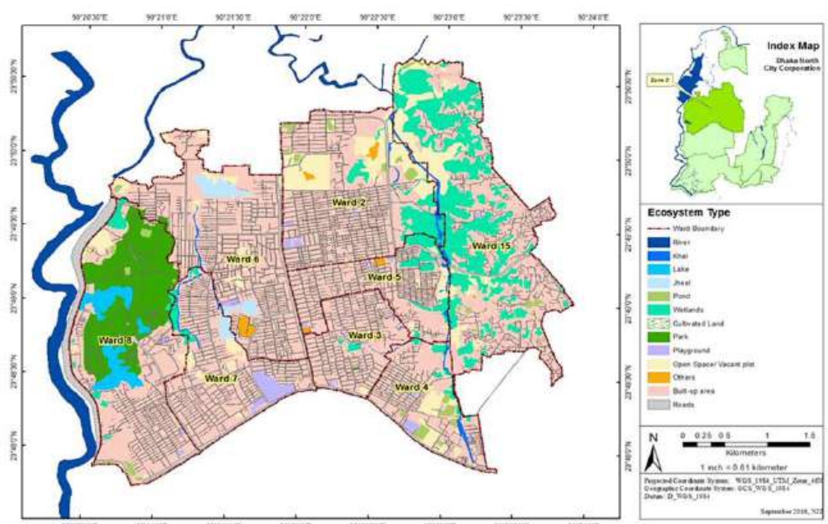
Methods

Ecosystem Identification



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Basic Framework

How to Begin?

Type of Valu	Ecosystem Services	Quantity Data Description	Data Collection Method				Valuation Method
			Review	Observation	Interview	Survey	
Provisioning Ecosystem Services							
DUV	Fruit and vegetable	Fruit and vegetable production			X	X	MP
DUV	Fish (culture fish)	Fish harvest			X		
DUV	Water supply (surface water)	Water use for natural irrigation		X	X		
DUV	Fodder	Fodder collection			X		
Regulating Ecosystem Services							
IUV	Particulate matter (PM) capture	Vegetation area measurement		X	X		ACM
		Average concentration of PM_{10}	X				
		Deposition velocity of PM_{10}	X				
IUV	Carbon sequestration	Tree diameter measurement				X	ACM
		Carbon stock and CO_2 equ conversion	X				
IUV	Drainage	Khal length estimation	X				BTM
		Benefit from avoided damage	X				
Cultural Ecosystem Services							
DUV	Recreation and other cultural services	Recreation			X	X	MP, CVM
		Filming			X		MP
		Fishing			X		
		Sports		X		X	
		Religious use		X	X	X	

Example 1: Cost Benefit Analysis for Investment Decision

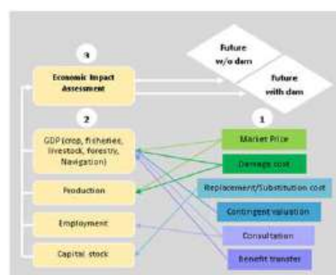
Case

The economic feasibility of the Forest Landscape Restoration (FLR) alternatives to develop a community-based FLR plan in the Hill Tracts

Landuse	Forest Landscape Restoration (FLR) alternatives	Assumptions	NPV (mill BDT) @ 12% discount rate	B/C ratio
Shifting cultivation	Do nothing/No additional intervention	i. Soil erosion is not prevented at all; ii. Assuming ground water infiltration rate is 25% of the rate of forest; iii. Current practice will continue as it is and the yearly values will remain constant.	4,543	5
	Strips of native trees along Jhum field boundaries	i. The locals agree to give up some jhum production land to have strips of native trees along jhum field boundaries; ii. Jhum cultivation happens once in every 4 years, i.e., 3 years fallow period is practiced; iii. Seedling and cultural operation cost for trees is incurred once in 30 years; iv. Production of paddy, sesame, turmeric, pigeon pea, chili, gourd, marfa, maize reduce by 10% from the baseline. The reduced yield is considered as a forgone cost; v. Since the jhum is repeated in every 4 years, an average reduction of soil erosion due to the tree strips is assumed. Soil loss reduced by 50% during year 3-4 and by 25% during year 5-10. vi. Ground water recharge doubles during year 2-4 but increases by 75% of the baseline during year 5-30; vii. Carbon sequestration happens due to the newly planted trees.	2,560	5
	Improved/Modified agroforestry based Jhum (Permaculture model)	i. The locals agree to convert jhum field into permaculture. Farmers are be trained to efficiently utilize the resources as per the principles of permaculture; ii. Seeds, Seedlings, fertilizer, cultural operation cost increase by 15% of the baseline; iii. Seedling and cultural operation cost for trees incurs once in 30 years; iv. Production of paddy, sesame, turmeric, pegion pea, chili, gourd, marfa, maize reduce by 10% from the baseline; v. Fruit trees are planted in 10% areas; vi. High value crops are cultivated along with the regular jhum crops; vii. Ground water recharge increases 1.5 times of the baseline during year 2-5 and 3 times during year 6-30; viii. Soil erosion is 0.75 times of the baseline during year 3-4 and is 0.25 times during year 5-30; ix. Carbon sequestration happens due to the newly planted trees.	12,694	9

Example 2: Economic Impact Assessment of Infrastructure Development

Case
The economic impact of dam construction on agriculture production



Crop	Baseline Condition: Total Production Process			FWOP (Regular flood): Stage I			FWOP (Regular flood): Stage II			FWIP (Dam break)		
	Study Area's Benefit (mill BDT)	Study Area's Cost (mill BDT)	Study Area's Contribution to GDP (mill BDT)	Study Area's Benefit (mill BDT)	Study Area's Cost (mill BDT)	Study Area's Contribution to GDP (mill BDT)	Study Area's Benefit (mill BDT)	Study Area's Cost (mill BDT)	Study Area's Contribution to GDP (mill BDT)	Study Area's Benefit (mill BDT)	Study Area's Cost (mill BDT)	Study Area's Contribution to GDP (mill BDT)
Local Aus	264.37	399.83	211.47	-	279.88	(37.03)	185.06	399.83	132.16	79.31	279.88	42.28
HYV Aus	5,888.81	5,839.47	6,876.53	-	4,087.63	(691.40)	4,122.17	5,839.47	3,134.45	1,766.64	4,087.63	1,075.24
B Aman	1,646.62	1,931.81	1,950.61	-	1,352.27	(212.79)	1,152.64	1,931.81	848.65	493.99	1,352.27	281.20
Local Aman	8,799.07	10,078.17	10,030.81	-	7,054.72	(862.22)	6,159.35	10,078.17	4,927.60	2,639.72	7,054.72	1,777.50
HYV Aman	31,429.21	25,884.64	35,284.71	-	18,119.24	(2,698.85)	22,000.45	25,884.64	18,144.94	9,428.76	18,119.24	6,729.91
Local Boro	1,861.23	1,799.66	2,069.04	-	1,259.77	(145.47)	1,302.86	1,799.66	1,095.06	558.37	1,259.77	412.90
HYV Boro	66,403.51	51,229.66	75,979.86	-	35,860.76	(6,703.44)	46,482.46	51,229.66	36,906.11	19,921.05	35,860.76	13,217.61
Hybrid Boro	10,851.25	7,601.04	12,134.70	-	5,320.73	(898.42)	7,595.87	7,601.04	6,312.42	3,255.37	5,320.73	2,356.96
Wheat	556.10	658.94	737.77	-	461.26	(127.17)	389.27	658.94	207.60	166.83	461.26	39.66
Oilseeds	1,052.42	956.52	1,207.18	-	669.56	(108.33)	736.70	956.52	581.94	315.73	669.56	207.40
Pulses	669.85	649.29	788.54	-	454.50	(83.08)	468.90	649.29	350.21	200.96	454.50	117.87
Spices	2,771.85	1,370.34	3,235.66	-	959.24	(324.66)	1,940.30	1,370.34	1,476.49	831.56	959.24	506.89
Potato	4,736.16	3,636.05	6,246.32	-	2,545.23	(1,057.11)	3,315.31	3,636.05	1,805.15	1,420.85	2,545.23	363.74
Winter Vegetables	6,974.56	4,365.13	7,791.43	-	3,055.59	(571.81)	4,882.19	4,365.13	4,065.32	2,092.37	3,055.59	1,520.56
Summer Vegetables	5,241.69	2,930.69	5,811.32	-	2,051.49	(398.74)	3,669.18	2,930.69	3,099.55	1,572.51	2,051.49	1,173.77
Jute	1,221.08	1,270.34	1,358.23	-	889.24	(96.01)	854.76	1,270.34	717.61	366.32	889.24	270.32
Total	**150,367.79**	**120,601.59**	**171,714.18**	-	**84,421.11**	**(15,016.54)**	**105,257.45**	**120,601.59**	**83,805.26**	**45,110.34**	**84,421.11**	**30,093.80**

Example 3: Economic Modeling of Adaptation Strategies

Case
The economic impact of climate change on agriculture, water resources, and food security and adaptation measures using seasonal and medium-range forecasts

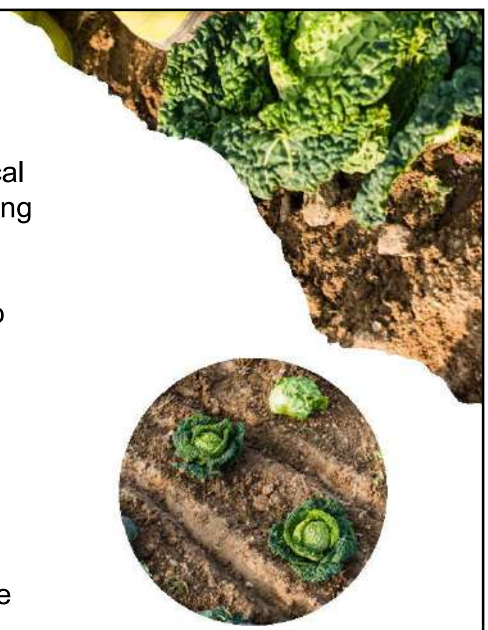
	Gross Return	Cult. Cost	B/C	NPV /GDP	IRR
W/t Sup. Irri					
W. Sup. Irri	0.7736	0.3684	2.0997	0.4052	20.7823
W/t CC	0.8073	0.3684	2.1913	0.4389	20.9680
W. Sup. Irri + /- 10 days	0.9082	0.3684	2.4649	0.5397	21.4480
				Loss of Net Benefit	
W/t Sup. Irri					
W. Sup. Irri				0.034	
W/t CC					0.186
W. Sup. Irri + /- 10 days				0.135	(0.480)

YEAR	GROSS RETURN (mill Tk)			TOTAL COST (mill Tk)		PHASING VECTOR (%)	NET RETURN WITH PHASING (mill Tk)			DISCOUNT FACTOR (at 12% interest rate)	PV OF GROSS BENEFIT (mill Tk)			PV OF COST (mill Tk)
	W. Sup. Irri	W/t CC	W. Sup. Irri + /- 10 days	Cult. Cost	Cult. Cost For IRR		W. Sup. Irri	W/t CC	W. Sup. Irri. + /- 10 days		W. Sup. Irri	W/t CC	W. Sup. Irri + /- 10 days	Cult. Cost
2012-13	0.088	0.088	0.088	0.040	0.030	0.9	0.052	0.052	0.052	1.000	0.088	0.088	0.088	0.0400140
2013-14	0.087	0.088	0.089	0.040	0.030	1	0.057	0.058	0.059	1.120	0.078	0.078	0.079	0.0357268
2014-15	0.087	0.088	0.090	0.040	0.030	1	0.057	0.058	0.060	1.254	0.069	0.070	0.072	0.0318989
2015-16	0.086	0.088	0.092	0.040	0.030	1	0.056	0.058	0.062	1.405	0.061	0.062	0.065	0.0284812
2016-17	0.086	0.088	0.093	0.040	0.030	1	0.056	0.058	0.063	1.574	0.054	0.056	0.059	0.0254296
2017-18	0.085	0.088	0.094	0.040	0.030	1	0.055	0.058	0.064	1.762	0.048	0.050	0.053	0.0227050
2018-19	0.085	0.088	0.096	0.040	0.030	1	0.055	0.058	0.066	1.974	0.043	0.044	0.048	0.0202723
2019-20	0.084	0.088	0.097	0.040	0.030	1	0.054	0.058	0.067	2.211	0.038	0.040	0.044	0.0181003
2020-21	0.084	0.088	0.098	0.040	0.030	1	0.054	0.058	0.068	2.476	0.034	0.035	0.040	0.0161610
2021-22	0.083	0.088	0.100	0.040	0.030	1	0.053	0.058	0.070	2.773	0.030	0.032	0.036	0.0144294
2022-23	0.083	0.088	0.101	0.040	0.030	1	0.053	0.058	0.071	3.106	0.027	0.028	0.033	0.0128834
2023-24	0.082	0.088	0.103	0.040	0.030	1	0.052	0.058	0.073	3.479	0.024	0.025	0.029	0.0115031
2024-25	0.082	0.088	0.104	0.040	0.030	1	0.052	0.058	0.074	3.896	0.021	0.023	0.027	0.0102706
2025-26	0.082	0.088	0.106	0.040	0.030	1	0.052	0.058	0.076	4.363	0.019	0.020	0.024	0.0091702

NAAMA1B | NAAMA2 | NAAMB1 | GOPRAMA1B | GOPRAMA2&B1 | GOBOA1B | GOBOA2 | GOBOB1 | NABOA1B | NABOA2 | NABOE

Key Messages

- ❑ Ecosystems play crucial roles in regulating ecological functions, supporting primary production, and creating food provision and non-material benefits.
- ❑ Apart from provisioning services, other benefits are often unacknowledged as prices are not attached to them (e.g., pollination).
- ❑ Ecosystems generate services (avoid costs) worth millions of dollars every year.
- ❑ It is important to maintain a long-term database of climate parameters and crucial ecosystem services quantities and their values.
- ❑ Economic valuation is important for policymaking regarding food security and for readiness to face the unknown future.



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ধন্যবাদ

Thank you

ROLE OF EARLY WARNING SYSTEMS FOR ADAPTATION TO CLIMATE CHANGE IN AGRICULTURE

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1. The context

Agriculture for its survival and flourish always attempt to 'adjust' with environment, both the below- and above-ground. This is a historic pathway. The climate governs the environment. This is why agricultural activities have specificity to climate. Climate change has become an important issue in agricultural research (R), development (D) and Extension (E).

To deal with the climate change, the theme, 'Climate Smart Agriculture' (CSA), is being widely used in the arena of agricultural R, D & E. It is undebated that CSA is an integrated approach to support sustainable agricultural development and food security in the context of climate change. It was first echoed in 2010 at the Conference on Agriculture, Food Security and Climate Change in the Hague. CSA aims to identify development pathways towards productive and profitable livelihoods for food producers that are well-adapted to climate change and minimize their greenhouse gas emissions. This is expressed in the main objectives, the so-called three pillars of CSA (FAO, 2017): (i) sustainably increase agricultural productivity and incomes of food producers; (ii) strengthen the capacities of agricultural communities to build resilience and adapt to the impacts of climate change; and (iii) reduce and/or remove greenhouse gas emissions, where possible. CSA seeks to identify and enhance synergies between the three objectives in order achieve triple wins. Where triple wins cannot be achieved it aims to avoid and reduce trade-offs as much as possible, based on national and local priorities. CSA encompasses a broad range of practices that can support the achievement of triple wins. However, it is important to note that CSA does not represent a given set of agricultural practices which are generally recommended as 'climate smart'. The approach rather aims to (i) identify suitable combinations of practices for a given context and (ii) create an enabling environment to facilitate the adoption of these practices. Early warning system (EWS) is a potential tool to address the first aim of CSA.

2. The concept of early warning system (EWS)

While each disaster and its impact may be unique, there is a game-changing solution that can be implemented anywhere in the world – this is the early warning systems. These systems, which provide critical information and timely alerts to authorities and communities, have been around for years. But now with the need for countries to begin seriously investing in adapting to climate change, their importance is growing. The UN and other global initiatives have recognized the importance of a robust early warning system as “low-hanging fruit of adaptation efforts”, which provides tangible adaptation measures (WEF 2023).

3. The power of early warning system in relation to adaptation to climate change under climate smart agriculture

The Early Warning System (EWS) is a critical tool for efficiently preventing hazards in agricultural productivity, as well as pests and illnesses. For example, early detection of plant diseases helps in increasing crop yields and decreasing losses (Elsayed and Moawad, 2022). A recent study compared evaluation of two crop management systems was performed involving farmers adopting a weather forecast-based advisory service (WFBAS) and usual farmers’ practice (FP). WFBAS crop management followed the generated weather forecast-based advice whereas the control farmers (FP) did not receive any weather forecast-based advice, rather following their usual rice cultivation practices. The results of the experiments revealed that WFBAS farmers had a significant yield advantage over FP farmers. With the WFBAS technology, the farmers used inputs judiciously, utilized the benefit of favorable weather and minimized the risk resulting from extreme weather events. As a result, besides the yield enhancement, WFBAS provided a scope to protect the environment with the minimum residual effect of fertilizer and pesticides. It also reduced the pressure on groundwater by ensuring efficient water management (Rahman et al., 2023). With just one day's notice, early warning systems can curtail damages by a staggering 30% (WEF 2023). To quantify success, a study found that weather warning systems have reduced injuries and fatalities in the United States by more than 40% (Miller 2018).

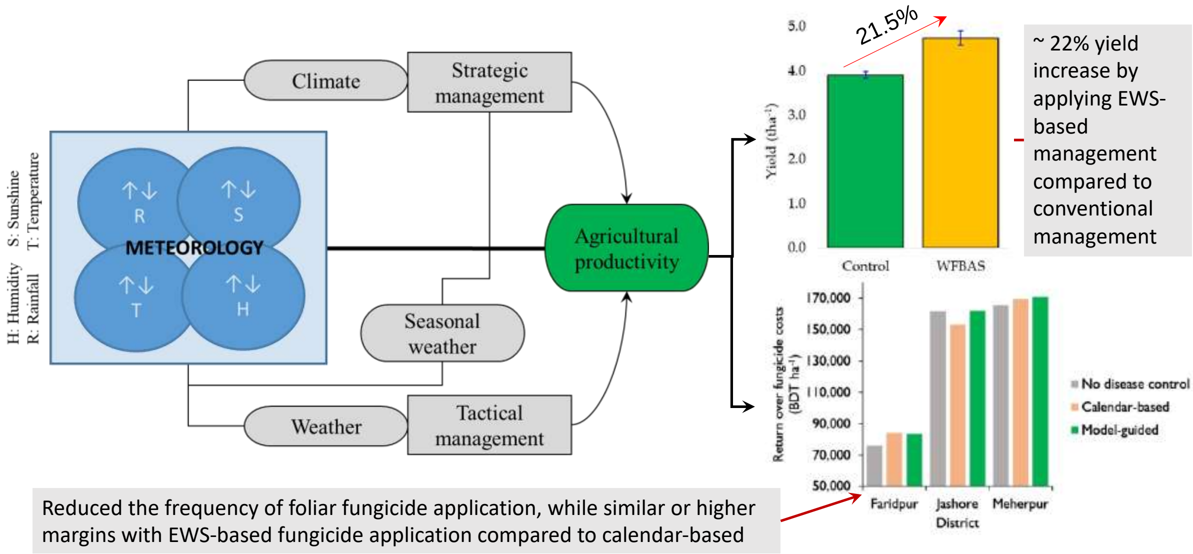
3. The application domain of early warning system in relation to adaptation to climate change under climate smart agriculture

According to the United Nations’ International Strategy for Disaster Reduction (IUN 2006), it integrates four main elements for the Early Warning Systems:

a. Risk Knowledge: specifies all sources of hazards and provide proactive procedures to mitigate the potential effects of hazards.
b. Monitoring and predicting: To generate precise warnings in a timely manner, continuous monitoring of hazard factors and precursors is required. Wherever practical, warning services for various dangers should be coordinated to take advantage of shared institutional, procedural, and communication networks.
c. Dissemination and communication: Warnings must offer clear, helpful information that facilitates suitable reactions in order for people to understand them. To ensure that everyone gets reached and to prevent any one route from failing, many communication routes must be employed, in addition to enhance the warning message.

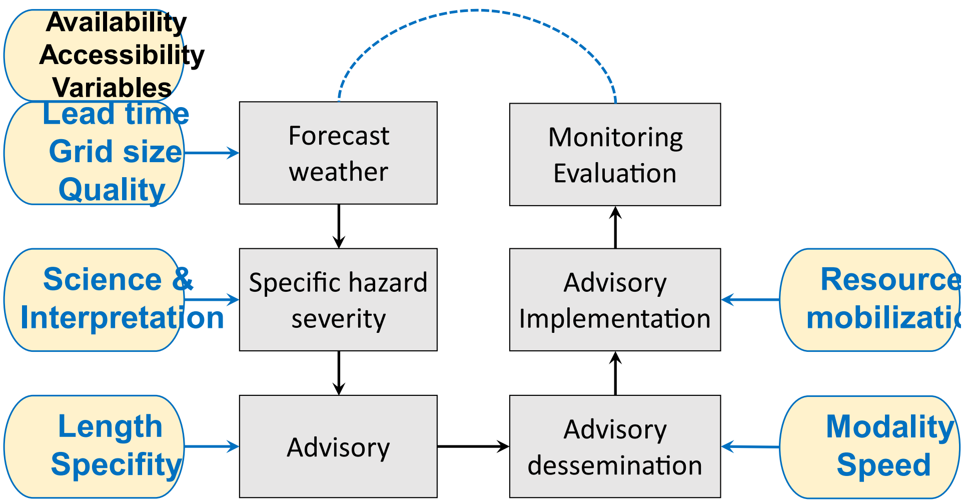
d. Response capability: The general population must also be informed of the warning system and how to respond to notifications. Disaster management authorities must lead organized education and preparation programs in order to achieve this.

The weather provides strategic and tactical management of agricultural commodities as depicted in the following figure.



5. Framework for an early warning system and advisory

The framework for implementing a successful early warning system and advisory in order to adapt short-term climatic conditions is presented below.



Framework for an early warning system and advisory

5. References

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Climate Smart Agriculture in BRAC Adaptation Clinics

BRAC
Climate Change Programme

1

Climate Change Vulnerability Context in Bangladesh

People living in the vulnerable settings are exposed to climate change impacts such as:

- Heat waves,
- Erratic rainfall,
- Sea level rise induced salinity intrusion,
- Increased and intensified cyclones, floods, riverbank erosion and droughts like situation.

Affecting

- Water availability,
- Agriculture and food security,
- Human health,
- Livelihood

- Increasing poverty
- Creating unprecedented displacement and social crisis.

2

Why Adaptation Clinic

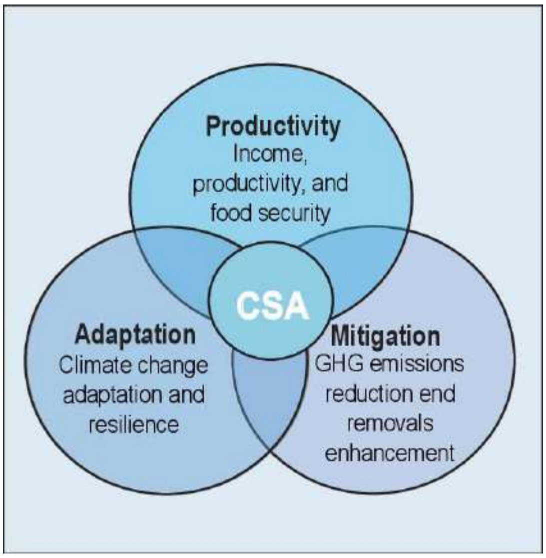
Climate Change Impacts
- Negatively affected by climate extremes (SLR, salinity intrusion, temperature and rainfall variability, increase frequency and intensity of weather events
- Lead to Falls in crop yield up to 30%

Food security
- 25% population remains food insecure
- Living with high recurrence of climate disasters

Unutilized fallow land
- 455,000 ha of land remains fallow - crucial for increasing food production
- Unavailability of suitable technologies and extension supports are the key challenges

The core tenets of Climate-Smart/ Adaptive Agriculture

- Sustainable increase of agricultural productivity and incomes
- Adapt and Build resilience of people and food systems to climate change impacts
- Mitigation and/or reduction of greenhouse gas emissions, where possible



Climate adaptation strategies

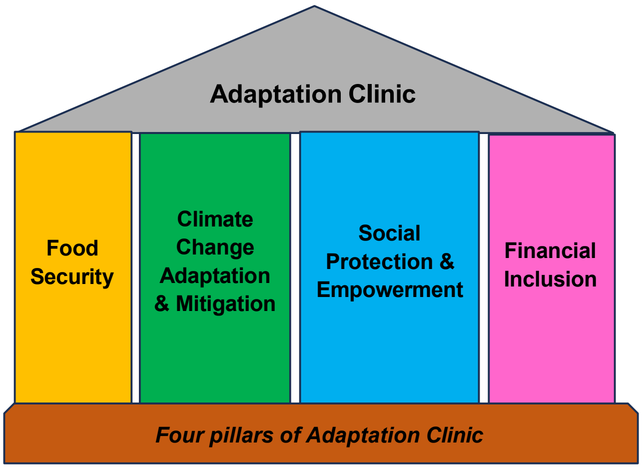
Appropriate combinations of the following measures:

- **Soil improvement:** farm-specific soil data, zero tillage, mulching, composting, liming, cover crops, crop rotations, intercropping
- **Seeds:** Stress tolerant, pest resistant varieties
- **Water:** More efficient, targeted irrigation systems and water use efficiency practices, effective rainwater harvesting, renewable energy, Mulching
- **Fertilizers:** Use of biologicals and soil amendments to optimise use efficiency, actionable recommendations from soil diagnostics
- **Decision-support tools:** digital tools to help extension officers
- **Innovative financial solutions:** use of climate data for insurance

BRAC's Adaptation Clinic to Build Resilience

Adaptation Clinic: A one-stop service centre for climate-vulnerable farming communities that provides holistic services, including -

- Climate-adaptive technologies and, Agri-inputs support
- Advisory support, referral for loans, crop insurance, market linkages
- Weather and climate-based information,
- Capacity building with a Climate Change Adaptation lens.



The four components of the Adaptation Clinic

Adaptation Clinic Holistic Services

Under 4 Components

Technologies and input support

Context–specific climate adaptive technologies identification and dissemination, Stress –tolerant crop varieties/ seeds promotion, Distribution and rational use of fertilizers and pesticides, User friendly agri –machineries making accessible to smallholder farmers.

Advisory Support

Providing information of year round crop production and management, Mobile adaptation clinic and office adaptation clinic advisory services, Referral for savings, loans, crop insurance, Market linkages support, Forming advisory committees for the community

Weather and Climate information

Dissemination of extreme weather information, Crop protection advice based on the weather information, Awareness on climatic events.

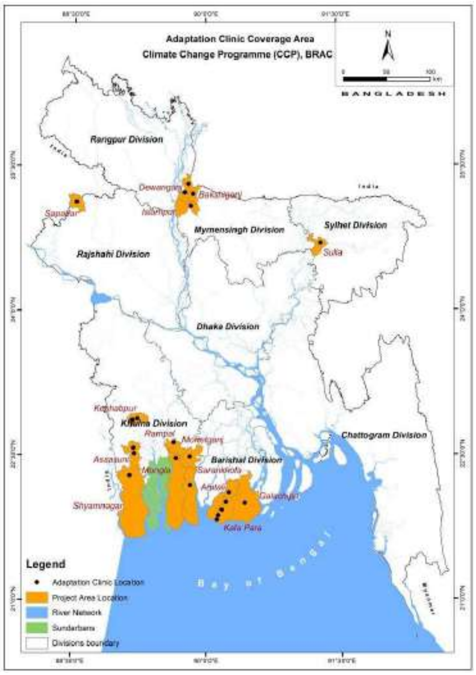
Farmers Capacity Building

Training on crop production technologies, Continuous hands –on coaching at the farmers' field, Farmers field visits and crop management support

Target Areas for the Adaptation Clinics

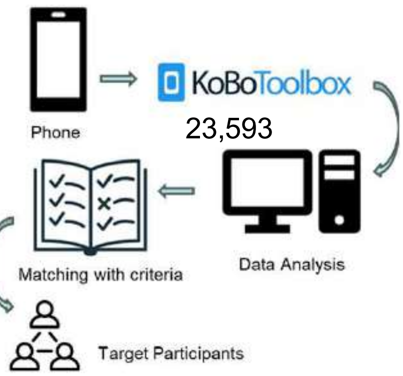
Vulnerable Regions of Bangladesh

- ❑ The Haor and Flash Flood Areas
- ❑ The River Systems and Estuaries
- ❑ Coastal Region
- ❑ The Barind and Drought Prone Areas
- ❑ Chittagong Hill Tracks



Vulnerability Assessment & Targeting (Cont.)

Participant Selection



Year Round Adaptive Agricultural Planning

Farmer's Card

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Vulnerability Assessment & Targeting

CCVA

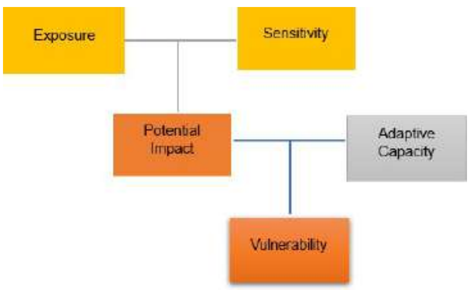
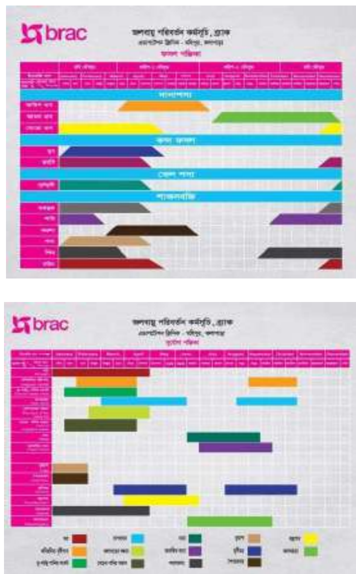


Figure : IPCC vulnerability framework for CCVA



Crop & Disaster Calendar

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Alternative Cropping Pattern Plan

Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar

Kharif-I (M-J) | **Kharif-II (J-N)** | **Rabi (N-M)**

Area	**Previous cropping pattern**			**Prescribed cropping pattern**		
	Kharif-I	**Kharif-II**	**Rabi**	**Kharif-I**	**Kharif-II**	**Rabi**
Patuakhali (Kalapara & Galachipa)	Fallow	Aman rice	Fallow/ Mungbean	Vegetables/ Aus rice	Aman rice	Sunflower/ Mungbean/ Chilli/ Maize
Satkhira (Assasuni, Shymnagar)	Fallow	Aman rice	Fallow	Sesame	Aman rice	Sunflower
Jamalpur (Dewanganj & Bakshiganj)	Fallow/ Aus rice	Aman rice	Mustard/ Maize	Jute	Aman rice	Mustard/ Maize/ Vegetables
Sapahar, Naogaon	Mango			Onion/ Garlic/ Potato/Vegetables intercropping in Mango field		

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Soil Health Management

Salinity Reduction :

Technologies	Before Intervention Soil Salinity measured	After Intervention Soil Salinity measured
Saline Soil pit managed using double layer mulching	8581 mS/m	2118 mS/m
Soil Salinity Reduced applying bio fertilizer	6665 mS/m	2023 mS/m

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Soil Health Management (Cont.)

Soil Fertility:

Mulching – Mulching conserves moisture in the soil, suppresses weed growth, moderates soil temperature, enhances soil biological activities, reduces erosion, and improves soil fertility.

Bio Fertilizer - Helps keep natural humidity of the soil, increase the water retention capacity and soil fertility

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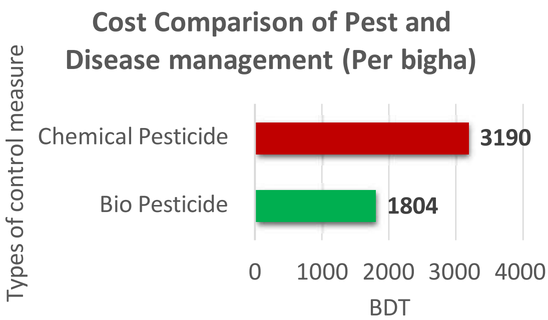
Promoting Bio-Pesticide

- Bio Pesticide is cost effective than using Chemical Pesticide
- It is useful for controlling crop pests in an environmental friendly way.



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Portable Solar Irrigation Pump


- ✓ For Irrigation purposes, Farmers spent 2400 taka per bigha previously but now the operation cost is very low. Farmers spend only 600 – 700 taka per bigha.
- ✓ This portable system can provide irrigation facilities to 100-120 farmers in a crop season

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Entrepreneurship Development Promoting Agri-machineries






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Community-based Agri-storage

- Grain storage for smallholder farmers
- Managed by the communities
- Ensuring better prices for the farmers
- Safe during floods/ cyclones
- 13 Agri-storage established in flood/cyclone-prone areas

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Climate Adaptive Aquaculture

Climate adaptive fish varieties

Large size fish fry with higher growth rate. eg. monosex tilapia, G3 rui

With special respiratory system for drought prone areas. eg. catfish and koi

Short cycle period eg. koi

Climate adaptive technologies

Encouraging natural feeds to grow and improving farm management quality

Netting is done to cope up with flooding

Weather information services/ good aquaculture practices

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Climate Resilience Homestead Aquaculture

- ❖ Aquaculture on slightly elevated ground
- ❖ Three cycles can be completed in a year
- ❖ Operated in a small area, so easily manageable.
- ❖ Waste water from mini ponds can be used for vegetable plantation.

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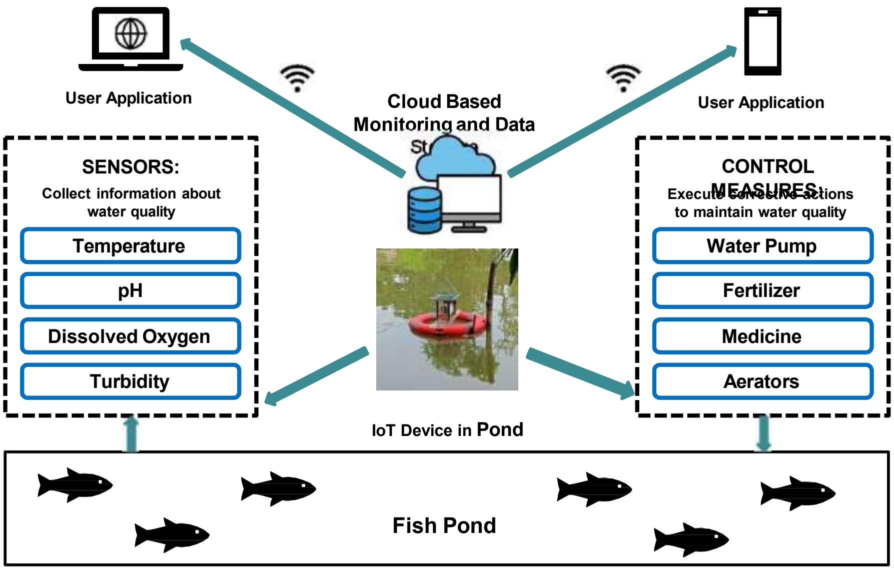

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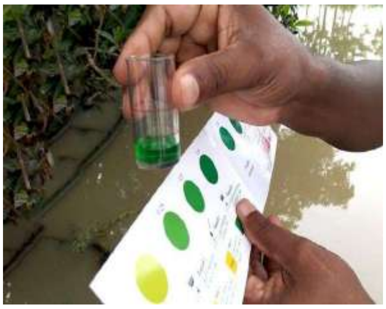
Aquaculture through Adaptation Clinics



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Mitigation : Increasing Green Coverage

Creating individual forest (*Amar Ban*) through mixed (woody, fruit and medicine) trees in a participatory approach to foster adaptation mitigation co- benefit

Creating 54.5 Acres of Mangrove plantation in a newly acclaimed lands of Mirersarai to sequester 820 ton of $CO2_{eq}$

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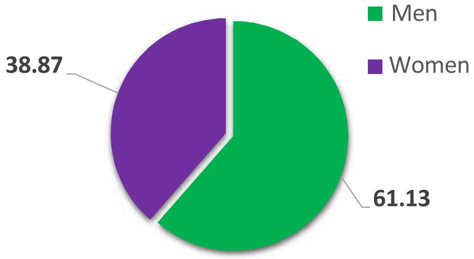
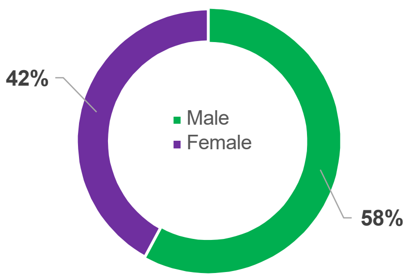
Women’s Participation in the Adaptation Clinics

Percentage of Receiving input support



Mobile Adaptation Clinic (Participation of Men - Women)



Advisory Services through Mobile Adaptation Clinic

- Diseases and pest management
- Participation of women farmers
- Farmers are satisfied under the advisory services of Adaptation Clinic.

Adaptation Clinic Advisory Committee

- Empower communities to co-design and co-implement locally-led adaptation approaches
- Participation of the community leaders in adaptive planning
- Community-led decision making
- Supporting implementation of the Adaptation clinic activities
- Coordinating disaster response in the community
- Committee consists of seven members from the community including an advisor from the Upazila Agriculture office

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How Adaptation Clinic Works

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Pictures of the Field Activities

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Informed Guidance for Proactive Climate Actions

Livelihoods & Adaptation Clinic: Informed Guidance

JAMEEL OBSERVATORY

Gearing up….

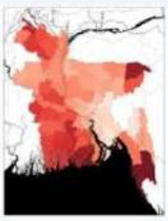
Climate change continues to alter the agricultural landscape in southwest Bangladesh, and farmers, technologists, and policymakers require advanced guidance and capabilities for future adaptation decisions

Climate Phenomena

- Heat extremes
- Changing precipitation
- Windspeed
- Flood inundation and salinity intrusion

Human System Impact Assessments

Project future climate and land cover / land use trends, with possible effects on crop suitability and yields



Informed Guidance

- For farmers on likely trends
- For technologists (and supporting research institutes) on capability gaps
- For government decisions and local authorities:
  - National 5-Year Plan
  - National Adaptation Plan
  - Bangladesh Climate Change Strategy and Action Plan
  - Delta Plan 2100
  - …

BRAC Adaptation Clinic: incorporation of new data and decision tools

Nation- and region-scale adaptation roadmaps

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Thank You

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THE SOIL – CLIMATE CHANGE CONNECTION: ADAPTATION AND MITIGATION OPTIONS IN BANGLADESH

Dr. Habib Mohammad Naser
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BARI, Gazipur

Soil is an important — and often neglected — element of the climate system. It is the second largest carbon store, or 'sink', after the oceans. Depending on the region, climate change might result in more carbon being stored in plants and soil due to vegetation growth, or more carbon being released into the atmosphere. Restoring key ecosystems on land, and a sustainable use of the land in urban and rural areas, can help us mitigate and adapt to climate change.

A. Climate change puts soil under pressure

Higher temperatures may lead to more vegetation growth and more carbon stored in the soil. However, higher temperatures could also increase decomposition and mineralisation of the organic matter in the soil, reducing organic carbon content. The organic matter can quickly break down, releasing carbon dioxide (CO_2) into the atmosphere. The increasing concentration of carbon dioxide in our atmosphere may cause the microbes in the soil to work faster to break down organic matter, potentially releasing even more carbon dioxide.

Climate change affects soils

Since temperature and precipitation affect the distribution of organic matter and the amount of carbon in soils. New research suggests that as global warming continues, soils will release more carbon than was previously thought. Earlier studies that heated soils 5 to 20 cm deep found that the soil would release 9 to12 percent more carbon dioxide than normal. But deeper levels of soil contain more than 50 percent of global soil carbon and after heating soils to 100 cm deep, scientists found that 4˚ C of warming could result in soils releasing as much as 37 percent more carbon dioxide than normal.

Temperature

The activity of many microbes acting on organic materials is a function of temperature. Low temperatures slow down decomposition, while warm temperatures speed up decomposition. The microbes that perform the bulk of the decomposition of organic material prefer room temperatures of 18 to 24°C, but they are active in the temperature range of 16 to 45°C.

Greater temperature extremes Climate change is associated with hotter summers and colder winters. Temperatures in Bangladesh have increased about 1°C in May and 0.5 °C in November between 1985 and 1998, and further temperature increases are expected. However, although the overall climate is warming, temperature extremes are increasing, and winter temperatures as low as 5°C have been recorded in January 2007, reportedly the lowest in 38 years.

Increase in surface air temperature in winter 1.3 °C and monsoon 0.7 °C

Items	Winter		Monsoon/summer	
	increase	decrease	increase	decrease
precipitation	-	3%	11%	-
evaporation	10%	-	2%	-
stream flow discharge	-	5%	20%	-

Moisture

Proper soil moisture enhances the growth of microorganisms that break down OM into humus. On the other hand, excess water can lead to anaerobic conditions which slow down the degradation process. Soil moisture of 50 to 70 percent of the soil's water-holding capacity is generally acceptable. At this moisture level, oxygen is in adequate supply for aerobic decomposition. Anaerobic decomposition is incomplete and does not yield as much energy as aerobic decomposition.

Increased drought stress during dry periods in Bangladesh

Climate change will exacerbate drought in Bangladesh both in terms of intensity and frequency linked to higher mean temperatures and potentially reduced dry season precipitation. Monsoon rains produce 80% of Bangladesh's annual precipitation, and when this is reduced, drought is a significant problem; between 1960 and 1991, a total of 19 droughts occurred in Bangladesh. The Southwest and Northwest regions are particularly susceptible to drought. Greater precipitation extremes associated with climate change also mean less rainfall in the dry season, which will increase water stress on those areas that already experience water shortages, particularly in the winter months.

B. Soils as a sink and source of atmospheric carbon dioxide

Soils of the world constitute the largest reservoir of terrestrial carbon (C) stocks. They comprise both soil organic carbon (SOC) and soil inorganic carbon (SIC) and are an important component of the global C cycle. Estimated to 1 m depth, terrestrial soil (2500 PgC; 1 PgC = petagram of carbon = 1 billion metric tons of carbon) and vegetation (620 PgC) hold three times more C than that in the atmosphere (880 PgC). However, estimates of soil C stocks are variable, depending on the methods used.

Soils are losing carbon

How much carbon soils can absorb and how long they can store it varies by location and is effectively determined by how the land is managed. Agricultural practices that disturb the soil—such as tilling, planting mono-crops, removing crop residue, excessive use of fertilizers and pesticides and over-grazing—expose the carbon in the soil to oxygen, allowing it to burn off into the atmosphere. Deforestation, thawing permafrost, and the draining of peatlands also cause soils to release carbon.

Soils can sequester more carbon

Soil carbon sequestration is defined as the process of transferring carbon dioxide from the atmosphere into the soil of a land unit through plants, plant residues, and other organic solids, which are stored or retained in the unit as part of the soil organic matter (humus). A 2017 study estimated that with better management, global croplands have the potential to store an additional 1.85 gigatons carbon each year—as much as the global transportation sector emits annually. Moreover, some scientists believe soils could continue to sequester carbon for 20 to 40 years before they become saturated.

C. Climate change impact on soil degradation

Soil erosion under climate change

Soil erosion under climate change is most directly affected by changes in extreme precipitation. Extreme precipitation is projected to increase as a result of the increasing moisture-holding capacity of a warmer atmosphere, resulting in a more vigorous. Soil erosion is expected to increase in the coming decades, considering the projected increase of extreme precipitation and the possible negative impact of land use change.

Potential impacts of **land use change:**

The possible impact of land use change includes reduced arable land, conversion of grassland to arable afforestation, alteration of soil properties like changes in the soil biota which may have modified effects on soil structural stability, soil biodiversity, plant-soil interactions and nutrient cycling. Further changes in vegetation cover could alter runoff and nutrient losses as well as SOM content. Afforestation results in a decrease in soil respiration and hence decrease soil CO_2 emissions although the reasons for this are not clear as there is only a significant relationship with temperature.

Increased salinity

The availability of freshwater will be reduced by increased salinity intrusion into fresh water sources during the low flow conditions in Bangladesh. In the coastal regions this is brought about by sea level rise resulting in saline water intrusion in the estuaries and into the groundwater. The effects are exacerbated by greater evaporation and evapotranspiration of freshwater as temperatures increase, coupled with a greater demand for fresh water in times of water stress

D. Impact of climate change on different soil parameters

a) Soil physical parameters

Soil water: Soil water can be fluctuated by a number through climate change such as precipitation causing rapid changes in soil water since the time-scale for response is usually within a few hours, temperature increase resulting in greater evapotranspiration loss of water from the soil and lastly the type of land use. The integral influence of climate-hydrology-vegetation-land use changes are reflected by the field water balance and soil moisture regime. Their components and the potential impact of four plausible climate change scenarios on these factors are summarized in their components and the potential.

Soil temperature

Trends in soil temperature are important but rarely reported, indicators of climate change**.** There is a close relationship between air temperature and soil temperature and a general increase in air temperature will inevitably lead to an increase in soil temperature. The temperature regime of the soil is governed by gains and losses of radiation at the surface, the process of evaporation, heat conduction through the soil profile and convective transfer via the movement of gas and water.

b) Soil biological parameters

Soil organic matter:

Soil organic matter is undoubtedly the most important soil component as it improves soil quality though the influences in soil structure, water holding capacity**,** soil stability, nutrient storage and turnover and oxygen-holding capacity. Organic matter is particularly important as the prime habitat for immense numbers and variety of soil fauna and microflora, which play a critical role in the health and productivity of soils.

c) Soil chemical parameters

Chemical processes in soils: The most rapid processes of chemical or mineralogical change under changing external conditions would be loss of salts and nutrient cations where leaching increases and salinization where net upward water movement occurs because of increased evapotranspiration or decreased rainfall or irrigation water supply[63].

Acidification, salinization, sodicity problem in soil: While temperature increases are forecast for most parts of the world, there is less certainty about precipitation changes.

Significant increases in rainfall will lead to increases in leaching, loss of nutrients and increasing acidification, depending on the buffering pools existing in soils. The direction of change towards increased leaching or increased evaporation will depend on the extent to which rainfall and temperature change and consequent changes to land use and its management. In either case the situation could lead to important changes in soils.

d) Soil fertility and nutrient acquisition: Climate change may have stronger or weaker, permanent or periodical, favourable or unfavourable, harmful (sometimes catastrophic), primary (direct) or secondary (indirect) impact on soil processes. Among these processes soil moisture regime plays a distinguished role. It determines the water supply of plants, influences the air and heat regimes, biological activity and plant nutrient status of soil.

E. Water logging soil in south-west Bangladesh

The major cause for water logging can be explained as rising of riverbed due to siltation as influenced by retardation of upstream river flow for human intervention, as well as deprivation of floodplain (low land, locally so called beel) to silt deposition due to embankment or polderization.

Floating bed cultivation of vegetables in Bangladesh

Floating gardens are most common in the districts of Gopalganj, Barisal and Pirojpur. Here, during monsoons the farmers gather weeds like water hyacinth or paddy stalks, and place them on stagnant water, beating them into shape and making rafts. In the wetlands of southern Bangladesh, most affected by floods, farmers don't have enough cropping space in terms of access to land, so people have learnt to make the most of flood water. In this context, they have developed a floating agricultural practice to rear plants and crops in floating bed, made of water hyacinth, algae or other plant residues.

There are many more important issues that are not discussed here. A lot remains unknown, but the better we understand the dynamics between soil, land and the climate, the better are our chances of designing and implementing sustainable solutions.

CLIMATE SMART RICE PRODUCTION TECHNOLOGIES IN BANGLADESH

Dr. Aminul Islam
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Bangladesh Rice Research Institute

Introduction

Across the globe, climate change is rapidly affecting every aspect of life, and the agricultural system is the most affected. There has been a steady yet significant increase in temperature (both maximum and minimum) trends across Bangladesh. There is also a rise in sea levels, and heavy rains, hailstorms, and droughts have occurred in different locations within the country. This has adversely affected the agricultural sector. Food and nutrition security of the farming households has been affected. The United Nations (UN) Sustainable Development Goals (SDGs) one and two (no poverty and zero hunger) may not be actualized on the continent, despite the efforts at different levels to end poverty and increase food and nutritional security globally. Climate change is greatly shifting the way agricultural activities are being conducted. Plants, animals, and ecosystems are adapting to the new, unbalanced climatic conditions.

The response of the ecosystem to changes is complex to decipher because each element in the system will respond independently and interact with other elements differently. For instance, many cultivated plants react favorably, in controlled conditions, to an increase of CO_2 in the atmosphere. However, at the same time, many weeds also react favorably to the same treatment. The result in the field can be an increase or decrease in the yield of the cultivated plants, depending on the level of competition for nutrients and water by the weeds as well as on the kind of agronomic practices.

Climate-smart agriculture (CSA) technologies have been developed by scientists and researchers amidst the high rise in climate change. Some of these technologies are improved versions of old practices while a few others are entirely new in the system. Appropriate technologies to adapt to the changing climatic condition will necessarily need to be drought-tolerant, grow and produce well within a short duration, tolerant to multiple pests and diseases, able to produce well under marginal soil fertility conditions, and high yielding among other desirable traits. These technological traits embedded in the seeds are vital and should be supported by appropriate agronomic practices to aid the climate change mitigation process. Mitigation efforts tend to be broad and exist at higher levels of governance and management of the ecosystem. Practices that reduce carbon emission, such as limiting the use of fossil fuels, reducing bush burning, etc., will require long-term advocacy for behavioral change among the populations within the country.

Rice is the staple food of Bangladeshi people and about 80% of land is occupied by rice. **Food security is synonymous to rice security** in Bangladesh. There is a myth that rice cultivation is responsible for global warming potentials by emitting methane gas to the atmosphere. In this lecture, I have discussed the currently available climate smart rice production technologies in Bangladesh.

What is climate smart agriculture?

Climate-smart agriculture (CSA) is an approach for developing agricultural strategies to secure sustainable food security under climate change. CSA aims to tackle three main objectives: sustainably increasing agricultural productivity and incomes; adapting and building resilience to climate change; and reducing and/or removing greenhouse gas emissions, where possible.

CSA aims to simultaneously achieve three outcomes:

1. Increased productivity: Produce more and better food to improve nutrition security and boost incomes, especially of 75 percent of the world's poor who live in rural areas and mainly rely on agriculture for their livelihoods.
2. Enhanced resilience: Reduce vulnerability to drought, pests, diseases and other climate-related risks and shocks; and improve capacity to adapt and grow in the face of longer-term stresses like shortened seasons and erratic weather patterns.
3. Reduced emissions: Pursue lower emissions for each calorie or kilo of food produced, avoid deforestation from agriculture and identify ways to absorb carbon out of the atmosphere.

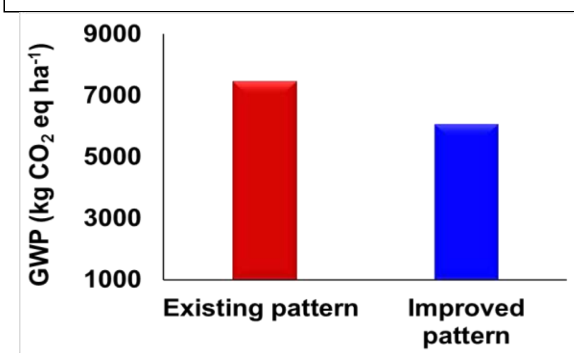
Climate Smart Rice production technologies

1. Climate resilient rice varieties/crop management
2. Rice Production Technologies: Soil and Fertilizer management, water management
3. Agro-forestry
4. Energy management

1. Climate resilient rice varieties/crop management

There are many ways of crop management that can be treated as climate-smart. Crop production by adopting diverse farming systems are subject to widely differing socio-economic, climatic and soil conditions. Moreover, increasing attention is now being given to the wide range of crop production practices that can be considered as 'climate-smart' either from an adaptation perspective, or for their mitigation potential. For example, crop interventions, like drought tolerance and shorter-duration varieties, can substantially reduce the risk of yield reduction or crop failure (Roy and Chan, 2014) (Table 1).

Climate resilient/ecosystems	**Rice varieties**
Submergence tolerant rice varieties	BRRI dhan51, 52, 79 (T. Aman)
Drought tolerant rice varieties	BRRI dhan56, 57, 66, 71 (T. Aman), BRRI dhan42, 43, 83 (B. Aus)
Saline tolerant rice varieties	BRRI dhan53, 54, 73 (T. Aman), BRRI dhan47, 67, 97, 99 (Boro)
Rice varieties for tidal ecosystem	BRRI dhan44, 76, 77 (T. Aman)
Rice varieties for waterlogged condition	BRRI dhan85 (T. Aus Non saline) BRRI dhan78 (T. Aman Saline condition)
Low input rice varieties (Require 20-30% less fertilizer)	BRRI dhan69 (Boro), BRRI dhan75 (T. Aman)
Cold tolerant rice varieties	BRRI dhan18, 36, 55, 69(Boro)



Net carbon stock as influence by tillage operations under rice-mustard-rice cropping patterns.

Year	Treatments	Input C ($t\ ha^{-1}$)	Output C ($t\ ha^{-1}$)	Yearly net C stock ($t\ C\ ha^{-1}$)
2021-22	Conventional tillage	11.90	10.21	1.68
	Strip tillage	12.21	10.37	**1.84**
2022-23	Conventional tillage	11.91	10.22	1.69
	Strip tillage	12.18	10.34	**1.85**

- Improved pattern (Mustard-Boro-T. Aman) reduced GWP 19% than existing pattern (Boro-Fallow-T. Aman).
- Tillage system enhanced C sequestration under rice-mustard-rice cropping system

2. Rice Production Technologies:

a) Soil management

Challenges of climate change to soils

Good soil health is essential for sustainable and productive agriculture. 'Healthy' soil helps to produce a good amount of crop production even in the context adverse climatic condition. Key aspects of 'healthy' soil include (i) a comprehensive soil covers of vegetation (ii) minimal loss of soil nutrients from the soil through leaching, (iii) zero or minimal rates of rainfall run-off and soil erosion, and (iv) no accumulation of contaminants in the soil. It is estimated that more than 100 kg nutrients per ha a year are getting out of the soil system (FAO, 2015). Bangladesh also has wide variety and complexity of soils at short distances due to a diverse nature of physiographic condition, parent materials, lands, and hydrology and drainage conditions. Due to intensive cropping to grow more food, continuous changes are taking place in the soil fertility status due to organic matter depletion, nutrient deficiencies, drainage impedance/water logging followed by degradation of physical and chemical properties of soil as well as salinity/acidity occurred due to climate change effects. Soil management contributes to CSA in a numerous way (Table 1).

Some Soil and Fertilizer Management options

BRRI organic Fertilizer

- Reduced 30% urea fertilizer
- Eliminate 100% TSP fertilizer
- Increase rice yield 5-20%
- Improve soil C stock and soil health

Soil Salinity Management

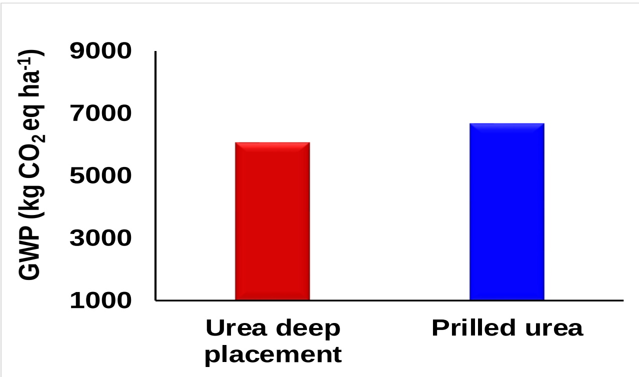
- Application of ash @ 5.0 t ha^{-1} at final land preparation
- Application of K-fertilizer (MoP) @ 40 kg K ha^{-1}
- Application of gypsum @ 1 t ha^{-1} and flashing with non-saline water after 30 days of gypsum application

Urea briquette and BRRI-organic fertilizer

- save 30% N
- reduce NH_3 & N_2O emission &
- increase N use efficiency

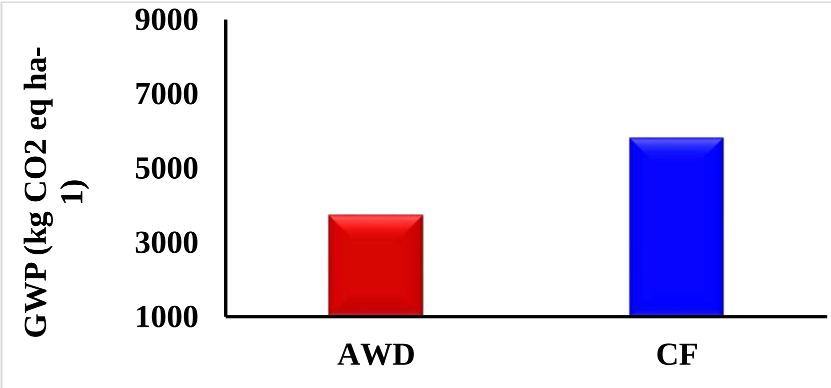
Fertilizer Management and Greenhouse Gas Emissions

- Urea deep placement reduced GWP 9% than prilled urea



b) Water management

Bauman *et al.* (2007) estimated that agriculture is the largest consumer of the world's freshwater resources, requiring 70% of available supply of which almost 40% are used for rice production. Accordingly, water stress has becoming a vital issue, in general, for agriculture and in particular, for rice production. In Bangladesh, occurrence of drought in the northwest region due to climate change is an alarming issue that should be addressed through water management practices. Flood, flash flood is also common in middle and north east that needs proper drainage system. Promoting water use efficiency, water management has huge potential for mitigation in rice cultivation. A range of contributions of water management to CSA have been reported (Table 1) in the recent literature such as Climate-Smart Sourcebook of FAO.



- Alternate wetting and drying (AWD) irrigation reduce 36% global warming potential (GWP) than continuous flooding (CF)

3. **Agroforestry**

Agroforestry is one of the vital management options for climate change mitigation through boosting carbon sequestration by increasing biomass both above and below ground**.** Key strategies include increasing tree cover (afforestation and reforestation) and reducing deforestation and degradation for climate change mitigation and adaptation. Table 1 presents main contribution of agro forestry to CSA.

4. **Energy management**

Energy plays an essential role in the pre-production stage of inputs; in the production of crops, and forestry products; in post-production and postharvest operations; in food storage and processing; in food transport and distribution; and in food preparation. These systems require (i) direct energy, namely, electricity, mechanical power, solid, liquid and gaseous fuels; and (ii) indirect energy like the energy required to manufacture inputs such as machinery, farm equipment, fertilizers and pesticides (FAO 2012). It is, therefore, efficient management of energy sources and diversification through the use of sustainable renewable energy can reduce reliance on fossil fuels, increase energy supply and access, and reduce the impact on agriculture/environment (Table 1). A couple of energy management interventions can be adopted such as (i) increasing energy efficiency, (ii) generating a supply of renewable energy from the sector, and (iii) broadening access to modern energy services (FAO 2013).

Table 1. Understanding contributions of broad practices and technologies to climate-smart agriculture

CSA practices & technologies	Productivity	Adaptation	Mitigation
Soil	Improving soil	Interventions like	Soils are an important below

CSA practices & technologies	Productivity	Adaptation	Mitigation
management	fertility, water availability and reducing the loss of nutrient-rich topsoil that improves productivity.	reducing the risks of run-off, contour ploughing, and land terracing act as adaptation measures.	ground 'sink' for carbon sequestration. Interventions are organic matter additions, and inclusion of trees in crop fields, etc.
Water management	Reduce crop water stresses by capturing and retention of rainfall, improving schedule of irrigation water boosts productivity.	Greater water use efficiency or improved irrigations systems (e.g. supplemental irrigation) are an important longer-term adaptation mechanism.	Alternate wetting and drying cycles and, irrigation strategies that reduce the amount of water required can reduce energy consumption for pumping, thereby reducing emissions
Crop production/ Management	Breeding of higher yielding crops, adopting improved nutrient management, and cultivating disaster-resilient varieties increase productivity.	Crop interventions can reduce the risk of yield reduction. Developing and planting of heat-tolerant, drought-tolerant or salinity tolerant crop varieties. Crop rotation, change in cropping pattern, relay, intercropping or zero tillage cropping are good adaptation practices	Mitigation potential of crop production largely stems from soil and water management, or the agroforestry systems. Perennial crops are able to sequester greater amounts of carbon below ground than annual crops.
Agroforestry	Agroforestry provides various ecosystem services like addition income, improves soil quality, etc that leads productivity	Agroforestry practices increase the absorptive capacity of soil and reduce evapotranspiration, and used as shelterbelts and windbreaks.	Actions that increase tree cover and reduce deforestation and degradation, increase carbon sequestration through increased biomass both above and below ground.
Energy management	Productivity can be increased through improving energy efficiency, reducing losses and diversifying energy sources, e.g. the use of renewable energy sources.	Reducing reliance on fossil energy and associated costs, and sustainable means of usage of biomass. Other adaptation benefits are improved health and increased food security.	Bioenergy and solar energy can replace fossil fuels. Energy management like identifying sustainable renewable energy resources, promoting efficient and replicable technologies are effective mitigation measures.

Source: FAO, 2010; FAO, 2013; Roy, 2015; FAO, 2015; Chan et al., 2016

Agro-region based climate change hot spots of Bangladesh

Around 41% of country's total area is under climate risk which is gradually being heightened in the contemporary development discourse (Mandal 2016). Literature (e.g., MoEF, 2005) review indicates that the major climate risk hotspots in Bangladesh are:

Cyclone risk hotspots: The cyclone starts from Bay of Bengal and damage crops, vegetation and lead to floods and storm surges. South, southeast-west region, i.e. Cox's Bazar, Chittagong, Patuakhali, Barguna, Sathkhira, Khulna districts in Bangladesh are vulnerable to cyclone and storm surges. Violent cyclone Sidr (2007), Aila (2009), Nargis, Mohasen heated those districts caused serious damage and losses.

Flash-flood and flood risk hotspots: North and northeast regions, namely, Sunamganj, Moulavi Bazaar, Hobiganj, Sylhet districts are flash-flood prone areas. Erratic and uneven rainfall caused by climate change results in sudden flooding in those areas make damages in standing crops, vegetation, soil erosion, livestock and poultry. Middle regions namely Manikganj, Munshiganj, Tangail, Dhaka, Cumilla, Brahmanbaria districts are flood prone areas where serious loss of crops and vegetables are accounted frequently.

Drought risk hotspots: Mainly located in northern west region which includes, Rajshahi, Chapainawabganj (Barind tract), Kurigram, Nilphamari, Rangpur and Dinajpur districts. Rice and other crop production are seriously hampered in those areas due to scarcity of irrigation water.

Salinity risk hotspots: Coastal belt south and southwest regions are identified as salinity vulnerable areas. It is reported that salinity has already been penetrated in 100 kilometer north to the Southwest coast. Patuakhali, Barguna, Sathkhira, Khulna, Pirojpur and Gopalganj districts are being reported as the salinity affected areas where local rice variety, rice other than saline tolerant varieties, vegetables are difficult to produce. Reviewing DAE documents revealed that there are manyCSA technologies and practices have been used in different regions. These technologies and

practices mainly used in agriculture sector especially in the crop subsector (Table 2).

AGROFORESTRY FOR CLIMATE SMART AGRICULTURE

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Concept

Developing countries (like Bangladesh) are going to bear the brunt of climate change and suffer most from its negative impacts. Developing countries are faced with urgent needs for development, to improve food security, reduce poverty and provide an adequate standard of living for growing populations. For some decades now agricultural research has been focusing on the questions of increasing resilience (against drought, erosion, fertility loss, etc.) and productivity of agricultural systems. Increasing system resilience is directly related to increasing the adaptive capacity of farmers.

Agroforestry provides a particular example of a set of innovative practices that are designed to enhance productivity in a way that often contributes to climate change mitigation through enhanced carbon sequestration, and that can also strengthen the system's ability to cope with adverse impacts of changing climate conditions. This paper investigates the adaptation and mitigation functions of agroforestry systems, reexamines the concept of sustainability and explores how agroforestry systems (and other innovations for that matter) might enhance resilience and thereby reduce vulnerability of smallholder farmers in the tropics.

Impact of Climate Change

Climate change is happening now (Ripple et al. 2019) and urgent action is required to limit the temperature increase to 1.5 degrees (IPCC, 2019). Climate change risks (e.g. severe droughts, flooding, diseases) can have extensive impacts on agricultural systems, triggering soil erosion, crop failure, loss of biodiversity, reduced soil moisture, pest damages and economic losses. More extreme events and greater occurrence of drier and wetter conditions are already making it difficult for farmers to plan planting and harvesting (SIWI, 2018), threatening current production systems and food security as a result. Trees, forests and agriculture are key to reducing carbon emissions and achieving the Paris Agreement targets. Replanting the right tree species in the right place can help farmers adapt to climatic impacts.

LAND DEGRADATION – A DRIVER OF CLIMATE CHANGE

About 25% of the Earth's ice-free land area is subject to human-induced degradation and many countries expected to be severely affected by climate change are in the tropics, with large parts of their populations dependent on agriculture (IPCC, 2019). Organic matter in soils contain approximately three times more carbon than the atmosphere (Jobbágy and Jackson, 2000), and it is easily removed by land degradation. Over time, soil can thus serve as a carbon sink or source depending on soil properties, local climate and land use (IPCC, 2019).

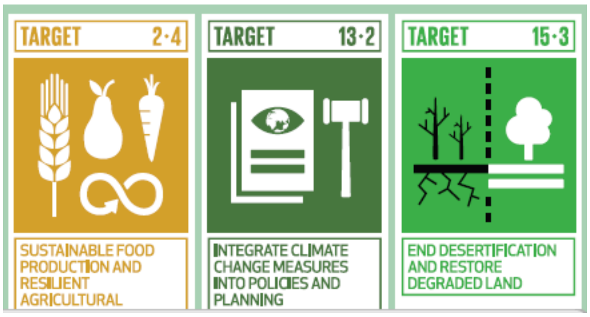
About 23% of the world's total emission of greenhouse gases (GHGs, e.g. CO2, N2O and CH4) come from agriculture, forestry and other land uses, for example from deforestation, livestock production and soil and biodiversity degradation (IPCC, 2019). Farming activities may generate significant amounts of GHGs, for instance from inorganic fertilizers, pesticides, fossil fuels, manure and crop residues, as well as increased numbers of livestock. At the same time, the impact of climate change make farming more difficult and unpredictable for smallholder farmers, while the demand for food increases as populations grow. Degraded landscapes mean lost opportunities and negative impacts for people, society, economies, and for ecosystem services and environmental flows.

Benefits of Agroforestry as CSA technology

Agroforestry is increasingly recognized as a land management system that can serve as a response option for both climate change adaptation and mitigation, while addressing many of the challenges that smallholder farmers are facing. Agroforestry can generate multiple livelihood and environmental benefits, as it can help to mitigate climate change and help farmers to adapt to extreme and variable weather (IPCC, 2019). Agroforestry supports tree-related ecosystem services, such as regulation of water and sediment flows, carbon and nutrient cycling in soils and it provides habitat for biodiversity. This leads to increased soil fertility, reduced soil erosion and flood and pest control. Benefits of agroforestry to smallholder farmers include increased farm productivity and reduction of external inputs such as conventional fertilizers and chemicals for pest management, leading to increased income.

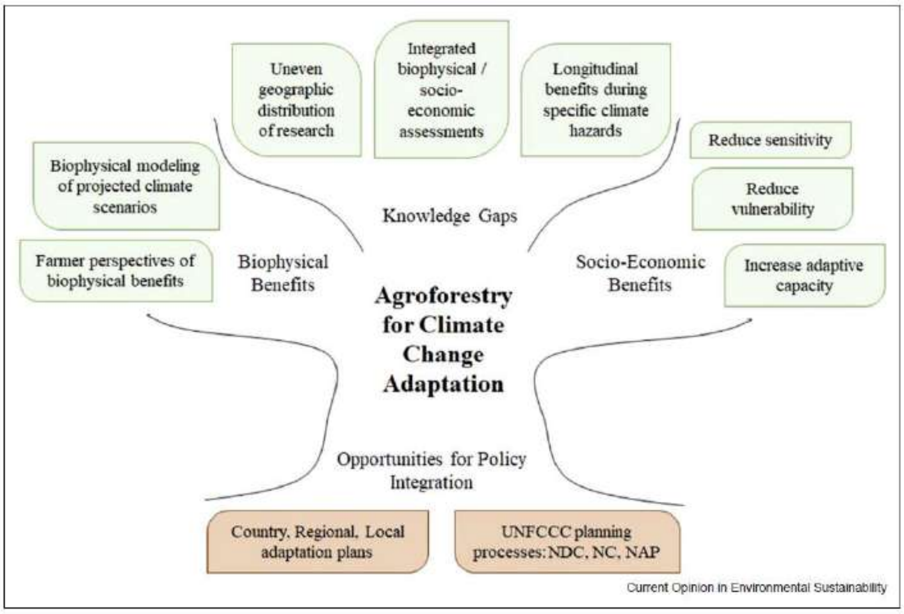
Sustainable Development Goals

Agroforestry contributes to many of the SDGs (Agroforestry Network, 2018). In this policy brief we focus on the following SDG targets:



Agroforestry for Climate change adaptation and ecosystem resilience

Climate change can increase risk for agriculture such as droughts, flooding and pests. Agroforestry for climate adaptation at the farm level and enhanced resilience at the landscape level can take many forms. For instance, agroforestry can reduce air pollution and enhance both warming and cooling of the atmosphere, creating a resilient microclimate for crops and livestock (Ellison et al., 2017). It also enhances water security through improved infiltration to soils and groundwater (Bargues Tobella et al., 2014), protecting water catchments and watersheds. The potential to improve soil properties and water availability to plants also make agroforestry practices suitable for landscape restoration. Moreover, trees provide a number of ecosystem services, such as water regulation, climate buffering, soil fertility, erosion and flood control, as well as food, fodder, medicine and wood – all important for resilience to climate change and reduced vulnerability of local people (Verchot et al., 2007; Mbow et al., 2014).



Summary of major concepts. This includes recent advances in our understanding of biophysical and socioeconomic benefits of agroforestry for adaptation, existing knowledge gaps, and opportunities for further integrating agroforestry into climate change adaptation policy.

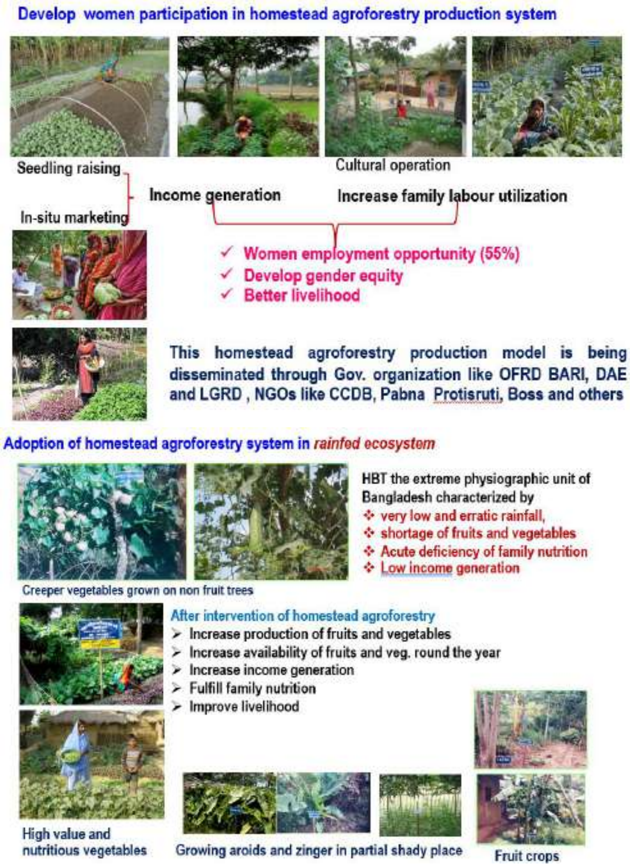
Biophysical benefits of Agroforestry as CSA technology

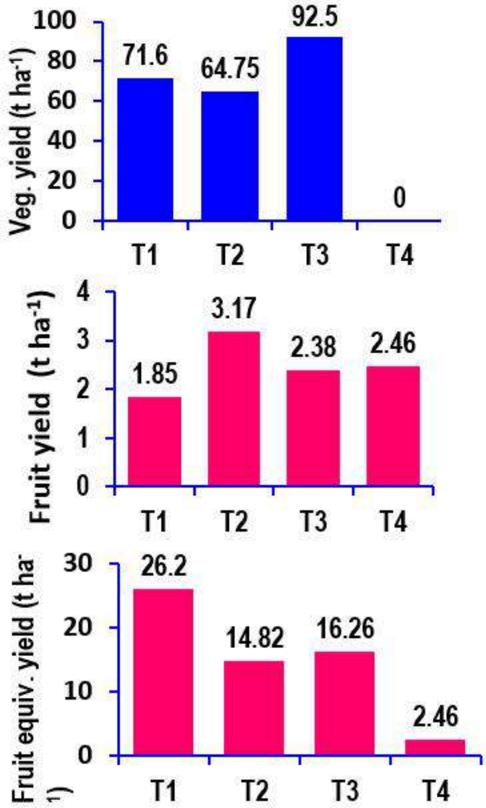
The general biophysical benefits of agroforestry systems are well understood at both the farm and landscape level [11,12]. Agroforestry can create microclimates with lower mean air temperatures [13], reduce crop transpiration rates by shading crops [14,15], draw water from deeper soil layers and support root water uptake by crops [16], minimize soil loss during heavy rainfall and/or downstream flood events [17,18], and create windbreaks and buffer crops from storms [19]. Agroforestry can increase the resilience of agricultural soils by increasing soil nitrogen and carbon [20], as well as increasing spatial heterogeneity of the soil microbial community [21].

Agroforestry as CSA for livelihood improvement of small farm households

Equally important, agroforestry can improve livelihoods in smallholder farming systems through diversified income and cash crop systems (e.g. cocoa, coffee, nuts), increased food security and improved access to nutritious food. Trees on farms can also help the farmers reduce the economic recovery time after natural disasters (Simelton et al., 2015). Climate adaptation is particularly important for female farmers as they often have less access to resources compared to their male counterparts (Kiptot et al., 2014). Female farmers produce a major part of the food in many developing regions, but generally do not have the same opportunities to improve their livelihoods (Agroforestry Network, 2018). It is also common that women are left in charge of the smallholder farm when their spouse is migrating for work, and therefore need more capacity to handle the increased workload (Leder et al., 2016). Agroforestry can be a suitable land management system to reduce gender inequalities related to natural resource access, while contributing to increased control of their benefits.

In Bangladesh, On-Farm Research Division of BARI has developed comprehensive research works and generated agroforestry technologies for the climate change adaptation and farmers livelihood improvement in homestead and crop field of rainfed, plainland, coastal and hill ecosystems.





T_1= Guava + Tomato, T_2= Guava + Cauliflower
T_3= Guava + Cabbage, T_4= Sole Guava

Agroforestry as a potential mitigation strategy

Agroforestry practices can reduce or remove significant amounts of GHGs through increased carbon storage in biomass above-ground and below-ground and in soil organic carbon (IPCC, 2019). Integrating agroforestry into cropping and livestock keeping systems can enhance carbon sequestration by significant amounts. Home gardening, boundary planting, fruit orchards, riverine, hedgerows, woodlots and firewood lots are major agroforestry practices that sequester CO2. Agroforestry stores more carbon than pastures and fields with annual crops, but less than forested areas (see Figure 1).

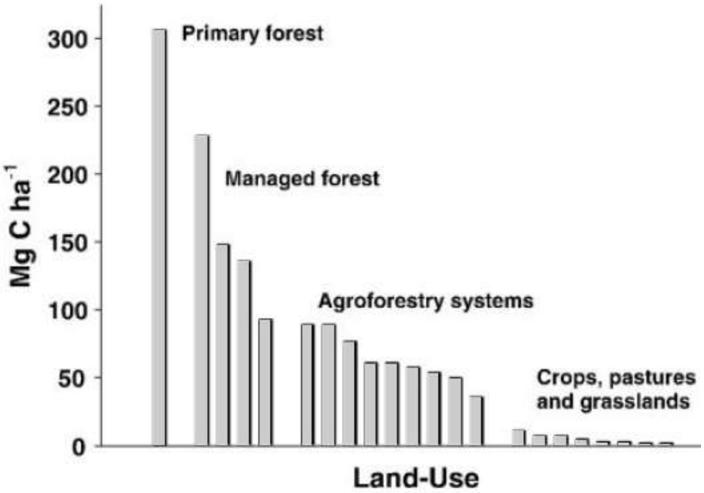


Figure 1. An illustration of different land use management systems and their potential to store carbon in the tropics (Verchot et al., 2007)

POLICY BENEFITS OF CLIMATE CHANGE ACTIONS THROUGH AGROFORESTRY

The United Nations Framework Convention on Climate Change (UNFCCC) and other international organizations and scientific panels are emphasizing the importance of using sustainable land management systems, such as agroforestry, to generate multiple environmental and socio-economic benefits (e.g. FAO, 2019; IPBES, 2019; IPCC, 2019). The implementation of agroforestry can help countries reach their goals related to climate change adaptation and mitigation, reforestation as well as SDG-targets related to food and water security. An analysis by CGIAR showed that, as of June 2018 over a third (59 of 147) of developing countries had proposed agroforestry as a climate change mitigation activity for achieving their Nationally Determined Contributions (NDC) under the UNFCCC (Rosenstock et al., 2018). Agroforestry can thus be a resilient land management solution with cross-cutting benefits for both adaptation and mitigation to climate change.

RECOMMENDATIONS TO POLICY- AND DECISION MAKERS

1. Support local communities in implementing agroforestry practices to tackle climate change with e.g. financial, capacity and legal support, to create multiple socio-environmental benefits, such as improved farm productivity and biodiversity, increased food and water security and soil health, as well as improved gender equality.
2. Secure land tenure rights and create incentives to encourage farmers to invest time and money in land use practices with a longer return on investment, such as agroforestry.
3. Make agroforestry visible, by exploring policy changes to include agroforestry, for instance in development co-operation strategies, technical assistance and budgets. A starting point is to make it easier to identify if development cooperation includes support to agroforestry.
4. Develop strategies, frameworks and indicators at all levels to continuously measure progress in agroforestry systems and their climate benefits.
5. Create effective, cost-efficient and equitable policies by using agroforestry to combine climate change adaptation and mitigation, as well as their cross-cutting synergies, with economic development.
6. Connect agroforestry to the climate agenda and report progress. As countries are committed to fulfilling their National Determined Contributions (NDC) under the United Nations Framework Convention on Climate Change (UNFCCC), supporting agroforestry makes sense from both an adaptation and mitigation standpoint.

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NDC OF BANGLADESH: IMPLICATION IN AGRICULTURE

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Introduction

Article 2 of the **Paris Agreement** presents the purpose of the Agreement by putting forward following statements: This Agreement, in enhancing the implementation of the Convention, including its objective, aims to strengthen the global response to the threat of climate change, in the context of sustainable development and efforts to eradicate poverty, including by:

(a) Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change;

(b) Increasing the ability to adapt to the adverse impacts of climate change and foster climate resilience and low greenhouse gas emissions development, in a manner that does not threaten food production; and

(c) Making finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development.

Nationally determined contributions (NDCs) are at the heart of the Paris Agreement and the achievement of its long-term goals. NDCs embody efforts by each country to reduce national emissions and adapt to the impacts of climate change. The Paris Agreement (Articles 4.2 and 4.9) requires each Party or country **shall** prepare and communicate successive NDCs every five years that it intends to achieve. Parties **shall** pursue domestic mitigation measures, with the aim of achieving the objectives of such contributions.

Together, these climate actions determine whether the world achieves the long-term goals of the Paris Agreement and to reach global peaking of greenhouse gas (GHG) emissions as soon as possible and to undertake rapid reductions thereafter in accordance with best available science, so as to achieve a balance between anthropogenic emissions by sources and removals by sinks of GHGs in the second half of this century. It is understood that the peaking of emissions will take longer for developing country Parties, and that emission reductions are undertaken on the basis of equity, and in the context of sustainable development and efforts to eradicate poverty, which are critical development priorities for many developing countries (Paris Agreement: Articles 2 and 4.1).

In order to enhance the ambition over time the Paris Agreement provide that successive NDCs will represent a progression compared to the previous NDC and reflect its highest possible ambition. After 1st NDCs in 2015, Parties are requested to submit the next round of NDCs (new NDCs or updated NDCs) by 2020 and every five years thereafter (e.g. by 2020, 2025, 2030), regardless of their respective implementation time frames. Moreover, Parties may at any time adjust their existing NDCs with a view to enhancing its level of ambition (Article 4.11).

NDCs will contain necessary information on both mitigation and adaptation actions to climate change, as well as information related to support provided or received in terms of finance, technology and capacity-building. However, communicating information on mitigation contributions through NDCs by all countries is a mandatory obligation in accordance Article 4.2 and Article 13.7 of the Paris Agreement, where information on adaptation activities is voluntary.

NDC 3.0 (to be submitted in 2025)

IPCC 6th Assessment Report, which was endorsed by the outcome of 1st Global Stocktake (as per Article 14 of the Paris Agreement) at COP28 in 2023 reveals that limiting global warming to 1.5°C with no or limited overshoot requires deep, rapid and sustained reductions in global greenhouse gas emissions of 43 per cent by 2030 and 60 per cent by 2035 relative to the 2019 level and reaching net zero carbon dioxide emissions by 2050. The first global stocktake recognized that the Paris Agreement has driven near-universal progress on climate action, however despite overall progress, the world is not on track to meet the long-term temperature goal of the Agreement. The outcome of the global stocktake (GST) will inform the preparation of subsequent NDCs, in order to allow for increased ambition and climate action to achieve the purpose of the Paris Agreement and its long-term goals. NDCs to be submitted in 2025, also known as NDC 3.0, are to be informed by the outcome of the first global stocktake. NDC 3.0 need to be progressive and more ambitious than current NDCs and may be the last opportunity to put the world on track with a global emission trajectory in line with the Paris Agreement's 1.5°C goal.

Bangladesh Response

Bangladesh, a signatory to the Paris Agreement and a strong supporter, is attempting to uphold the commitments made through its nationally determined contributions. Bangladesh submitted its Intended Nationally Determined Contributions (INDC) or NDC 1.0 to UNFCCC in September 2015 for three sectors such as power, industry, and transport. By 2030, Bangladesh's INDC called for an unconditional reduction in GHG emissions of 12 million tons (5%) from the Business as Usual (BAU) scenario and a conditional reduction of additional 24 million tons (10%) with assistance from the international community, considering 2011 as the base year.

Bangladesh updated the NDC (NDC 2.0) in 2021, including new sectors and gas as part of the global initiative and adhering to the IPCC Guidelines. The updated NDC or NDC 2.0 covers Energy, Industrial Processes and Product Use (IPPU), Agriculture, Forestry, and Other Land Use (AFOLU), and the Waste sectors. In NDC 2.0, Bangladesh put forward quantified emissions reduction commitments of 6.73%, i.e., 27.56 MtC_O2e reductions below the business-as-usual scenario by 2030 unconditionally, and an additional 15.12%, i.e., 61.91 MtCO2e reductions by 2030 conditionally, only if there is external financial and technical support. Following table 1 shows the **GHG emission reduction scenario presented in NDC 2.0:**

Total GHG Emissions of Bangladesh

Table 2: Sector-wise National GHG emissions from 2013 to 2019

Sector (Gg CO_2eq)	2013	2014	2015	2016	2017	2018	2019
Energy	86.31	90.85	96.68	105.00	105.00	112.00	115.00
IPPU	2.91	3.07	2.84	3.12	3.22	3.10	4.30
Agriculture, Forestry and Other Land use	66.39	67.51	69.22	70.34	69.80	71.83	72.63
Waste	17.08	17.55	18.60	19.15	19.77	20.40	21.04
Total GHG emission (million tons)	**173**	**179**	**187**	**198**	**198**	**207**	**213**

Table 3: Total GHG emissions of All Sectors for 2019

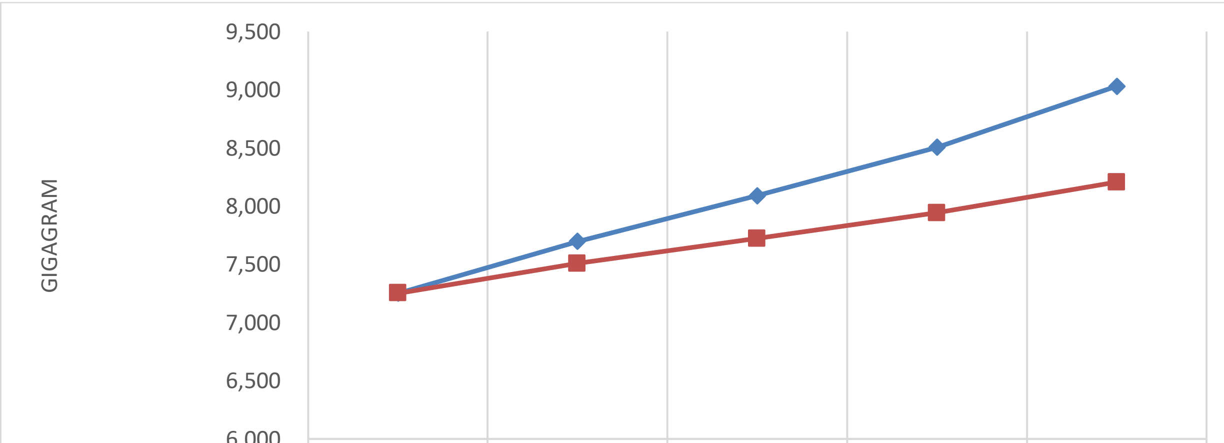
Inventory Year: 2019			
	Emissions (Gg)		
Greenhouse gas source and sink categories	CO_2 Emissions (Gg)	CH_4 Emission	N_2O Emission
Total National Emissions and Removals			
1 - Energy	**105865**	**326.73**	**4.16**
1.A - Fuel Combustion Activities_Energy Industries	105865	119.31	4.16
1. A1- Electricity Generation	46679	1.03	0.15
1. A2- Manufacturing Industries and Construction	26765	1.790	0.26
1.A.3-Transport	15895	114.00	3.69
1.A.4- Other Sectors	16526	2.50	0.05
1.B.2 Fugitive Emissions from Natural Gas	0.02	207.42	0.00
2 - Industrial Processes and Product Use	**4298**		
2.A - Mineral Industry	480		
2 A.1-Cement production	422		
2 A.3 Glass Production	58		
2.B - Chemical Industry	2026		
2.B. 1 - Ammonia Production	2026		
2 C-Metal Industry	33		
2 C.1 Iron and Steel Production			
2.D - Non-Energy Products from Fuels and Solvent Use	94		
2D 1-Lubricant use	94		
2.F - Product Uses as Substitutes for Ozone Depleting Substances	1665		
2.F.1 - Refrigeration and Air Conditioning	1665		
3 - GHG Emissions Agriculture, Livestock & Forest and other Land -Use Sector	**12640**	**1819**	**48.76**
CH4 emission from rice field		609.6	
Indirect Nitrous Oxide (N2O) from N based fertilizer			6.60
Direct Nitrous Oxide (N2O) emissions from Fertilizer Application			20.58
Direct Carbon Dioxide emissions from urea fertilizer	1870		
Total Enteric CH4 Emissions		1111	
Total Manure CH4 Emissions		98.4	
Total Direct N2O Emissions from Manure System			14.38
Total Indirect N2O Emissions - Volatilization			5.65
Total Indirect N2O Emissions - Leaching/Runoff			1.55
3.B - Land-use change and Forestry	10770		
4 - Waste		**766**	**6.34**
4 A- Solid Waste Disposal		164	
B- Methane emission from domestic waste water		540	
C-Nitrous Oxide Emission from Domestic wastewater			6.34
D- Metahne emission from Industrial waste water		61.83	
Memo Items (5)			
International Bunkers	**474.90**	**0.01**	**0.01**
A- International Aviation (International Bunkers)	398.54	0.00	0.01
B- International water-borne navigation (International bunkers)	76.36	0.007	0.00
Information Items			
CO2 from Biomass burning for Energy purpose	**76000**		
Total CO2e emission from all sources	**213241**	**Gigagrams**	
Total CO2e emission from all sources	**213**	**Million Tons**	

Mitigation in Agriculture

A. Mitigation Scenario of Energy Use in Agriculture

As a part of the mitigation strategy, a target has been set to power 10% of irrigation pumps using solar energy instead of diesel pumps by the year 2041. This mitigation action has been incorporated into the LEAP Modelling framework. However, it is noteworthy that the mitigation scenario only takes into account the use of diesel pumps and no other mode of agricultural vehicles have been considered. Therefore, the extent of the potential impact of this mitigation measure on overall greenhouse gas emissions in the agricultural sector of Bangladesh needs to be further assessed.

Figure shows the comparison BAU and the mitigation scenario in terms of gigagram CO_2 equivalent emissions for the year 2019, 2025, 2030, 2035, and 2041. In the mitigation scenario, the emissions are projected to be 8,207 gigagram CO_2 equivalent in 2041 which is 9% less than the BAU scenario.



	2019	2025	2030	2035	2041
Business As Usual	7,251	7,698	8,091	8,505	9,030
Mitigation Scenario	7,251	7,506	7,723	7,941	8,207

Figure 1: Energy use in agriculture, BAU vs mitigation scenario

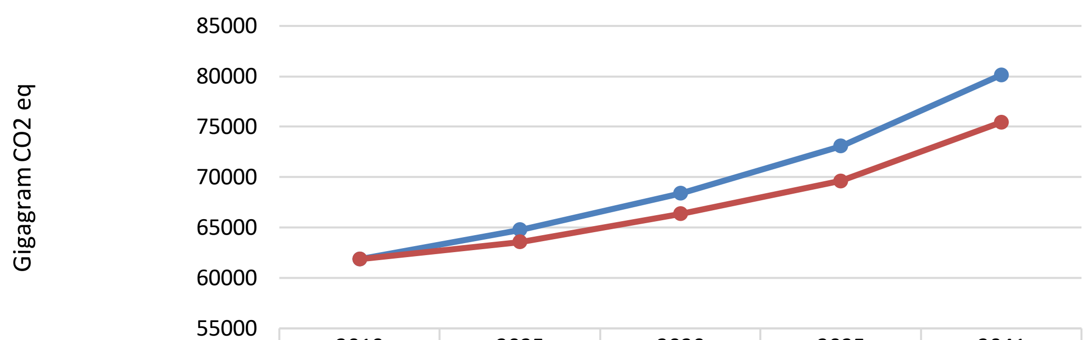
Mitigating GHG emissions from the energy use in the agriculture requires implementing effective mitigation action. One possible solution is upgrading irrigation pumps and fishing boats with energy-efficient technologies. This may involve incorporating more efficient engines, improved fuel injection systems, or electric motors. Additionally, the adoption of sustainable farming practices such as crop rotation, mulching, and cover cropping can reduce the need for irrigation and lower emissions from agricultural vehicles. By implementing these strategies, it is possible to mitigate GHG emissions from the agriculture sector in a cost-effective and sustainable manner.

B. Mitigation Scenarios in Agriculture and Livestock

The group of experts, stakeholders, consultants, and research team have examined various mitigation measures that could potentially reduce the projected greenhouse gas emissions in the business-as-usual scenario.

- Improved nutrient management: Improving the timing, placement, and application rates of N-based fertilizers, as well as utilizing precision agriculture methods, can lead to the efficient use of these fertilizers.

- Adoption of best management practices: Implementing best management practices for rice cultivation, such as alternate wetting and drying and aerobic rice cultivation, can significantly reduce emissions from rice fields.
- Use of low-emission feeds: Livestock feed additives can be used to reduce enteric fermentation emissions. For example, using ionophores or tannins in livestock diets has been shown to reduce methane emissions.
- Implementation of manure management practices: Capturing and using methane from manure can be an effective way to reduce emissions from manure management. Additionally, practices such as composting and anaerobic digestion can reduce emissions from manure.



	2019	2025	2030	2035	2041
Business As Usual	61864	64772	68391	73086	80140
Mitigation Scenario	61864	63578	66357	69636	75438

Figure 2: Emission from agriculture sector, BAU vs mitigation scenario

The implementation of the mentioned mitigation measure in the agriculture sector can lead to a reduction of approximately 6% in greenhouse gas emissions compared to the business-as-usual scenario. Figure 2 illustrates the comparison between the BAU and mitigation scenarios, indicating a potential reduction of 4702 gigagrams of CO_2 equivalent emissions in 2041.

Mitigation Action

The government of Bangladesh, in collaboration with national and international organizations, has initiated several major projects in the field of agriculture with the objective of climate change adaptation, production efficiency, and low carbon emissions. One such project titled "Integrated Manure Management and Climate Smart Livestock Production System" was submitted to the Ministry of Fisheries and Livestock in 2021. The proposed projects below are expected to contribute significantly to the development of the sector and to the reduction of carbon emissions from agriculture land.

- Developing and Defining Climate Smart Agriculture Practices portfolios in South Asia
- Design and development of fertilizer deep placement mechanism for existing rice transplanter
- Modeling climate change impact on agriculture and developing mitigation and adaptation strategies for sustaining agricultural production in Bangladesh
- Monsoon Asia climate solution by paddy water management

- Climate Change Adaptation of Khulna Agricultural Region through Climate-Smart Technologies
- Environment Friendly Safe Crop Production Through Good Agricultural Practices (GAP) for Food Security Program

To reduce emissions in the agriculture sector, the following mitigation actions can be taken:

- Implementing improved dietary manipulation practices for ruminant animals
- Introducing regenerative agriculture and integrated agriculture practices.
- Optimizing irrigation water use to reduce methane emissions from rice cultivation, and introducing sprinkler and drip irrigation techniques where possible.
- Practicing minimum tillage to reduce soil exposure and increase soil moisture retention, thereby reducing emissions of CO_2 and methane.
- Upscaling the use of Alternate Wetting and Drying techniques.
- Producing bio-gas and organic manure to reduce land degradation and emissions.
- Increasing livestock productivity through breed development.

Implementing integrated manure management practices to reuse manure as bio-fertilizer, compost, and biogas plant feedstock.

IRRIGATION AND WATER MANAGEMENT TECHNOLOGIES FOR CLIMATE SMART AGRICULTURE

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Summary

Maintaining sustainability in agricultural water usage is a critical concern, particularly when the burgeoning population demands more food, while adverse climate change affects water availability. Despite this, the climate-water-crop nexus is still poorly understood in many regions. This report assesses the sustainability challenges of the current agricultural water use scenario in Bangladesh and identifies climate-smart water management practices at farm level to watershed level. The water use sustainability in the two most water-exporting divisions (Rajshahi and Rangpur) is at great stake because total rainfall in July is decreasing significantly (2.90 mm/yr) in Rajshahi and the number of rainless days in August is significantly increasing (0.033 day/yr) in Rangpur. Irrigated rice production is predicted to face water scarcity because the dry season water level in both rivers (63%) and groundwater (92%) shows a declining trend. The ratio of green (rainfed) to blue (irrigation) water use in the country was estimated at 2.5, which needs to be increased. It is imperative to build resilience to the threats brought on by climate change. Climate change is expected to lead to more droughts, more often. There will be less fresh water to drink and irrigate. Water will become scarcer, and more expensive. Some people will be affected worse than others. We have to identify and implement the best climate-resilient water management practices at farm level to watershed level, which may include precision irrigation, reduced irrigation, point irrigation, water-dynamic crop rotation, conservation tillage, rainwater harvesting, infiltration and runoff management, virtual water transport, use of modern computing technologies, educating stakeholders, and use of renewable energy. The study findings will be useful references for developing effective agricultural water management strategies considering the diverse nature of the potential sustainability challenges.

1. Introduction

Detrimental effects of the rapidly changing global climate are being increasingly recognized. Climate change may lead to increased water stress due to declining precipitation and higher water demand in many parts of the world (Ercin and Hoekstra, 2016). Water availability is a key to food security. Water-food security nexus is, however, facing enormous challenges because of high population growth, rising water demand, scarce water resources, and climate change (Yillia, 2016). Freshwater scarcity is projected to exacerbate in the future due to a significant increase in water demand, which will affect water security for food production and environmental sustainability (Alcamo et al., 2003; Zakar et al., 2012; Ercin and Hoekstra, 2016). It is estimated that annual global water withdrawal will grow from 4,500 billion m^3 in 2009 to 6,900 billion m^3 by 2030 (McKinsey, 2009). Ludwig et al. (2009) reported that climate change could affect the distribution of global water resources, by altering the timing, variability, and reliability of rainfall and the increasing occurrence of extreme weather events. Valipour (2017) reported that 46% of global cultivable areas remained unsuitable for rainfed agriculture due to climate change and other meteorological issues. The projected temperature increase associated with climate change will imply higher evaporation and drier conditions. Consequently, the water and food security nexus will become more complex to manage (Hanjra and Qureshi, 2010).

Like many other countries, Bangladesh is struggling to maintain water security for food production (Mahmud et al., 2021). Increasing water demand and competition over freshwater resources have already been felt during the previous decades (Mancosu et al., 2015; Arfanuzzaman and Rahman, 2017). The population of the country is projected to reach about 214 million by 2050, which will cause a twofold increase in annual domestic and fourfold increase in industrial water demand (Ismail, 2016). Ensuring adequate water share for crop agriculture is a great challenge because of the limited water availability and its high-water footprint. Rice is the main crop in the region, which has a higher water footprint than any other crops of comparable value and growth duration (Allen et al., 1998; Saha et al., 2013). Rice is farmed both during dry and wet seasons, covering nearly 80% of the gross cropped area and consuming over 80% of the water used for agriculture (BBS, 2012–2017; Mahmud et al., 2021). The wet-season rice is primarily rainfed, but the dry-season rice is an irrigated crop and contributes nearly 55% to the total rice production. High water-consuming, high-yielding rice varieties have been predominantly cultivated in the dry season with the expansion of irrigation facilities since the 1990s (Alauddin and Tisdell, 1991). Over time, irrigation in Bangladesh has become increasingly dependent on groundwater because of the easy availability of low-cost equipment to tap shallow aquifers and the limited availability of surface water during the dry season due to huge withdrawal at the upper catchment. Although the demand for irrigated agriculture is still on the rise to meet the challenges of food security, further expansion of irrigated agriculture is questionable because of groundwater depletion (Rahman et al., 2016). The condition is likely to be worse with shortened monsoon season and less dry season rainfall under the changing climate and resulting in reduced groundwater recharge (Shamsudduha, 2018).

A new paradigm shift in water management strategies is immensely felt at a national and international scale to deal with the emerging water and food security issues. For better water management, it is essential to understand the present agricultural water use scenario at a spatial and temporal scale and their influencing factors. Evaluating the trends of hydro-meteorological variables is needed for assessing the possible impacts of climate change on agricultural water usage (Valipour et al., 2020) and help develop its sustainable management (Valipour, 2016). Similarly, assessment of the long-term trends of maximum and minimum river stage and groundwater level is important to assess the sustainability issues of water resources. Identifying and implementing the best irrigation and water management practices would help develop climate-smart agriculture.

2. Water Management Challenges

2.1 Changing rainfall pattern

Annual consecutive dry days (drought index) in different divisions of Bangladesh showed both increasing and decreasing trends (Table 1), which were statistically significant only in Dhaka and Mymensingh, showing the probability of more frequent drought in Dhaka and less frequent in Mymensingh. However, the annual drought index does not reveal which crop will be affected more. Therefore, the monthly drought index is necessary for predicting future crop-specific water management requirements. The drought index for the dry months, e.g., December, January and February, showed no considerable trend meaning that the dry-winter season will remain mostly rainless as usual. In contrast, in the pre-monsoon months, March–May, most of the divisions experienced either increasing or decreasing magnitude of drought. The northern parts, e.g., Rajshahi, Rangpur and Mymensingh, will probably be less drought-prone in April, but the southern and eastern parts, e.g., Dhaka, Chattogram, Khulna, Sylhet and Barishal, had insignificant increasing trends in March and April. Drought frequency in May decreased significantly in Barishal and Mymensingh. Drought index in monsoon months, i.e. June, July, and August, had no trend throughout the country except in Barishal and Rangpur (Table 1). However, the increasing drought trend for August (0.033 days/yr) in Rangpur was statistically significant. Drought conditions in September remained the same in all the divisions. For October, only Mymensingh showed a significant negative drought index suggesting that the number of rainless days will diminish in this month.

Table 1. Trend of monthly and yearly consecutive dry days over the period of 1965–2015 (Source: Mahmud et al., 2021).

Month	Dhaka	Chattogram	Rajshahi	Khulna	Sylhet	Barishal	Rangpur	Mymensingh
Jan.	0[§]	0	0	0	0	0	0	0
Feb.	0.067	0	0	0	0	0	0	-0.04
Mar.	0.118	0.067	0	0	0.067	0	0.034	0
Apr.	0.053	0.043	-0.094	0.063	0	0.053	-0.11*	-0.074
May	0	-0.032	0	-0.032	0	-0.06$^+$	0	-0.067*
Jun.	0	0	0	0	0	0.021	0	0
Jul.	0	0	0	0	0	0	0	0
Aug.	0	0	0	0	0	0	0.033$^+$	0
Sept.	0	0	0	0	0	0	0	0
Oct.	0	0	0	0	0.043	0	0	-0.09$^+$
Nov.	0.045	0	0	0.053	0.053	0	0	0
Dec.	0	0	0	0	0	0	0	0
Yearly	0.33*	0.188	0.065	0.297	0.244	0	0.203	-0.409*

[§]All values are in day/yr; $^+$ is for $p < 0.1$ and * for $p < 0.05$ level of significance; and negative sign indicates decreasing trend.

Table 2. Trend of monthly and yearly total rainfall throughout 1965–2015 (Mahmud et al., 2021).

Month	Dhaka	Chattogram	Rajshahi	Khulna	Sylhet	Barishal	Rangpur	Mymensingh
Jan.	0[§]	0	0	0	0	0	0	0
Feb.	-0.03	0	-0.03	0.07	0	0	0.03	0.1
Mar.	-0.3	0	0.05	0.03	-0.60	0	-0.05	0.1
Apr.	0	0.5	0.37	-0.15	1.16	-0.13	0.82	1.33$^+$
May	-1.52	3.58*	1.26$^+$	-0.27	2.70	-0.10	-0.26	1.0
June	-0.06	2.25	-0.74	-1.70	-0.09	-0.63	1.06	3.1
July	1.11	0.63	-2.90*	3.76*	-4.78	1.18	-2.0	-0.11
Aug.	-0.80	-0.29	-1.0	-0.40	0.29	-1.32	-0.87	2.4
Sept.	-0.58	-0.24	-0.15	4.5**	-0.1	-0.12	0.28	-0.09
Oct.	-0.41	1.75	-0.19	2.2*	-0.56	-0.49	1.44	0.71
Nov.	-0.14*	0	0	0	-0.03	-0.08	0	0
Dec.	0	0	0	0	0	0	0	0
Yearly	-1.95	14.0*	-3.82	8.57*	1.14	-2.3	4.45	4.0

[§]All values are in mm/yr; $^+$ is for $p < 0.1$, * for $p < 0.05$ and ** for $p < 0.01$ level of significance; and negative sign indicates decreasing trend.

Annual total rainfall decreased insignificantly in Dhaka, Rajshahi, and Barishal but increased in others. Chattogram and Khulna, two coastal divisions, had significant increasing rates of total rainfall of 14.0 and 8.57 mm/yr, respectively (Table 2). Total rainfall in the dry months, December and January, had no trend throughout the country. February rainfall showed an insignificantly decreasing trend in Dhaka and Rajshahi whereas either increasing or no trend in other parts of the country (Table 2). Among pre-monsoon months, April rainfall in Mymensingh and May rainfall in Chattogram and Rajshahi increased significantly at 1.33, 3.58, and 1.26 mm/yr, respectively. The July rainfall significantly decreased at a rate of 2.90 mm/yr in Rajshahi, which can pose a great risk for rainfed rice production and groundwater recharge potential. On the other hand, the southwest division Khulna had an increasing rate of rainfall in July, September and October showing an agreement with the trend of its annual total rainfall.

2.2 Groundwater depletion

The annual minimum groundwater level in the northwest region usually occurred during April–May and the maximum in September–October. Except for well 5, all observation wells showed declining trends both in annual maximum and minimum groundwater levels (Fig. 1). The results are in line with the findings of other studies in the region showing water tables declining steadily at 0.1–0.5 m/yr making the use of shallow aquifers unsustainable (Shamsudduha et al., 2009). Moreover, the declining maximum groundwater level indicates that there is not enough recharge potential to get the aquifer fully recharged. The unchanged gap between the maximum and minimum groundwater levels of some observation wells reveals an equal annual recharge over the years (well 3, 4 and 8; Fig. 1). In other observation wells, the gap is either increasing (well 9 and 12) or decreasing (well 2 and 5) depicting increasing or decreasing annual net recharge, respectively. The findings also suggest that the problem of continual groundwater declination needs site-specific interventions.

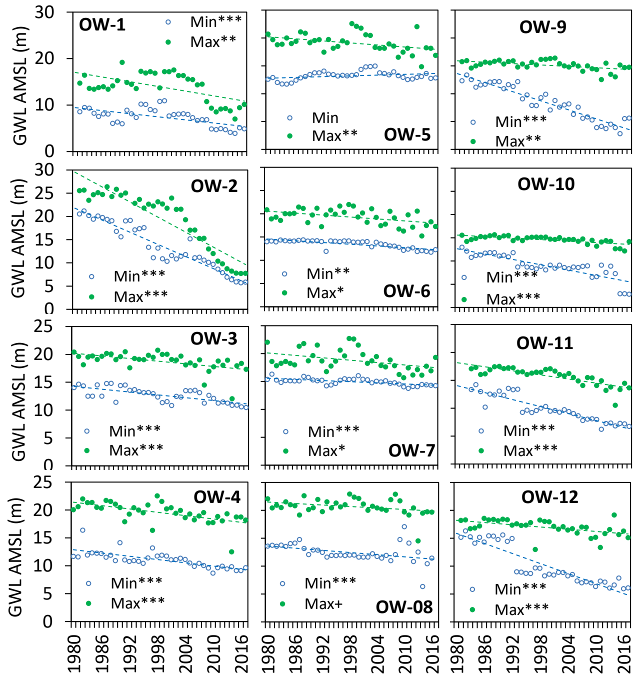

Fig. 1. Changing pattern of yearly maximum (solid circle) and minimum (open circle) groundwater level above mean sea level (GWL AMSL) over the period 1981–2017 at different observation wells (OW) located in Rajshahi Division (Different signs with the legends, i.e. + is for < 0.1, * for < 0.05, ** for < 0.01 and *** for < 0.001 level of significance, indicate whether the trends are significant or not) (Source: Mahmud et al., 2021).

2.3 Surface water availability trend

Annual maximum and minimum river stages of eight selected river sections were subjected to the trend analysis. The annual fluctuations of river stages ranged 3–10 m (Fig. 2). Rivers in

Bangladesh generally experience peak flow during July–September because of the combined effect of concentrated monsoon rainfall (80% of the annual total) and Himalayan snow melting and encounter very low flow during February–April due to a large abstraction for irrigation throughout the watershed. The availability of surface water in the dry winter irrigation season is already very low and still decreasing in some rivers. The Ichamati (Chattogram), the Mohananda (Rajshahi), the Rupsa (Khulna) and the Old Brahmaputra (Mymensingh) showed significant decreasing trends in the annual minimum river stages (Fig. 2). The annual minimum flow in other rivers did not show any trend, but the flow volumes were considerably low.

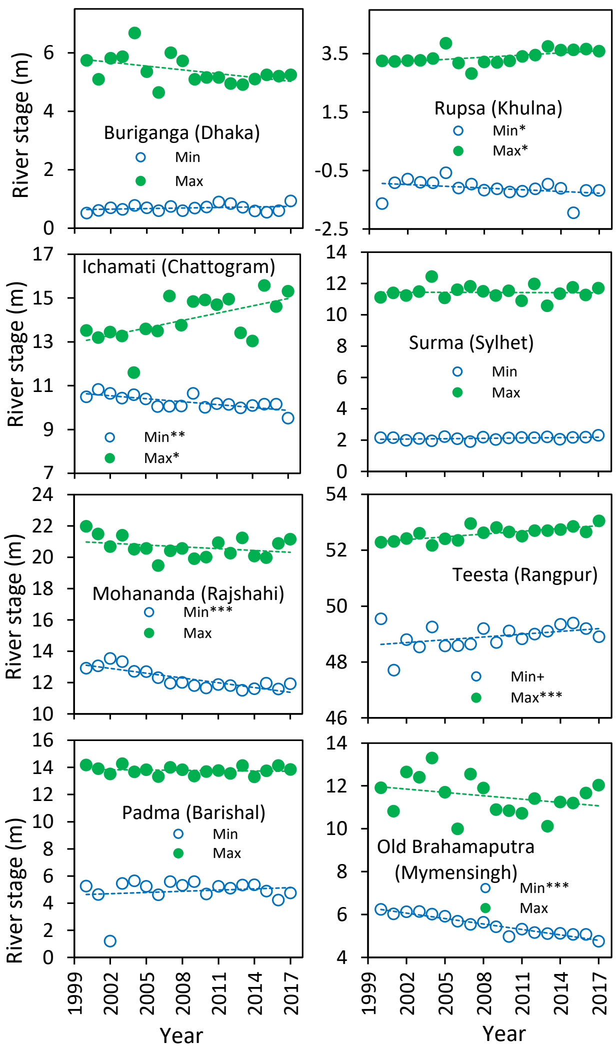

Fig. 2. Trend of the annual maximum (solid circle) and minimum (Open circle) river stage above mean sea level of eight rivers representing eight divisions in Bangladesh (Different signs with the legends, i.e. + is for < 0.1, * for < 0.05, ** for < 0.01 and *** for < 0.001 level of significance, indicate whether the trends are significant or not) (Source: Mahmud et al., 2021).

2.4 Changing crop water demand

Sustainability challenges of agricultural water usage in the country vary at spatial and temporal scales and are affected by different factors. Change in crop water demand induced by climate change is another factor that would exert pressure on sustainable water use. Potential evapotranspiration (ET) and crop water requirement of dry season rice decreased in the northwest (Acharjee et al., 2017a; Islam et al., 2019) but increased in the central and southwest regions (Islam et al., 2019) due to the past climate change. In contrast, under future climate change scenarios dry season water requirement has been projected to increase in the north and northwest regions and decrease in the southwest region (Islam et al., 2018). Acharjee et al. (2017b) showed that the daily potential ET in northwestern Bangladesh would increase in the future, but the potential crop water requirement would decrease because of a shorter growing period induced by the increased temperature. Analyzing the drought events under different future climate scenarios, Kamruzzaman et al. (2019) predicted that the drought-prone area will probably shift from the northwestern into the central or the southwest regions. The results indicate that uncertainties exist in the future climate change impacts in different regions of the country.

2.5 Land-use changes

Projected climate change may have both positive and negative impacts on water availability and demands (Kirby et al., 2016), but the water demand will increase and the available sources of water will be scarcer under the impacts of the growing population and land-use changes. Land-use change is another important challenge for the sustainability of crop production and its water usage. Bangladesh has been experiencing rapid land-use changes during the last five decades. The yearly average loss of agricultural land was 23,391 ha (0.26%) during 1976–2000 and 56,537 ha (0.45%) during 2000–2010 (Hasan et al., 2013). In contrast, lands gained in a rural settlement, urban and industry, and aquaculture are 30,809, 4,012 and 3,216 ha/yr, respectively, during 2000–2010. Expansion of built-up areas by the transformation of agricultural lands and water areas in Dhaka, Chattogram and Rajshahi was faster than that in other divisions (Dewan and Yamaguchi, 2009; Hassan and Nazem, 2016; Hasan et al., 2013). Rajshahi, a major food-producing division, lost 15,945 ha cropland during 2000–2010 (Hasan et al., 2013; Mahbub, 2003). Hasan et al. (2017) projected a further decline in cultivated land under both environmental protection and economic growth scenarios. Loss of agricultural lands and water areas will put multifaceted pressures, such as more water-demanding crop cultivation in limited agricultural land, decreased availability of water resources, and increased competition for water resources.

2.6 Global food security challenges

Climate change affects the growth and yield of crops worldwide and creates a yield gap, which threatens global food security. The yield gap is the difference between estimated yield and actual yield. Factors affecting yield gaps include soil quality, weather, crop resilience, harvest time, and interactions with biological systems, like insects, weeds, and pathogens. All these factors were affected by climate change in different degrees. Poor land management also leads to low crop productivity. Together, these factors create a negative feedback loop, causing land degradation. Innovative agricultural and land management practices must be used to make crops resistant to climate change. Sustainable agricultural practices need to be adopted and crop resistance should be improved. Instead of maximizing the production of a few crops, a wider variety of food crops should be grown.

2.7 Climate denialism

There is a school of thought that argues against the impact of human activities on the environment and disregards the need for climate change mitigation. While 'climate denialism' and 'climate-impact skepticism' imply ignorance regarding climate change, 'climate delay discourses' accept its existence but overlook the need for interventions (Lamb et al., 2020). A new study presents the underlying logic behind such behaviors, from redirecting responsibilities, proposing non-transformative solutions, emphasizing the downsides, to surrendering to climate change. The redirection of responsibility results from a reluctance to accept that individual efforts can make a difference. Additionally, a ‘free rider’ approach or relying on the efforts of others and claiming that they have a larger share in the carbon footprint than one’s own is also responsible. Can countries still prosper while cutting carbon emissions? Cutting carbon emissions does not have to be bad for economic growth.

2.8 Climate change and new diseases

Zoonotic diseases are diseases that spread from animals to humans. They are linked to environmental change. For example, when animal habitats are destroyed by climate change, the animals move and can come into closer contact with humans. This can lead to new diseases. In another example, warmer global temperatures are causing frozen soil (permafrost) to melt. Sometimes these soils contain bacteria or viruses which are released when the land defrosts and can infect humans. Zoonotic diseases are a big threat to public health; coronavirus is one example of a zoonotic disease, and over 5 million people have died from it. We need to invest in a more joined-up approach to researching and managing diseases that are being caused or made worse by climate change. There needs to be a global collaboration between environmental scientists, zoologists, microbiologists, veterinarians, and public health professionals.

3. Climate Resilient Water Management

The processes of developing climate-smart agriculture are broad, including rainfed agriculture, climate change, genetics, water capture in soil, soil quality, carbon management, salinity, irrigation efficiency, drainage, water productivity, and water footprint/life cycle analysis. These issues fit into three categories: (i) water shortage (competition, climate change, groundwater depletion), (ii) water excesses (climate change, erosion, drainage, development), and (iii) water quality (nutrient management, salinity, subsurface nitrogen, off-site losses) (Vocasek and Peterson, 2015). Some processes are discussed below:

3.1 On-farm water management options

A variety of cultural practices can be employed in irrigated crop production systems specifically to improve crop water productivity. In general, practices that improve crop vigor can improve crop water productivity (Passioura, 2006). These approaches can be coupled with improvements in crop genetics to help meet increasing blue (irrigation) water demand. Critical practices include control of weeds, pests, and diseases that reduce yield. A few other common cultural approaches that influence water productivity are highlighted here (Hansen, 2015):

3.1.1 Micro-irrigation/Drip Irrigation

Micro-irrigation systems, including surface or subsurface drip irrigation (Lamm et al., 2012) can carefully control the timing and amount of applied water to reduce deep percolation, evaporation, and runoff losses. By applying water in the immediate root zone of the crop, the uptake and use of the water are more efficient. The abilities to use chemigation and precision nutrient management are further advantages for drip irrigation systems. In one U.S. Great Plains study, irrigation requirements were reduced by 25% using subsurface drip irrigation compared with sprinkler irrigation without any loss in crop productivity (Lamm and Trooien, 2003).

3.1.2 Conservation tillage

Crop residues managed with conservation tillage systems can be an effective means of reducing the loss of soil water to direct soil evaporation. Further, crop residues can reduce losses of water because of runoff from intense precipitation or heavy irrigation. In irrigated systems, conservation tillage can delay the time of the first needed irrigation by capturing and retaining offseason precipitation. Improvements in the capture and storage of precipitation (green water) from conservation tillage can reduce crop demand for irrigation (blue water), resulting in an increase in the ratio of green water/blue water use by an irrigated crop. The ratio of green (rainfed) to blue (irrigation) water use in Bangladesh was estimated at 2.5, which needs to be increased (Mahmud et al., 2021).

3.1.3 Limited irrigation

Irrigating to meet a crop's full ET demand often results in lower marginal water productivity than supplemental or deficit irrigation practices that target a smaller volume of irrigation towards critical crop growth stages. Specifically, limited irrigation practices avoid drought stress during anthesis, when the effects of drought on crop yield are most pronounced. Passioura (2006) anticipates that "as water for irrigated agriculture becomes scarcer, it is likely that full irrigation will be replaced by deficit irrigations targeted to periods without rain that coincide with especially sensitive stages of a crop's life."

3.1.4 Precision irrigation

Site-specific irrigation management is a developing technology that allows for spatial and temporal control of applied irrigation (Kranz et al., 2012). Due to the inherent spatial variability of soil and topography in agricultural fields, uniform irrigation across a field can lead to water shortages or losses. By precisely meeting the crop water demands according to the spatial variation of the field, water use efficiency is improved through reduced losses of water to evaporation, drainage, or runoff and avoiding localized water deficits. Precision irrigation control systems have already been developed and are commercially available, especially for self-propelled sprinkler irrigation systems, but there is a need for further development of approaches to develop irrigation management zones and sensor systems for precision irrigation control.

3.1.5 Water dynamic crop rotations

Crop rotations can be implemented to diversify crop water use patterns and increase efficiency. For example, the inclusion of perennials and cool-season annuals in rotations with summer annual crops spreads the peak irrigation demand of the different crops over time, avoiding deficits associated with the peak demand of a single crop type. In many climates, cool-season crops like winter wheat use a greater proportion of green water relative to blue water when compared to warm-season crops like corn and therefore may be more compatible in water-short areas. Water productivity advantages can be gained from rotations of fully irrigated high-value crops with low-input crops managed with limited irrigation or rainfed production.

3.1.6 Rainwater harvesting

In some geographic regions, improving the ability to capture rain during wet periods has the potential to reduce demand for groundwater resources during dry periods. Rainwater harvesting structures can recharge aquifers and improve water storage in the soil. These structures include ponds, percolation tanks, check dams, stream bunds, and gully plugs. In many states in India, large areas of rainwater harvesting have been successfully implemented (Kahlon et al., 2012).

3.2 Watershed-Scale Water Management

We can intervene at the following points for developing a climate-resilient water management system at the watershed scale.

3.2.1 Stopping water at its highest point in the watershed

Storing water at the highest point in the watershed will reduce water pumping and conveyance costs. The water stored at the highest point can be distributed over the watershed using gravity energy. The reduced runoff will help reduce soil and nutrient erosion and protect soil health and water quality.

3.2.2 Capturing precipitation in the soil rather than allowing runoff

Capturing precipitation in the soil augments soil water storage and enhances the effective use of rainwater. It also increases groundwater recharge potential. Moreover, the natural water security of a country depends on whether the water used derives from green water (e.g., effective rainfall or soil moisture) or blue water (e.g., water from different surface and groundwater sources) (Wichelns, 2010). Capturing precipitation in the soil also reduces flood magnitude by reducing the overland flow (runoff).

3.2.3 Using the water soon after it is received to improve efficiency

To reduce water losses through evaporation, percolation, and runoff, water should be used soon after receiving it. Crop period and rotation can be designed in a way so that the plants utilize the rainwater as much as possible. It will reduce the need for irrigation.

3.2.4 Moving excess water to areas of shortage in space and time

Assessment of the virtual water transport among the regions of a country can provide a clear picture of the spatial distribution of water use (Hoekstra and Hung, 2005). Virtual water (VW) is the amount of water used for producing any kind of commodity, goods or service (Allen, 1998; Carr et al., 2013; Hoekstra and Hung, 2005). Identifying the amount of virtual water embedded in crops has greater implications for water management, practice, and policy (Ray et al., 2018). The concept of virtual water trade provides a novel way of exploring sustainable water use options (Carr et al., 2013; Hoekstra and Hung, 2005). If one region exports a water-intensive product to another region, it exports water in virtual form (Hoekstra and Hung, 2005; Oki and Kanae, 2004). Hence, water scarcity can be minimized in a place by importing water-intensive products instead of producing them locally (El-Sadek, 2010; Matchaya et al., 2019). The virtual water concept has provisions to separate the proportions of green and blue water used to produce crops. Overall, the virtual water trade concept can help improve water use efficiency and water allocation efficiency at local or national scales (Zeitoun et al., 2010). Studies dealing with virtual water and water footprint concept are very few in Bangladesh. Some studies have assessed the water footprint for rice production in the country (Rahman et al., 2016; Mullick et al., 2020). However, no studies have yet explored the virtual water flows/ across different regions of the country considering different agricultural crops. Assessing the regional virtual water trade can help identify which parts of the country are in the virtual water surplus or deficit zones in terms of different crops grown. It is also important to evaluate the extent to which the current regional virtual water exchange pattern is sustainable in terms of pressures on water demand and availability.

3.2.5 Creating nutrient management plans

Crop production with better nutrient management plans will increase yield per unit nutrient application. The higher crop yield will also reduce the water footprint. The plans also reduce nutrient losses to the atmosphere and water bodies, which will help cut greenhouse gas emissions and water pollution.

3.2.6 Educating stakeholders

Education for both the agricultural sector and the general public about the critical nature of water security is needed.

3.3 Use of modern technologies

Remote sensing is one of the ways scientists gather information about climate change. Once the information has been gathered, scientists need to analyze it. They sometimes share the computer programs they have written to do this. This helps scientists see changes in how land is being used. Even with these advances, it is still hard to make sense of the information that comes out of these processes. Computer programs, such as GIS, take information and turn it into pictures. This makes it easier to show how land use has changed over time. This new program is speeding up the process of climate research. For example, it makes it easier and quicker for scientists to see when forests have been cut down. They can then bear this in mind when looking at other changes in the area, which may help in understanding cause and effect. Such practices could make use of artificial intelligence, machine learning, and other modern tools.

3.4 Utilization of renewable energy

The growing human population and rising energy demands have led to a rapid depletion of non-renewable energy sources with a steep increase in carbon emissions. Transitioning to a renewable energy economy is, therefore, imperative to achieve sustainable development. However, the full potential of renewable energy resources remains to be harnessed, particularly in developing and under-developed countries. Collaborations between the government and other energy stakeholders, strong regulatory policies, capacity building through the acquisition of equipment and technical expertise, and enhancing socio-political support can help improve the management of renewable energy resources.

3.5 Reduction of GHG emission

Knowledge in geoscience can help us reduce our carbon emissions by using hydropower and geothermal energy and carbon capture and storage. Governments and other decision-makers need to understand the role geoscientific solutions can play in reducing carbon emissions. Recycling carbon emissions can be done with electrochemical reduction. In this process, electricity is used to drive a CO_2 reduction reaction that converts CO_2 into important chemicals that would otherwise need to be derived from fossil fuels. In doing so, the method indirectly lowers CO_2 levels by reducing fossil fuel consumption. The polluter pays principle was to be used for settling the economic aspects of environmental disputes. It intended to discourage pollution by adding the cost of pollution prevention measures to the cost of products and services that cause pollution during their manufacture, consumption, or operation.

4. Conclusions

It is imperative to build resilience to the threats brought on by climate change. Resilience means how well we can cope with, and recover from, the effects of climate change. Coping with climate change involves making difficult decisions. We have to balance different priorities. We need to get better at gathering and using information. Water is a basic human right, but the human right to water is threatened by climate change. Climate change is expected to lead to more droughts, more often. As glaciers melt, there will be less fresh water to drink and irrigate. Water will become scarcer, and more expensive. We need laws to protect the human right to water, but developing those laws is complicated. We need to explain climate science better so that governments will make stronger policies to protect the human right to water. As well as better education, we may also need to provide economic incentives to change behaviors that threaten the human right to water. Economic incentives might mean paying people to do things differently or giving them tax breaks or other kinds of discounts. We need to create and enforce climate-smart water management practices from farm level to watershed level.

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ACCOUNTING CARBON AND WATER FOOTPRINTS IN CLIMATE SMART AGRICULTURE

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Summary

Approximately 8.9% of the global population remains hungry every day. Therefore, 70% more food production is needed by 2050 to feed 9 billion people. Agriculture is a major part of the climate problem. Agricultural GDP is reducing 3.1% per annum due to climate change. A huge amount of water (75%) is consumed by the agriculture sector, and a significant amount of this water is lost. The agriculture sector generates 19–29% of GHG emissions. Without action, that percentage could rise. Addressing food loss and waste is critical because 1/3 of food produced globally is either lost or wasted. To achieve the goal of climate-smart agriculture, the water and carbon footprint of different crops need to assessed and reduced as much as possible. The issues of the water and carbon footprint of different crops have been discussed in this chapter.

1. Water footprint

1.1 Introduction

The water footprint (WF) is an indicator of freshwater use to produce a commodity. In agricultural production, the WF can be a game-changer for detecting water networks and the transfer of freshwater among the watersheds. The WF is one of the analytical tools employed to detect intensively the contribution of different water sources on crop production under a given catchment (Aldaya and Hoekstra, 2010). In short, WF could be used for proper water management at the micro level for a given territory without hampering or affecting water bodies. These actions may be helpful for further decision-making in better use of land and resources and allocation programs where necessary for crop production (Hoekstra et al., 2009). The WF accounts for both the direct and indirect water use of a consumer or producer, which depends on the skill of the operator or farmer. The WF may categories under different classes. Mostly used sub-divisions are green water footprint (GWF) and blue water footprint (BWF). The GWF is water from precipitation that is stored in the root zone of the soil and evaporated, transpired, or incorporated by plants. It is particularly relevant for agricultural production (Gerbens-Leenes et al., 2009; Aldaya and Hoekstra, 2010; Tian, 2013; Ababaei and Ramezani Etedali, 2014; Antonelli and Sartori, 2015). The BWF is water that has been sourced from surface or groundwater resources and is either evaporated, incorporated into a crop field, or taken from one body of water and returned to another, or returned at a different time. The WF of crop production, the most widely used indicator of water use, is likely to be affected by the changes in climate (Zhang et al., 2015).

The green and blue water consumption of a crop show how much groundwater and rainwater contribute to the production of the crop in field conditions. It can assist the total groundwater needed in a site for successful crop production after influenced by seasonal rainfall. Here effective rainfall is an important issue. Well-distributed rainfall all over the season needs to take into account, rather than the unutilized overflowed rainwater for a small period (1 or 2 days of heavy rainfall). BWF also helps to assess the impact on the aquifer for crop production, which can be well managed without causing serious damage to the aquifer due to the unnecessary withdrawal of groundwater. By this process, integrated approaches may achieve in a short duration for better water resources management.

The main benefits of determining Green and Blue WF include comparing the relative contribution of groundwater and rainwater for successful cropping. The water footprint could be used as a monitoring indicator to evaluate applied agricultural schemes and potential adaptation measures in cultivated regions in Bangladesh concerning the consumption of freshwater resources and deterioration of water receptors considering climate change scenarios. Detection of Blue transpiration and Blue evaporation, which refers combined Blue ET can be done. Using Blue ET, crop water footprint and irrigation efficiency can be obtained (Perry, 2007; Contor and Taylor, 2013; Grafton et al., 2018). Better watershed management can be obtained from the analysis of WF. Assistance may serve to the inter catchment water movement manner for different hydraulic character containing regions. For large-scale policymaking, the blue water, green water movement, and contribution pattern in the various crops could be guided by the policymakers to get appropriate direction in this climate-changing situation. Assist farmers in crop selection and pattern of farming system in a most benefited way.

A new paradigm shift in water management strategies is immensely felt at a national and international scale to deal with the emerging water and food security issues. For better water management, it is essential to understand the present agricultural water use scenario at a spatial and temporal scale as well as their influencing factors. Assessment of the virtual water transport among the regions of a country can provide a clear picture of the spatial distribution of water use (Hoekstra and Hung, 2005). Virtual water (VW) is the amount of water used for producing any kind of commodity, goods or service (Allen, 1998; Carr et al., 2013; Hoekstra and Hung, 2005). Identifying the amount of virtual water embedded in crops has greater implications for water management, practice, and policy (Ray et al., 2018). The concept of virtual water trade provides a novel way of exploring sustainable water use options (Carr et al., 2013; Hoekstra and Hung, 2005). If one region exports a water-intensive product to another region, it exports water in virtual form (Hoekstra and Hung, 2005; Oki and Kanae, 2004). Hence, water scarcity can be minimized in a place by importing water-intensive products instead of producing them locally (El-Sadek, 2010; Matchaya et al., 2019). Moreover, the natural water security of a state depends on whether the water used derives from green water (e.g., effective rainfall or soil moisture) or blue water (e.g., water from different surface and groundwater sources) (Wichelns, 2010). Virtual water concept has provision to separate the proportions of green and blue water used to produce crops. Overall, virtual water trade concept can help improve water use efficiency and water allocation efficiency at local or national scales (Zeitoun et al., 2010).

Studies dealing with virtual water and water footprint concept are very few in Bangladesh. Some studies have assessed the water footprint for rice production in the country (Rahman et al., 2016; Mullick et al., 2020). However, no studies have yet explored the virtual water flows/ across different regions of the country considering different agricultural crops. Assessing the regional virtual water trade can help identify which parts of the country are in the virtual water surplus or deficit zones in terms of different crops grown. Linking to this, it is also inevitable to evaluate to what extent the current regional virtual water exchange pattern is sustainable in terms of pressures on water demand and availability.

1.2 Understanding the scale

Water resources categories:

- Blue water is the fresh surface and groundwater (e.g., water in lakes, rivers, and aquifers),
- Green water is the precipitation on land that is stored in the soil for plant use,
- Grey water is contaminated by human use, and
- Virtual water is embedded in agricultural and industrial produce.

Water security:

- Water scarcity, when demand exceeds supply, occurs wherever the per capita availability of renewable freshwater is <1700 m^3/yr.
- In contrast, water stress occurs when the per capita availability of renewable freshwater is <1000 m^3/yr.
- Therefore, water security exists when all people at all times have physical and economic access to sufficient, safe, and clean water that meets their basic needs for an active and healthy life.

1.3 Water footprints of major agricultural produces

These footprints (Table 1) include all losses of water from source to destination.

Table 1. Water footprints of major agricultural produces.

Foodstuff	Quantity	Water consumption (L)
Beef	1 kg	15,415
Sheep Meat	1 kg	10,412
Butter	1 kg	5,553
Chicken meat	1 kg	4,325
Cheese	1 kg	3,178
Olives	1 kg	3,025
Rice	1 kg	1500-2500
Bread	1 kg	1,608
Pizza	1 unit	1,239
Apple	1 kg	822
Banana	1 kg	790
Potatoes	1 kg	287
Milk	One glass	255
Cabbage	1 kg	237
Tomato	1 kg	214
Egg	1	196
Tea	250 ml cup	27

1.4 Uneven distribution in water footprint in Bangladesh

Plenty of water was virtually transported from the paddy side as it had a large production area (11.24 M ha) and higher water impressions. Five of the eight divisions of Bangladesh have exported water in terms of produces to other three divisions (Fig. 1). Rangpur had the highest amount of surplus virtual water in the national equilibrium which was 5733 Mm^3, followed by Rajshahi (4610 Mm^3). Rangpur added the largest amount of virtual water to the national budget, followed by Rajshahi (43343 Mm^3), Khulna (28969 Mm^3), Mymensingh (1608 Mm^3), and Barisal (393 Mm^3) (Mahmud et al., 2021).

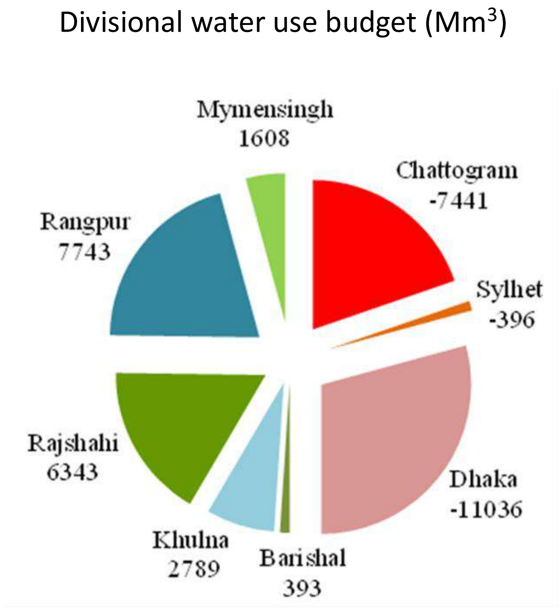


Fig. 1 Divisional water use budget for crop production in Bangladesh (Source: Mahmud et al., 2021)

1.5 Changing crop water demand

Daily potential ET would increase in the future for increased temperature. Potential crop water requirement would decrease because of a shorter growing period induced by the increased temperature. The overall crop water demand will be increased due to the changes in per capita food demand, crop water use, and water productivity (Table 2, Fig. 2-4).

Table 2. Per capita food demand, projected 2010, 2030, and 2030.

Commodity	2010	2030	2050
	kg $capita^{-1}$ yr^{-1}		
Beef	10	12	14
Pork	16	14	13
Sheep and goat	2	3	3
Poultry	12	15	18
Rice	53	49	43
Wheat	67	67	68
Maize	19	19	20
Milk	47	52	57
Potato	32	33	33
Sweet potato	13	13	13
Cassava and other R and T	20	21	23
Vegetables	82	87	87
Sub-tropical fruits	49	52	56
Temperate fruits	13	14	14
Sugar	18	18	20

† IFPRI IMPACT Simulations (2013).

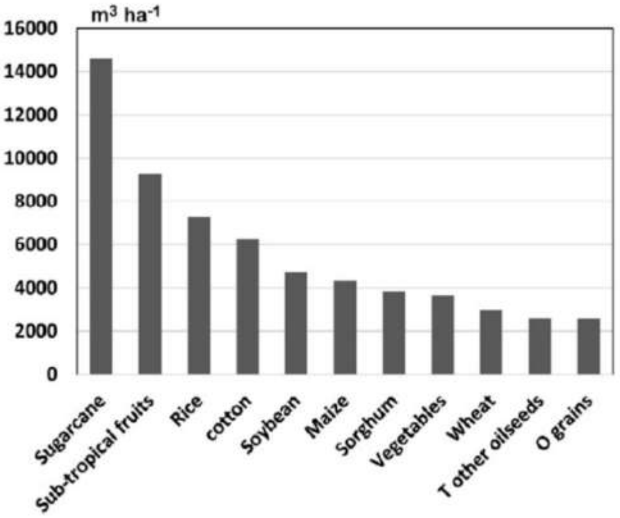


Fig. 2. Crop water use for different crops (IFRI IMPACT Simulations, 2013).

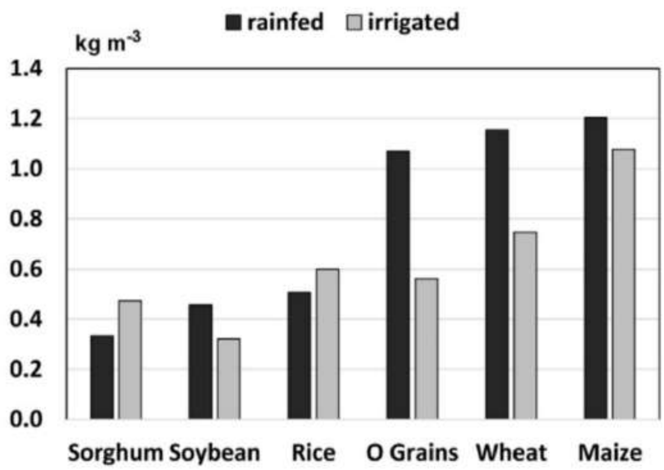


Fig. 3. Water productivity for different crops (IFRI IMPACT Simulations, 2013).

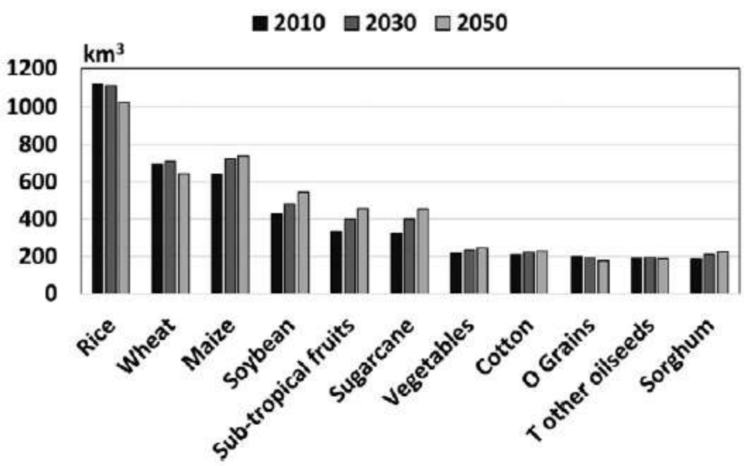


Fig. 4. Total crop water use for different crops (IFRI IMPACT Simulations, 2013).

2. Carbon footprint

2.1 Introduction

A carbon footprint is the total amount of greenhouse gases (including carbon dioxide and methane) that are generated by our actions. In some cases, the carbon footprint is expressed as the carbon dioxide equivalent (CO_2e) which is meant to sum up the total greenhouse gas (GHG) emissions caused by an individual, event, organization, service, place or product. The average carbon footprint for a person in the United States is 16 tons, one of the highest rates in the world. Globally, the average carbon footprint is closer to 4 tons. To have the best chance of avoiding a 2℃ rise in global temperatures, the average global carbon footprint per year needs to drop to under 2 tons by 2050. Lowering individual carbon footprints from 16 tons to 2 tons will not happen quickly. By making small changes to our actions, like eating less meat, taking fewer connecting flights and line drying our clothes, we can start making a big difference (https://www.nature.org/en-us/get-involved/how-to-help/carbon-footprint-calculator/).

The average carbon footprint per unit (kWh) electricity is 0.7 kg CO_2e. The three main grain crops, rice (4871 ± 418 kg CO_2e/ha), wheat (2766 ± 552 kg CO_2e/ha), and maize (2439 ± 530 kg CO_2e/ha), showed the highest carbon footprint and contribution to the total greenhouse gas (GHG) emissions, mainly due to their larger cultivated areas and higher fertilizer application rates. CH_4 emission was the major component of the carbon footprint for rice production, accounting for 48-66%, while fertilizer production and usage were the largest components of carbon footprint for dryland crops, making up to 26-49% for different crops (Fan et al., 2022).

2.2 System boundaries and functional units

Total GHG emissions throughout the whole crop production process are quantitatively assessed. The system boundary of crop production is defined as the whole life cycle from the process of mining, production, and transportation of agricultural materials (chemical fertilizers, seeds, pesticides, etc.), to the completion of crop harvesting (Fig. 5). Therefore, the sources of GHG emissions includes the production, storage, transportation, and application of agricultural inputs, the energy consumption for machinery operation, CH_4 emission from paddy fields, and N_2O emission from N fertilizer application (Fig. 5). The functional units (FU) can be defined based on both the area and product, i.e., the kg CO_2e/ha of sown area and kg CO_2e/kg of crop yield. FU based on area are used to compare the environmental effects, while FU based on the product are used to compare the production efficiency.

Greenhouse gases warm the Earth by absorbing energy and slowing the rate at which the energy escapes to space; they act like a blanket insulating the Earth. Different GHGs can have different effects on the Earth's warming. Two key ways in which these gases differ from each other are their ability to absorb energy (their "radiative efficiency"), and how long they stay in the atmosphere (also known as their "lifetime"). The Global Warming Potential (GWP) was developed to allow comparisons of the global warming impacts of different gases. Specifically, it is a measure of how much energy the emissions of 1 ton of a gas will absorb over a given period of time, relative to the emissions of 1 ton of carbon dioxide (CO_2). The larger the GWP, the more that a given gas warms the Earth compared to CO_2 over that time period. The time period usually used for GWPs is 100 years. GWPs provide a common unit of measure, which allows analysts to add up emissions estimates of different gases (e.g., to compile a national GHG inventory), and allows policymakers to compare emissions reduction opportunities across sectors and gases (https://www.epa.gov/ ghgemissions/understanding-global-warming-potentials).

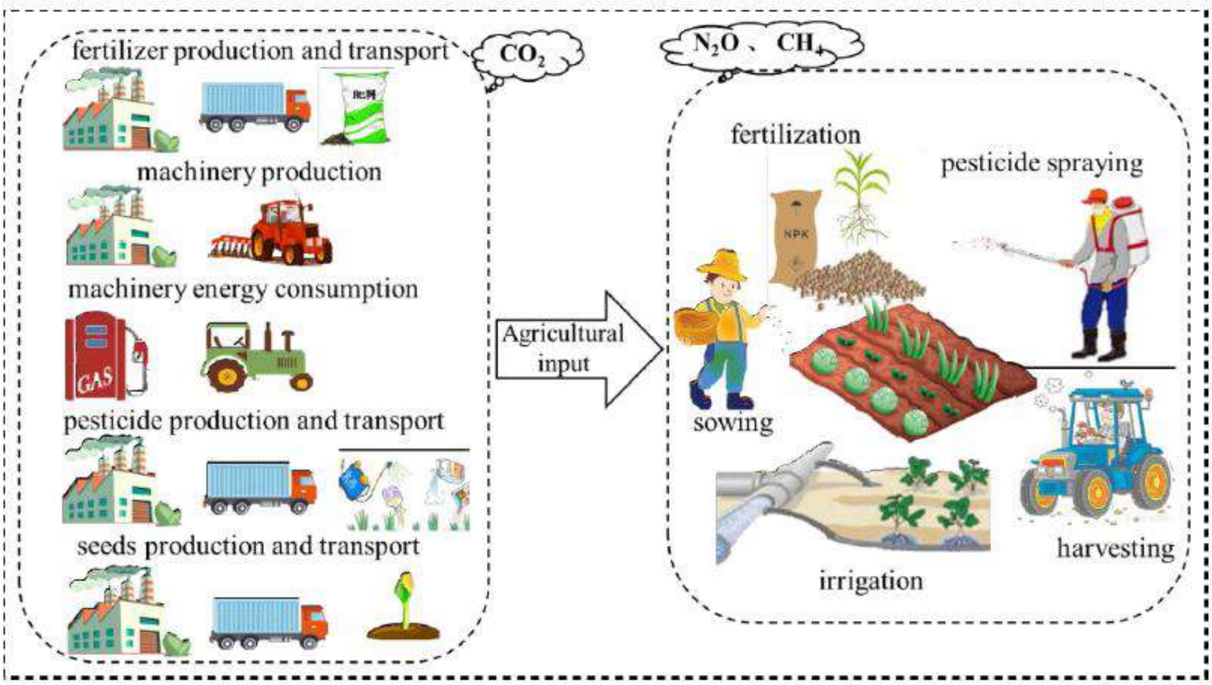


Fig. 5. System boundary of major crop production (Source: Fan et al., 2022).

2.3 Carbon footprint calculation

The carboon footprint for a crop production can be calculated by using the following equaitons:

Total carbon footprint of a crop = Carbon equivalent footprint (input) + Carbon equivalent footprint (N_2O) + Carbon equivalent footprint (CH_4)

where

(i) Carbon equivalent footprint (input) = $D_1\ EF_1 + D_2\ EF_2 + D_3\ EF_3 + D_4\ EF_4$ + ...

where D the input of an agricultural material for a crop and EF is the emission factor of the agricultural material for the crop.

(ii) Carbon equivalent footprint (N_2O) = {(N × N_2O direct emission factor × 44/28) + (N × volatilization rate of ammonia and NOx × N_2O indirect emission factor caused by nitrogen deposition × 44/28) + (N × leaching and runoff rate × N_2O indirect emission factor caused by leaching and runoff × 44/28)} × 265

where 44/28 is the ratio of N_2O-N to N_2O molecular weight, 265 is the global warming potential value of N_2O at the 100-year time horizon.

(iii) Carbon equivalent footprint (CH_4) = $F_{-CH4} \times 28$

where F_{-CH4} is the CH_4 emission factor for crop fields and 28 is the global warming potential of CH_4 at the 100-year time horizon.

2.4 Temporal dynamics of carbon footprint for major crops

Temporal dynamics of the carbon footprint per unit area and per unit yield of major crops in China from 1990 to 2019, and the averaged carbon footprint per unit area and per unit yield of major crops in China is shown in Fig. 6 (Fan et al., 2022).

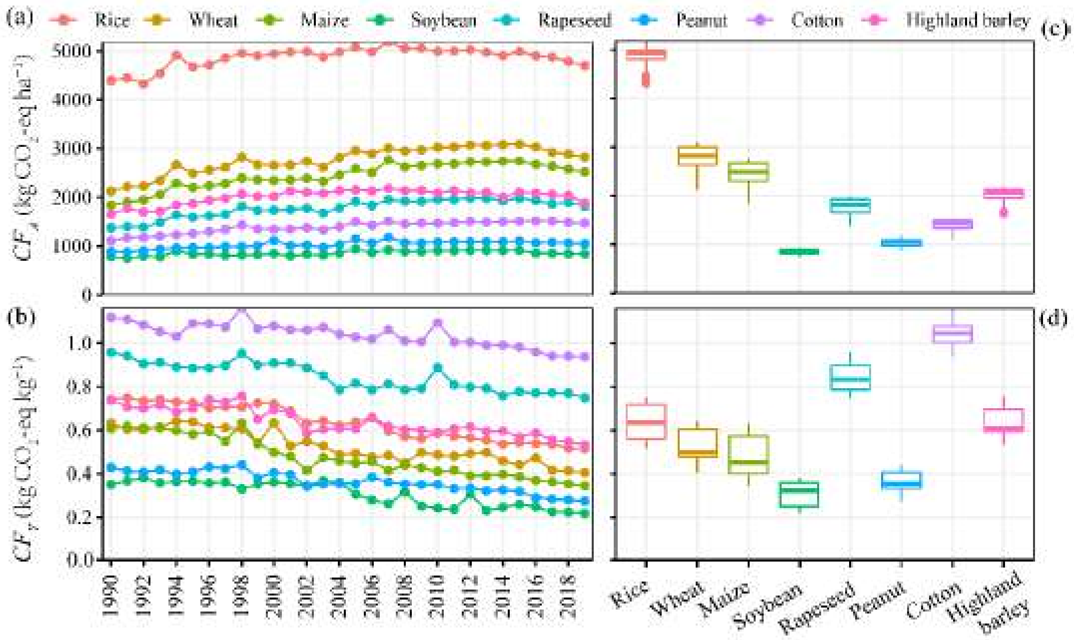


Fig. 6. Temporal dynamics of the carbon footprint (a) per unit area and (b) per unit yield of major crops in China from 1990 to 2019, and the averaged carbon footprint (c) per unit area and (d) per unit yield of major crops in China (Source: Fan et al., 2022).

3.5 Distribution of carbon footprint in different regions

The spatial distribution of the annual total carbon footprint (Fig. 7) is ettential to mange cop production at large scale.

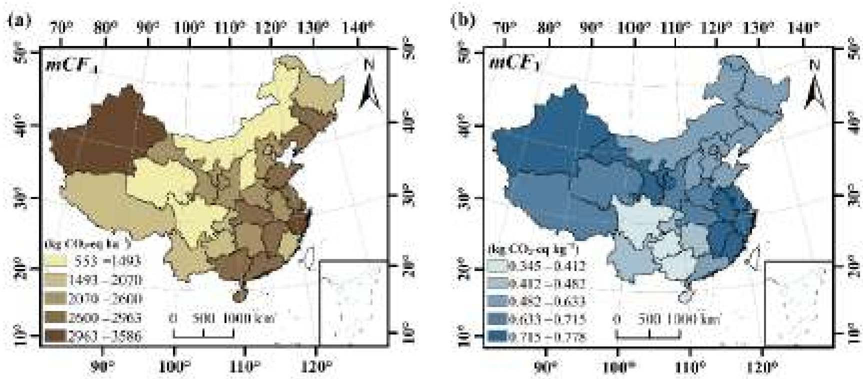


Fig. 7. Spatial distributions of the annual total mean carbon footprint (a) per unit area and (b) per unit yield in China from 1990 to 2019 (Source: Fan et al., 2022).

3.6 Composition of carbon footprint for different crops

Compositions of the annual mean carbon footprints per unit area and per unit yield for different crops can be different (Fig. 8).

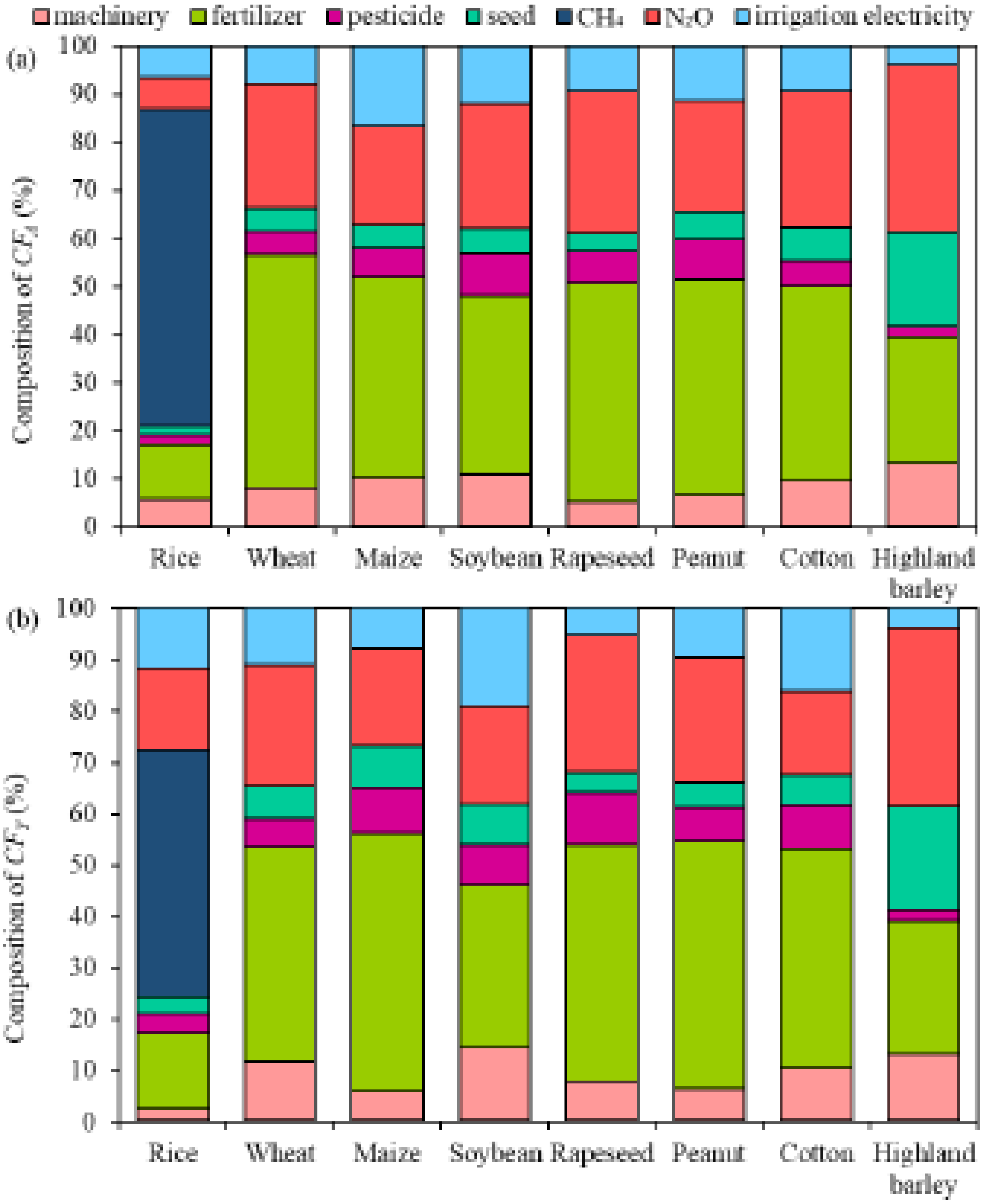


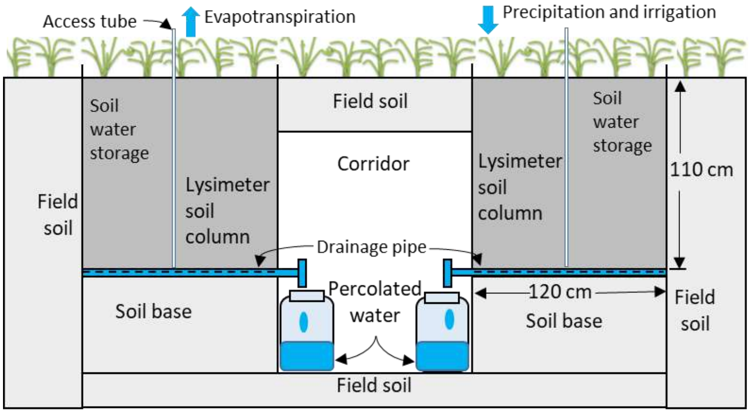
Fig. 8. Compositions of the annual mean carbon footprints (a) per unit area and (b) per unit yield for different crops in China from 1990 to 2019 (Source: Fan et al., 2022).

3. Examples of activities in climate smart agriculture in different countries

Objectives to be achieved	**Required practices**
Improving emissions intensity and production efficiency in livestock farms	Improvements in feeding strategies, animal health, breeding, manure and waste management; milk chilling and transport
Resilient and lower-emissions agriculture practices	Better water-use efficiency and new technologies for improved soil conditions
Biodiversity and aquatic resources	Manage biodiversity conservation and fisheries resources
Improved energy efficiency and soil-management capacity	Establishment of an Agricultural Information/ Decision Support System/ soil management plans
Low-carbon agriculture while boosting private profitability	Technical assistance and training to adopt sustainable land management practices
Strengthen climate resilience across all four dimensions of food security	Economic inclusion of youth/ marketing efficiency/ environmental sustainability of agri-food value chains/ promote precision agriculture/ improved extension services / promote agro-ecology
Farm management approaches	Enhance resilience to changes in climate and pests/ improving the capacity to monitor meteorological data/ shift away from monoculture toward a farming system/ reduce land degradation
Sustainable farming practices	Distribution of improved, drought-tolerant seeds, more efficient irrigation, and expanded use of forestry for farming and conservation agriculture techniques
Low-carbon agriculture while boosting private profitability	Technical assistance and training to adopt sustainable land management practices
Improved of water productivity in irrigated agriculture	Improving irrigation and drainage technologies/access to technologies such as efficient water-harvesting systems/ resilience to droughts/ improving soil health/ climate-smart varieties of staple crops, such as rice, plantains, and maize/ agricultural production, employment, and incomes, higher living standards and positive environmental outcomes
Agricultural productivity in smallholder farming and pastoral communities	Scaling up CSA practices, strengthening CSA research and seed systems, and supporting agrometeorological, market, climate, and advisory services
Beef sector sustainability and climate-change mitigation	Addressing land degradation, biodiversity conservation, pollution control, and mitigation of GHG emissions along the value chain

4. Agricultural management practices to reduce water and carbon footprint

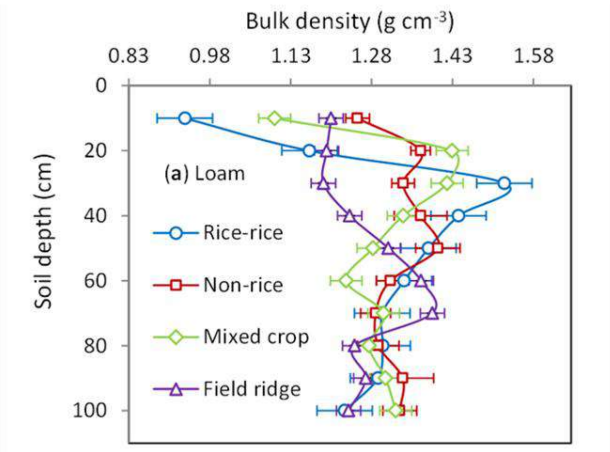
4.1 Alternate wetting and drying irrigation



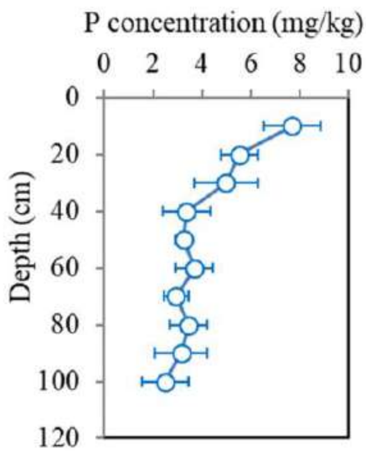
Results/Issues	Synergy	Trade-off
Grain yield		
Water saving		
Nutrient loss		
Peak leaching		
Nutrient runoff		
Residual nutrient		
GHG emission		

(Source: Amin et al. 2021. Journal of Environmental Management, 297:113402. https://doi.org/10.1016/j.jenvman.2021.113402 and Amin et al. 2022. International Journal of Plant Production. https://doi.org/10.1007/s42106-022-00221-4)

4.2 Plow pan management



Bulk density at different soil layers



Phosphorus concentration in different soil layers

(Source: Amin et al. 2021. Journal of Environmental Management, 297:113402. https://doi.org/10.1016/j.jenvman.2021.113402)

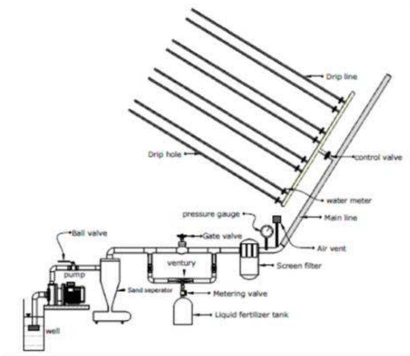
4.3 Organic fertilization for rice cultivation

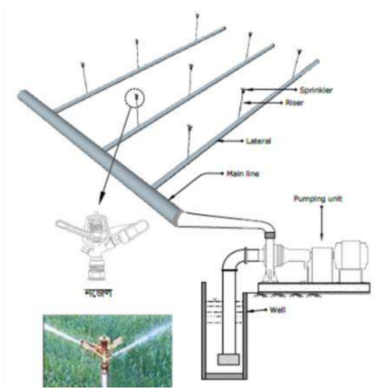
<table>
<tr><th style="background:#e6b8b7">Results/Issues</th><th style="background:#e6b8b7">Synergy</th><th style="background:#e6b8b7">Trade-off</th></tr>
<tr><td>Grain yield</td><td style="background:#c4d79b"></td><td></td></tr>
<tr><td>Water saving</td><td style="background:#c4d79b"></td><td></td></tr>
<tr><td>Nutrient loss</td><td style="background:#c4d79b"></td><td></td></tr>
<tr><td>Peak leaching</td><td style="background:#c4d79b"></td><td></td></tr>
<tr><td>Nutrient runoff</td><td></td><td style="background:#ffff00"></td></tr>
<tr><td>Residual nutrient</td><td></td><td style="background:#ffff00"></td></tr>
<tr><td>GHG emission</td><td style="background:#c4d79b"></td><td></td></tr>
<tr><td>Microorganisms</td><td></td><td style="background:#ffff00"></td></tr>
</table>

(Source: Amin et al. 2022. International Journal of Plant Production. https://doi.org/10.1007/s42106-022-00221-4 and Ananna et al. 2021. Water Science and Engineering, 14 (4):314–322. https://doi.org/10.1016/j.wse.2021.11.001)

4.4 Pressurized irrigation

<table>
<tr><th style="background:#e6b8b7">Results/Issues</th><th style="background:#e6b8b7">Synergy</th><th style="background:#e6b8b7">Trade-off</th></tr>
<tr><td>Grain yield</td><td style="background:#c4d79b"></td><td style="background:#ffff00"></td></tr>
<tr><td>Water saving</td><td style="background:#c4d79b"></td><td></td></tr>
<tr><td>Soil health</td><td style="background:#c4d79b"></td><td></td></tr>
<tr><td>Nutrient loss</td><td style="background:#c4d79b"></td><td></td></tr>
<tr><td>Soil erosion</td><td style="background:#c4d79b"></td><td></td></tr>
<tr><td>GHG emission</td><td style="background:#c4d79b"></td><td></td></tr>
<tr><td>Nutrient uptake</td><td style="background:#c4d79b"></td><td style="background:#ffff00"></td></tr>
<tr><td>Topography</td><td style="background:#c4d79b"></td><td></td></tr>
<tr><td>Crop-specific</td><td></td><td style="background:#ffff00"></td></tr>
<tr><td>Energy required</td><td></td><td style="background:#ffff00"></td></tr>
<tr><td>Cost & maintenance</td><td></td><td style="background:#ffff00"></td></tr>
</table>





4.5 Mulching for non-rice crop

Results/Issues	Synergy	Trade-off
Grain yield		
Water saving		
Soil health		
Nutrient leaching		
Nutrient runoff		
Residual nutrient		
GHG emission		
Waste disposal		

4.6 Conservation tillage

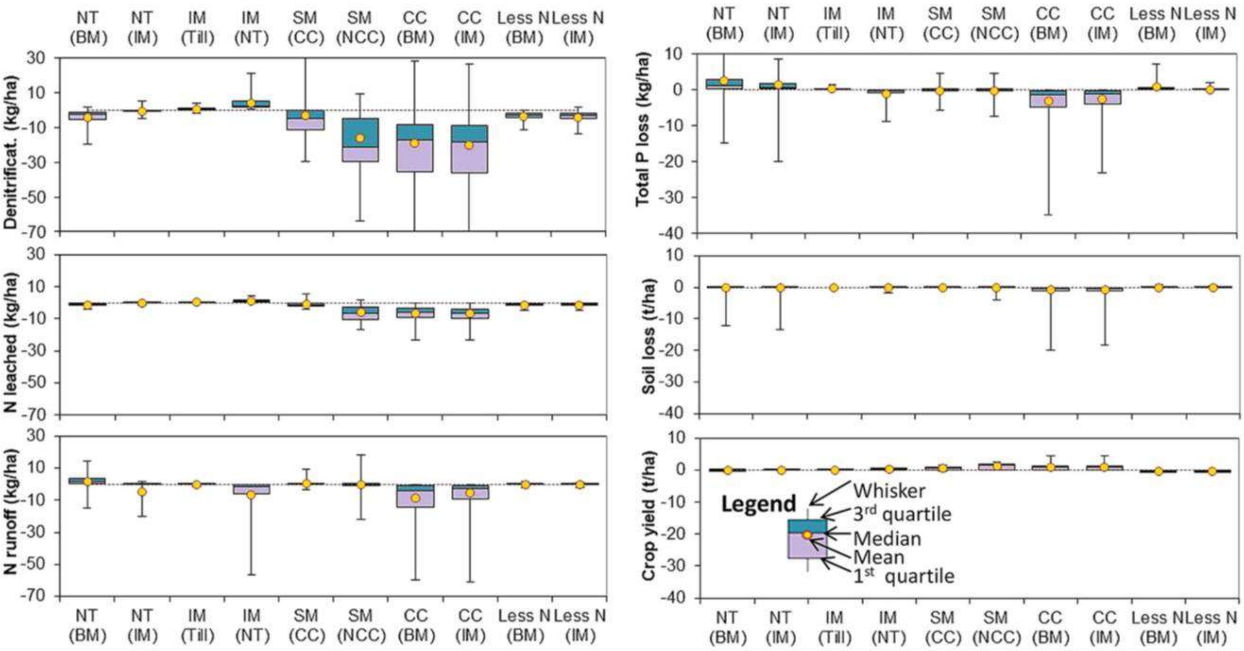
Results/Issues	Synergy	Trade-off
Grain yield		
Water saving		
Soil health		
Peak leaching		
Phosphorus runoff		
GHG emission		

4.7 Better crop rotation

Grain rotation: Alfalfa-Corn Silage-Soybean-Rye cover Crop-Corn Grain-Oat
VS.
Forage rotation: Alfalfa-Corn Silage-Rye-Red clover- Corn Silage-Oat Cover-Alfalfa

Results/Issues	Synergy	Trade-off
Grain yield		
Water saving		
Soil health		
Nutrient loss		
Soil erosion		
GHG emission		
Nutrient uptake		
Mineralization		
Immobilization		

5. Uncertainty in effectiveness of management practices



Nutrient (N and P) losses, sediment (soil) loss, and crop yield by different management practices. Dotted lines indicate-no change, NT = no-till, BM = broadcast manure, IM = injected manure, SM = spring applied manure, CC = cover crop, NCC = no cover crop, less N = 15% less N input.

6. Conclusions

To achieve the goal of climate-smart agriculture, the water and carbon footprint of different crops need to assessed and reduced as much as possible. The issues of the water and carbon footprint of different crops have been discussed in this chapter.

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FARM MECHANIZATION FOR CLIMATE SMART AGRICULTURE

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Background

Agriculture is a key component of Bangladesh economy, producing approximately 11.6% of the country's gross domestic product (World Bank, 20021) and employing approximately 40.6% of the working force (World Bank, 2019). Bangladesh is one of the densely populated countries. The area of Bangladesh is 147570 square kilometres where 168.22 million people are living (BBS, 2021). The cultivable land is 59.83% of the total land area of the country. Bangladesh grows rice, wheat, maize, pulses, vegetables, fruits, spices etc. There are substantial increases of livestock and fish production. Bangladesh is now 4th largest producer of rice in the world and attained self-sufficiency in rice production. The country is also 3rd largest vegetable and inland fish producer, and 5th largest aquaculture fish producer. Moreover, the country produces sufficient amount of meat and egg for meeting up the internal demand.

Despite, tremendous growth of agricultural production, the country is facing some crucial challenges in ensuring food and nutrition security for growing population in Bangladesh. The cultivable land of Bangladesh is decreasing by 0.5% per year due to urbanization and industrialization (FAO, 2014). On the other hand, the employment in agricultural sector is only 40.6% which is going to be 20% by 2030 (FAO, 2019). Greenhouse gas (GHG) emission from agriculture, energy, land use change, waste management and industrial process is 39%, 32%, 15%, 10% and 4%, respectively (FAO, 2019). The projected changes in temperature and precipitation in Bangladesh by 2050 are 1.7^{o}C and 10.9%, respectively because of GHG emission in Bangladesh as well as in other part of the world. Therefore, today, and in to the coming decades, the country is likely to be negatively affected by sea level rise and saltwater intrusion, mean temperature increases (1.7^{o}C by 2050), rainfall variability, and an increase in the frequency and intensity of extreme weather events. Each of these factors will have considerable impacts on agricultural production and economic development in the country. To sustain our agricultural productivity by combating natural calamities and adverse climatic conditions, there are no alternative of adaptation agricultural mechanization and climate smart agriculture (CSA).

Climate Smart Agriculture

Climate-smart agriculture (CSA) is an integrated approach to managing landscapes—cropland, livestock, forests and fisheries--that address the interlinked challenges of food security and climate change (World Bank, 2022). FAO defined, Climate-smart agriculture (CSA) is an approach that helps guide actions to transform agri-food systems towards green and climate resilient practices (FAO, 2021). CSA supports reaching internationally agreed goals such as the

SDGs and the Paris Agreement. On the other hand, ASEAN–CRN mentioned that Climate-smart agriculture (CSA) is an approach for transforming and reorienting agricultural systems to support food security under the new realities of climate change. (Lipper et. al., 2014)

There are three pillars of CSA (FAO 2019). The pillars are

CSA Pillar 1 – Sustainably increase agricultural **productivity** and incomes

The CSA action categories for achieving CSA Pillar 1 objectives are:

- increase resource use efficiency;
- diversify production system;
- manage agro-ecosystems, ecosystem services and biodiversity

CSA Pillar 2 – Build resilience and **adapt** to climate change

The CSA action categories for achieving CSA Pillar 2 objectives are:

- diversify production system;
- plan production activities to reduce risk exposure, sensitivity, and adapt to changing conditions;
- manage agro-ecosystems, ecosystem services and biodiversity

CSA Pillar 3 – **Reduce and/or remove** GHG emissions, where possible

The CSA action categories for achieving CSA Pillar 3 objectives are:

- increase resource use efficiency;
- retain and sequester carbon in agro-ecosystems;
- replace fossil fuel-based energy with renewable energy

Sustainable Development Goals

In 2015, 195 nations agreed with the United Nation that they can change the world for the better. The Sustainable Development Goals (SDGs), also known as the Global Goals, were adopted by the United Nations in 2015 as a universal call to action to end poverty, protect the planet, and ensure that by 2030 all people enjoy peace and prosperity (UNDP). The 17 SDGs are integrated—they recognize that action in one area will affect outcomes in others, and that development must balance social, economic and environmental sustainability. There are 169 targets and 232 indicators in 17 SDGs (World Bank, FAO 2019). The 17 SDGs are given Figure 1.

Figure 1: Sustainable Development Goals

All the sustainable development goals are directly or indirectly connected to sustainable and healthy food (Rockström and Sukhdev, 2016) and showed as wedding cake (Figure 2). CSA can support achieving all 17 SDGs. Global food security agenda is summed up in SDG 2. The biosphere dimension (6, 13, 14 and 15) is what contains and supports any social and economic plan. The transformation of food systems can transform the world.

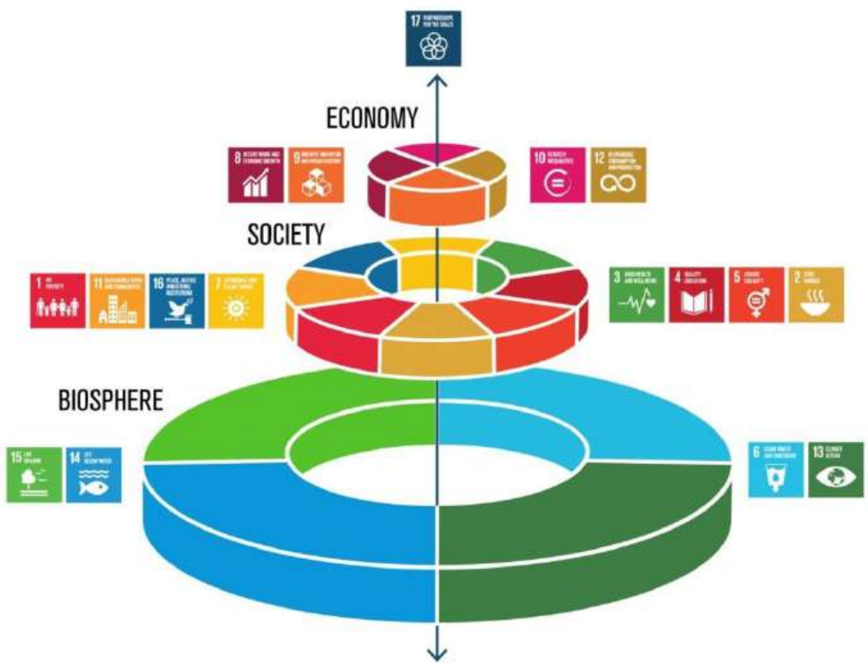
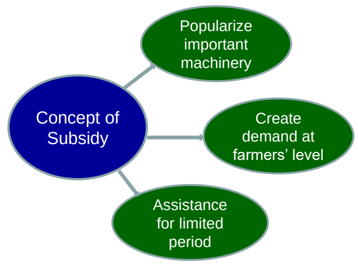


Figure 2: Sustainable Development Goals 2030 (SDGs) wedding cake from Azote Images for Stockholm Resilience Centre, 2016 (Rockström and Sukhdev, 2016)

Agricultural Mechanization in Bangladesh

Agricultural mechanization in Bangladesh has received major boost due to public and private sector initiatives with government favourable policies. Government has granted 3020 crore taka for popularizing transplanting, weeder, harvesting, threshers and dryers etc through Department of Agricultural Extension (DAE) in 70% subsidy in haor and coastal areas and 50% in other areas of Bangladesh. The present power available in agricultural production is 3.24 kW/ha (Alam et. al., 2023). On the other hand, power available in agriculture in Japan, China and India are 8.75, 5.7 and 2.22 kW/ha, respectively (2015).



Subsidy Level
70% for Haor & Coastal areas; 50% for rest of Bangladesh

Figure 3: Farm mechanization through integrated management project through DAE

Appropriate Scale Mechanization Innovation Hub (ASMIH) –Bangladesh findings showed that appropriate scale machinery can save time, cost and labour. However, paddy production cost can be lowered to 40 to 50%. On the other hand, combine harvester, BAU-STR dryer and hermetic bags can reduce the loss from 15.24% to 2.28% (ASMIH-BD, 2022; PHLIL-BD, 2020). Because of these appropriate loss saving technologies, 7.1-million-ton paddy per year can potentially be saved.

Fourth Industrial Revolution (4IR) in Bangladesh Agriculture

Bangladesh agriculture needs to move from semi-mechanized to mechanize with smart application of digital and artificial intelligence. The Fourth Industrial Revolution, or 4IR, refers to the oncoming revolutionary era in which information and communication technology (ICT) will converge. The revolution will spark new technological innovations in six areas: artificial intelligence, robotics, Internet of things (IoT), unmanned vehicles, three-dimensional printing, and nanotechnology. The 4IR will include a variety of new technologies that use big data to incorporate the physical, biological, and digital worlds in a way that will affect all sectors of life including agriculture, industry and economy.

In response to this trend, future agriculture is expected to evolve into high-tech industries where systems are coupled with artificial intelligence and big data. The systems will converge into a single unit in which farm machinery, seeding the soil, farm management, production forecasting, and irrigation are combined. Using the core technology of the 4IR, robots, big data, and AI will combine with agriculture to create a new era of superfusion. The era will evolve multifaceted economic, social, and ethical values fused with various industries and expressed in business models.

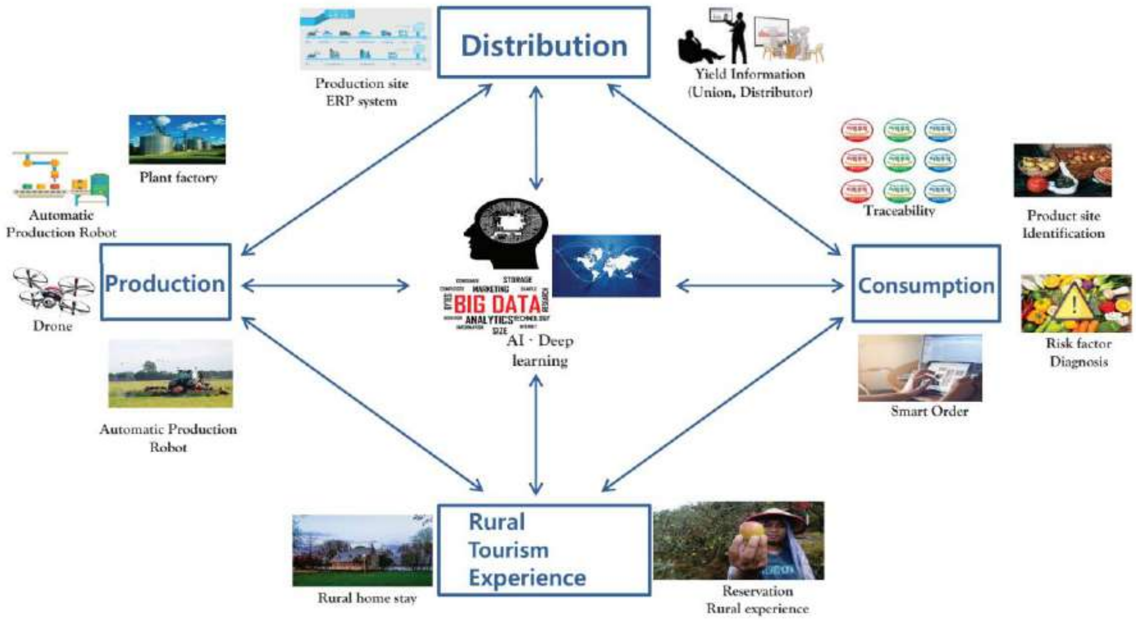


Figure 4: Illustration of the future agriculture with the Fourth Industrial Revolution

(Source: Fourth Industrial Revolution and Agriculture, Korea institute of planning and evaluation for technology in food, agriculture and forestry, 2016)

The agricultural friendly Fourth Industrial Revolution will expand the scope of agriculture in various fields, such as culture, welfare, and healing in production-oriented agriculture. As shown in Figure 4, the 4IR will lead to a greater amount of communal and independent cultivation through cultural activities, such as combining agriculture with games and leisure, human welfare agriculture in the age of aging, and agricultural activities with plants and animals. The expansion of agriculture through the 4IR is expected to vary greatly in the fields of production, distribution, and consumption.

Mechanization and Climate Smart Agriculture

Climate smart agriculture (CSA) is obvious option for sustaining agricultural production in the changing climate condition of Bangladesh. Without agricultural mechanization with appropriate technologies, it is difficult to adapt and continue CSA practices. One of the examples of climate smart agriculture practices in Bangladesh illustrated in Figure 5.

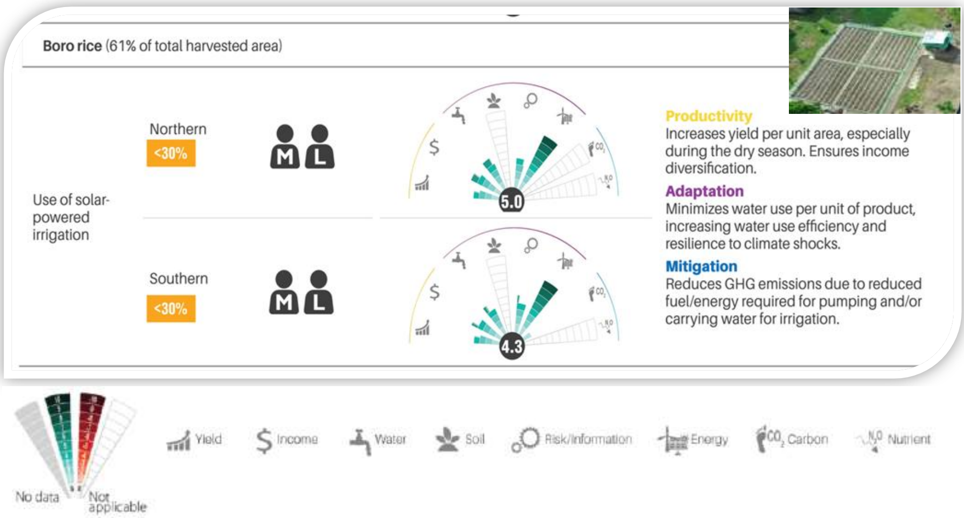


Figure 5: Present practices of CSA with use of solar powered irrigation application in Boro rice production

Figure 6: Future smart IoT-Based Irrigation and Fertilization System in CSA (Ahmad et. Al., 2022)

The proposed fertigation system consists of physical modules electrically powered by a photovoltaic power supply and a cloud computing infrastructure for managing the physical modules in an automated way (Figure 6). In fact, despite the informatics infrastructure, it is possible to control and activate the fertigation phases according to the crop type and their growth phase, create a history of operations, and share data by using a tracking system on environmental conditions.

Conclusion

Bangladesh is already in good shape in adapting climate smart agricultural practices. The level adaption can be increased with the introduction of appropriate scale mechanization for making agriculture profitable. However, we need to prepare ourselves adapting 4IR based precision agricultural technologies for achieving sustainable development goals in Bangladesh.

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CLIMATE SMART AGRICULTURE FOR CIRCULAR BIOECONOMY

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Agriculture is the most important sector of Bangladesh economy due to its role in food security, employment and livelihood. The agriculture of Bangladesh is dominated by crops which accounts almost half of the total agriculture GDP (13.29%). There are number of mentionable successes in Bangladesh agriculture. Bangladesh is 4th largest rice producer, 3rd largest vegetable and inland water fish producer in the world. Bangladesh has also attained self-sufficiency in egg and meat production. On the other hand, Agricultural land is decreasing by 0.5% every year (FAO, 2014) due to urbanization and industrialization. Post-harvest losses of cereals, fruits and vegetables are from 14 to 44% (PHLIL-2021; Hasan et. al., 2010), amounting US$4000 million a year (Bangladesh Delta Plan 2100). However, a significant amount of wastes is generating from agriculture and household food consumption which are contributing in GHG emission. Application of too much chemical fertilizer is deteriorating soil health where urgent need of replenishment with organic matter and fertilizer in order to enhance crop productivity. Coastal zone and the low-lying area of Bangladesh are highly vulnerable, especially to cyclones and storm surges. In addition, salt-water intrusion, floods, sea level rise intensify with vulnerability of the community of the areas. These problems likely to become even worse due to climate change adverse impact.

Global food security agenda is summed up in sustainable development goal (SDG) no 2 i.e. zero hunger. SDG 2 aims to end hunger, achieve food security, improve nutrition and promotes sustainable agriculture. The zero hunger challenges are: (a) all food systems from production to consumption are sustainable, (b) an end to rural poverty by doubling small scale producer incomes and productivity, (c) adapt all food systems to eliminate loss or waste of food, (d) access adequate food and healthy diets for all peoples all year round and end to malnutrition in all its forms. But, Bangladesh food and agricultural production systems are linear where losses and wastes are occurred along the value chain. Therefore, transformation of our food systems is necessary for achieving SDG no 2.

World is transiting toward more circular systems for keeping products & materials in use, design out waste & pollutions and regenerate natural systems (Resource, 2021). These are linked to zero hunger challenges and sustainable development goals. In agriculture, there are opportunities to reuse outputs such as waste, at all stages of the production process and use them as inputs for other production chains. In UN food system summit 2021, all the scientists and country leaders talked about sustainable resource efficient food systems with less waste. In UN global food systems summit 2021, our honorable prime minister, H. E. Sheikh Hasina iterated the same. Bangladesh needs to act seriously for adapting circular food systems for feeding our growing population as well as conserve nature and soil health.

The circular food system or circular bioeconomy can be defined as the production, utilization, conservation, and regeneration of biological resources, including related knowledge, science, technology, and innovation, to provide sustainable solutions (information, products, processes and services) within and across all economic sectors and enable a transformation to a sustainable economy (San Juan et al., 2022).

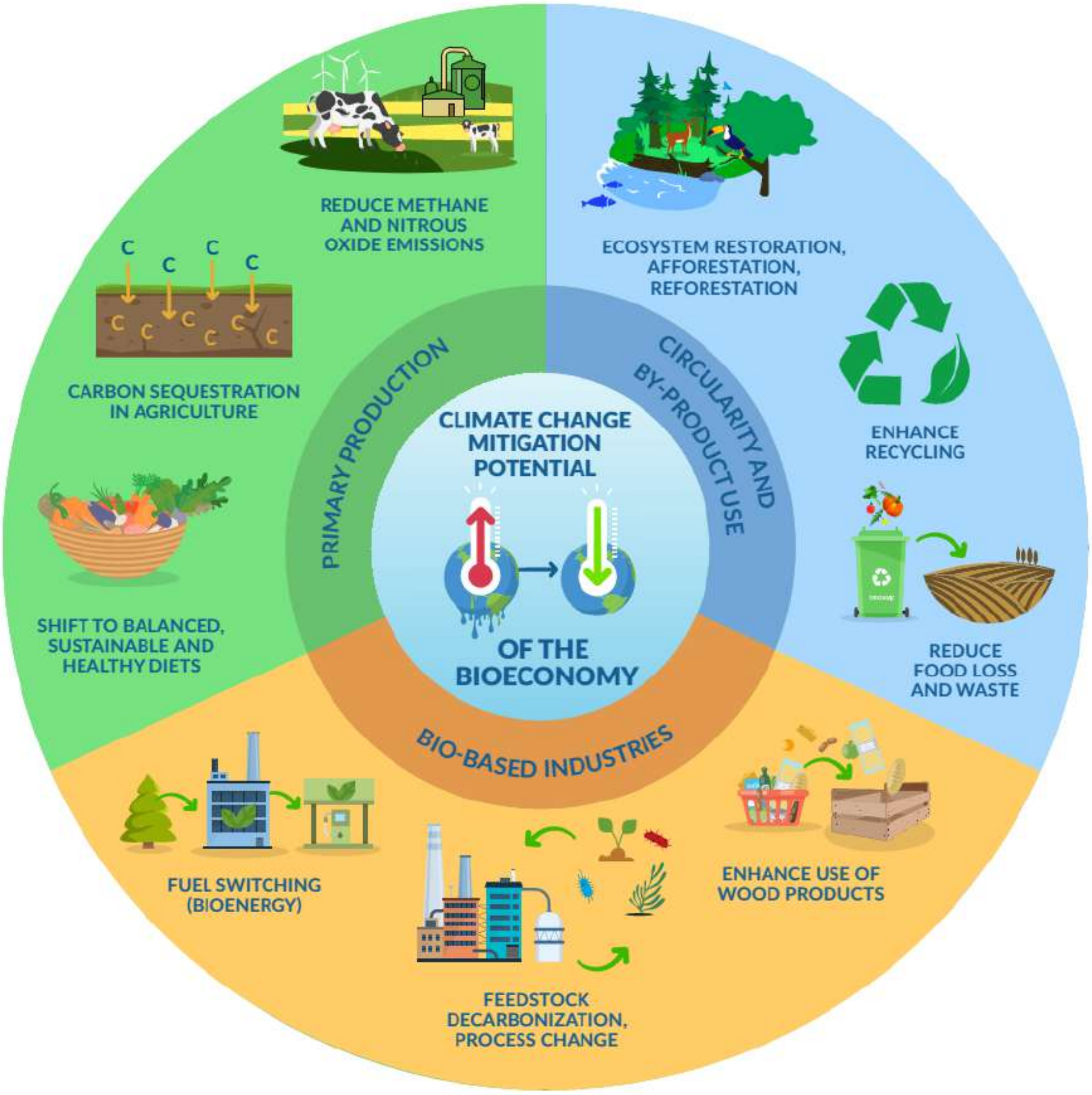

Figure 1. IPCC mitigation options that bio-economy can support along the whole agrifood system (San Juan et al., 2022)

Bioeconomy examples can effectively contribute to some IPCC mitigation options, drawing a link between bioeconomy and climate change mitigation. Nine bioeconomy examples have been chosen in three main macrosectors that relate to agrifood systems: primary production (agriculture, forestry and other land use (AFOLU) and fisheries); bio-based industries; and circularity and by-product use (Figure 1). These are linked to climate smart agriculture i.e. resource efficiency, productivity, and reuse.

Now, the question is how to ensure circular food systems and zero hunger challenges in Bangladesh by overcoming all the adverse conditions as stated earlier. First of all, we might consider integrated production approach including crop-fisheries and livestock together (Figure 1). However, adaption of mechanization and precision farming are also needed to be integrated for sustaining this approach. As for example, paddy transplanting and harvesting by machines can save cost 30 to 60%. On the other hand, ensuring comfort with adequate fresh air can help to increase milk production of existing dairy farms. Adaption of modern fish farming like biofloc technology can help to increase fish production in many folds.

Beside open field production, controlled environment food and agricultural systems are unique food and agriculture system which can be adapted in saline and drought prone areas of

Bangladesh. One of the best examples of controlled environment food and agriculture system is greenhouse system. Greenhouse production systems are more sustainable than conventional production system because they greatly reduce need of water, land and chemicals. The CO_2 level is often enriched to complement the enhanced lighting level & increased production in many folds. As for example, Bangladesh produces 4 to 10 kg tomato per square meter in open field; on the other hand, Netherlands and India produce 50 to 70 and 25 to 30 kg tomato per square meter, respectively in the greenhouse in a year. However, vertical farms and plant factories adapt advanced manufacturing concepts to the production of plant based materials for food and other uses, such as pharmaceuticals and chemical feedstock. They are suitable for the areas that are not conducive to conventional food production and in location impacted by disasters.

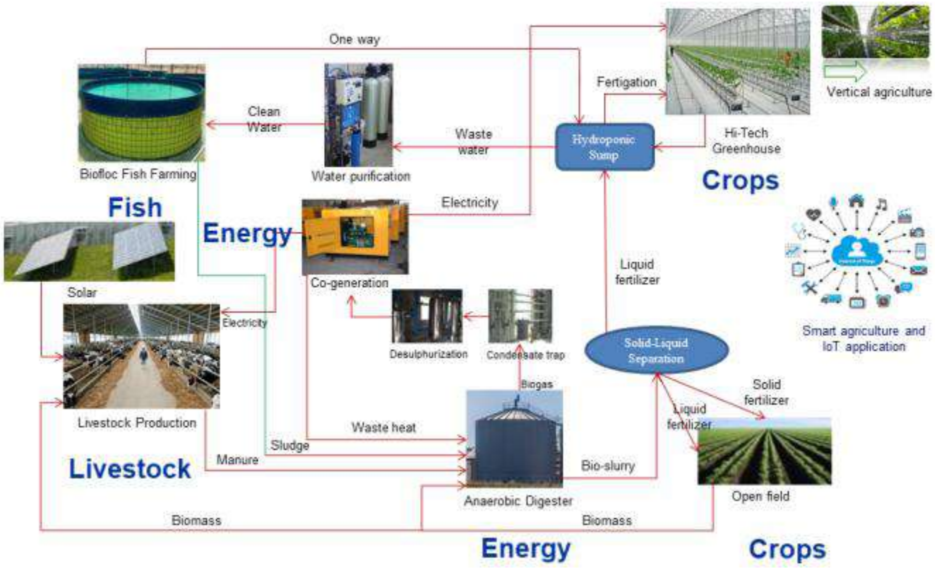

Figure 1: Circular Production System with solar-biogas-internet of think (IoT) nexus

As stated earlier, reduction of post-harvest loss is one of the zero hunger challenges in achieving SDG no 2. For reducing post-harvest loss of cereals, vegetables and fruits, adaption of appropriate post-harvest management and processing technologies are necessary to add large amount food in the food baskets. As for example, appropriate mechanized harvesting, drying and storage solutions at farmers and traders level can save 7.1 million ton of paddy per year. Despite huge production of fruits and vegetables in seasons, we could not ensure healthy and nutritious high value crop like fruits and vegetables year round due to lack of adequate appropriate storage facilities. Only ensuring cold storage for potato, we can add 0.6 million ton more potato every year. There are also lack of cold storage and appropriate transportation facilities like cool vane for other fruits and vegetables. However, affordable low cost dry chain of fruits and vegetables are not developed yet in Bangladesh due to our food consumption habit & lack of appropriate drying, packaging & storage solutions as well as awareness. However, there is a potential export market of dried and processed fruits and vegetables. We need to take drastic initiative, make proper guideline and programs for reducing post-harvest losses, making available healthy food, and earn foreign revenue.

On the other hand, waste generated from crop, livestock and fishes as well as process crop residues and city wastes can be useful sources of bioenergy. Approximately 61 million ton of residues/wastes are being generated every year which can be utilized to produce biogas 10,000 million m^3 through anaerobic co-digestion (Saha, 2021). This produced biogas can be converted to renewable electricity which is about 19000 gWh per year. Even if we can utilize 50% of biogenic residues and wastes for renewable energy production, this will help to fulfill to some extent the government goal of 20% electricity from renewable resources by 2030 which is linked to SDG 7-affordable clean energy. Bio-slurry that comes out from biogas plants after digestion can be a good source of bio-fertilizer or soil conditioners for improving soil health and crop yield. At the same time, one of our calculation shown that biogas production through anaerobic co-digestion can reduce global warming potential or greenhouse gas emission from agriculture by 93% in comparison to open land filling.

Therefore, climate smart agriculture is necessary for achieving circular Bioeconomy System as there are linked to resource efficiency with the increase of production, adaptation of new techniques and reduction of green house gas emission by recycling and reusing biomass and wastes.

Conclusion

Adaption of circular food systems with precision mechanized agriculture (crop, fish and livestock) would be future agriculture for ensuring food and nutrition security of Bangladesh as well as achieving sustainable development goals. Introducing appropriate smart technologies along the food supply chain can significantly reduce the food loss and wastes. Million tons of available biogenic residues/wastes can be used for producing affordable clean energy through co-digestion for achieving SDG and at the same time reducing greenhouse gas emission while adapting concept of CSA or circular food system in Bangladesh. Priority interventions are needed to make the agricultural production and processing systems optimal and efficient, especially in the areas of smart farming, precision agriculture (machine vision, drone, nano-technologies etc.), controlled environment agriculture, dry and cold chain, renewable biogas and solar nexus smart micro-grid etc. A climate-smart agriculture approach often requires institutional capacity-building and development of institutional coordination mechanisms, which can enhance the efficiency, accountability and transparency of governance. However, research, investment & advance technology sharing for agricultural development through national and global partnerships are necessary for ensuring resilience food systems in Bangladesh.

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IoT, Big Data, AI and Cloud Computing in Climate Smart Agriculture (CSA)

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Introduction:

Smart agriculture (SA) proves to be a transformative paradigm in modern farming practices, using cutting-edge technologies to increase efficiency, productivity, and sustainability. At its core, SA integrates a diverse array of technological components, starting with the deployment of sensors and Internet of Things (IoT) devices. SA operates on key principles such as optimization of resources, precision and accuracy in farming practices, data-driven decision-making, sustainability, and integration with market access platforms. The key application areas of SA include crop growth, crop monitoring, livestock management, irrigation management, pest and disease control, supply chain optimization, farm management systems, etc.

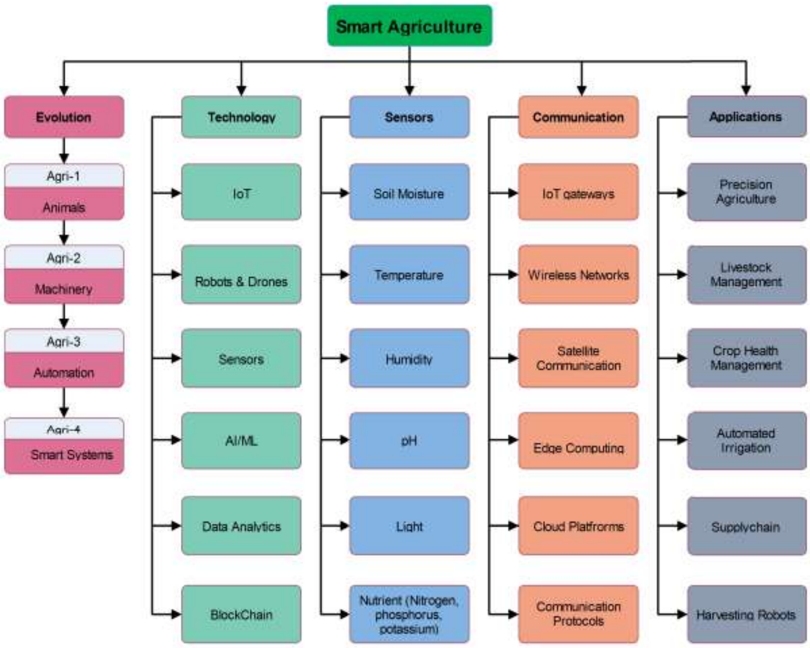

Figure 1: Overview of Smart Agriculture.

In the 1980s, the use of GPS technology laid the foundation for precision farming, enabling farmers to map and manage their fields with unprecedented accuracy. The rise of the IoT and sensor technologies ushered in an era of real-time data collection from fields, enabling farmers to observe soil conditions, crop health, and weather patterns more comprehensively. The widespread application of artificial intelligence (AI) and machine learning in agriculture during the 2010s was a major advancement, where advanced analytics empowered farmers to make decisions based on data, optimizing resources and increasing productiveness. Drones and robotics gained prominence, automating various farming tasks and further enhancing precision. Thus the evolution of traditional farming into a technology-driven approach represents a profound shift in agricultural practices, enhancing efficiency, sustainability, and productivity. SA is continually evolving, integrating advanced technologies to optimize farming processes.

The emerging trends collectively aim to revolutionize farming methods to make them more effective, sustainable, and capable of meeting the increasing global food demand while minimizing the environmental impact (See Figure 1).

Smart Agriculture uses internet of things (IoT) solutions together with Big Data, Cloud Computing and AI methods to provide for more efficient management of resources that includes the management of crop yields, seeding, fertilizer use and water. The benefits of precision agriculture (PA) include increased profitability and reduced environmental impact.

In the early years, PA consisted mainly of map-based technologies using geo-statistical methods like GIS and satellite remote sensing and the main application of PA was to manage fertilizer use. Sensor use was not widespread since sensors were either too costly, too inaccurate or unavailable for the applications required. Surveys during the early 2000's showed that few farmers used PA technologies and the main barriers to the adoption of these methods were the lack of technologies to deal with the large amounts of information, the lack of scientific validation, high costs and no training or technology transfer. However, this has changed with the development and testing of prototype PA systems, the rapid development of IoT and Big Data, and the decreased cost of sensors.

Climate Smart Agriculture (CSA) is an integrated approach to manage the crops, livestock, forests, and fisheries to address the interlinked challenges of food security and climate change. The integration of **IoT**, **Big Data**, **AI (Artificial Intelligence)**, and **Cloud Computing** plays a pivotal role in enabling CSA by enhancing productivity, resilience, and sustainability.

Major Components and Relevant Technologies:

A. Major Components:

IoT based smart agriculture consist of four major components, namely (1) **physical structure**, (2) data acquisition, (3) data processing, and (4) data analytics.

(1) The physical structure - is the most important factor for precision agriculture to avoid any unwanted happening. Whole system is designed in such a way which controls the sensors, actuators, and devices. A sensor performs multiple tasks like soil sensing, temperature sensing, weather sensing, light sensing, and moisture sensing. Similarly devices perform many control functions like, node discovery, device identification and naming services etc. All these functions are performed by any device or sensor which is controlled through a microcontroller. This controlling operation is performed by any remote device or a computer which is connected through the Internet.

(2) Data Acquisition - is further divided into two sub components namely: (1) IoT data acquisition and (2) standard data acquisition. The IoT data acquisition component consists of 07 protocols that are (1) Message Queuing Telemetry Transport (MQTT), (2) Websocket, (3) Advanced Message Queuing Protocol (AMQP), (4) Node, (5) Constrained Application Protocol (CoAP), (6) Data Distribution Service (DDS), and (7) Hyper Text Transfer Protocol (HTTP). Depending on the requirements and condition more protocols can be used for the implementation of smart agriculture. Whereas, in the standard **data acquisition** - ZigBee, WIFI, Long Range Wide Area Network (LoraWan), SigFox and ISOBUS protocols have been used.

(3) Data processing - consists of multiple features that are image or video processing, data loading, decision support system, and data mining. According to the system requirements any feature may be added that may work in parallel to provide other services.

(4) Data analytics consists of two main features that are: (1) monitoring and (2) controlling. Monitoring involves 03 main application in smart agriculture that are: (1) Live Stock Monitoring, (2) Field Monitoring, and (3) Green house Monitoring. IoT enables farmers to monitor livestock via multiple sensors which are used to monitor different animal's diseases like temperature, heart rate, digestion, etc. Whereas, field monitoring applications intend to report different conditions of field like soil richness, temperature, humidity, gas, pressure (air pressure and water pressure), and crop disease monitoring.

B. Relevant Technologies

A Large number of technologies are being used in CSA solutions. However, here our discussion focus on several core technologies which have played a vital role to modernize the CSA. They are: (1) IoT, (2) Big Data, (3) AI, and (4) Cloud Computing. Below we describe them briefly.

(1) IoT in CSA IoT involves interconnected devices and sensors that collect real-time data from the environment, crops, livestock, and machinery.

In CSA, IoT enables:

- **Precision Agriculture**
  - Sensors monitor soil moisture, temperature, humidity, and nutrient levels, allowing farmers to optimize irrigation and fertilization.
- **Livestock Monitoring**
  - Wearable IoT devices track animal health, behavior, and location, improving livestock management.
- **Weather Monitoring**
  - IoT-based weather stations provide hyper-local climate data, helping farmers make informed decisions.
- **Automation**
  - IoT-enabled machinery (e.g., drones, tractors) automates tasks like planting, spraying, and harvesting, reducing labor and resource use.

(2) Big Data in CSA Big Data refers to the massive volumes of structured and unstructured data generated by IoT devices, satellites, and other sources. In CSA, Big Data helps:

- **Data-Driven Decisions**
  - Farmers can analyze historical and real-time data to predict crop yields, pest outbreaks, and weather patterns.
- **Resource Optimization**
  - By analyzing data on water usage, soil health, and crop performance, farmers can reduce waste and improve efficiency.
- **Supply Chain Management**
  - Big Data enables better tracking of produce from farm to market, reducing food loss and improving traceability.

(3) AI in CSA AI and ML are at the forefront of revolutionizing SA, providing farmers with powerful tools to optimize decision-making processes and enhance overall productivity. AI and ML algorithms leverage the large amounts of data gathered by drones, sensors, and other IoT devices in SA systems. In precision farming, AI systems use both historical and current data to forecast agricultural production, optimize irrigation schedules, and identify potential pest or disease outbreaks. Machine learning algorithms can recognize patterns in crop images, helping farmers assess plant health and identify stress factors.

AI leverages machine learning, computer vision, and predictive analytics to process and interpret data. In CSA, AI contributes by:

- **Predictive Analytics**: AI models predict crop yields, disease outbreaks, and climate impacts, enabling proactive decision-making.
- **Pest and Disease Detection**: AI-powered image recognition identifies pests and diseases early, allowing for targeted interventions.
- **Crop and Soil Analysis**: AI algorithms analyze soil health and recommend optimal crops and practices for specific conditions.
- **Autonomous Farming**: AI-driven robots and drones perform tasks like weeding, planting, and harvesting with precision.

(4) Cloud Computing in CSA Cloud Computing provides the infrastructure to store, process, and share data from IoT devices and AI models. In CSA, Cloud Computing enables:

- **Scalable Data Storage**: Farmers and organizations can store vast amounts of agricultural data without on-site infrastructure.
- **Real-Time Collaboration**: Cloud platforms allow stakeholders (farmers, researchers, policymakers) to share data and insights in real time.
- **Accessibility**: Farmers in remote areas can access AI-powered tools and insights via cloud-based applications.
- **Cost Efficiency**: Cloud services reduce the need for expensive hardware and software, making advanced technologies more accessible.

Other Relevant Technologies:

(5) Communication Networks and Protocols IoT agricultural network consist of different kinds of long ranges and short ranges networks for communications. Several IoT networks technologies help to design a crop or field monitoring sensors and devices. Communication protocols are the backbone of IoT agricultural network system and applications. They are used to exchange all agricultural data or information over the network.

(6) Robotics Multiple Agribots have been developed for the purpose of smart agriculture which are minimizing the amount of farmers by increasing the speed of work through advance techniques. Agribots performs elementary functions like weeding, spraying and sowing etc. All these robots are controlled by using IoT to increase the crop productivity and efficient resource utilization.

IOT Agricultural Networks:

IoT network for agriculture is one of the vital elements of IoT in agriculture. It helps to monitor agriculture data and facilitate the transmission and reception of agriculture data.

A. IoT Agricultural Network Architecture The IoT agricultural network is the main factor of IoT in agriculture field. IoT Agricultural network architecture suggests an outline for the specification of an IoT agricultural network physical elements as well as their working principles, and techniques. Most of the IoT applications usually follow the four layer architecture: (1) Application layer, (2) Transport Layer (3) Network Layer, and (4) Physical and Mac Layer.

B. IoT Agricultural Network Platform IoT agricultural network platform refers to both (1) the big data analytics model and (2) cloud model.

C. IoT Agricultural Network Topology and Protocols IoT agricultural network topology shows the arrangement of multiple elements of an IoT Agricultural network and represents an ideal scenario for smart agriculture. They are: (1) Low Power WSN Topology and (2) IoT Protocols for Agriculture.

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