TRAINING OF TRAINERS (TOT)

CLIMATE SMART IRRIGATION AND WATER MANAGEMENT

TRAINING MANUAL 2025

Agricultural Engineering Unit
Natural Resources Management Division
Bangladesh Agricultural Research Council

Training of Trainers (ToT)

CLIMATE SMART IRRIGATION AND WATER MANAGEMENT

TRAINING MANUAL 2025

Compiled and Edited by

Dr. AFM Tariqul Islam
Principal Scientific Officer (Agricultural Engineering)

Dr. Md. Ashraful Alam
Principal Scientific Officer (Agricultural Engineering)

&

Dr. Md. Baktear Hossain
Member Director (NRM)

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

May 2025

Published on: May 2025

No. of Copies: 30

Publication No. 27

Published by
Agricultural Engineering Unit
Bangladesh Agricultural Research Council (BARC)
Farmgate, Dhaka-1215

Funded by
PARTNER, APCU-BARC

Compiled and Edited by
Dr. AFM Tariqul Islam, Principal Scientific Officer (Agril. Engg.)
Dr. Md. Ashraful Alam, Principal Scientific Officer (Agril. Engg.)
Dr. Md. Baktear Hossain, Member Director (NRM)

Design
Dr. AFM Tariqul Islam, Principal Scientific Officer (Agril. Engg.)
Dr. Md. Ashraful Alam, Principal Scientific Officer (Agril. Engg.)

Printed at
Mojumdar Computers, 412, Gausul Azam Super Market, Nilkhet, New Market, Dhaka-1205.

Citation
Islam AFMT, Alam MA, and Hossain MB (2025). Training of Trainers (ToT) on Climate-Smart Irrigation and Water Management Training Manual 2025. Agricultural Engineering Unit, Natural Resources Management Division, Bangladesh Agricultural Research Council, Farmgate, Dhaka. pp.125.

FOREWARD

In Bangladesh, where agriculture forms the backbone of the economy and sustains the livelihoods of millions, the effective and efficient management of water resources is critical. In the face of climate change and its far-reaching impacts on water availability and crop productivity, the need for climate-smart and water-efficient irrigation practices has never been more urgent.

This manual, titled *"Training of Trainers on Climate Smart Irrigation and Water Management,"* has been developed as a comprehensive guide to build capacity among trainers who will, in turn, empower farmers, extension workers, and local stakeholders. The goal is to promote sustainable irrigation practices that optimize water use while building resilience against climate-related challenges.

Combining cutting-edge research, field-proven techniques, and real-world case studies, this manual offers practical and contextual guidance on water-saving technologies, climate-resilient crop choices, irrigation scheduling, and adaptive strategies tailored to the diverse agro-climatic zones of Bangladesh. Designed with clarity and usability in mind, it includes step-by-step instructions, illustrative visuals, and actionable tools to support learning and application in the field.

A distinctive feature of this manual is its holistic approach—merging traditional knowledge with scientific innovation, community engagement, and supportive policy frameworks. By focusing on training the trainers, this manual aims to create a ripple effect of knowledge dissemination, collaboration, and continuous improvement across the agricultural sector.

We express our heartfelt appreciation to the experts, practitioners, and policymakers who contributed to the development of this manual. Special thanks are due to the dedicated resource speakers who meticulously prepared lecture notes for each topic, and to the scientists and staffs of the Agricultural Engineering Unit for their unwavering commitment to both the preparation of this manual and the organization of this vital training course.

It is our hope that this manual not only serves as a valuable resource but also inspires proactive efforts toward a more water-efficient, climate-smart agricultural future in Bangladesh.

Dr. Md. Baktear Hossain
Member Director (NRM)
Bangladesh Agricultural Research Council
Farmgate, Dhaka-1215

CONTENTS

Hydrologic Cycle and Water Balance in Irrigated Agriculture

Dr. M. G. Mostofa Amin
Professor, Department of IWM
Bangladesh Agricultural University, Mymensingh 2202

1. Introduction

The hydrological cycle, commonly known as the "water cycle," is Earth's natural water recycling system. Driven by solar radiation, water evaporates primarily from the sea and lakes, and it also evaporates from plant leaves through a process called transpiration. As this vapor rises into the atmosphere, it cools and condenses, eventually returning to the surface as precipitation. Precipitation falls as surface water, shaping the landscape and creating streams, lakes, and rivers. Some of this precipitation seeps into the ground, moving downward through soil and rock formations to form aquifers. Eventually, a portion of both surface and groundwater makes its way back to the sea. The hydrological cycle is crucial for transporting and cycling nutrients and energy. Understanding the various components of this cycle—known as constructing a water budget for a specific area—is essential for effective and equitable water management. Human activities have altered the hydrological cycle by impacting various components of the water budget and the flow of water within the system (Inglezakis et al., 2016).

A water budget is a basic tool that can be used to evaluate the occurrence and movement of water through the natural environment. Water budgets provide a foundation for evaluating its use in relationship to other important influencing conditions such as ecological systems and features and social and economic components. It is a process that can encompass various levels of assessment, which start simple and grow more complex if there are concerns about how much water is available at any level. The higher the 'tier', or level, the more complex the science involved and the narrower the geographic focus. Water budget studies consider the volumes of water within the various reservoirs of the hydrologic cycle and the flow paths from recharge to discharge. It needs to consider this information on a variety of spatial and temporal scales (Kumara, 2020).

Global warming can alter the hydrological cycle in various forms such as increased cloudiness and latent heat fluxes, leading to more intensive and frequent precipitation extreme events (e.g., droughts, storms, and floods). These extreme events have received increased attention in the past few decades because of the associated economic loss, deaths, and many other severe consequences for human society. Climate change can also cause significant shifts in the spatial and temporal patterns of precipitation, bringing many unprecedented challenges for water resource management at regional and local scales. In addition to these common hydrological challenges, coastal communities are further threatened by rising sea levels and increasing storm surge and erosion. Adapting to these challenges requires a thorough understanding of the potential impacts of climate change from a long-term and systematic perspective.

As the world is facing unprecedented climate uncertainties, a more rigorous understanding of the impacts of climate change is gaining higher significance. A growing body of knowledge is centered on the multidimensional perspectives of the impacts of climate change on the hydrological cycle, water-related hazards, and agricultural water management at various scales for understanding the short- and long-term consequences in different parts of the world.

2. Hydrologic cycle at global scale

Hydrological cycle is the normal water recycling system on Earth (Fig. 1). Due to solar radiation, water evaporates, generally from the sea, lakes, etc. Water also evaporates from plant leaves through the mechanism of transpiration. As the steam rises in the atmosphere, it is being cooled, condensed, and returned to the land and the sea as precipitation. Precipitation falls on the earth as surface water and shapes the surface, creating thus streams of water that result in lakes and rivers. A part of the water precipitating penetrates the ground and moves downward through the incisions, forming aquifers. Finally, a part of the surface and underground water leads to sea. During this trip, water is converted in all phases: gas, liquid, and solid. As mentioned above, water always changes states between liquid, vapor, and ice, with these processes happening in the blink of an eye and over millions of years (Inglezakis et al., 2016).

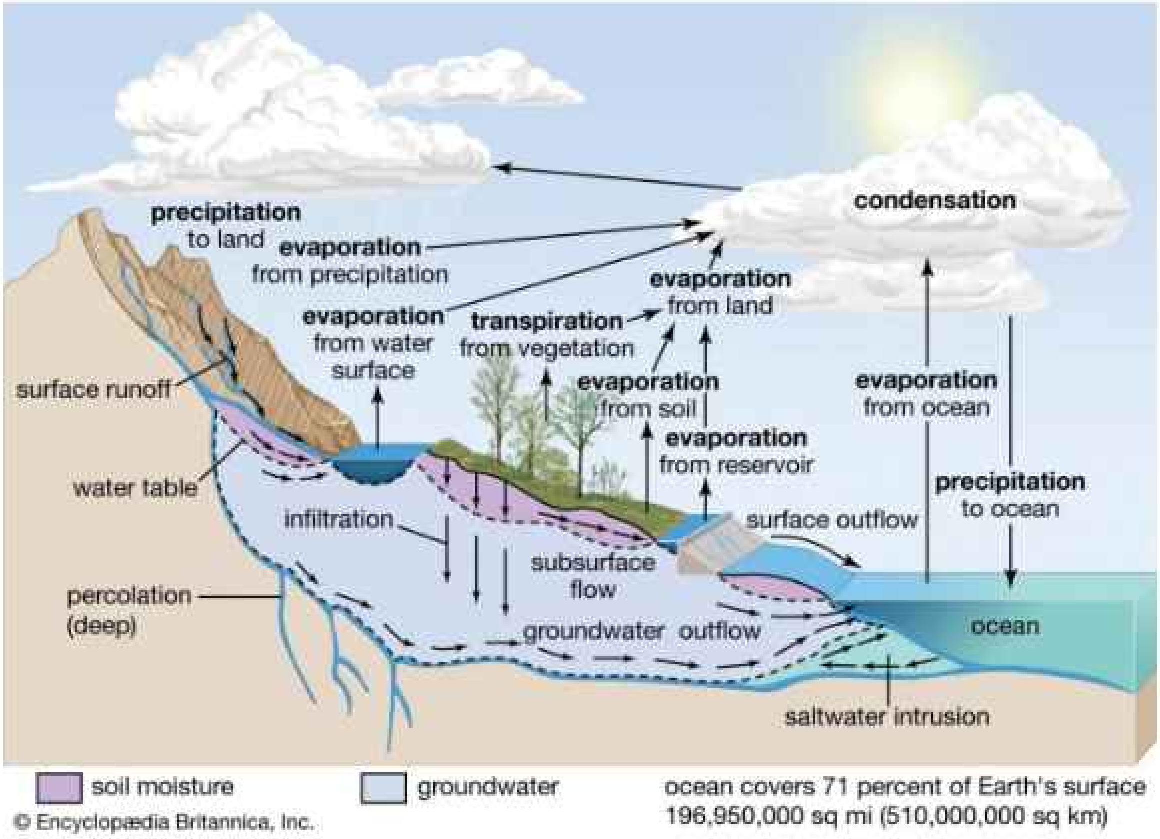


Fig. 1. Hydrologic cycle on earth

The hydrological cycle of the earth is the sum total of all processes in which water moves from the land and ocean surface to the atmosphere and back in form of precipitation (Fig. 2). The hydrological cycle is dependent on various factors and is equally affected by oceans and land surfaces. In the case of the land surface, vegetation plays a vital role in the maintenance of the hydrologic budget. The presence of vegetation increases the capacity of the land surface to retain moisture. Precipitation is then intercepted by plants and directly evaporated when captured by the canopy. The plants themselves transpire and aid in the creation of a major amount of water vapor through evapotranspiration processes. The surface runoff, in the case of bare ground, is much greater than in vegetated lands. As plants dominate the processes of energy, water vapor, and carbon exchange, their presence is critical to the functioning of the hydrological cycle (Chakravarty and Kumar, 2019).

3. Water balance at different scales

Water budgets are provided for two defined areas: the earth as a whole and the watershed of a small inland lake (Robertson et al., 2022). Given a specific area with well-defined boundaries, constructing a water budget consists of quantifying the amount and relationships among inflow, outflow, and change in storage within a defined area of the hydrological cycle, water budgets relevant to inland waters and aquatic ecosystems, and how the hydrological cycle and water budgets have been affected by anthropogenic modifications (Robertson et al., 2022).

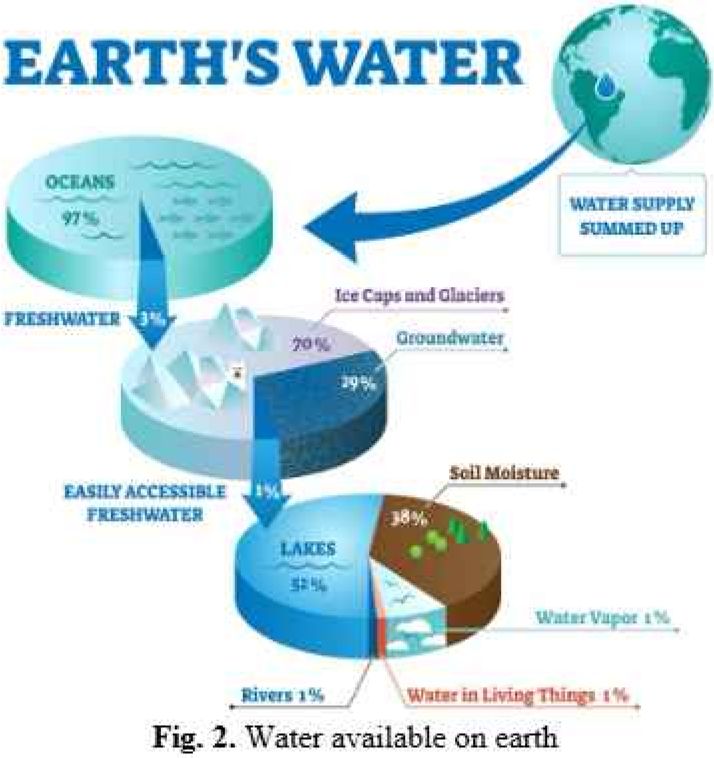


Fig. 2. Water available on earth

A water budget is very much like a financial budget, but instead of tracing how money flows in and out, it traces water (Fig. 2). A water budget accounts for all water into and out of a watershed (or sub-watershed). This includes precipitation, evaporation, transpiration, runoff, as well as the movement of water within the watershed, such as infiltration, recharge to groundwater, and reservoir storage (lakes, wetlands, aquifers).

The general equations to be satisfied for a water budget are:

Inputs = Outputs + Change in Storage

$$P + Swin + Gwin + ANTHin + Din = ET + SWout + GWout + ANTHout + Dout + \Delta S$$

where P = precipitation, SWin = surface water flow in, GWin = groundwater flow in, ANTHin = anthropogenic or human inputs, Din = diversion into the watershed, ET = evaporation and transpiration, SWout = surface water flow out, GWout = groundwater flow out, ANTHout = anthropogenic or human abstractions, Dout = diversion out of the watershed, ΔS = change in storage (Water Budgets, 2011).

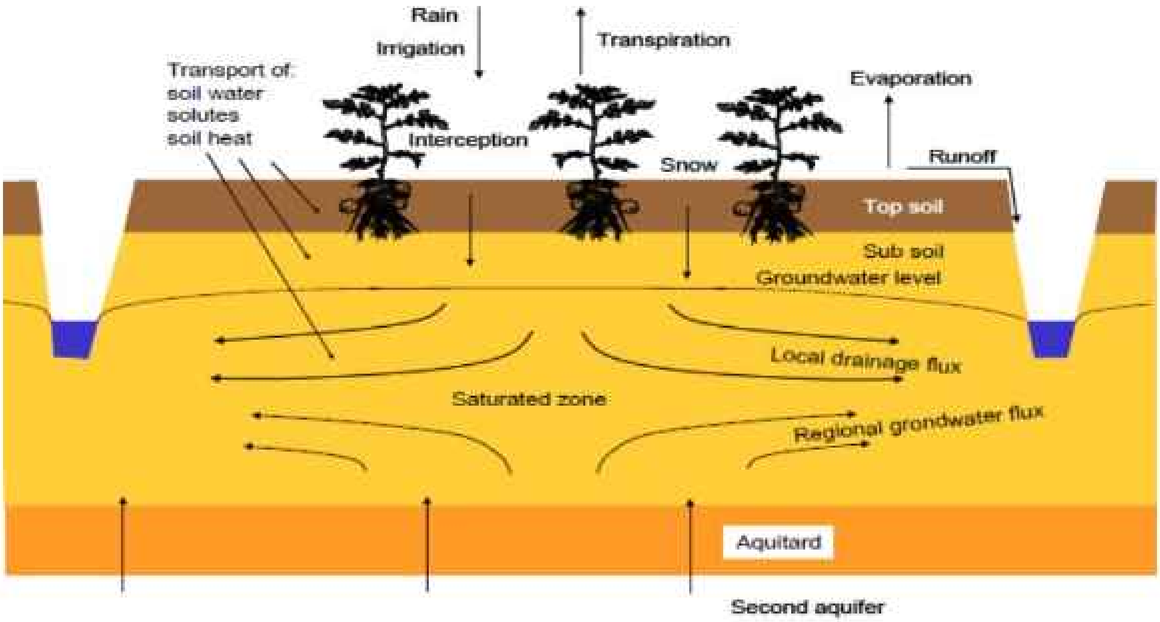


Fig. 3. Water balance components at watershed scale (SWAT Model Manual, 2012)

The general equations for a water budget at an irrigated field (Fig. 4) scale are:

Inputs = Outputs + Change in Storage

Rainfall + Irrigation + Capillary rise + Surface Run-on = ETc (Evaporation + Transpiration) + Surface Run-off + Capillary rise+ Percolation + Change in Soil Water Storage

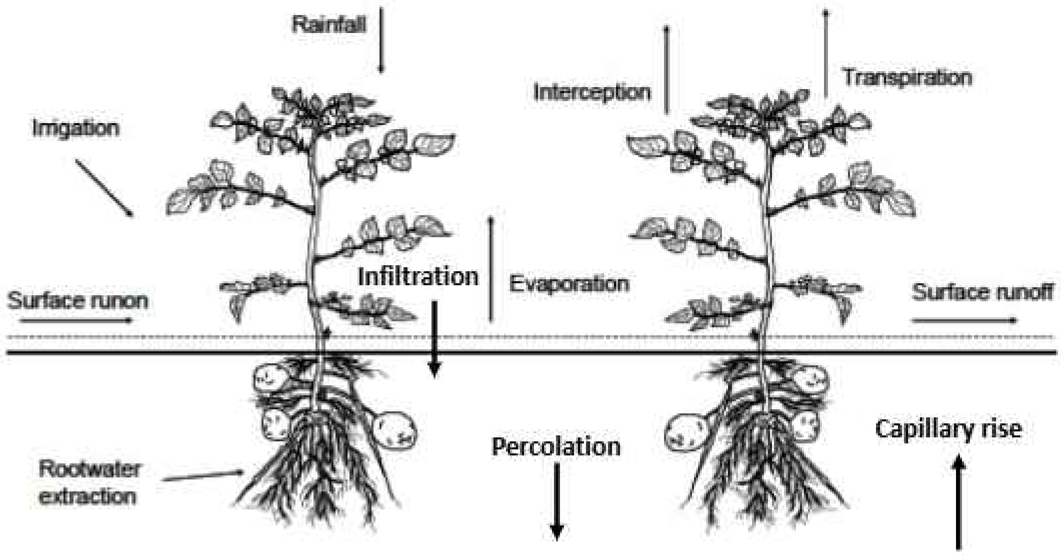


Fig. 4. Water balance components at field scale (SWAT Model Manual, 2012)

The general equations for a water budget at a column scale (Fig. 5) are:

Inputs = Outputs + Change in Storage

Rainfall + Irrigation = ETc (Evaporation + Transpiration) + Percolation + Change in Soil Water Storage

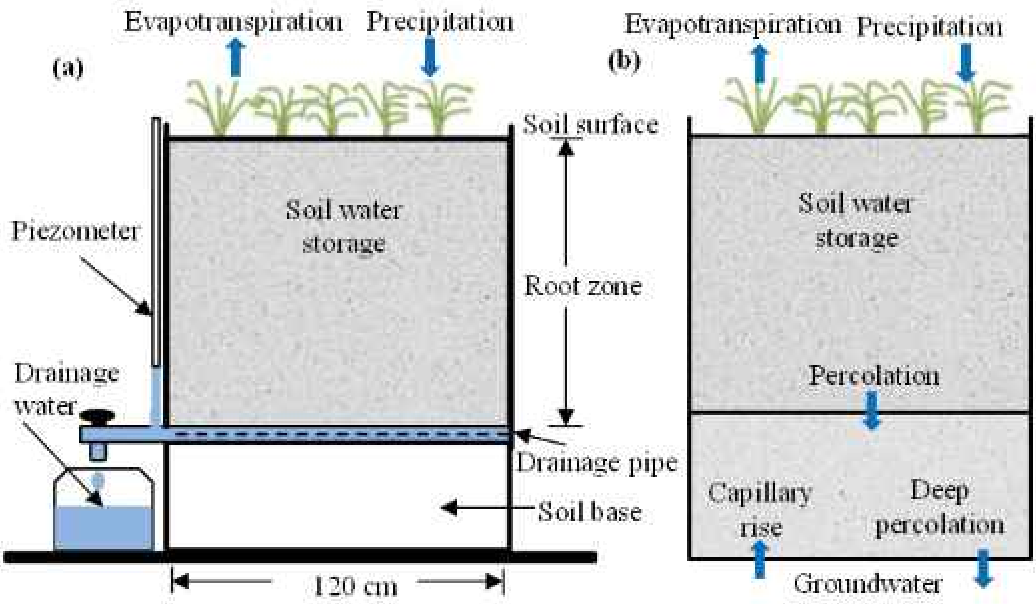


Fig. 5. Water balance components at column scale (Amin et al., 2023)

References

Amin MGM, Mahbub SMM, Hasan MM, Pervin W, Sharmin J, Hossain MD. 2023. Plant–water relations in subtropical maize fields under mulching and organic fertilization. Agricultural Water Management, 286:108394. https://doi.org/10.1016/j.agwat.2023.108394

Chakravarty P, Kumar M, 2019. Chapter 6 - Floral Species in Pollution Remediation and Augmentation of Micrometeorological Conditions and Microclimate: An Integrated Approach, Editor(s): Vimal Chandra Pandey, Kuldeep Bauddh, Phytomanagement of Polluted Sites, Elsevier, pp.203-219. https://doi.org/10.1016/B978-0-12-813912-7.00006-5.

Inglezakis V.J., S.G. Poulopoulos, E. Arkhangelsky, A.A. Zorpas, A.N. Menegaki, 2016. Chapter 3 - Aquatic Environment, Editor(s): Stavros G. Poulopoulos, Vassilis J. Inglezakis, Environment and Development, Elsevier, pp.137-212. https://doi.org/10.1016/B978-0-444-62733-9.00003-4.

Robertson D.M., Howard A. Perlman, T.N. Narisimhan, 2022. Hydrological Cycle and Water Budgets, Editor(s): Thomas Mehner, Klement Tockner, Encyclopedia of Inland Waters (Second Edition), Elsevier, pp.19-27, https://doi.org/10.1016/B978-0-12-819166-8.00008-6.

Water Budgets, 2011. Cataraqui Source Protection Area Amended Proposed Assessment Report 34 Chapter 3 – Water Budgets https://www.cleanwatercataraqui.ca/publications/updatedAssessmentReport/Chapter3a.pdf

Kumara S. 2020. Budgeting of Water in a Watershed http://courseware.cutm.ac.in/wp-content/uploads/2020/06/Budgeting-of-Water-in-a-Watershed.pdf

SWAT Model Manual. 2012. https://swat.tamu.edu/docs/

Integrated Assessment of Water Resources and Availability for Irrigated Agriculture: Tools, Techniques and Applications

Dr. M. G. Mostofa Amin
Professor, Department of IWM
Bangladesh Agricultural University, Mymensingh

1. Introduction

Prediction of water availability for irrigated agriculture through integrated assessment is critically important. 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. Freshwater scarcity is projected to be exacerbated in the future because of a significant increase in water demand, which will affect water security for food production and environmental sustainability. 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). 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 (2020) reported that 46% of global cultivable areas remained unsuitable for rainfed agriculture because of climate change and other meteorological issues. The projected temperature increase associated with climate change will imply higher evaporation and drier conditions. Consequently, water and food security nexus will become more complex to manage.

Like many other countries, Bangladesh struggles to maintain water security for food production. Increasing water demand and competition over freshwater resources are reported (Mahmud et al., 2021). Ensuring adequate water share for crop agriculture is a significant challenge because of the limited water availability and its high-water footprint. Rice is the main crop in the region, and it has a higher water footprint than any other crop of comparable value and growth duration. Rice is farmed during dry and wet seasons covering nearly 80% of the gross cropped area. The wet-season rice is primarily rainfed, but the dry-season rice is an irrigated crop and contributes almost 55% to the total rice production. High-water-consuming, high-yielding rice varieties have been predominantly cultivated. Over time, irrigation in Bangladesh has become increasingly dependent on groundwater due to the easy availability of low-cost equipment to tap shallow aquifers and the limited availability of surface water during the dry season because of 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. The condition is likely to be worse with a shortened monsoon season and less dry season rainfall under the changing climate, thereby 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 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 a key indicator for assessing the possible impacts of climate change on water availability and water use policy and helps develop a sustainable management plan.

2. Water use policy

According to the Water Act 2013, the use of water from any water stress area shall be made in accordance with the following order for the national interest as potable, in households, agriculture, aquaculture, and for balancing the ecosystem. The government may, on the recommendation made upon the results of necessary inquiry or scrutiny or survey, declare any area or any land connected with a water resource as a water stress area for a specified period. To keep the flow of water course normal, the authority may impose any restriction by issuing a protection order. No person or organization shall stop the natural flow of any watercourse or create obstacles to such flow or divert or attempt to divert the direction of any water course by constructing any structure, whether it is on the bank or not, of any water source, or by filling any water source or by extracting sand or mud from any water source.

For groundwater management, the government may fix the lowest safe yield level to regulate groundwater abstraction. Besides, in the Groundwater Management for Agricultural Purposes Act, 2018, some restrictions (licensing system) have been imposed on groundwater pumping to protect the surrounding environment. The National Agriculture Policy encourages programs for more surface water irrigation. Infrastructures will be built to capture surface water and increase the availability of irrigation water by using high-capacity power pumps.

The National Water Policy 1999 has included the following issues for agricultural water management: (a) Encourage and promote continued development of minor irrigation, where feasible, without affecting drinking water supplies, (b) Encourage future groundwater development for irrigation by both the public and the private sectors, subject to regulations that may be prescribed by Government from time to time, (c) Improve efficiency of resource utilization through conjunctive use of all forms of surface water and groundwater for irrigation and urban water supply, (d) Strengthen crop diversification programs for efficient water utilization, and (e) Strengthen appropriate monitoring organizations for tracking groundwater recharge, surface and groundwater use, and changes in surface and groundwater quality. Khaals, ponds, etc. will be re-excavated to augment water flow for expanding irrigation facilities.

3. Groundwater Assessment

3.1 Groundwater level trend analysis

Groundwater is the primary source of both drinking and irrigation water in Bangladesh, with approximately 80% of extracted groundwater allocated for irrigation (Qureshi et al., 2014). This water supports the cultivation of rice, the country's staple food, during two growing seasons. However, groundwater depletion can occur when pumping rates exceed natural recharge over prolonged periods and large areas, leading to a decline in the water table. This decline increases pumping costs and disrupts groundwater discharge to streams, springs, and wetlands, affecting related ecosystems. In addition to over-extraction for irrigation, climate change also contributes to groundwater depletion in some regions. The annual minimum groundwater level in the northwest region usually occurred during April–May and the maximum in September–October. In a case study, all the studied observation wells in Rajshahi region 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., 2018). Moreover, the declining maximum groundwater level indicates that there is not enough recharge potential to get the aquifer fully recharged. The findings also suggest that the problem of continual groundwater declination needs site-specific interventions.

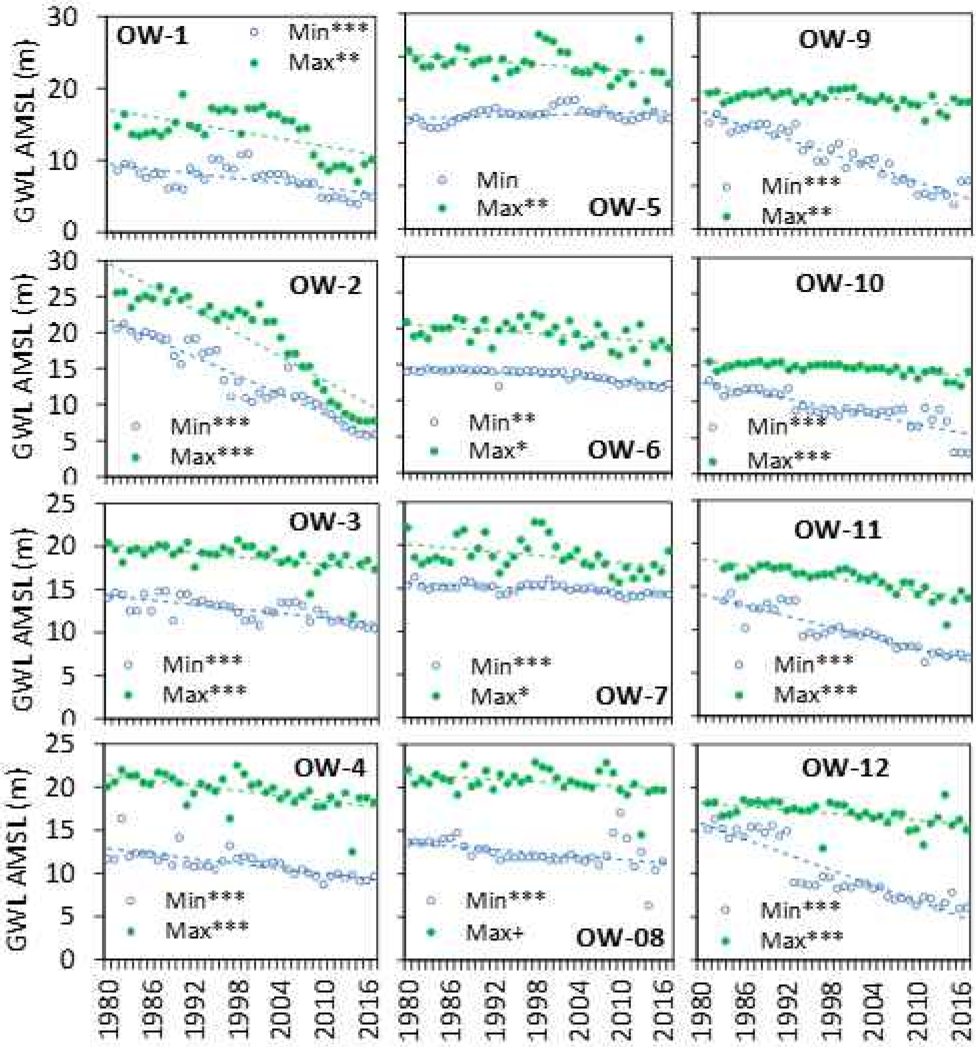


Fig. 1. Changing pattern of yearly maximum (solid circle) and minimum (open circle) groundwater level above mean sea level (GWL AMSL) over the period 1981–2017 at different observation wells (OW) located in Rajshahi Division (Different signs with the legends, i.e. + is for < 0.1, * for < 0.05, ** for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

3.2 Groundwater safe yield

Todd (1959) defined "safe yield" as the maximum volume of water that can be extracted from an underground reservoir without compromising the future supply. He argued that unless extraction is limited to safe yield levels, permanent depletion or damage to groundwater resources is likely to occur. The procedure for estimating the sustained yield of an aquifer can be summarized in the following six steps by Mandel (1973):

a) Determine average annual replenishment.
b) Identify the most stringent constraint, i.e., the first unacceptable effect that will occur when water levels are lowered.
c) Find the quantitative relation between water level elevations and the occurrence of this unacceptable effect. In many cases it is possible to confine attention to certain key locations that are especially sensitive to water level changes.
d) Define minimal water levels for the whole aquifer or for the above-mentioned key positions.
e) Compute the rate of natural outflow that will occur when a quasi-steady state of flow commensurate with minimal water levels is established.
f) The sustained yield is the difference between (a) and (b)

The safe yield can be calculated through the static method as follows (Δh = diffeerence in groundwater level and Sy = specific yield of the aquifer):

$$\text{Safe yield } (m^3/\text{ year}) = \Delta h \text{ (m)} * \text{Area } (m^2) * Sy$$

4. Surface water assessment

4.1 River flow trends

The river flow trend is the first step in understanding whether the river flow is decreasing or increasing over the years. The methodology and results of a case study are described here. Daily river stage data of major river sections from 1998 to 2017 were collected from BWDB. The daily data was processed to identify any missing values and errors. The annual maximum and minimum river stage values were identified from the daily data and the trend analysis of the identified data was performed. A long-term trend analysis tool called the MAKESENS model was used for this study (Salmi et al., 2002). The MAKSENS performs two types of statistical analysis. First, it detects the presence of any monotonic increasing or decreasing trend with the nonparametric Mann-Kendall test and then estimates the slope of a linear trend with the nonparametric Sen's method (Mahmud et al., 2021). The annual fluctuations of river stages ranged 3–10 m (Fig. 2).

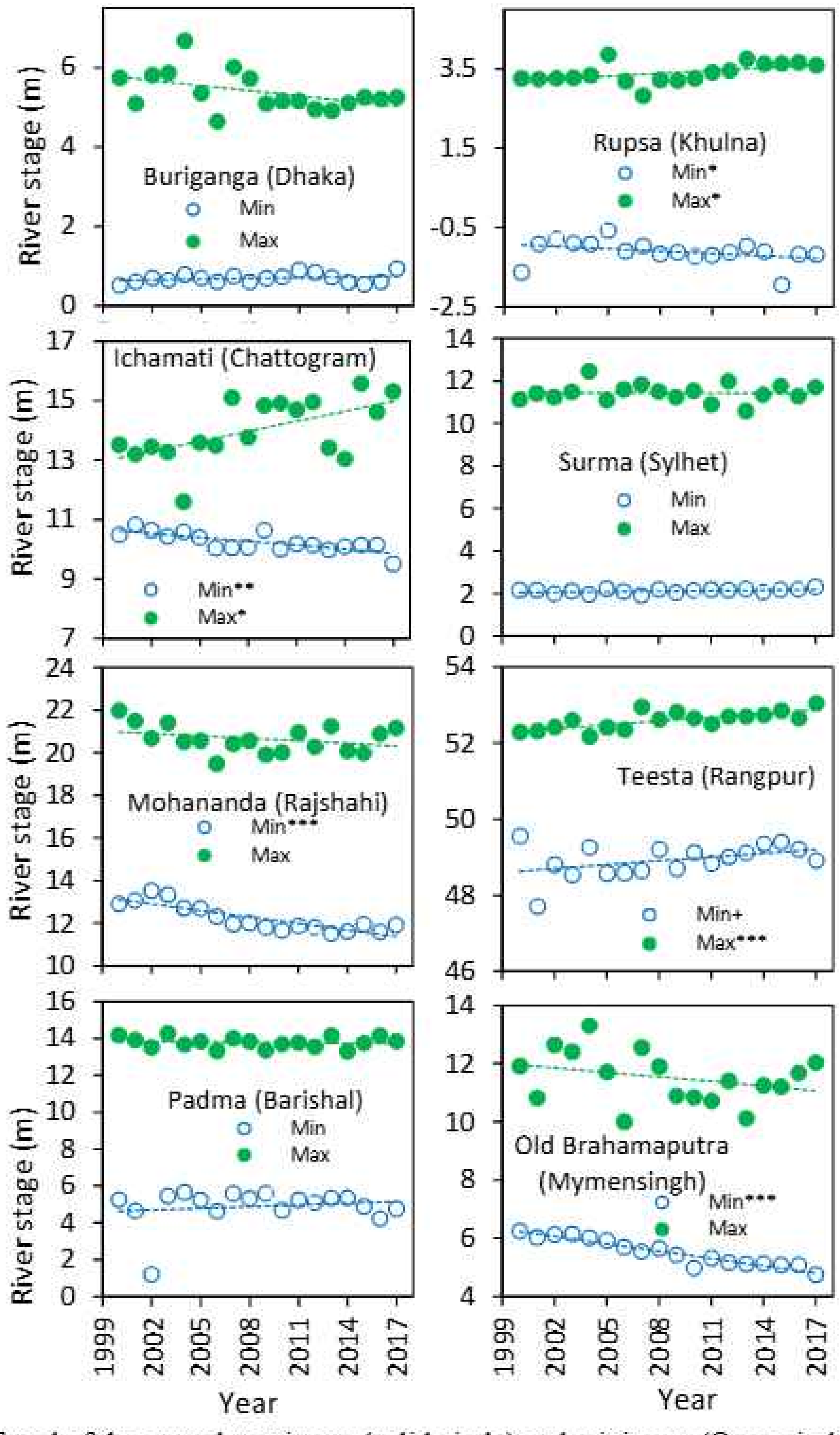


Fig. 2. Trend of the annual maximum (solid circle) and minimum (Open circle) river stage above mean sea level of eight rivers representing eight divisions in Bangladesh (Different signs with the legends, i.e. + is for < 0.1, * for < 0.05, ** for < 0.01 and *** for < 0.001 level of significance, indicate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

4.2 Environmental River flow assessment

Environmental flow determination is a complex process. Knowledge in hydrology, ecology, and other related disciplines can provide valuable insights and help refine the analysis. To calculate the minimum river flow required for environmental and ecological sustainability, several factors and methods can be considered. However, a generalized step-by-step guide is: (i) collecting historical data (20–30 years) of river discharge or stage and the data need to be in consistent units and are organized chronologically; (ii) determining ecologically significant flow thresholds through research to understand what flow rates are significant for the river's ecosystem (For instance, certain flow rates might be critical for fish migration, wetland inundation, or maintaining riverbank vegetation); and (iii) statistical analysis. A case study indicates that most of the rivers could not maintain the same environmental flow thresholds during most of the time of the years in the last decades (an example in Fig. 3). The small rivers are relatively more affected than the large ones because of the weak connectivity with their sources and a higher percentage of water extraction.

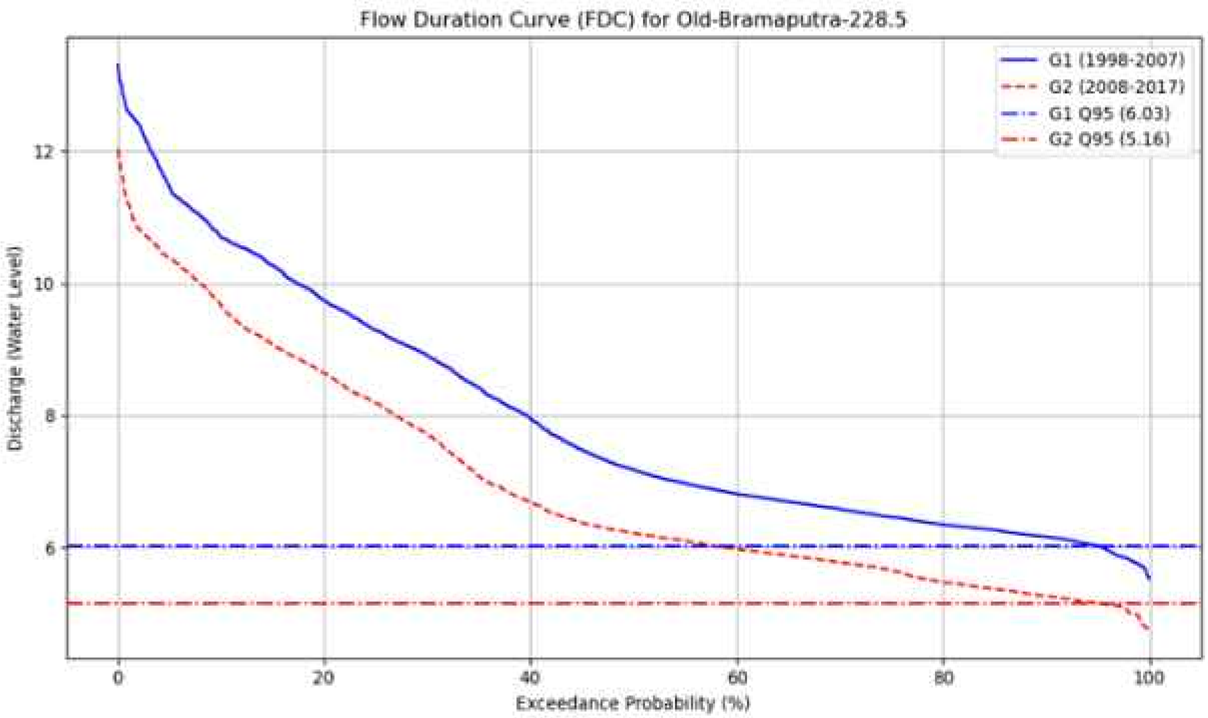


Fig. 3. Changes in exceedance probabilities of the river water level between 1998–2007 and 2008–2017 (The two Q95 lines indicate the environmental river water levels of the two decades).

4.3 Temporal variation in river flow trend

The mean monthly water level during 2008–2017 was considerably lower than that during 1998–2007. The decreasing rate was similar for all the months (Fig. 4), which indicates that the water extraction for irrigation is not the only reason.

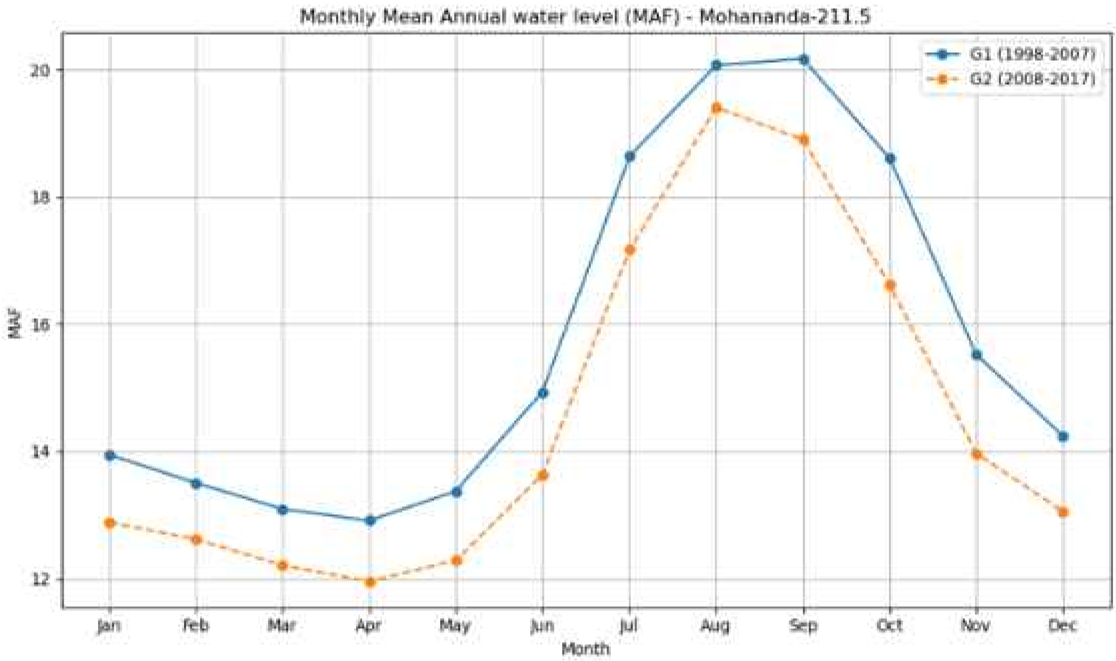


Fig. 4. The mean monthly water level during 2008–2017 and 1998–2007 for the Mahananda River.

5. Integrated assessment of water resources

5.1 Surface water and groundwater interactions

As groundwater and surface water are interconnected in the hydrologic cycle, their interactions need to be assessed critically.

5.2 Statistical analysis for dependable water availability

To calculate how much water is available from a surface water or groundwater source for a certain exceedance probability, the statistical methods for hydrology can be used.

5.3 Model prediction

Different numerical models are often used for integrated assessment of water resources and availability for irrigated agriculture. The watershed scale model, such as SWAT and MODFLOW, can predict the availability of surface water and groundwater under different climate and management scenarios. On the other hand, models like DSSAT, Aquacrop, HYDRUS and APSIM can robustly estimate crop water demand, water productivity, yield, etc. under different climate and management scenarios.

References

Mahmud K, Amin MGM, Ahmed U, Chowdhury AI, Hasan MM, Rahman MN, Khan MH. 2021. Status and sustainability challenges of agricultural water usage in Bangladesh. Agric. Eng. Int. CIGR J. 23(3):84–100.

Valipour M, SM Bateni, MAG Sefidkouhi, M Raeini-Sarjaz, VP Singh. 2020. Complexity of forces driving trend of reference evapotranspiration and signals of climate change. Atmosphere, 11(10): 1081.

Shamsudduha M. 2018. Impacts of human development and climate change on groundwater resources in Bangladesh. In Groundwater of South Asia, ed. A. Mukherjee, ch. 31, 523-544. Singapore: Springer.

Salmi T, A Määttä, P Antilla, T Ruoho-Airola, T Amnell. 2002. Detecting trends of annual values of atmospheric pollutants by the Mann-Kendall test and Sen's slope estimates–the Excel template application MAKESENS. Helsinki, Finland: Finnish Met. Institute.

Ercin AE, AY Hoekstra. 2016. European water footprint scenarios for 2050. Water, 8(6): 226.

Qureshi AS, Ahmed Z, Krupnik TJ. 2014. Groundwater management in Bangladesh: An analysis of problems and opportunities. Cereal Systems Initi. for South Asia Mecha. & Irrigation (CSISA-MI) Project, Research Report No. 2., Dhaka, Bangladesh: CIMMYT.

Todd DK. 1959. Groundwater hydrology. John Wily & Sons, Inc., New York.

Mandel S. 1973. Hydrology of Arid Zones. In: Yaron, B., Danfors, E., Vaadia, Y. (eds) Arid Zone Irrigation. Ecological Studies, vol 5. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-65570-8_4

Fundamentals of Irrigation and On-Farm Water Management: Concepts and Components

Dr. Md. Hossain Ali
Director (Research)
Bangladesh Institute of Nuclear Agriculture (BINA)

1. Introduction

Mankind can not produce their own food, but depends on the plant community for their food and fibre directly and indirectly. Plants can produce their own food by using the natural resources like soil, water, air and sunlight. They can also produce more than they need for their survival and reproduction. Plants can not survive and produce their food without water. One of the main factors for the intensification of the agricultural production of plants is the irrigation (artificial application of water to the plants root zone). In order to get the optimal benefits from irrigation, it is necessary to calculate the required quantity of water in dependence of some parameters, for example of the environment, the subsurface geo-hydrological condition, type of crop and of the stage of the growth.

Irrigation practice has been started from ancient time, with different modes and types. But with rapid increase in population and industrialization, the demands on available water resource have increased both in the quantity of water required and quality standard. Increased demands currently being placed on water supply have necessitated for broader concepts in the application of engineering principles than those originally envisioned. In recent time, some of the fundamental aspects are how to obtain knowledge of specific process within a complex system of interacting and interdependent phenomena, and then how to reintegrate such knowledge so as to obtain a comprehensive and accurate solution of the phenomena.

2. Availability of water – time varying phenomena

Water covers about 70% of the earth's surface, but it is difficult to comprehend the total amount of water when we only see a small portion of it. The oceans contain about 97.5% of the earth's water, land 2.4%, and the atmosphere holds less than 0.001%. We get water from the sources of surface water, groundwater and rainwater. Surface sources include natural depressions, lakes, ponds, rivers, reservoirs, etc. Volume of fresh water on the earth is about 0.25 % of the earth's total water. About 0.3 % of the fresh water is held in surface storage, the remainder is stored as glaciers, snow and underground aquifers. Among all fresh water, groundwater holds about 30 %.

Variability of water with time and space

The existence and quantity of water on the earth surface varies with time and space. The global water cycle encompasses the distribution and movement of water in its three phases (solid, liquid, vapour) throughout the earth system. These include precipitation, surface storage, groundwater, surface and subsurface runoff, oceans, cloud, atmospheric water vapour, soil moisture, etc. The yearly precipitation amount varies greatly from place to place (spatial variability) and its distribution throughout the year (temporal variability) is also highly erratic and variable. The spatial and temporal variability of water on the earth makes the water as critical resource.

3. Concept of irrigation and irrigation scheduling

3.1 General concept of irrigation

Plants need water for its proper growth and development. The demand for water by the crop must be met by the water in the soil, via the root system. Application of water to meet the crop water demand at proper time in proper way is termed as irrigation. If the crop water demand is meet by other ways (such as rainfall, capillary rise from groundwater table, etc.), there is no need of irrigation. Irrigation water requirement for cereals and non-cereals are not same. Among cereals, irrigation water requirement of rice is the highest. On the contrary, irrigation requirement of wheat is less compared to rice. Proper irrigation scheduling also affects the irrigation requirement of different crops.

3.2 Irrigation scheduling

The problem of irrigation scheduling consists of: (i) when to irrigate, (ii) how much to irrigate, and (iii) how to apply irrigation water. The amount of irrigation is obtained through field measurement or predicted through indirect method. The amount of irrigation is defined as the depth of water needed to meet the crop water loss through evapotranspiration under the growing environment. Although both timing and amount of water applied affect irrigation water productivity, timing has the greatest effect on crop yield and quality because at some growth stages, excessive soil moisture stress caused by delayed irrigation can irreversibly reduce the potential yield or quality or both. Different approaches used for irrigation scheduling are soil moisture basis, pan evaporation, leaf water potential, and growth stage basis. In all approaches, the water demand can be met by full or partial.

3.2.1 Full irrigation

Under adequate water supply (i.e. full irrigation), the crop water requirement is fully met. Crop water consumption (ET_a) in this case is equal to the maximum evapotranspiration (ET_m), i.e. $ET_a = ET_m$. No water stress develop under such condition, and crop yield (Y_a) is expected to be potential yield (Y_m), i.e. $Y_a = Y_m$ (if other production factors are not limiting).

3.2.2 Deficit irrigation

Under limited water supply (i.e. water stress or water deficit), the level of soil water status within the plant root zone is less than what would be under full irrigation. Crop water consumption in this case (ET_a) fall below maximum evapotranspiration (ET_m), i.e. $ET_a < ET_m$. Under such condition, water stress will develop in the plant which adversely affect crop growth, and therefore the expected yield (i.e. actual yield, Y_a) will be less than potential yield, i.e. $Y_a < Y_m$.

4 Objectives and goals of irrigation scheduling

The objectives of irrigation scheduling are to maximize yield, irrigation effectiveness/ efficiency, and crop quality by applying the exact amount of water needed by the crop (or to replenish the soil moisture to the desired level).

Proper irrigation scheduling minimizes:

- yield reduction
- wastage of water (deep percolation loss and runoff) and energy
- irrigation cost
- excess groundwater withdrawal (aquifer exploitation)
- nutrient leaching
- pollution of surface and groundwater by agro-chemicals
- drainage requirement
- water-logging and salinity hazard
- environmental and health hazard (disease)

On the other hand, irrigation scheduling saves water, energy and labour. Irrigation scheduling maximizes yield response to other management practices (e.g. fertilizer application). It also keeps the water environment clean and safe. The decision in irrigation scheduling thus involve optimally manage the existing resources (water, labour and equipment).

Factors affecting irrigation scheduling

Irrigation scheduling is complicated due to the fact that irrigation timing and amount of water to be applied are not independent of each other. Both depend on other numerous factors. Knowledge of soil, water, plant, and their inter-relationships is essential for proper irrigation scheduling. When to irrigate depends on water use rate by the plant (depends on weather), total available soil moisture within the plant's root zone (depends on soil and plant factor), other form of water source (if any, e.g. rainfall, snow, capillary rise from groundwater or saturated zone), maximum allowable *or* management allowable soil moisture depletion level, plant's response to soil moisture deficit, other form of abiotic stress (if any, e.g. salinity stress), etc. How much water to apply depends on moisture storage capacity of the soil, present level of moisture at which irrigation is to be started, root zone depth (depends on plant factor), any other sink of water other than plant (if any, e.g. salt leaching), depth to water-table (risk of rising), sub-surface drainage facility (if any), efficiency of the irrigation system, etc.

Thus, the factors influencing irrigation scheduling include:

- Goal and/or strategy of irrigation
- soil factor, plant *or* crop factor, weather factor, cost / economic factor
- crop response to water stress
- water-table depth, water quality
- design of existing irrigation system (or the cost of proposed irrigation system)
- volume of soil to be irrigated / effective root zone depth
- cultural / management practices

Goal/ strategy of irrigation

Both the time and amount of irrigation is influenced by the goal of irrigation. The possible irrigation goals may be:

- maximizing yield per unit of land (*i.e. maximizing land productivity*)
- maximizing yield per unit of water (*i.e. maximizing water productivity*)
- maximizing yield per unit of energy
- profit maximizing

Irrigation scheduling strategy for different goals may differ from each other. Based on the irrigator's goal, criteria for irrigation timing and amount are fixed up. However, the irrigation goal can be affected by existing land, labour and/or water resource conditions, such as:

- water-limiting condition
- land-limiting condition
- abundant water and land condition
- labour-limiting condition

Water-limiting condition is one in which water is limited but the land is abundant, and additional land can be brought under irrigation if extra water is available. Land-limiting condition is one in which land is limited but water is abundant. Under water-limiting condition, irrigation scheduling strategy may be such that yield is maximized per unit of water (i.e. maximize water use efficiency or water productivity), while under land-limiting condition the strategy may be producing maximum yield per unit of land.

If the goal is profiting maximizing, irrigation scheduling should be such that the net profit (total gross income minus total cost) would be maximum (under both land- and water-limiting condition). Profit maximization occurs at the point in which the marginal benefit of irrigation equals its marginal cost.

In areas with abundant land and water, the aim should be producing optimum yields without incurring wasteful losses of water. The optimum irrigation amount occurs when the increase in yield of the last unit of water applied becomes very low.

In addition, irrigation scheduling may be motivated by the type and value of the crop. High value crops may be irrigated frequently, and the vice versa.

Thus, it is revealed that, when to irrigate and how much to irrigate depends on the strategy selected by the irrigator based on the prevailing resource condition (water, land, labour, & capital) and the type and value of the crop.

5 Challenges and Opportunities in Irrigation & Water Management

Challenging factors

Challenges in irrigation and water management for food security and agricultural trade come from several aspects:

- Domestic resources condition
- Behavioural / Used-to factor
- Economic development level
- Climate change
- Pollution of water resources due to industrial & agricultural effluents
- Competition of water among different sectors of user
- International markets and price

Due to unequal distribution of world natural water resources, the water management and agricultural development level of different countries are very unequal. Many developing countries are confronted with the situation that per capita resources are in shortage because of large populations. Domestic food production cannot meet the consumption demand. Uncertainty of future natural rainfall due to global warming and climate change faces the water management issues in more uncertain.

Opportunities

For better water resources management towards better world agricultural development and food security, important measures are to enhance water management technology development, and utilization of new technologies in all aspects of agriculture. Specially, more crops per drop of water (i.e. water productivity) may be achieved through improved irrigation methods and means. Faced with a continuous large gap between globally potential and attainable water productivity, adoption of multiple options would play a promising role in enhancing water productivity and satisfying regional food requirement for the current as well as the future centuries. Globally, water resources may be used more efficiently when food will be imported from the countries with high crop water productivity (CWP) to the countries with low CWP.

Strategies to Improve On-Farm Water Use Efficiency, Water Productivity and Footprint

Dr. Md. Hossain Ali
Director (Research)
Bangladesh Institute of Nuclear Agriculture (BINA)

1.1 Water in the world: challenges for the 21st century

Water availability and water demand

Global demand for fresh water is constantly rising as a consequence of population growth and a rise in living standards. Meanwhile, pollution decreases the availability of clean fresh water. In the near future, covering global water demand will only be possible when it is used more efficiently, and by reducing waste and pollution.

Water footprints

The water footprint of a country is defined as the total volume of fresh water that is used to produce the goods and services consumed by the inhabitants of the country. The water used in agriculture determines largely the water footprint of a country. Producing the daily food for one person ranges from 2,000 to 6,000 liters of water.

1.2 Challenges for irrigated agriculture

The agricultural sector uses 70 % of the total fresh water resources to produce food. Given its productivity, irrigated agriculture is under heavy pressure to take its part in producing more food to cover the growing global demand. But it has to be done with less water ('more crop per drop'). Crop water productivity

How efficient are crops in their water use

Water productivity refers to the amount of crop yield that can be obtained with a quantity of water. Distinction is made between productivity expressed in kilogram yield per cubic meter of water consumed (WPET) and expressed per unit supplied water (WPsupply). The water supplied to an irrigation scheme is often more than twice the amount of water consumed by all crops in the scheme.

Several ways to improve crop water productivity:

– Enhancing crop growth by guaranteeing good environmental conditions;
– Improving the water supply to and inside the irrigation schemes (technical interventions);
– Improving irrigation water management.

1.3 How to improve water management

Design of irrigation plans to match water supply with demand.

The exact knowledge of the plant water requirement within a certain climate, together with the understanding of the decision-making process of farmers will guarantee a closer match between the amount of water supplied and the amount requested.

Irrigation charts for farmers.

The unreliability of rainfall and the absence of guidelines at a short time-step often complicate decision-making during the irrigation season. With the help of irrigation charts farmers can be provided with simple guidelines on how to adjust their irrigation during the growing season to the actual weather condition.

Deficit irrigation: deliberately provoking water stress.

Deficit irrigation is an optimization strategy in which practically no irrigation is applied in the stages where the crop is tolerant to water stress. Irrigation is concentrated in the drought sensitive growth stages of the crop. Recent findings confirm the hypothesis of increasing crop water productivity by deficit irrigation.

Simulation of crop development and yield

Simulation as a tool to obtain promising field management strategies. Simulation is done by means of mathematical models which are simplified representations of a particular system. A system is a part of reality that the engineer wants to study. With good models, realistic estimations of crop yield can be simulated for various environmental conditions. The models are valuable for outscaling the experimental findings to new environments.

1.5 Details of deficit irrigation

9.1.1 Deficit irrigation

Background

All growth stages of crops are not identical in their susceptibility to any moisture deficit. The sensitivity of various growth stages to water stress have been variable, depending upon variety, plant types (tall or dwarf), and maturity period. Generally, water stress reduces biological yield, but it does not always decrease economic yield; in fact, in some cases, it may increase it. In water-scarce areas, water (not land) is the primary limiting factor to improve agricultural production. Accordingly, maximizing yield per unit of water, and not yield per unit of land, is a more viable objective for on-farm water management. Scarce water now used for full irrigation may be revised for improved water productivity.

Concept and definition

Deficit evapotranspiration is among the techniques of increasing effective use of water. Crops are exposed to water stress up to certain degree either throughout the entire growth season or at certain growth stages. The main approach in deficit irrigation practice is to increase crop water productivity by eliminating those irrigations with the least impact on crop yield.

By definition, deficit irrigation is the deliberate and systematic under-irrigation of a crop (Marshal, 1990). Simply speaking, deficit irrigation means less application of water than a plant has the potential to use or would normally use. Sometimes it is referred to as partial irrigation. Under deficit irrigation, crops are deliberately allowed to sustain some water deficit and yield reduction.

The concept of deficit irrigation is based on the assumption that in field crops, imposing water stress at specific growth stages may not cause significant yield reduction and irrigation in these stages can be ignored which will save substantial amount of irrigation water. Although yields will be reduced under deficit irrigation, the reduction in irrigation costs and the opportunity costs of water may be more than the compensation for lower yields. When the amount of land under irrigation is constrained by limited water availability, the economic returns to water will be maximized by reducing the depth of water applied and increasing the area of land under irrigation.

In essence, deficit irrigation implies an optimization strategy in which irrigation is applied during drought-sensitive growth stages of the crop. A decision to practice deficit irrigation implies a willingness to accept reduced yields in exchange for increased net farm income. The specific objective is to optimize yield and income by allocating water to the most sensitive crop stages. Correct application of deficit irrigation requires a thorough assessment of the economic impact of the yield reduction caused by deficit irrigation.

Need of deficit irrigation

Deficit irrigation (DI) is needed and/or practiced where essential resources such as water, capital, energy and/or labor are scarce and limited. The potential benefits of deficit irrigation may be achieved from the following factors:

(i) Increased irrigation efficiency,

(ii) Reduced costs of irrigation, and

(iii) The opportunity costs of water

As the efficiency and profit are both increased with reduced levels of applied water, the net income per unit of applied water is increased. If the water saved by reducing the depth of irrigation is then used to bring additional land under irrigation (with the same incremental profit per unit of land, or even something less), the total farm profit is still more. The net income from the additional land represents the opportunity cost of water. The term 'opportunity cost' has been described in detail in Chapter 11 (Economic in Irrigation). The potential advantages of deficit irrigation appear to be quite significant, particularly in a water limiting situations, and the associated risks may be quite acceptable.

Modes of deficit irrigation

Deficit irrigation has been practiced in different modes or ways. These are:

(i) *Increasing interval between irrigations*:
The irrigation frequencies are reduced by increasing the days of interval between successive irrigations.

(ii) *Omitting irrigation during certain growth stages*:
Irrigation can be omitted during the stage or stages which are less sensitive to moisture deficit.

(iii) Providing a part of evapotranspiration (ET) demand (i.e. reducing irrigation depth)

(iv) Wetting partial root zone

(v) Wetting alternate furrows

(vi) Allowing root zone soil-water depletion to a particular level

(vii) Allowing root zone soil-water depletion to reach a particular level of leaf water potential.

(viii) Any combination of the above.

Procedure for adopting deficit irrigation

The relationship between the crop water stress and yield is very important in scheduling deficit irrigation. In other words, to utilize this approach in practice, sensitivity of different growth stages to water stress (single stress in a particular stage, or alternate stress in several stages, or stress at a stretch) should be determined for each crop at each agro-ecological and/or geo-hydrological situation. After establishing the sensitivity of growth stages, irrigation can be avoided at less sensitive stage(s); and this saved water can be used to irrigate more cropped area or other valuable crops.

Risk/uncertainty, advantage and constraint of deficit irrigation

Risk

The uncertainty associated with this type of irrigation system from the fact that the cost of the water used and the yield function are not precisely known. If precisely known, it would be a simple matter to choose an optimum level of water use. The yield function tends to be uncertain due to the difficulty in estimating the water losses by inefficient application, by deep percolation and by surface and sub-surface runoff. Deficit irrigation may require modification of some cultural practices which may include: lower plant densities, flexible planting dates and selection of shorter duration crops.

Advantages

- Deficit irrigation maximizes productivity of water (also termed as 'water use efficiency')
- In water limiting areas, this practice is economically more profitable than maximizing yield per unit area
- It creates less humid environment around the crop than full irrigation, thus decreasing the risk of fungal and associated diseases
- Increases quality of the yield (protein content, sugar content, grain size, etc.)
- Reduce nutrient loss through leaching, thus require less fertilizer application and improve groundwater quality
- Increases assimilate partitioning to grain from vegetative parts
- Reduces crop cycle length (i.e. crop period), thus facilitates to increase cropping intensity

Constraints

Along with the above advantages, deficit irrigation (DI) entails a number of constraints. The following conditions should be met to use DI:

- yield response to water deficit or drought stress at different growth stages should be studied carefully
- water should be available at sensitive growth stages
- in saline area, leaching of salts from the root zone is lower under DI than under full irrigation

Reasons /mechanisms for increased water productivity under deficit irrigation

- water loss due to evaporation is reduced
- water loss through transpiration is also reduced
- soil-moisture extraction from deeper layer is increased
- water is used most efficiently within the plant system
- assimilate portioning rate in DI plants (during start of ripening) from vegetative part to grain is higher compared to well-irrigated plants, thus increased harvest ratio (grain: straw weight)
- negative impact on crop growth such as infestation of pests, diseases, anaerobic conditions in the root zone, etc. are reduced, and hence produces higher yield

1.6 Concept of WP and strategies/ways to improve WUE, WP and WF

Concepts of water productivity

Different water productivity indicators result from different options:

WP_1 = Grain or seed yield / Water applied to the field, ($kg\ ha^{-1}\ cm^{-1}$) (1)

WP_2 = Total dry matter yield / Water applied to the field, ($kg\ ha^{-1}\ cm^{-1}$) (2)

WP_3 = Total monetary value / Water applied to the field, ($\$\ m^{-3}$) (3)

Techniques to improve WP

The term 'increasing or improving water productivity' implies how we can most effectively improve the outcome or yield of a crop with the water currently in use. The answer lies in three main pathways (Passioura, 2006): (i) transpire most of the supplied water (minimization of unwanted loss), (ii) exchange transpired water for CO_2 more effectively in producing biomass, and (iii) convert most of the biomass into grain or other form of harvestable product.

Many technologies to improve WP and the management of scarce water resources are available. Among the most promising and efficient proven techniques are: (i) limited supplemental irrigation for optimizing the use of the limited water, and (ii) water harvesting for improved farm income in drier environment. Improving crop water productivity, however, requires exploiting not only water management but also other inputs such as improved cultivars, fertility management and cultural practices which influence yield.

- Deficit irrigation
- Proper sequencing of water deficit
- Surge irrigation management in vertisol
- Increasing soil fertility
- Improving assimilates partitioning to grain (by increasing harvest index: ratio)
- Manipulation of seedling age
- Wet-seeded or direct-seeded rice
- Priming or soaking of seed
- Application of organic matter, farmyard manure and biofertilizer
- Tillage and sub-soiling

- Other management factors
- Water harvesting
- Minimizing transpiration
- Water-saving irrigation
- Crop choice
- High value crop selection
- Modernization of irrigation system

1.7 Use of simulation model in optimizing yield and water use

AquaCrop: A crop water productivity model from FAO.

AquaCrop estimates the crop yield that can be expected in a given environment. The environment is specified by the user as input. It consists of weather conditions (rainfall, air temperature and the evaporative demand of the atmosphere), soil and plant characteristics, and field management practices (fertilizer management, irrigation, etc.). By altering the input, the expected crop production and yield can be simulated for different environmental conditions. In this way the effect of the environment on crop production can be better understood and guidelines for farmers to improve the water productivity can be derived and formulated.

In AquaCrop, crop yield is simulated in three steps:

- By means of a soil water balance crop transpiration is simulated;
- Plant biomass production is obtained from the close link with crop transpiration;
- Crop yield is derived from the simulated biomass with the help of a harvest index.
- Which results can be expected?

AquaCrop will be useful to develop irrigation strategies under water deficit conditions, to find the most suitable crop calendar under rainfed conditions, and to obtain reliable yield estimates for field crops that can be expected under various environmental conditions. The model is intended to provide guidelines to mainly a practitioner type of end-user such as people working for extension services, governmental agencies, NGOs and various kinds of farmers associations. With the guidelines, the farmer should be able to produce more yields with less water.

Srategies to Valuing Water for Efficient Irrigation anagement: Shadow Pricing Perspective

Dr. Md. Aminul Haque
Chief Scientific Officer (Water Resources)
WARPO, Dhaka
Email: maminul05@yahoo.com

Introduction

Water, particularly fresh water, is a scarce resource and so its use needs to be allocated based on sound economic principles including its "value" to guide such allocation among competing needs. HLPW of UN, of which Hon'ble PM is a member, recommended that countries take measures to value water in their specific contexts, based on Bellagio Principles, 2017 to guide such allocation. Consequently, it was decided that an exercise be carried out in Bangladesh for Valuing Water and related actionable issues. WARPO on behalf of the MoWR to carry out the specific activities to develop a framework for valuing water, estimate operational shadow price for water and related activities.

The shadow price of a product or service that is marketed may be defined as the price that it will attract if there is no market distortion. Market distortions may be natural like its structure (such as a monopoly which can influence the product price) or may be due to government interventions such as a tax or a subsidy or an administered price. There are cases where in fact there may be no market such as the ecosystem services. In all such cases a shadow price is an artificial construct which indicates its true value to the society. In case of water, the literature review shows that the shadow price of water may be assessed in several ways. It can be computed either based upon the users' behaviour or based upon the value of alternative use (e.g., different user or different time). Four types of approaches are available in the literature. Water, particularly fresh water, is a scarce resource and so its use needs to be allocated based on sound economic principles including its "value" to guide such allocation among competing needs.

Concept of Valuing Water:
Valuing Water Concept is considering total economic value. Total economic value (TEV) of water comprises of both direct, indirect use and also future use of water. This concept has direct relevance in studying valuation of water in Bangladesh where water has a multifarious use ranging from economic purposes to recreational and ecosystem preservation purposes. Direct use values of water arise out of direct use of water such as water for drinking, irrigation purposes, industrial uses, etc.
Valuing water, particularly in the context of irrigation in Bangladesh, requires a nuanced understanding of its multi-faceted importance. Operational shadow pricing serves as a tool to estimate the economic value of water, factoring in both tangible and intangible costs and benefits.

Steps for water valuation:
Five steps are followed for water valuation such as (a) Develop Shadow Price of Water (b) Streamlining Valuing Water into Public Statement Decision Making (c) Operationalization of Valuation of Water for Pricing of Water in Private Sector Decision Making (d) Preparation of Technical Reports and Dissemination to Relevant Stakeholders (e) Sharing the Outputs for feedbacks from Relevant Stakeholders. Conceptualization and

Understanding of Shadow Prices will be discussed broadly. For economic sectors and subsectors in agriculture and industry either a normal production function or a fixed proportion production function method (both with water as an input) is used as appropriate particularly depending on availability of requisite data. Marginal products of water and their values are estimated the latter being the financial value of water. Wherever applicable and available, these are converted into shadow price of water which represent the social (or "true") value of water. For non-economic uses of water as is the case with municipal residential and ecosystem services, other specific methods are used.

Shadow pricing:
Water is a natural resource, and its availability largely depends on the nature. Too much or too little availability of water cause a serious water management problem. At the same time, when water is underpriced, there is a danger of over-use of water which in turn reduces availability of water in other sectors. To solve this problem, economists often argued for pricing water fairly so that efficient allocation occurs. Actually, shadow price is required for decision making for public sector but can be utilized for efficient and pricing in private sector business, industry and residential house. For example, in case of residential use of water supplied by utilities, the issue of affordability becomes important as one of the SDGs. Thus, shadow price provides the guidance to a fair system of pricing of water. At the same time, there are sectors where water has no market price, like environment and ecosystem, where availability of water is only residual, finding value of water is most challenging.

Shadow prices were estimated in four sectors (Agriculture, Industry, Municipality, and Ecosystem). The basic method for finding the value of water in irrigated agriculture is to estimate the value of marginal product of water. To estimate the value of water in the Muhuri Irrigation Project Area, a production function was estimated. On the other hand, water is a non-consumable input in the production of electricity from power plants. Water requirement for production of electricity can be divided in two parts, first, for construction of the power plant itself and secondly in actual power generation. The value of water for household use (quantity) may be measured using the productivity of water in terms of reducing incidences of water scarcity related illness using the cost of health approach. Cost of illness were assessed by comparing households with adequate supply of water (connected to pipe water supply) and without piped water supply connections. The costs included a) cost of treatment, b) cost of doctors / hospitalization, and c) workdays and consequently income lost between these two types of households.

Operational Shadow Pricing:
Operational shadow pricing offers a methodological framework to assess the economic worth of water resources, especially in contexts where market prices are absent or inadequate. Specifically, for irrigation water in Bangladesh, shadow pricing involves estimating its economic value by considering the opportunity cost, i.e., the value of its next best alternative use. This approach encompasses direct costs such as production inputs, labor, and infrastructure investments, as well as indirect costs like environmental degradation, health impacts, and social welfare considerations.

Application to Irrigation Water in Bangladesh:
Bangladesh heavily relies on irrigation to support its predominantly agrarian economy, with the vast majority of arable land being cultivated for food production.
Operational shadow pricing for irrigation water in Bangladesh necessitates a comprehensive assessment of its economic, social, and environmental implications.

Economic valuation involves quantifying the contributions of irrigation water to crop yields, farm incomes, and overall agricultural productivity, considering factors such as crop types, water availability, and market dynamics.

Social valuation encompasses the role of irrigation in ensuring food security, alleviating poverty, and fostering rural livelihoods, particularly among smallholder farmers and marginalized communities.

Environmental valuation addresses the ecological impacts of irrigation water use, including water pollution, soil degradation, loss of biodiversity, and implications for ecosystem services such as flood regulation and water purification.

Challenges and Considerations:
Estimating the economic value of irrigation water in Bangladesh is beset with challenges, including data limitations, methodological complexities, and uncertainties associated with climate change and hydrological variability.Social and environmental valuation requires interdisciplinary approaches that integrate insights from economics, sociology, ecology, and hydrology, while accounting for local contexts and stakeholders' perspectives.Implementing operational shadow pricing necessitates institutional capacity building, stakeholder engagement, and policy reforms to align water management practices with sustainable development goals and climate resilience objectives.

In essence, valuing irrigation water in Bangladesh entails recognizing its diverse contributions to the economy, society, and environment, and operationalizing shadow pricing as a means to inform policy decisions, investment priorities, and resource allocation strategies aimed at fostering water security, agricultural sustainability, and inclusive growth.

Framework for Valuing Water:

Sectors	Type of Services and Value	Valuation Method	Data Need/Requirement	Data Source
Agricultural Use– Irrigation	Provisioning service of water	Production function approach	Crop production (kg); agricultural land; inputs (seeds, fertilizer, energy, labor etc.); costs of production water use, cost of water	Primary (field survey) data on boro crops from Northwest and Southeast regions.
Industrial Use – Construction, Power, Apparel Sector, Food and Beverage Sector	Provisioning service of water	Fixed proportion production function method or Input-Output Method	Volume of water use from selected producers, unit cost of production, unit price of output	Key informant interviews from selected producers
Municipal Water Use/ Urban	Provisioning service of water	Health cost approach	Incidence of water borne diseases in urban areas with and	Household Income and Expenditure

Domestic Use of Water			without water supply system, Cost of prevention, cost of mitigation, average daily income, no of days lost due to illness in urban areas	Survey(HIES) 2016 data
Ecological Service of Water – Flood Control function of Tanguar haor	Regulatory Service of Water	Output Change Approach	Extent of inundation with and without haor ecosystem services, agricultural production and cost data	Simulate using GIS models at CEGIS, secondary data from agricultural data of BBS
Ecological Service of Water – Spawning ground for fishes in Halda River	Supporting Service of Water/ Habitat service of a river	Replacement Cost Approach or Productivity Change Approach		

Summary of Results of all four sectors

Sector	Sub Sector	Shadow price
Agriculture	BMDA	Taka 2.5 to 2.8, near about US cents 3.
	Muhuri	Taka 17.8
Industry	Construction	Tk 298 to Tk 65 with an average of Tk 169
	Food& Beverage	Carbonated and bottled Water: US cents 16 to 18 Cerelac: Tk 212/cum of water Noodles: Tk 132/ cu m of water
	Power	Tk 600 per cum on average
	Apparel	Tk 75
Municipal Water Use		• Dhaka: 61.59 taka/cum of water /day, • Khulna: 39.17 taka/cum of water /day • Combined: 60.38 taka/cum of water/day.
Ecosystem Services	Tanguar	Total benefits **200 thousand crores/yr**
	Halda	

Data Limitation issues

- Severe data limitations
- For part of agriculture, Muhuri, no volume of use of water available – had to estimate under assumptions
- For industry, only a few data points available and also limited to only output and water use – restricted proper econometric estimation except for power
- For municipality, secondary data source did not include many information needed and had to assume under stringent conditions

- For ecosystem, single haor estimation of ecosystem services not possible. Had to do for haor system as a whole – for Halda major question marks remain – in both cases existential value of the ecosystem could not be estimated due to severe data limitations

Use of Shadow Prices of Water for Planning Purposes:

- At present, financial and economic feasibility appraisal through CBA only in case of power, transport and agriculture.
- Shadow price of water not used.
- Should we use these now? Very likely not as the present estimates are rather rudimentary, although indicative of wide differences by sector.
- Minimum that should be done right away is each public sector project should indicate the volume of water used in investment and O&M phase, state clearly sources of water and what externalities like effluents are caused and their environmental impacts and value them as possible.

Under the study Some best Practices Identified, which needs to promote in future:

- Alternate Wet and Dry Method (AWD)
- Managed Aquifer Recharge
- Rain Water Harvesting
- Circular Use Of Water (Reduce, Reuse, Recycle)
- Water Smart Urban Development
- Integrated Water Resources Management (IWRM)
- No Waste or Zero Waste
- Volumetric Allocation of Water
- Adoption of Cleaner Production

Some Recommended Incentive Mechanism

- Payment for Ecosystem Services
- Certification of Water Efficient Industries
- Tax subsidization for valuing water
- Promoting water and Energy efficient financing
- Education and Outreach
- Each public sector project should indicate the volume of water used in investment and O & M phase
- Lack of conversion factor and backdated conversion factor need to be updated
- Sectoral more detail study and mass sensitization on valuing water is important
- Valuing water has been included in the strategy for water resources in the current five-year plan of the country.
- DPP format need to be updated through inclusion of Shadow Prices after more fine tuning and discussion
- Valuing Water and Shadow prices need to included in relevant academic curriculum and regular training
- Mass awareness and intensive dissemination of the issues of valuing water is important.

Impact of Climate Change on Agriculture and Water Sector

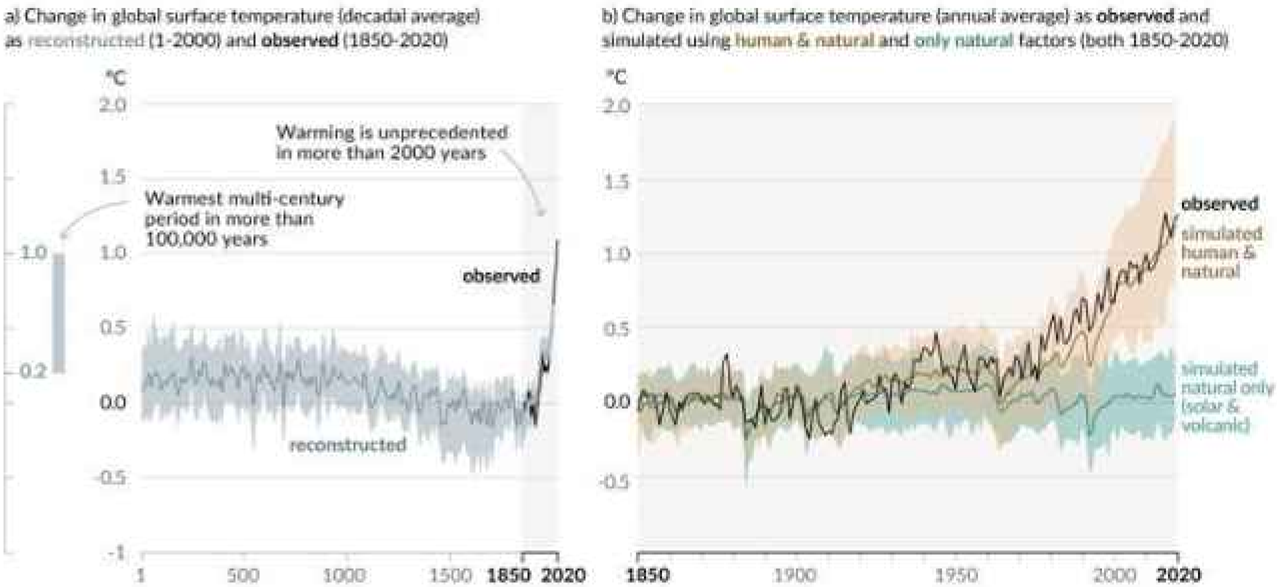
A.K.M. Saiful Islam
Professor, IWFM, BUET, Dhaka
Email: saiful3@gmail.com

Introduction

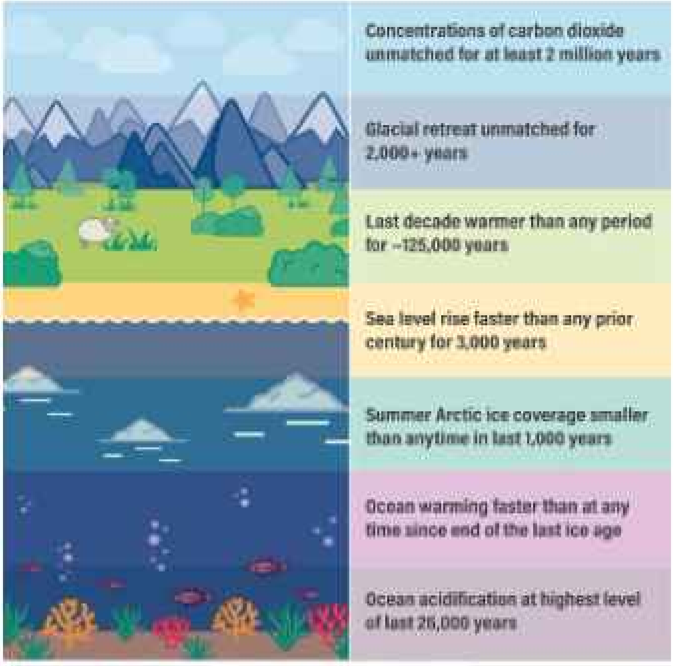
In an era defined by growing concerns over water scarcity and the impacts of climate change, adopting water-efficient and climate-smart irrigation management practices has become imperative for sustainable agriculture. As global temperatures rise and weather patterns become increasingly unpredictable, traditional irrigation methods are proving to be inefficient and unsustainable. Water-efficient and climate-smart irrigation techniques offer innovative solutions to mitigate these challenges, optimizing water use while enhancing crop yields and resilience to climate variability. By integrating advanced technologies, data-driven decision-making, and holistic approaches to water management, farmers and stakeholders can not only conserve precious water resources but also contribute to building a more resilient and sustainable agricultural system for future generations

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

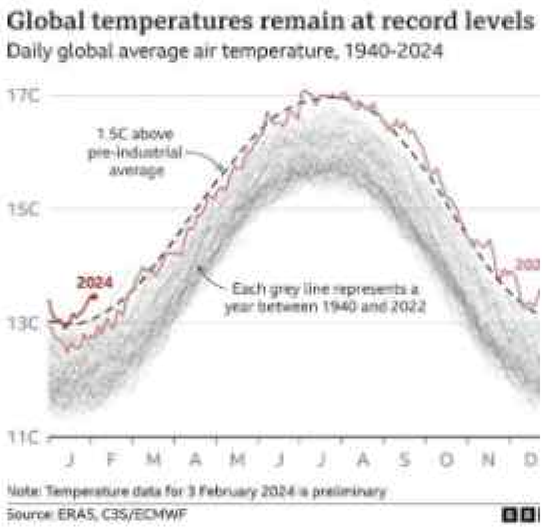
Changes in global surface temperature relative to 1850-1900

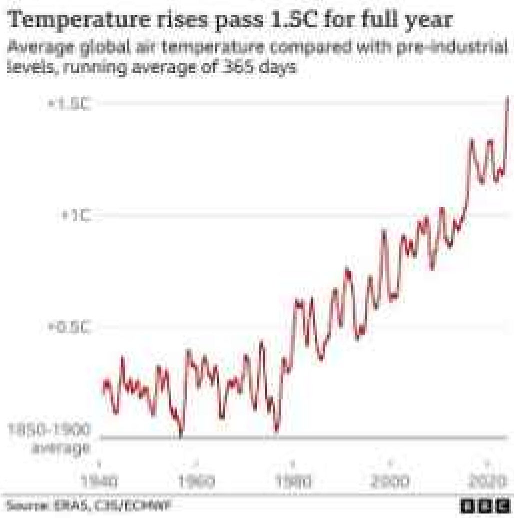


Evidence of global warming



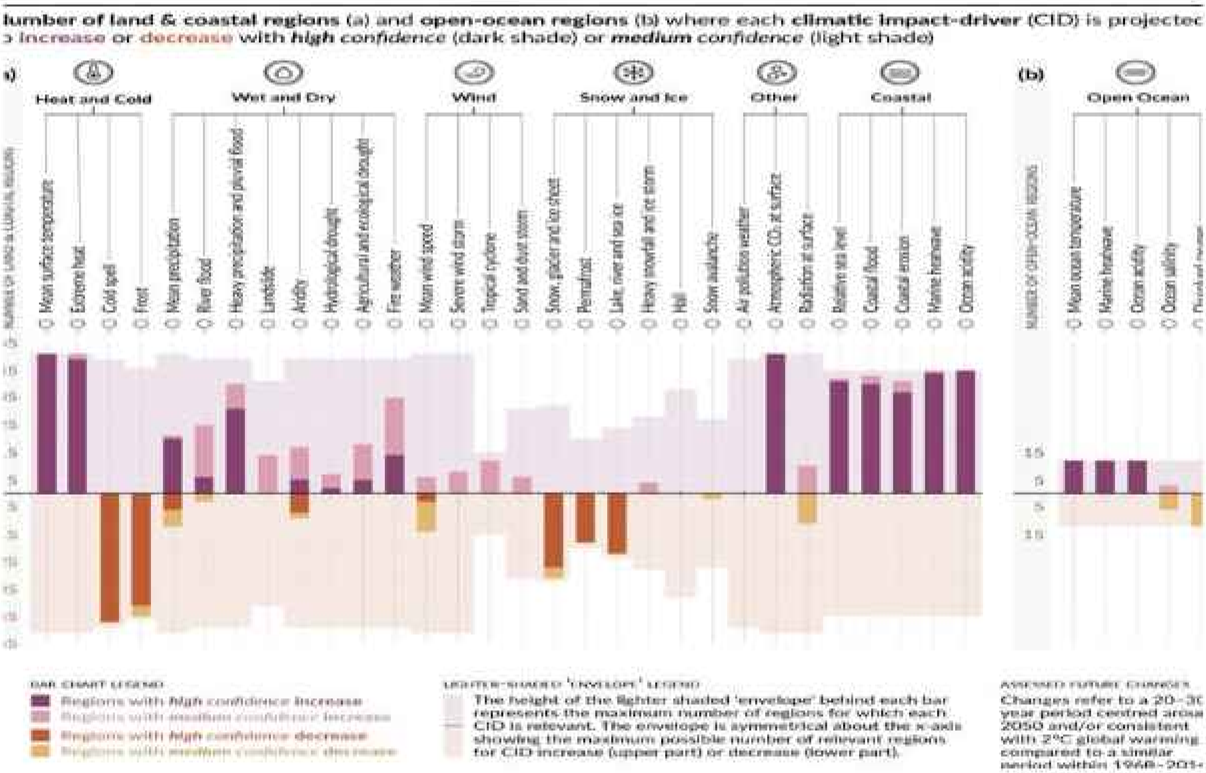
Temperature Record in 2023



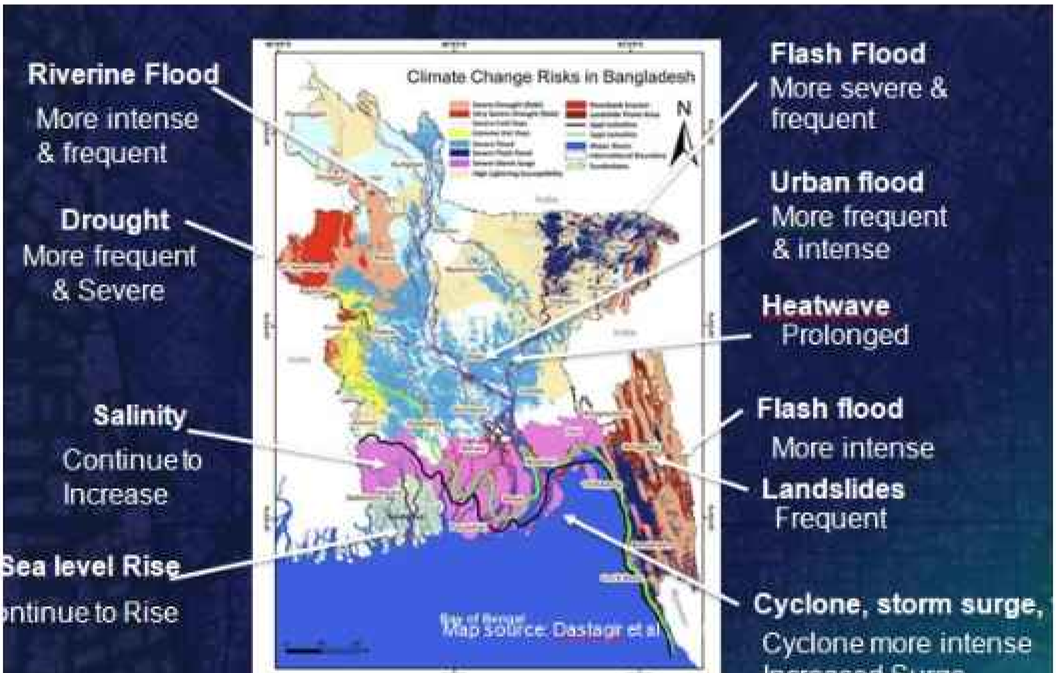


Response of climate system relative to 1850-1900

Projected changes of CDIs for all region

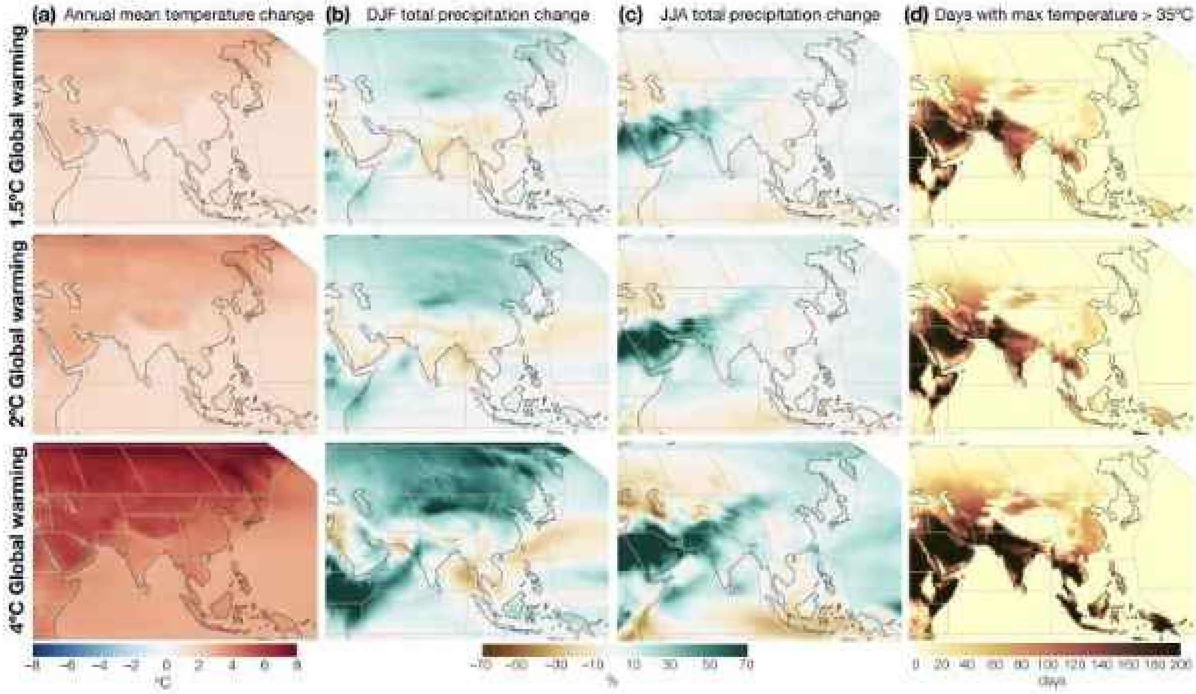


Natural Hazards Expected to Change under Global Warming

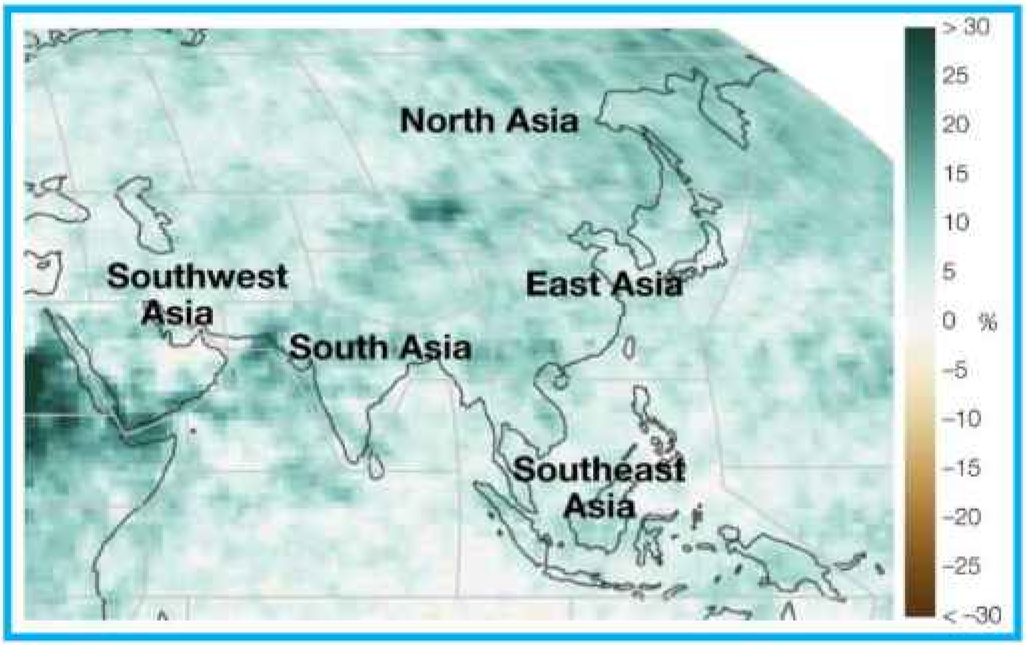


Extreme Events: Floods

- Between 22%-30% of Bangladesh's territory is inundated yearly 45. In 2022, Bangladesh suffered one of the 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 muchof Asia (high to medium confidence).



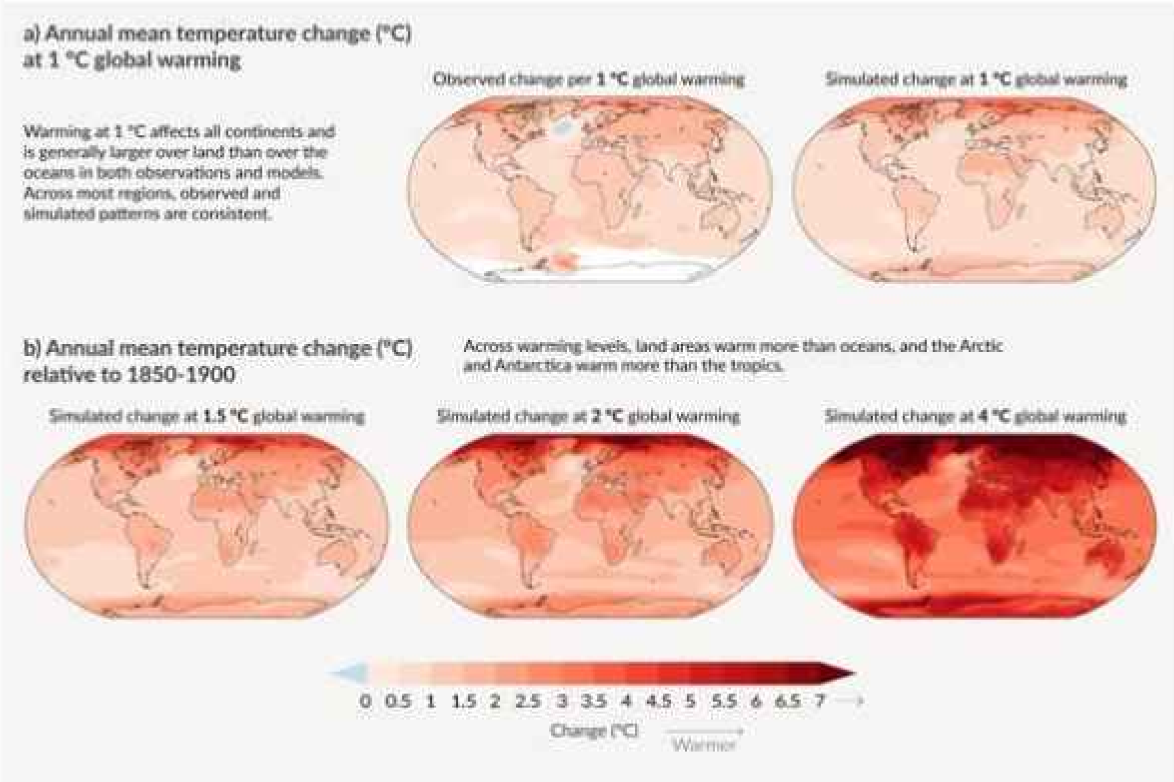
Urban Floods



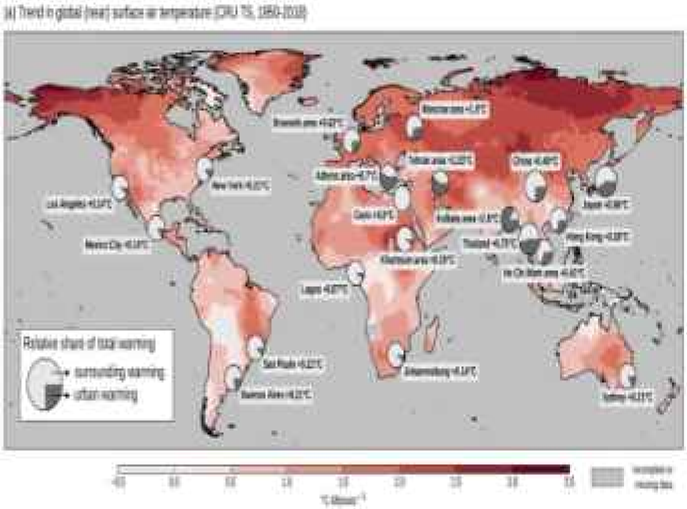
- According to IPCC, Projected changes in maximum 1-day precipitation at 2ºC global warming under SSP5-8.5
- Scenario relative to the 1995-2014 baseline (From Interactive Atlas).

Heat wave:

- 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, dangeroushumid heat thresholds, such as the NOAAHeat Index (HI) of 41°C, will be exceeded much more frequently under the SSP5-8.5scenario 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 than100 days relative to the recent past under SSP5-8.5, while this increase will belimited to less than 50 days under SSP1-2.6 (high confidence)

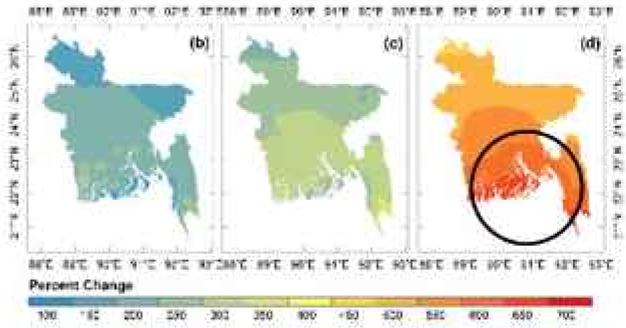


Observed trend in global surface air temperature

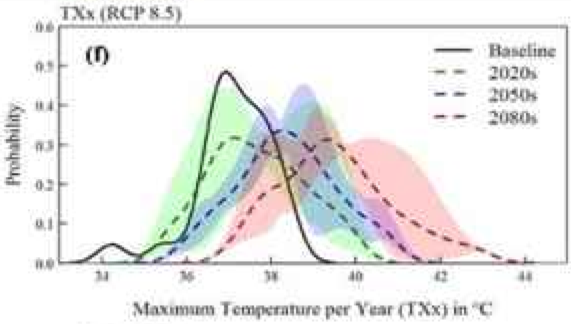


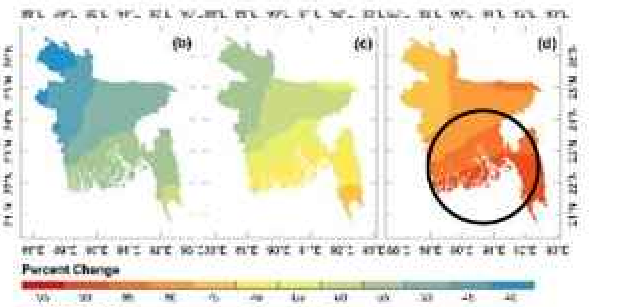
- Temperature extremes are increasing – heat wave and health stress will be more intense and frequent
- TX90P – Percentage of days when maximum temperature is higher than 90th percentile value.

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

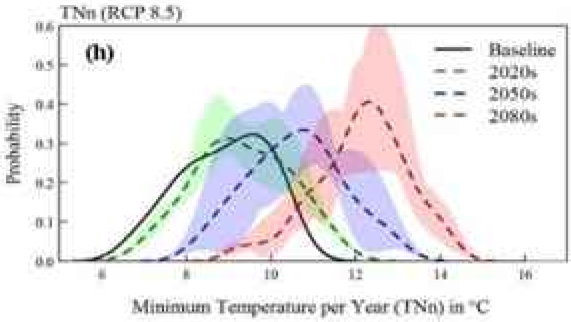


TXx- maximum of daily maximum temperature





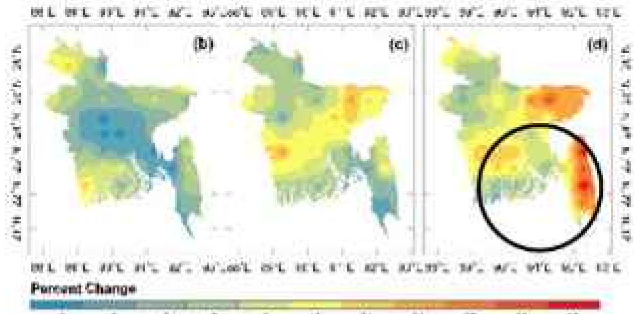
TX10P- Percentage of days when maximum temperature is lower than 10th percentile value



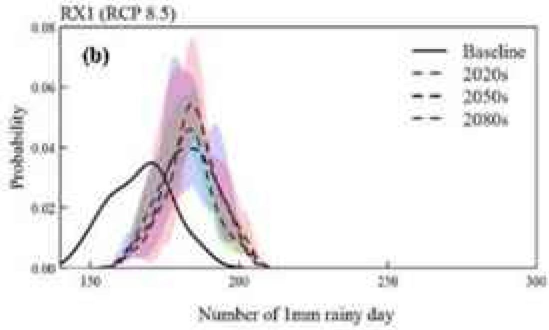
TNn- minimum of daily minimum temperature

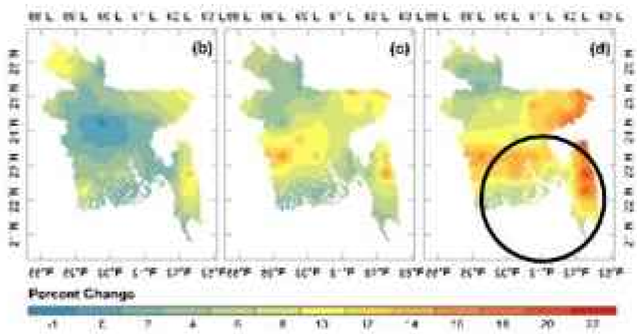
Changes of Extreme Rainfall - more flash floods and landslides are expected

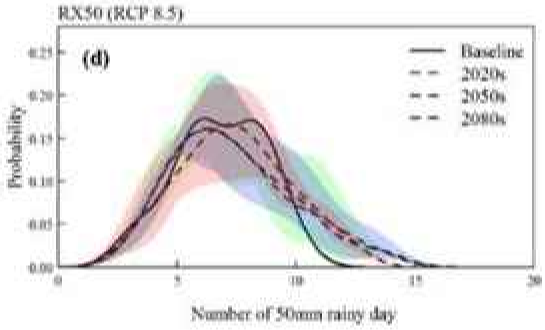
Rx1- maximum 1-day rainfall



Rx1- maximum 1-day rainfall







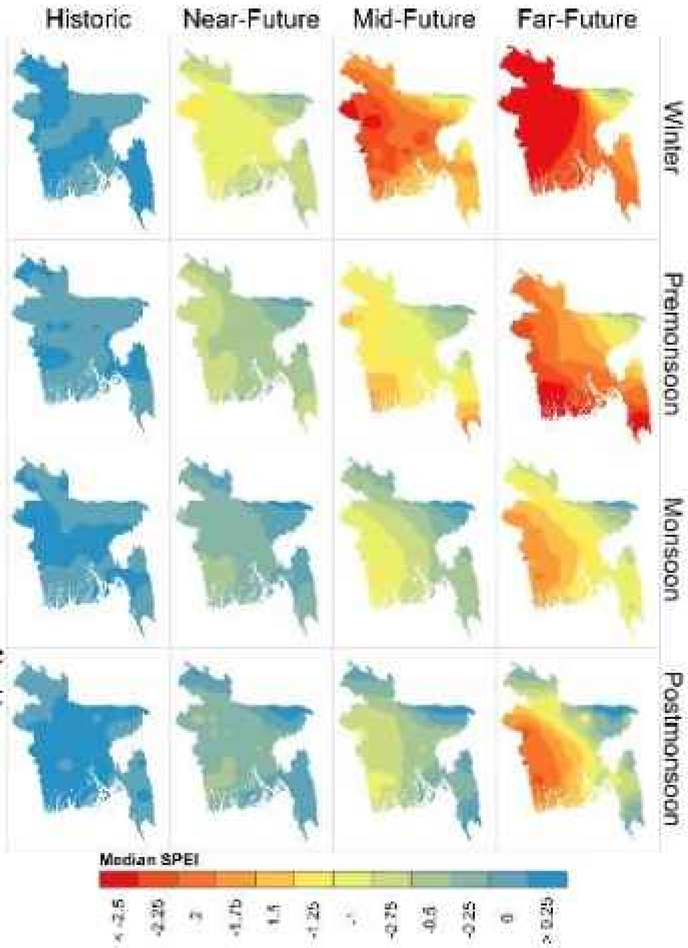
Rx50- number of days when rainfall > 50mm

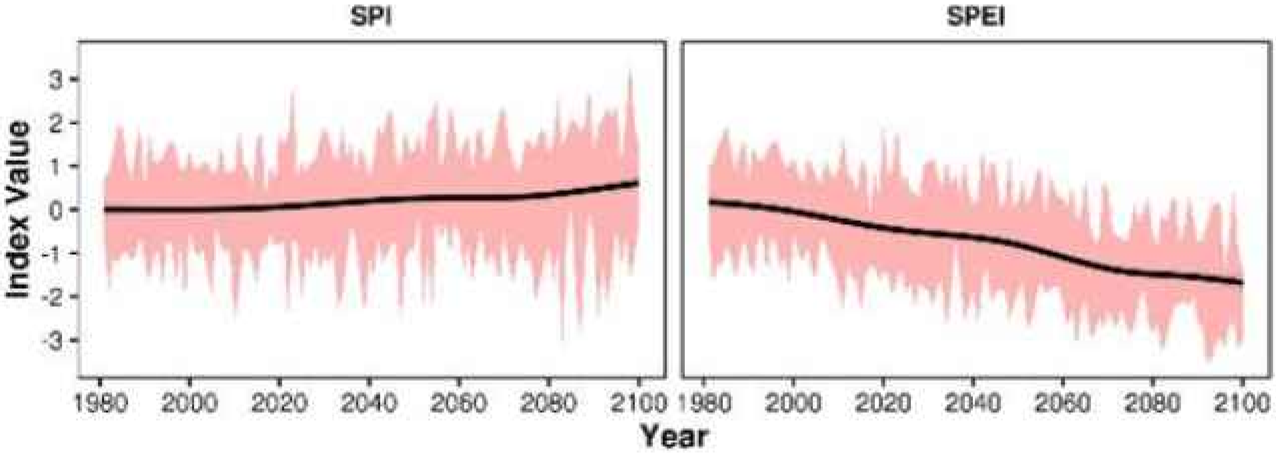
Rx50- number of days when rainfall > 50mm

Changes of Meteorological Droughts

Spatial Changes of Meteorological Droughts

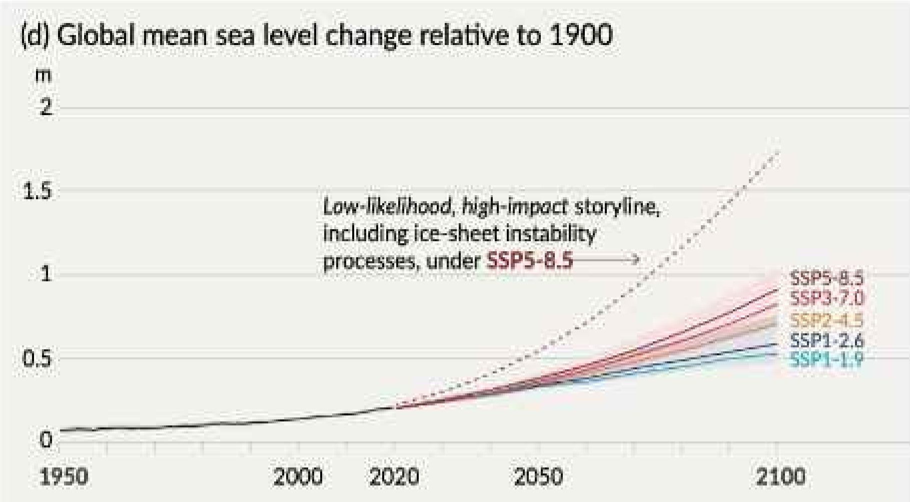
- Inclusion of evapotranspiration in the evaluation of drought is important in the context of global warming.
- The country is expected see more and more deviation from the climatic mean condition.
- At the end of the century, the climate of the country may settle to a condition which may be considered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





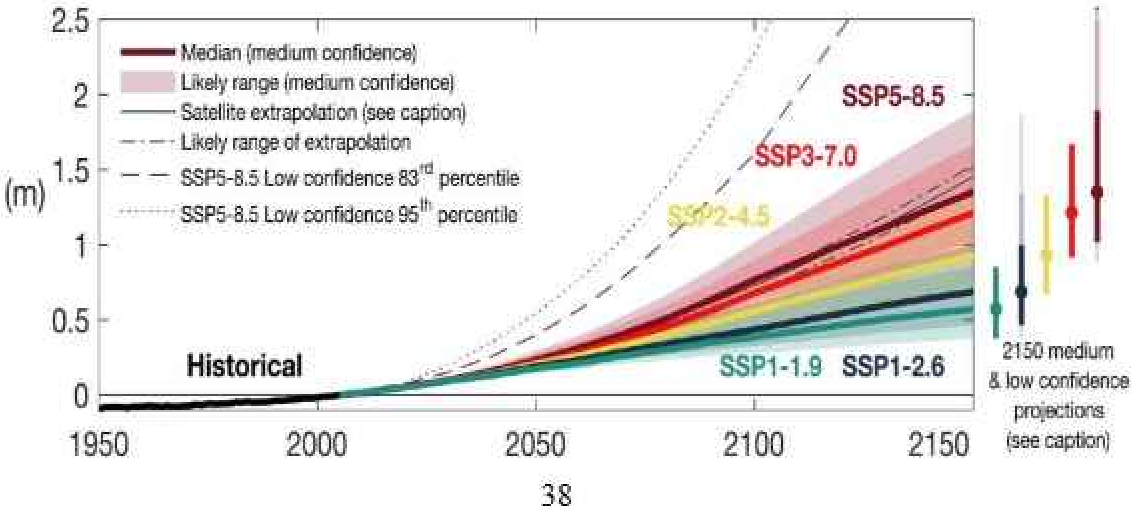
Extreme Events: Sea Level Rise

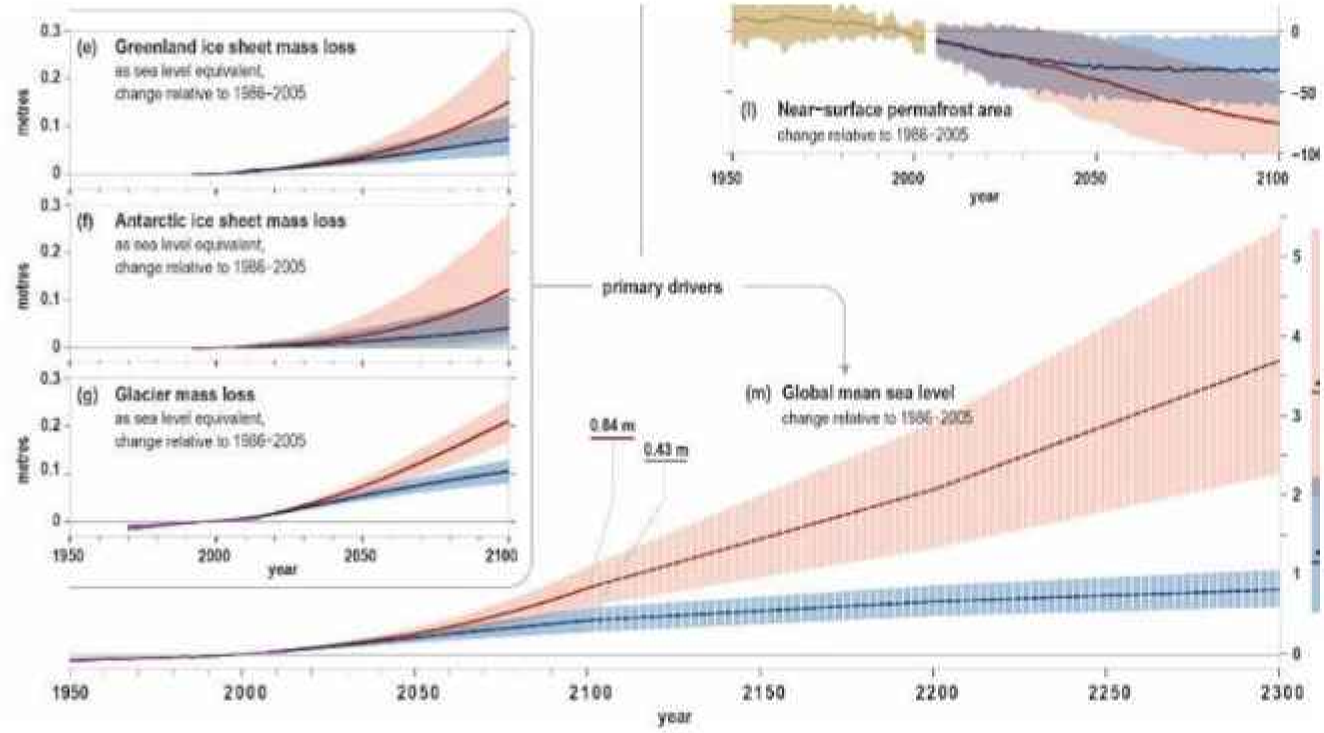
- Over the 21st century, the majority of coastal locations have a median projected regional sea level rise within ± 20% of the projected GMSL change (*medium confidence*).
- Relative sea level rise is very likely to virtually certain (depending on the region) to continue during the 21st century, contributing 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)

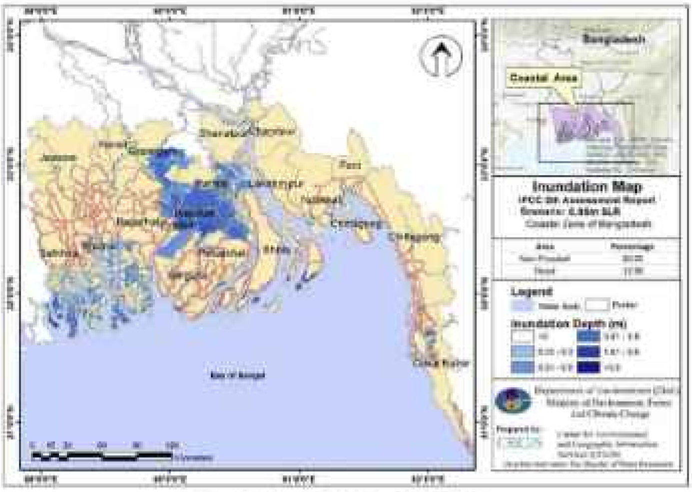


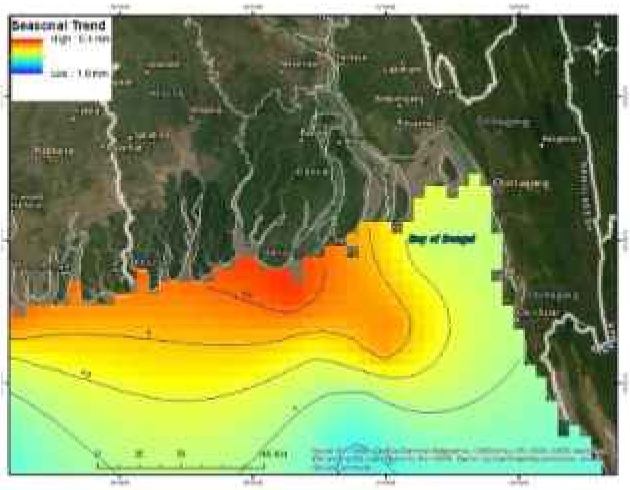
Projected Ice loss and SLR (SROCC, 2019)

- Bangladesh has been experiencing arising 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 temperatureand subsequent changes in pH (Srideviet al., 2021).





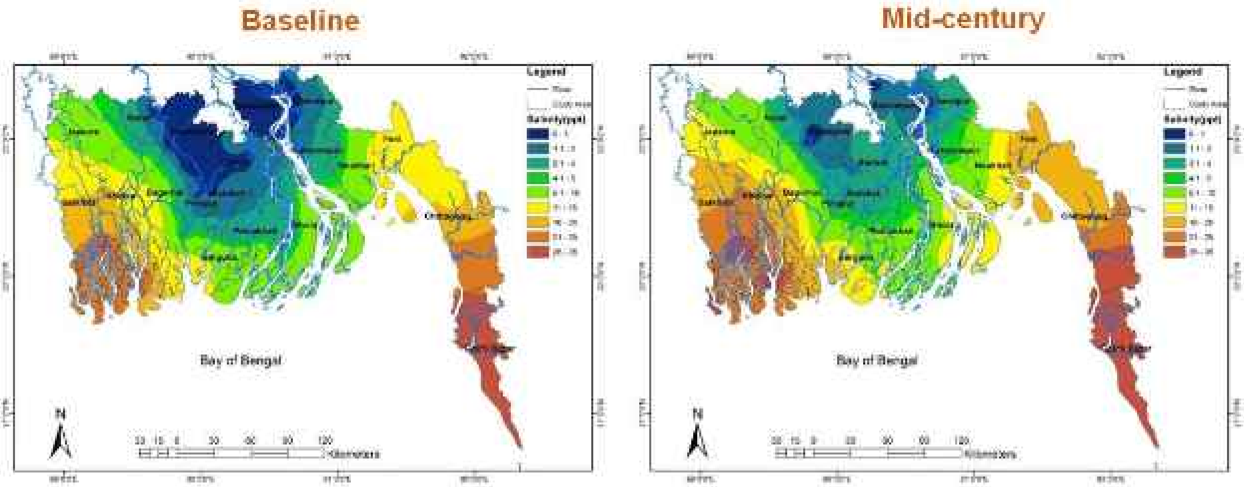




Changes of inundation patterns or cyclone Sidr (2007), Aila (2009) and Roanu (2016)
Change in Salinity

- Water and soil salinity is a common hazard 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.



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 analysed over the study area to determine erosion and accretion. It has been found that major accretion is observed in the Rangabali Upazila while erosion is observed in many locations of the Patharghata, Taltali, Kalapara, Galachipa, Amtali and Barguna Sadar.

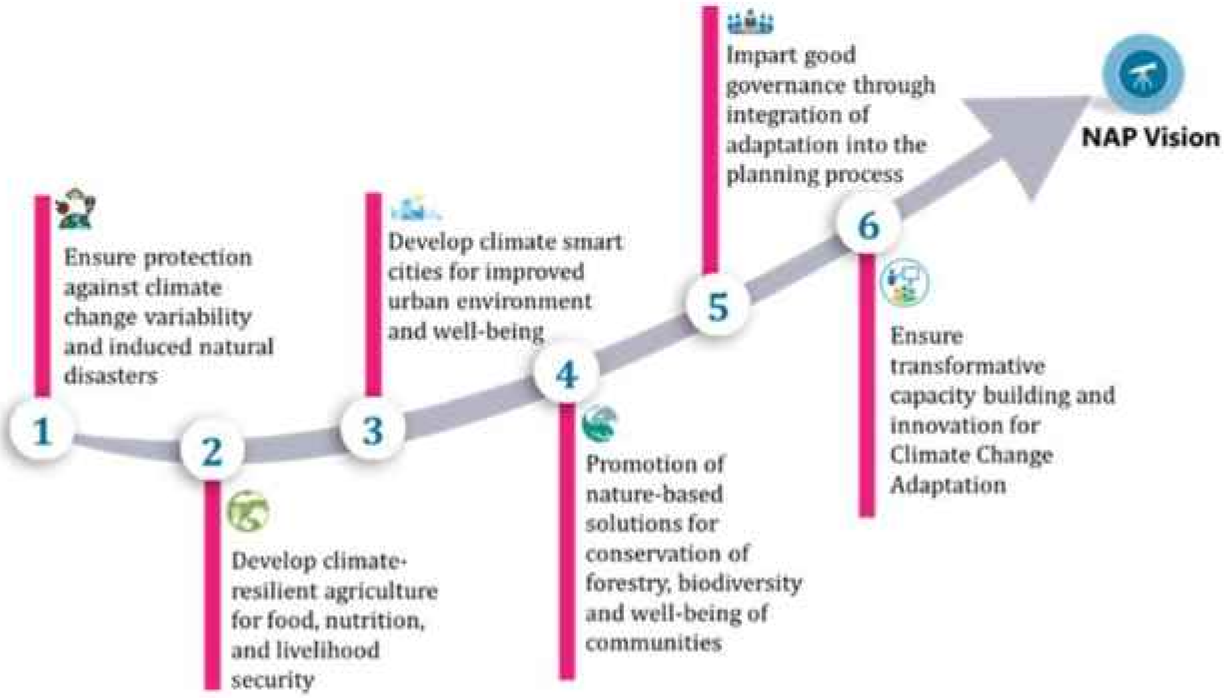
Climate Change Adaptation and Mitigation in Agriculture and Water Resources

A.K.M. Saiful Islam
Professor, IWFM, BUET, Dhaka
Email: saiful3@gmail.com

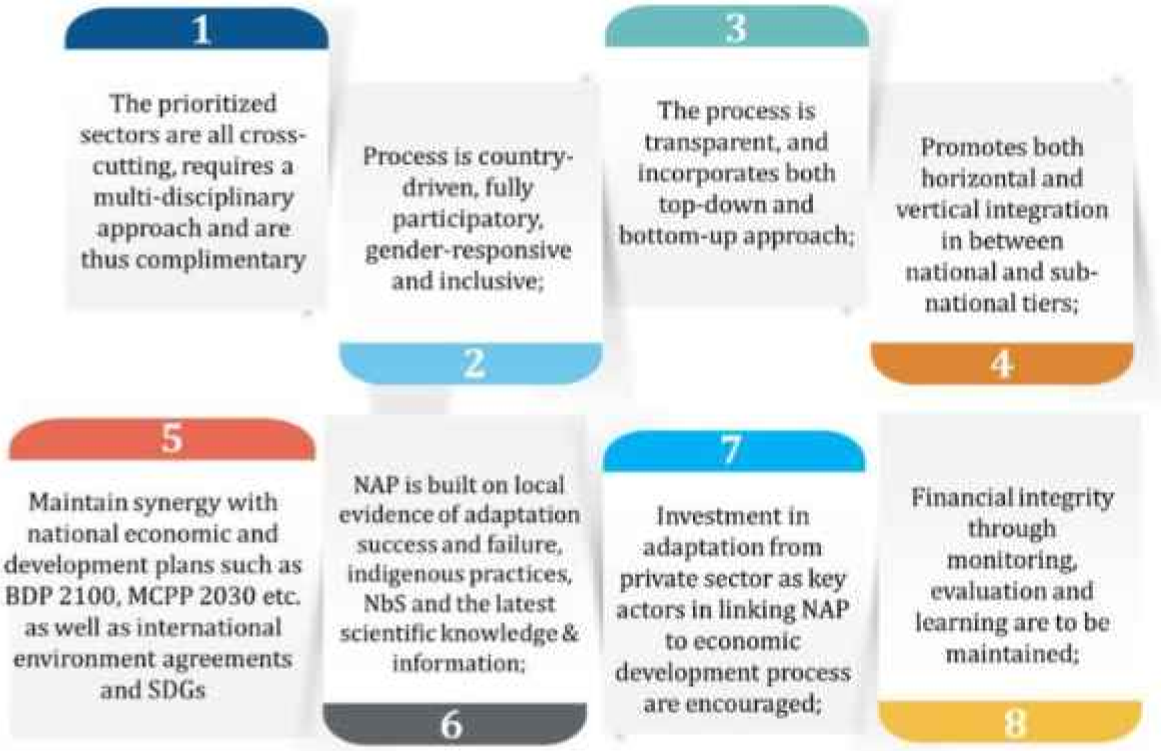
In the face of escalating climate change impacts, adaptation and mitigation measures in the agriculture and water sectors have become paramount for ensuring food security, water availability, and sustainable development. Agriculture and water resources, vital pillars of global economies and livelihoods, are increasingly vulnerable to the adverse effects of climate variability and extremes. From shifting precipitation patterns to rising temperatures and more frequent extreme weather events, these sectors are confronting unprecedented challenges. Effective adaptation strategies, including crop diversification, improved irrigation techniques, and resilient infrastructure, are essential for safeguarding agricultural productivity and water security. Simultaneously, mitigation efforts, such as reducing greenhouse gas emissions from agricultural practices and enhancing carbon sequestration in soils and vegetation, are critical for curbing further climate change impacts. Through integrated approaches that combine adaptation and mitigation, stakeholders can foster resilience, mitigate risks, and ensure the long-term sustainability of agriculture and water resources in the face of a changing climate

National adaptation plan

Vision of NAP to ensure protection against climate change variability and natural disasters



Principles of NAP:



Principles of NAP

Sectors of NAP:

Sectors of NAP

Noteworthy Adaptation Initiatives

Water, Flood and Erosion Management

- 231.40 km of embankment
- 590.60 km canals excavated/re-excavated
- Flood forecast lead time 3 to 5 days
- 5 rubber dam and 2 Spars
- 18 regulators, 16 outlets and 12 inlets
- 1457 km river-bank protection
- 4,375 km river excavation and dredging
- 5,355 km irrigation canal and 4,502 km drainage canal

Climate Resilience and Livelihoods

- 12 stress tolerant crops varieties
- 19428MT stress tolerant seeds
- 8529 climate resilient house
- 2451 water purification solar plant
- 12900 floating vegetables bed
- 5.4 million Palm trees for lightning
- 4184 no. deep tube-wells installed
- 340 flood Shelters with 393 under construction.
- 550 Mujib Killa, raised land, for the people and livestock

Enhanced DRR

- 4,530 Cyclone Shelters
- 14 schools cum cyclone shelter
- 14,205 volunteers and coastal fisherman trained for Cyclone preparedness
- 76000 volunteers (50% women) of Cyclone Preparedness Programme (CPP)
- 60 Disability inclusive Multipurpose Rescue Boats
- 65 Disaster Relief Warehouse-cum-Disaster Information Center
- 18 community radio (FM) for EWS

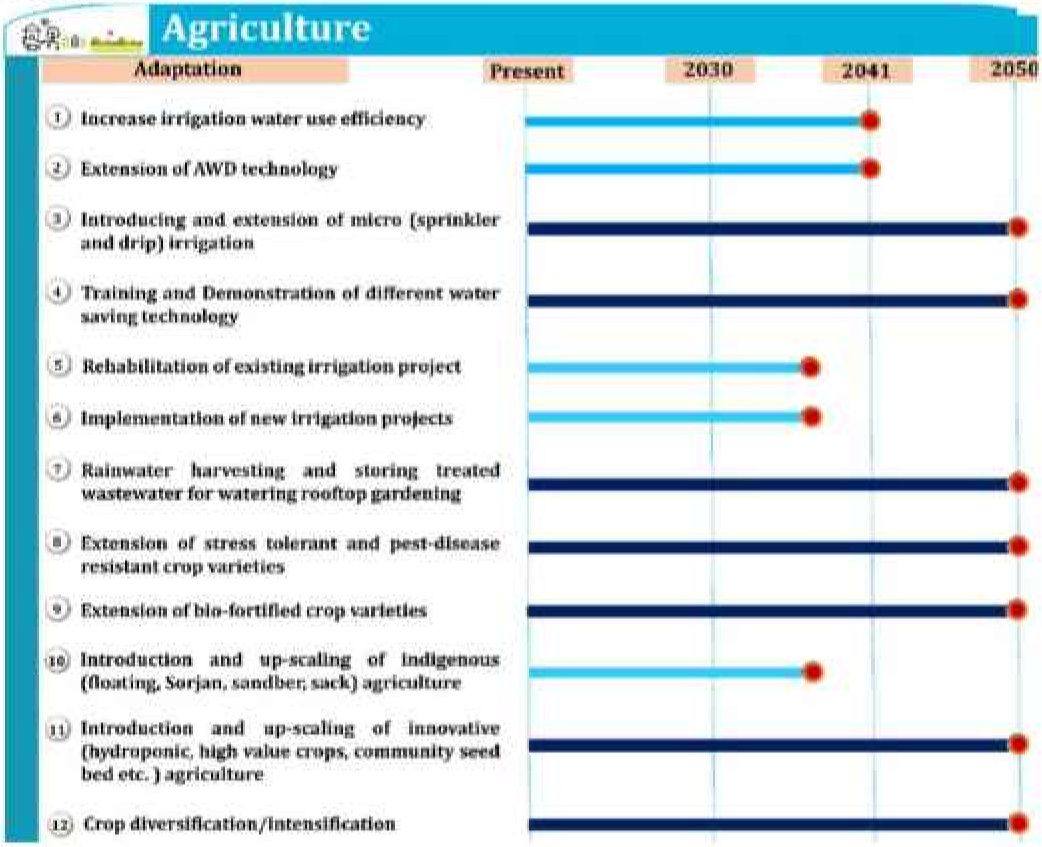
"Ashrayan" Project

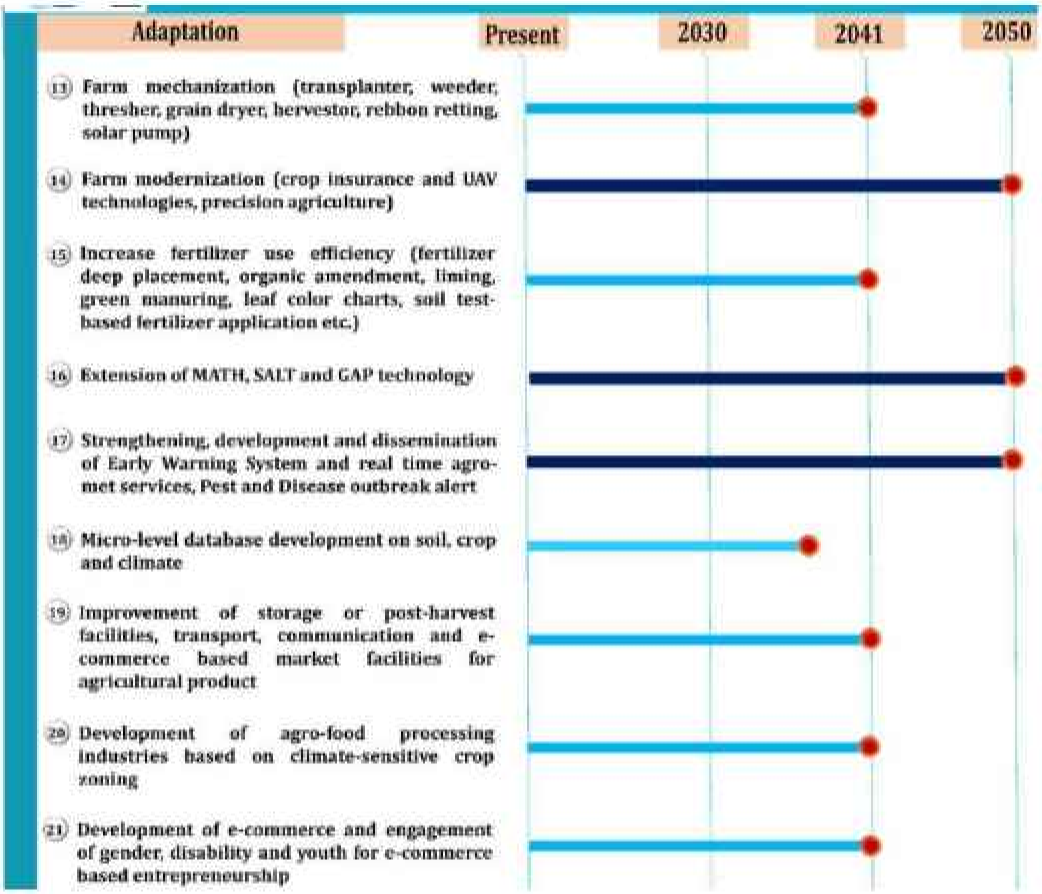
- Houses for 538,139 landless families
- 1.5 million tree plantations
- Rainwater harvesting, solar home systems and improved cook stoves

Khurushkul Ashrayan Project

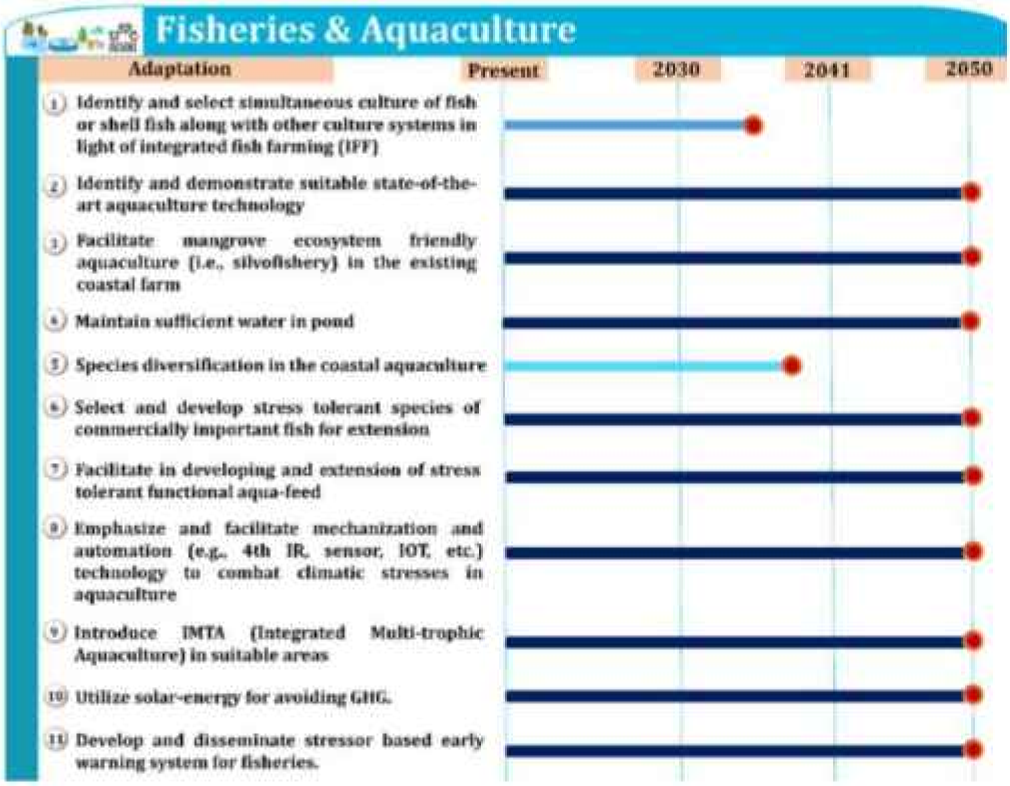
- 139 five-storey buildings with modern facilities to shelter 4,409 climate refugee families

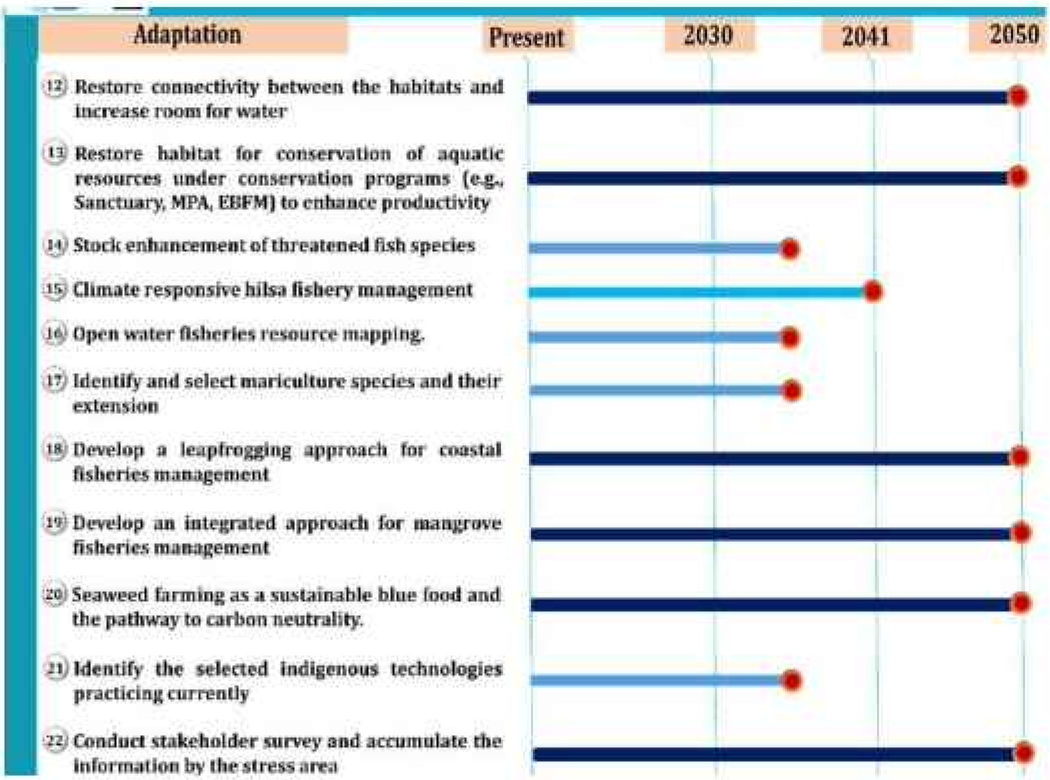
Agriculture



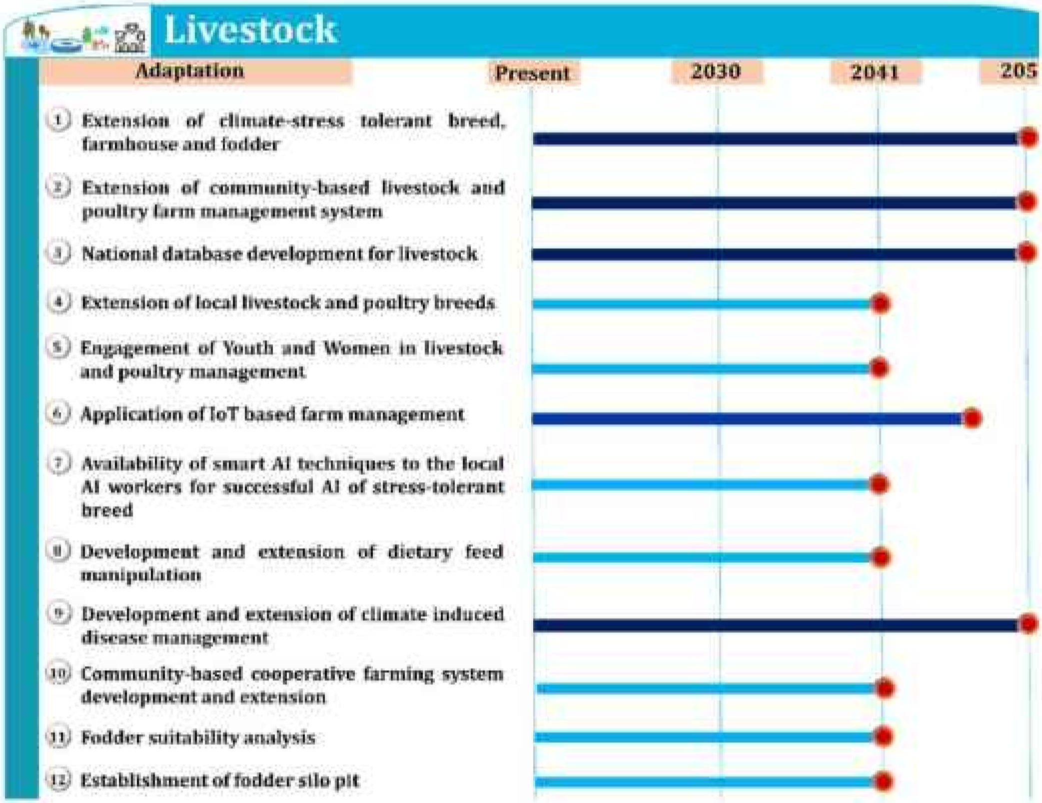


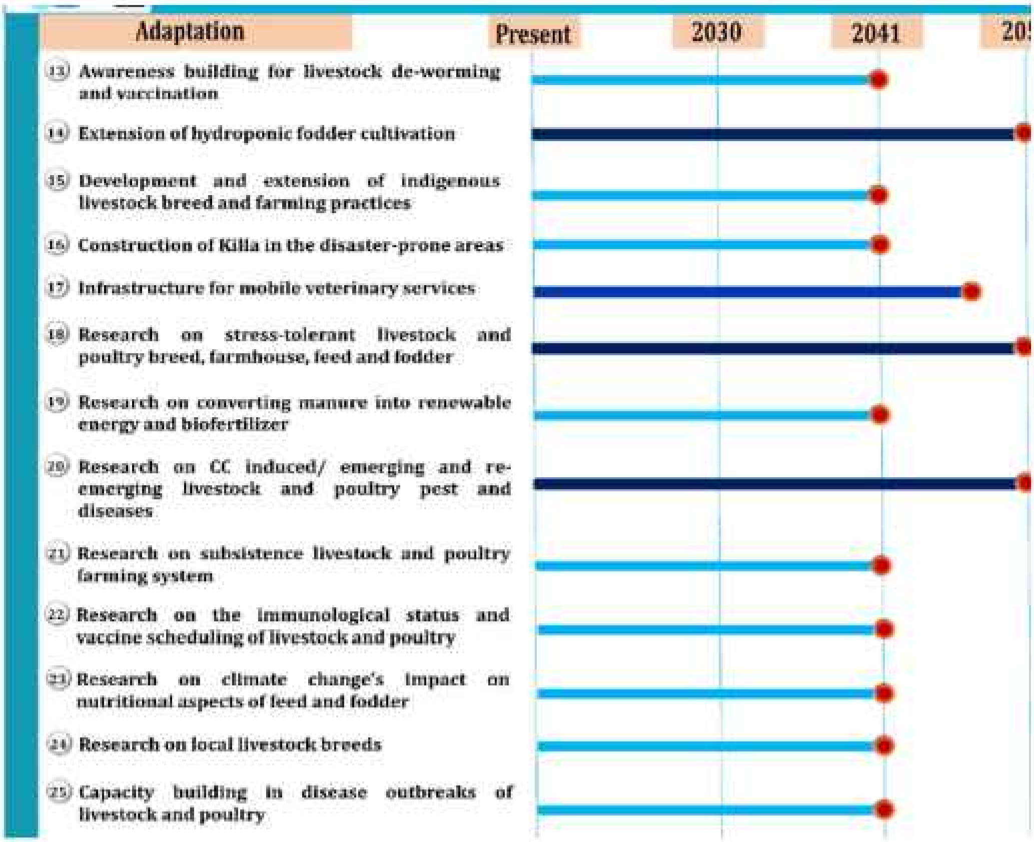
Fisheries and Aquaculture



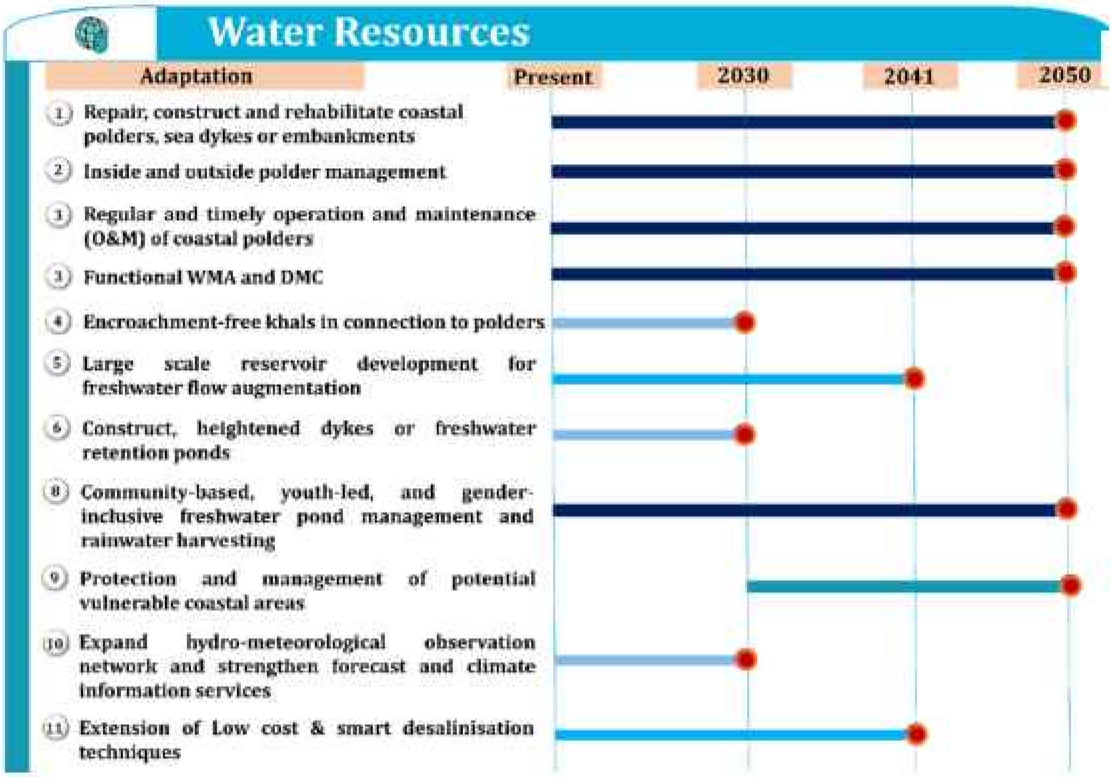


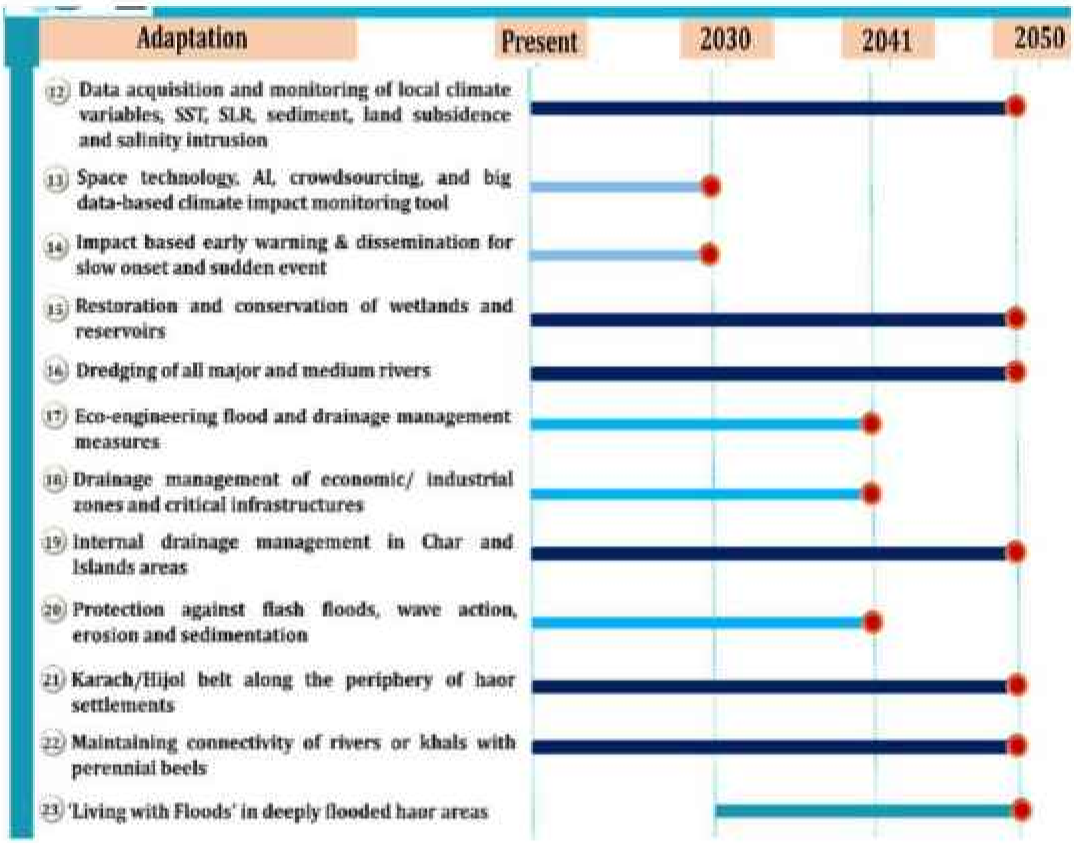
Livestock


Livestock
Adaptation
Present
2030
2041
205
1 Extension of climate-stress tolerant breed, farmhouse and fodder
2 Extension of community-based livestock and poultry farm management system
3 National database development for livestock
4 Extension of local livestock and poultry breeds
5 Engagement of Youth and Women in livestock and poultry management
6 Application of IoT based farm management
7 Availability of smart AI techniques to the local AI workers for successful AI of stress-tolerant breed
8 Development and extension of dietary feed manipulation
9 Development and extension of climate induced disease management
10 Community-based cooperative farming system development and extension
11 Fodder suitability analysis
12 Establishment of fodder silo pit


Adaptation
Present
2030
2041
20
13 Awareness building for livestock de-worming and vaccination
14 Extension of hydroponic fodder cultivation
15 Development and extension of indigenous livestock breed and farming practices
16 Construction of Killa in the disaster-prone areas
17 Infrastructure for mobile veterinary services
18 Research on stress-tolerant livestock and poultry breed, farmhouse, feed and fodder
19 Research on converting manure into renewable energy and biofertilizer
20 Research on CC induced/ emerging and re-emerging livestock and poultry pest and diseases
21 Research on subsistence livestock and poultry farming system
22 Research on the immunological status and vaccine scheduling of livestock and poultry
23 Research on climate change's impact on nutritional aspects of feed and fodder
24 Research on local livestock breeds
25 Capacity building in disease outbreaks of livestock and poultry

Water Resources





Interventions:

Investment summary of the NAP

Climate-Smart Agriculture in Bangladesh: Technologies and Practices

Dr. Md. Baktear Hossain[1] and Dr. M. Jahiruddin[2]
[1]Member Director (NRM), BARC; [2]Prof. (Rtd.), BAU
[1]**Email:** baktear.sac@gmail.com

1. Introduction

Bangladesh, the eighth most populous nation worldwide, is home to 169.4 million people in an area of 148,460 square kilometers (14.85 million hectares). Agriculture plays a vital role in the livelihoods of the people, providing employment and contributing significantly to the GDP. Over 40% of the country's workforce is employed in the agricultural sector, contribution 11.6% to the GDP, with the crops sub-sector alone contributing 7.25% (WB, 2022). Bangladesh has achieved food self-sufficiency, particularly in rice, fruits, fish, meat and eggs, transforming from a food deficit to a food-sufficient nation (Bokhtiar and Samsuzzaman, 2023). Agricultural policy reforms and technological innovations have played a crucial role in this transformation. The cropping intensity has increased from 177% in 2000 to 198% in 2020. Major crops grown in Bangladesh include rice, wheat, maize, potato, jute sugarcane, pulses, and vegetables. In addition to crop farming, livestock, and fisheries are vital components of the agricultural sector.

Despite recent achievement in agriculture, Bangladesh faces several challenges that could threaten its progress. The cultivable area has decreased, from 9.44 million hectares in 2000 to 8.77 million ha in 2020 while the population continues to increase by 2 million per year (http://www.worlddata). Climate vulnerability poses significant challenges, leading to issues such as sea level rise, salinity, drought, and floods. Bangladesh is vulnerable to both disaster and climate change and ranked the seventh extreme disaster risk prone country in the world as per the report from the Global Climate Risk Index 2021. Five fragile ecosystems are identified across the country – Barind, Char, Coastal, Hoar, and Hill ecosystems –where cropping intensity and crop productivity are notably low (Bokhtiar et al, 2023).

Climate change exerts profound influence over agriculture and the adoption of climate-smart technologies. The impacts are multifaceted, encompassing extreme weather events (droughts, floods, salinity, heatwaves), shifts in crop growing conditions (alterations in growing season timing and duration), soil fertility degradation (intensified by high temperatures and submergence), pest and disease outbreaks (driven by changing pest and disease distribution), and water scarcity (stemming from erratic rainfall patterns and flood-related water waste).

Climate-smart Agriculture (CSA) represents a farming approach designed to tackle the challenges that climate change presents to food production, all while fostering sustainable agriculture and rural progress. This approach recognizes the necessity of bolstering food output to sustain a growing populace, concurrently curbing greenhouse gas emissions, and heightening resilience against climate change impacts. The core tenets of Climate-smart Agriculture encompass:

I. **Sustainable enhancement of agricultural productivity and incomes:** This involves optimizing production efficiency and augmenting yields via novel technologies, as well as better management of natural resources like water and soil.
II. **Cultivating resilience against climate change impacts:** This entails fortifying farming systems to withstand the repercussions of shifting weather patterns and other climate-associated risks.
III. **Mitigation and/or reduce of greenhouse gas emissions:** This centers on diminishing emissions arising from agricultural activities, such as fertilizer usage, and augmenting carbon storage within the soil.

Presently, Bangladesh boasts 61 available CSA technologies. These technologies and practices are actively applied to endorse sustainable agricultural production and elevate resilience against climate change repercussions. Notable CSA technologies encompass:

i. **Precision agriculture (GPS and remote sensing):** Utilizing GPS and remote sensing to enhance farming accuracy.
ii. **Climate-resilient crop varieties:** Incorporating varieties that endure challenging conditions such as salinity, drought, submergence, cold, and shorter growth cycles.
iii. **Improved water management systems:** Optimizing water usage and efficiency, in addition to conservation-oriented practices.
iv. **Conservation agriculture:** Embracing practices like reduced tillage, cover cropping, and legume-based crop rotations.
v. **Enhanced livestock management:** Enhancing livestock efficiency, curbing emissions, and enhancing animal health.
vi. **Year-round aquaculture:** Providing a consistent source of protein-rich food for Bangladesh throughout the year.

These CSA technologies embody a proactive stance in facing the complexities of climate change while concurrently bolstering agricultural sustainability and securing food production.

2. Concept and Pillars of CSA

Climate Smart Agriculture (CSA) encompasses practices aimed at enhancing crop productivity and bolstering land resilience against the backdrop of climate change impacts. This practice involves the fusion of sustainable farming techniques tailored to address the specific climate challenges encountered by distinct agricultural communities, culminating in what can be termed as "climate-smart agriculture," a facet akin to sustainable farming practices. The initial stride entails a meticulous evaluation of precise climate risks. For instance, a farm grappling with prolonged water scarcity necessitates disparate strategies from those required by one facing recurrent inundation. Diverse tools are available to assess climate risk and ecosystem vulnerability, guiding the selection of suitable crops for specific environments. According to the FAO (2010), Climate Smart Agriculture (CSA) delineates

an approach for augmenting productivity, adaptation, and resilience to climate change, while concurrently curbing or eliminating greenhouse gas (GHG) emissions.
CSA is upheld by three foundational pillars:

- ♣ **Sustainable Enhancement of Food Security:** Achieved by elevating agricultural productivity and incomes.
- ♣ **Enhanced Resilience and Adaptation:** Ensuring farms are equipped to weather the challenges posed by climate change.
- ♣ **Greenhouse Gas Emission Mitigation:** Creating avenues to reduce emissions in comparison to projected trends, wherever feasible.

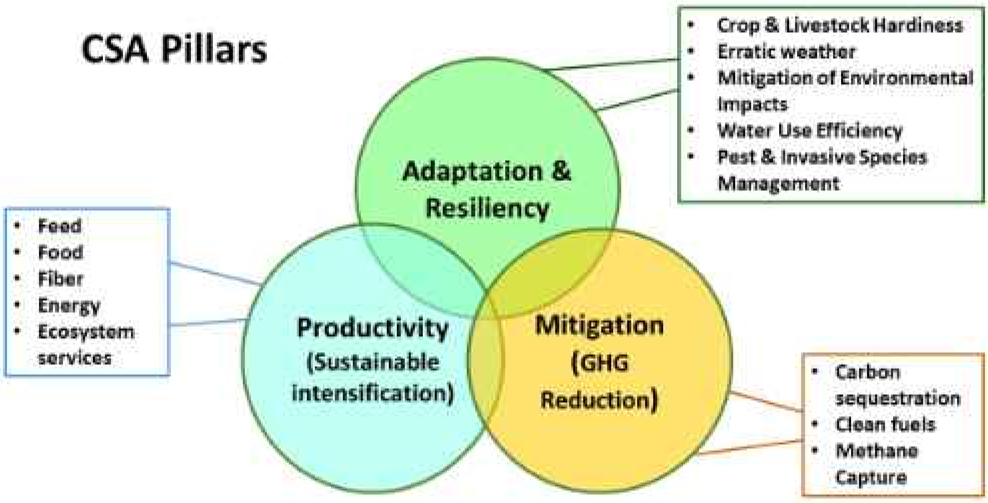


Fig. 1 Three pillars of climate-smart agriculture

(Source: FAO, 2013)

3. Brief Description of Individual Technology

Currently, the nation boasts a total of 61 available CSA technologies and practices under the project "Consortium for Scaling up Climate-Smart Agriculture in South Asia (C-SUCSeS) of SAARC Agriculture Centre in 2022. These technologies and practices can be classified into six distinct categories (Aggarwal et al. 2013) based on different dimensions and level of climate-smartness, namely Weather-smart, Carbon-smart, Water-smart, Nutrient-smart, Energy-smart, and Knowledge-smart. For a comprehensive overview, Table 1 displays the entire roster of 61 CSA technologies and practices, delineating their respective categories and priority standings.

Table 1 Climate Smart Agricultural technologies and their categories

Name of CSA Technologies and Practices	Categories of CSA technologies	Priority ranking* (High-H, Medium-M, Low-L)
1. Saline-tolerant rice	Weather-smart, Knowledge-smart	H
2. Saline-tolerant potato	Weather-smart, Knowledge-smart	M
3. Saline-tolerant mustard	Weather-smart, Knowledge-smart	M
4. Heat-tolerant wheat	Weather-smart, Knowledge-smart	M

5. Heat-tolerant maize	Weather-smart, Knowledge-smart	M
6. Heat-tolerant sweet potato	Weather-smart, Knowledge-smart	M
7. Heat-tolerant grass pea and lentil	Weather-smart, Knowledge-smart	M
8. Heat-tolerant barley	Weather-smart, Knowledge-smart	M
9. Heat-tolerant foxtail millet	Weather-smart, Nutrient-smart	M
10. Heat-tolerant proso millet	Weather-smart, Nutrient-smart	M
11. Heat-tolerant groundnut	Weather-smart, Nutrient-smart	M
12. Drought-tolerant rice	Weather-smart, Knowledge-smart	M
13. Short duration T. Aman rice	Weather-smart, Knowledge-smart	M
14. Late blight-resistant potato	Knowledge-smart	H
15. Disease-resistant sugarcane	Weather-smart, Knowledge-smart	L
16. Biochar application	Nutrient-smart, Carbon-smart	H
17. Zero tillage garlic cultivation	Carbon-smart, Energy-smart, knowledge-smart	H
18. Inclusion of mustard in the single cropping pattern	Knowledge-smart	M
19. Double transplanting of T. *Aman* rice	Knowledge-smart	M
20. Less irrigation requiring cropping pattern	Water-smart	M
21. Levee management in T. Aman rice season	Water-smart	L
22. Growing vegetables with low-land rice	Knowledge-smart	M
23. Dibbling method of planting in zero-tilled wetland	Knowledge-smart	M
24. Relay cropping of cowpea/ grass pea in T. Aman rice for coastal areas	Knowledge-smart	M
25. Maize seedling transplanting system	Knowledge-smart	M
26. Floating agriculture system	Weather-smart, Knowledge-smart	M
27. Sorjan farming in coastal saline soil	Weather-smart, Knowledge-smart	M
28. Furrow and ridge cropping for coastal saline areas	Weather-smart, Knowledge-smart	M
29. Pyramid cropping for coastal saline areas	Weather-smart, Knowledge-smart	M
30. Maize-kenaf cropping system in haor areas	Knowledge-smart, Water-smart	M
31. Silicon-enriched rice husk ash management in wheat	Nutrient-smart, Knowledge-smart	M
32. Liming	Carbon-smart, Nutrient-smart, and Knowledge-smart	M
33. Integrated nutrient management	Carbon-smart, Nutrient-smart, and Knowledge-smart	H
34. Black gram production technology in haor areas	Weather-smart, Knowledge-smart	M
35. Mulching in watermelon field	Water-smart, Knowledge-smart	M
36. Mixed/Intercropping	Carbon-smart, Knowledge-smart	H
37. Integrated rice –fish-vegetables system	Weather-smart, Knowledge-smart	M
38. Spaced transplanting (STP) for sugarcane	Weather-smart, Knowledge-smart	L
39. Litchi-based agroforestry system	Carbon-smart	H
40. Integrated pest management of cucurbit fruit fly	Knowledge-smart	M

41. Integrated pest management of mango/guava fruit fly	Knowledge-smart	M
42. Management of litchi fruit borer	Knowledge-smart	M
43. Management of banana leaf and fruit beetle	Knowledge-smart	M
44. Bio-rational management of varroa mite in honeybee colony	Weather-smart, Knowledge-smart	L
45. Bio-rational management of *Spodoptera litura* in vegetables and aroid	Knowledge-smart	M
46. Integrated management of powdery mildew and root-knot diseases of cucurbits	Knowledge-smart	L
47. Integrated viral disease management of vegetable crops	Knowledge-smart	M
48. Integrated management of bacterial wilt disease of brinjal, tomato, and potato	Knowledge-smart	M
49. Biological control of sugarcane stem borer	Weather-smart, Knowledge-smart	L
50. Rainwater Harvest	Weather-smart, Knowledge-smart	M
51. Alternate Wetting and Drying (AWD) technology	Water-smart, Weather-smart, and Knowledge-smart	H
52. Solar-powered irrigation	Energy-smart	M
53. Alternate furrow irrigation technology	Water-smart, Weather-smart, and Knowledge-smart	M
54. Drip irrigation/fertigation technology	Water-smart, Weather-smart, and Knowledge-smart	H
55. Conjunctive use of fresh and saline water in coastal areas	Water-smart, Weather-smart	M
56. Surface drainage technique	Knowledge-smart	H
57. Non-puddled mechanical rice seedling transplanter	Energy-smart	H
58. Raised bed planter	Carbon-smart, Energy-smart, Knowledge-smart	H
59. Laser land leveling	Water-smart, Knowledge-smart	M
60. Reduced tillage machinery for sugarcane cultivation	Energy-smart, Weather-smart	M
61. Strip planting system	All six categories	H

*Priority ranking of the CSA technologies were done based on the farmers' preferences and willingness-to-pay for the respective technology.

The details of all these listed technologies are stated below.

A. Climate Resilient Crop Varieties

A growing emphasis is placed on an extensive array of crop production practices that can be deemed 'climate-smart,' as viewed through both adaptation and mitigation lenses. Notably, crop-based measures, such as drought-tolerant and short-duration varieties, wield the potential to significantly curtail the perils of yield decline or crop loss (Roy et al., 2014) (Refer to Table 2). Predominantly, salinity, drought, and heat constitute major abiotic stresses that exert a detrimental impact on crop productivity, consequently impinging upon food security. This challenge is exacerbated particularly in light of climate change occurrences and their escalating consequences.

Table 2 Stress-tolerant crop varieties

Types of stress-tolerant varieties	Crop varieties
Salinity-tolerant rice varieties	BRRI dhan47, 53, 54, 55, 61, 67, 73, 78, 97 & 99 Bina dhan- 8 & 10
Drought-tolerant rice varieties	BRRI dhan56, 57, 66 & 71
Short duration or early maturing T. Aman rice	BRRI dhan76, 77 & 87
Submergence-tolerant rice varieties	BRRI dhan51, 52 & 79 (T. Aman) BRRI dhan78 (T. Aman Saline condition) Binadhan-11, 12 & 23 (T. Aman)
Cold-tolerant rice varieties	BRRI dhan18, 36, 55 & 69 (Boro)
Heat-tolerant crop varieties	BARI Gom-33, BWMRI Gom-1, 2 BARI Barley-1, 2, 3, 4, 5 & 6 BARI hybrid maize-12, 13 & 16 BARI Alu-72 & 73; BARI Mistialu-8 BARI Khesari-3, BARI Masur-8; BARI Chinabadam-10 BARI Kaon-1, 2 & 3; BARI Cheena-1
Salt tolerant other crops	BARI Sarisha-11 & 16; BARI Alu-72, 73 & 78 BARI Sweet potato-6 & 7; BARI Til-4; BARI Masur-1; BARI Tomato-14; BARI Gom-25; BARI Barley-7 Binagom1; Binachinabadam-6, 7, 8 & 9; Binatil1 Binasoyabean-2 & 6; BJRI Deshi Pat-10
Late blight disease-resistant potato	BARI Alu-77, 90 & 91
Red rot and Smut disease-resistant sugarcane	Isd 39, Isd 40, BSRI Akh 41, BSRI Akh 43, BSRI Akh 44, BSRI Akh 45 and BSRI Akh 46.

4. Conclusions and Recommendations

Bangladesh has achieved remarkable progress in food production; however, the sustainability of this achievement faces numerous challenges, with climate change effects being a major concern. The country identifies five fragile ecosystems, referred to as hotspots in the Bangladesh Delta Plan 2100: Barind, Char, Coastal, Haor, and Hill ecosystems. In these areas, cropping intensity and crop productivity are generally low to very low. Consequently, there is an opportunity to develop and introduce suitable CSA technologies that align with the impacts of climate change, including salinity, drought, floods, erratic rainfall, and more.

Inventory of CSA Technologies and Practices in Bangladesh was conducted as one of the activities under the project "Consortium for Scaling up Climate-Smart Agriculture in South Asia (C-SUCSeS) of SAARC Agriculture Centre in 2022. The scientists of OFRD, BAR have compiled an inventory of 61 CSA technologies tailored to the vulnerable ecosystems experiencing rapid climate change. These technologies consist of both newly developed methods and age-old practices. The adoption of these technologies is essential for ensuring sustainable agricultural production and building resilience against the effects of climate change. These climate-resilient technologies can be categorized into five groups: (i) Improved crop varieties: These include varieties that are tolerant to salt, heat, drought, submergence, cold, diseases, and have shorter growth durations; (ii) Soil and crop management: Practices like biochar utilization, liming, composting, integrated nutrient management, floating agriculture, sorjan farming, silicon application, green manure, mulching, conservation agriculture, integrated rice-fish-vegetables systems, spaced transplanting (STP) for sugarcane, and agroforestry systems are beneficial in these contexts; (iii) Pest management: Techniques such as integrated pest management, bio-rational pest control, and biological pest control play a crucial role in controlling pests sustainably; (iv) Irrigation management: Methods such as rainwater harvesting, solar-powered irrigation, alternate wetting and drying (AWD), and drip irrigation contribute to efficient water use in agriculture; and (v) Farm mechanization: Technologies like raised bed planters, laser land leveling (LLP), strip and zero planting systems, and others promote efficiency in farming practices. The Conservation Agriculture (CA) approach encompasses reduced tillage, residue retention, and legume-based crop rotations, which hold significant value in improving soil health and crop productivity sustainably.

It's important to note that not all these CSA technologies are equally suitable for every ecosystem, cropping season, or farm category. Recognizing this diversity, the Bangladesh Government formulated the National Agriculture Policy 2018 and adopted strategies to promote sustainable and profitable agriculture across the country. Consequently, the future of food and nutrition security depends on the effective and widespread adoption of climate-resilient practices, particularly in ecologically challenged areas.

5. References

Bokhtiar, S. M., & Samsuzzaman, S. (2023). *A Development Trajectory: From Food Deficit to Surplus*. Bangladesh Agricultural Research Council.

Bokhtiar, S. M., Samsuzzaman, S., Jahiruddin, M., & Panaullah, G. M. (2023). *Agricultural Development for Fragile Ecosystems in Bangladesh*. Bangladesh Agricultural Research Council.

FAO. (2010). Climate-smart agriculture: Policies, practices, and financing for food security, adaptation, and mitigation. Food and Agriculture Organization (FAO) of the United Nations, Rome, Italy.

Roy, R., Chan, N. W., & Rainis, R. (2014). Rice farming sustainability assessment in Bangladesh. *Sustainability Science*, 9, 31–44. https://doi.org/10.1007/s11625-013-0234-4

WB (World Bank). (2022). Bangladesh Country Climate and Development Report. CCDR Series; World Bank Group, Washington, DC.

Crop Simulation Modelling in Climate-Smart Irrigation Management: Techniques and Application

Mohammad Abdur Rashid
Principal Specialist, Agricultural and Fisheries Division
CEGIS, Dhaka
Email: arashid@cegisbd.com

Introduction

Modeling is the use of equations or sets of equations to represent the behavior of a system. In effect crop models are computer programmes that mimic the growth and development of crops (USDA, 2007). Model simulates or imitates the behavior of a real crop by predicting the growth of its components, such as leaves, roots, stems and grains. Thus, a crop growth simulation model not only predicts the final state of crop production or harvestable yield, but also contains quantitative information about major processes involved in the growth and development of the crop.

Crop simulation models

Crop simulation models integrate current scientific knowledge from many different disciplines, including: crop physiology, plant breeding, agronomy, agro-meteorology, soil physics, soil chemistry, pathology and entomology etc. Cropping systems models pro-vide a cost-effective framework for assessing water man-agement strategies to optimize the use of limited water re-sources in both irrigated and dryland cropping systems.This collection highlights the state of the art in: (1) evapo-transpiration modeling, (2) model development and param-eterization, (3) application of crop models for irrigationscheduling, (4) coordinated water and nutrient manage-ment, (5) soil water management, (6) risk assessment ofwater-limited irrigation management, and (7) regional as-sessments of climate impact.

Input data requirements for crop models

Weather: Maximum and minimum temperature, rainfall, relative humidity, solar radiation and wind speed. Weather data is required at daily time step to assess daily crop growth processes.

Soil: Thickness of soil layer, pH, EC, N, P, K, soil organic carbon, soil texture, sand and clay percent, soil moisture, saturation, field capacity and wilting point of soil, bulk density.

Crop: Crop variety, crop growth stage, date of sowing date/transplanting, harvesting date, crop co-efficient, rooting depth, crop phenotype and genetic information

Crop management: Seed rate and depth of seeding, Use of inputs in the crop field, namely, irrigation, fertilizer, manure, crop residue etc. Amount of these inputs are specified along with their type, date of application and depth of placement.

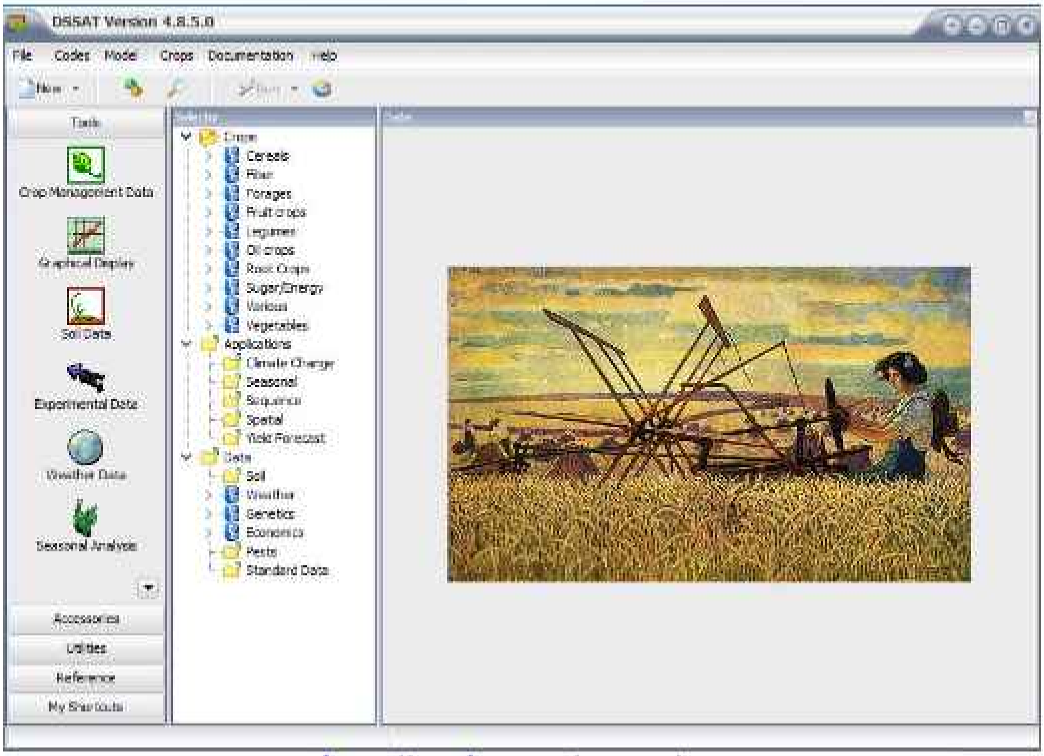
Challenges of crop modeling

- Corp models required large amount of input data, which may not be available with the user
- Requires skilled manpower, good knowledge of computers and computer languages, and multidisciplinary knowledge.
- No model can take into account all the existing complexity of biological systems. Hence simulation results cannot be very accurate in reality.
- A model can always a tool for improving critical thought, but not a substitute for it.
- Models can help formulate hypotheses and improve efficiency of field experiments, but they do not eliminate the need for continued field experimentation.
- Models developed for a specific region cannot be used as such in another region.
- Proper parameterization and calibration is needed before using a model.

Available Crop Model in the Region

DSSAT - The Decision Support System for Agrotechnology Transfer

International Benchmark Sites Network for Agrotechnology Transfer Project (IBSNAT), University of Florida & IFDC.



https://get.dssat.net/request/

Key Input

- ✓ daily weather data,
- ✓ soil surface and profile information,
- ✓ crop management, including crop, variety, planting date, plant spacing, and inputs such as fertilizer and irrigation
- ✓ crop phenotype and genetic information

Key Output

- to determine the impact of climate change on production and potential adaptation practices that should be developed for farmers at a farm level.
- to determine the impact of climate change at different spatial scales at a regional level

DSSAT can be used for any region across the world, as long as the local input data are available. DSSAT has been used by more than 30,000 researchers, educators, consultants, extension agents, growers, and policy and decision makers in over 198 countries worldwide.

APSIM Model -The Agricultural Production Systems sIMulator (APSIM)

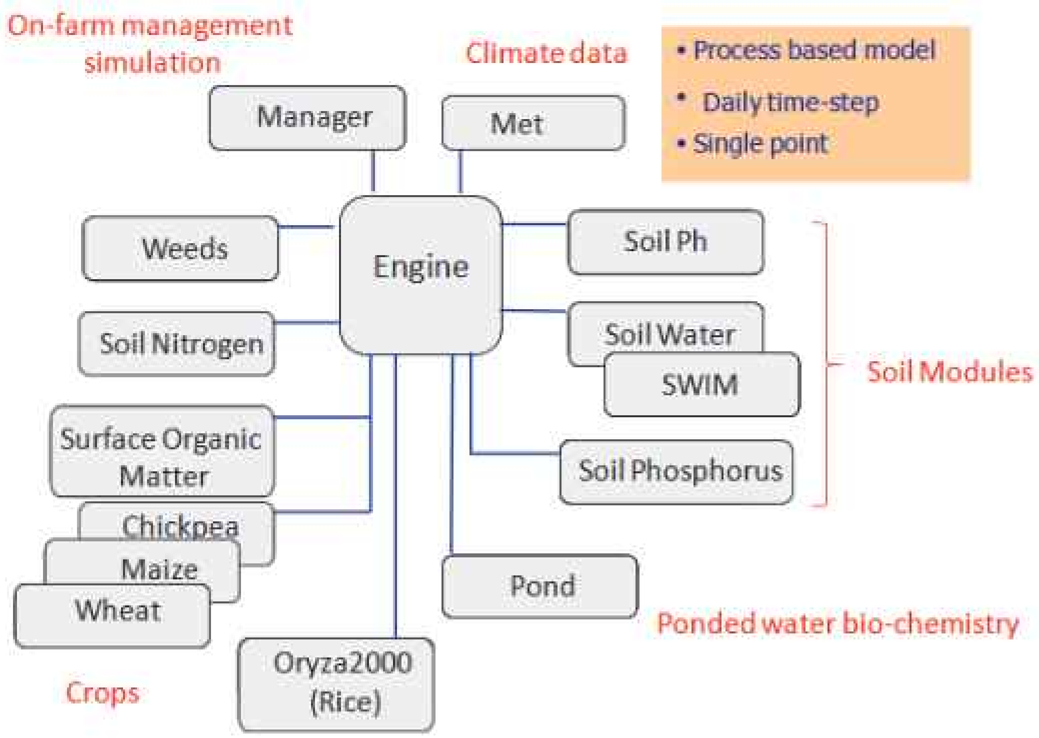
Key Input

- ✓ daily weather data,
- ✓ soil properties,
- ✓ cultivar characteristics
- ✓ agronomic management

Key Outputs

- ✓ climate change impact on crop and pasture yields, yield components, soil erosion losses.

Used in Australia, APN projects in Asia, and AIACC activities in South America.



https://www.apsim.info/download-apsim/

InfoCrop: A dynamic simulation model for the assessment of crop yields, losses due to pests, and environmental impact of agro-ecosystems in tropical environments.
National Agricultural Technology Project (NATP) of Indian Council of Agricultural Research (ICAR)

Key input

- ✓ Environment: Radiation, temperature, rainfall, wind speed, vapour pressure, flooding, frost
- ✓ Soil: Depth, pH, texture, fertility
- ✓ Variety: Its physiology
- ✓ Agronomic Management: Dates of planting/transplanting, seed rates, amount and time of irrigation and N fertilization (including organic)in different soil depths.
- ✓ Pests: population/severity of pests and their timing of appearance
    - ✓ https://www.quantitative-plant.org/model/InfoCrop

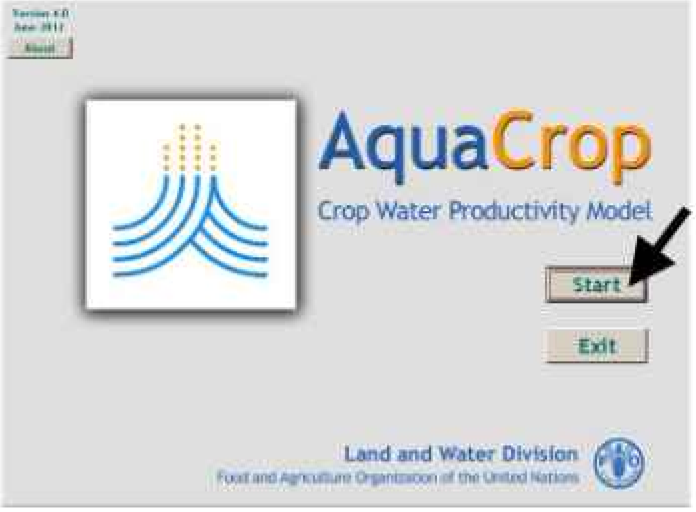
It provides daily and summary outputs on various growth and yield parameters, nitrogen uptake, green house gas emissions, soil water and nitrogen balance. It is used for several applications including yield forecast and climate change studies. It is known to perform better for tropical regions.

AquaCrop - AquaCrop is a crop water productivity model

The Land and Water Division of FAO

Key input

- ✓ climate (air temperature, reference evapotranspiration and rainfall),
- ✓ Crop (initial, final and rate of change in % Canopy Cover; initial, final and rate of deepening in root depth; biomass water productivity; harvest index; typical management conditions such as irrigation dates and amounts, sowing and harvest dates, mulching, etc,
- ✓ soil profile (sand, clay, loam, in %),
- ✓ groundwater table, field and irrigation management



https://www.fao.org/aquacrop/software/software-download/en/

It can predict biomass and yield response to water under any climatic and soil conditions, including climate change cases.

CROPWAT

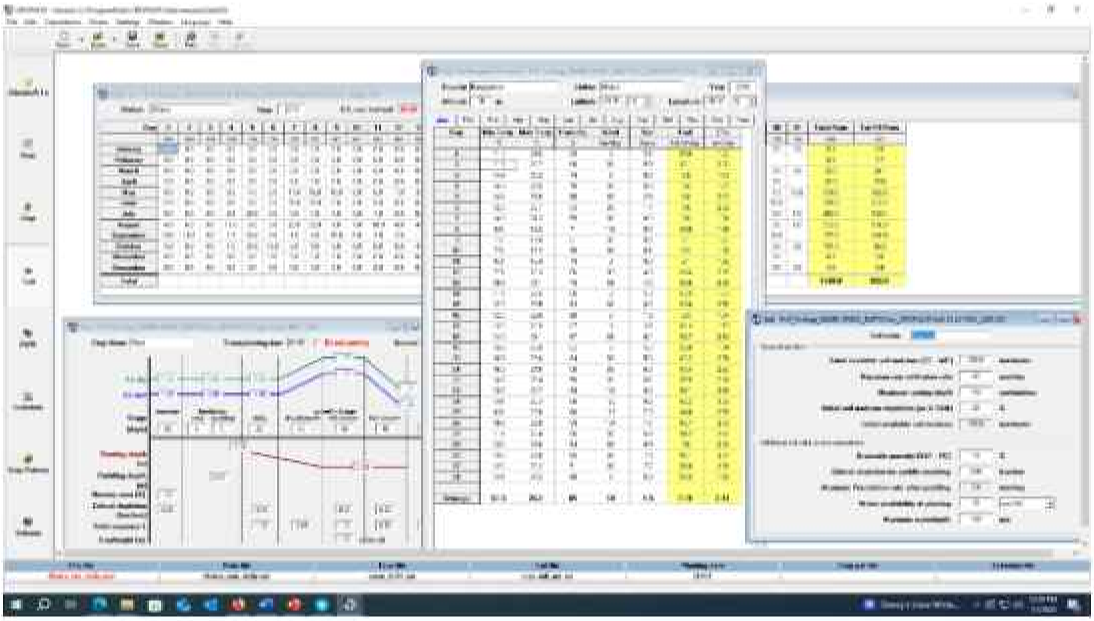
The Land and Water Division of FAO

Key Input

- ✓ reference Crop Evapotranspiration,
- ✓ rainfall data
- ✓ soil properties
- ✓ cultivar characteristics
- ✓ agronomic management
- ✓ scheduling Criteria

Key Output

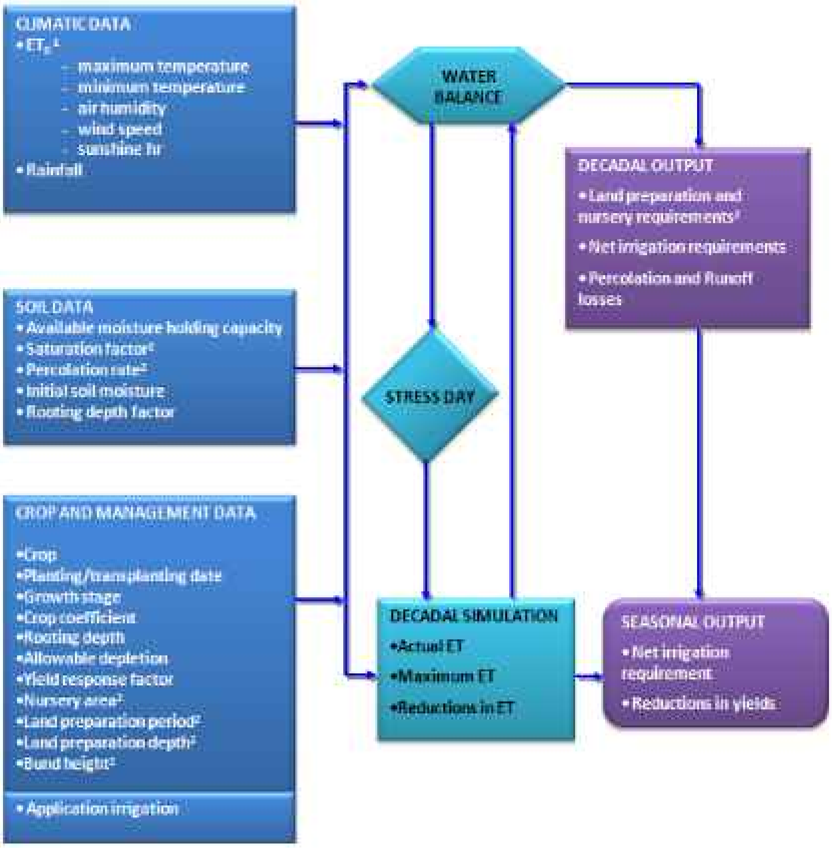
- effective rain (mm/period)
- crop water requirements CWR or Etm;
- irrigation requirements-IWR (mm/period);
- total available moisture -TAM (mm);
- readily available moisture - RAM (mm);
- daily soil moisture deficit (mm);
- irrigation interval (days)
- estimated yields reduction



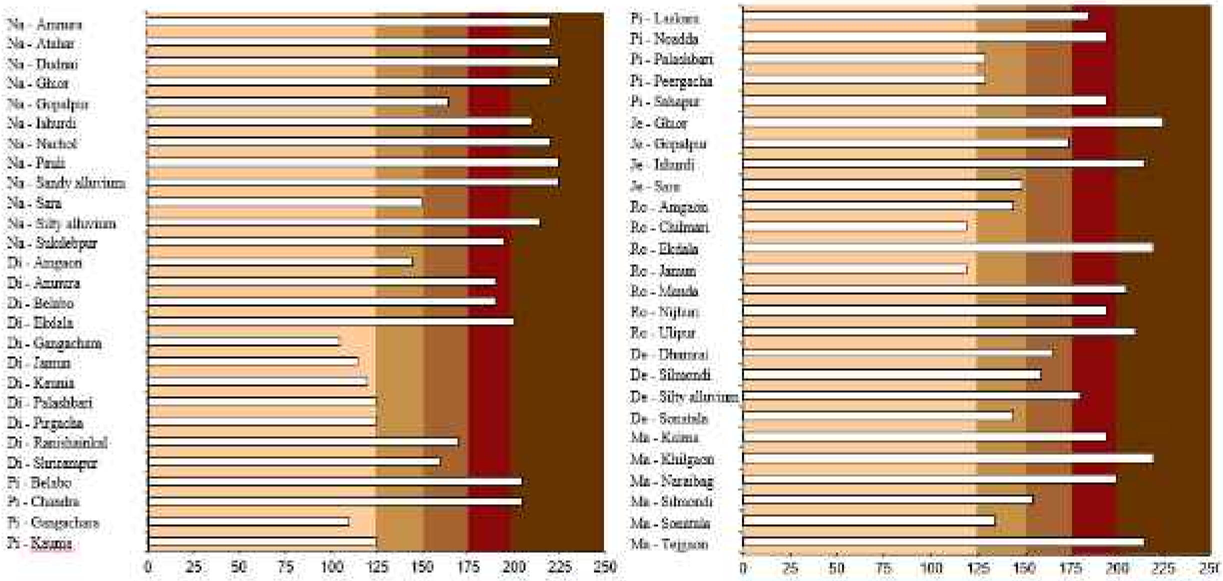
https://www.fao.org/land-water/databases-and-software/cropwat/en/

DRAS-GIS based Drought Assessment and Irrigation Water Management

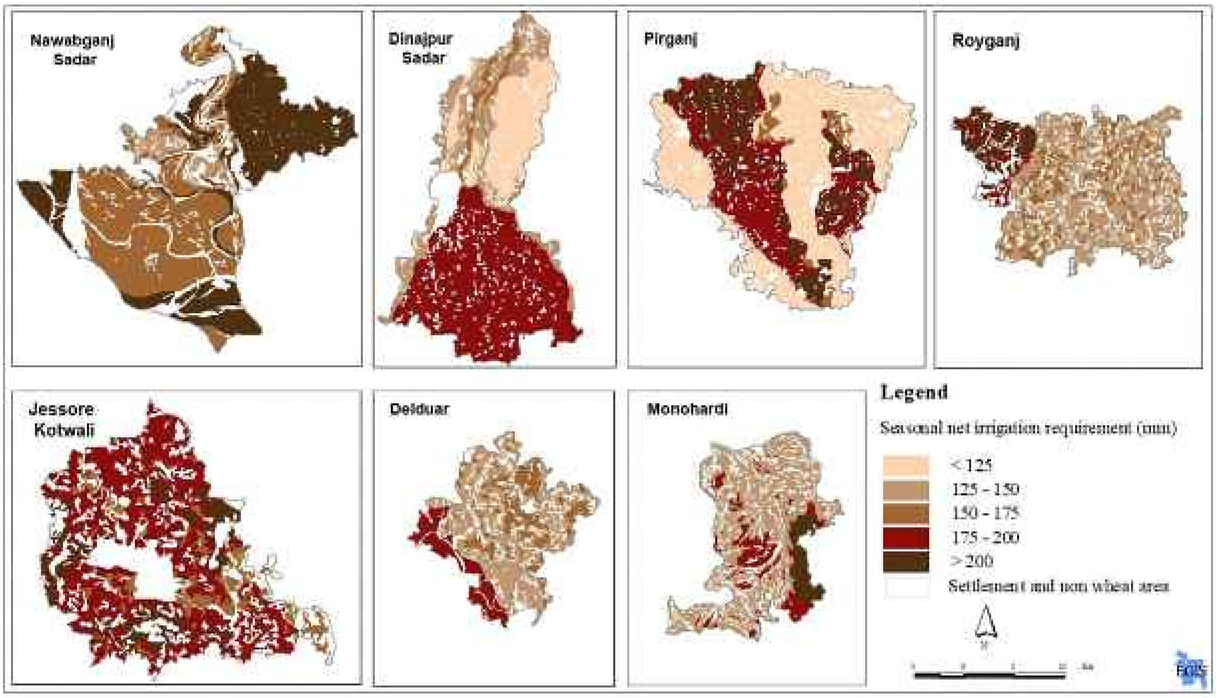
- CEGIS has developed the DRAS in collaboration with BARC. DRAS is a GIS based model and output can be visualized through maps for better understanding and planning purposes
- DRAS helps in managing the agriculture crops by- Drought Assessment and Irrigation Water Management



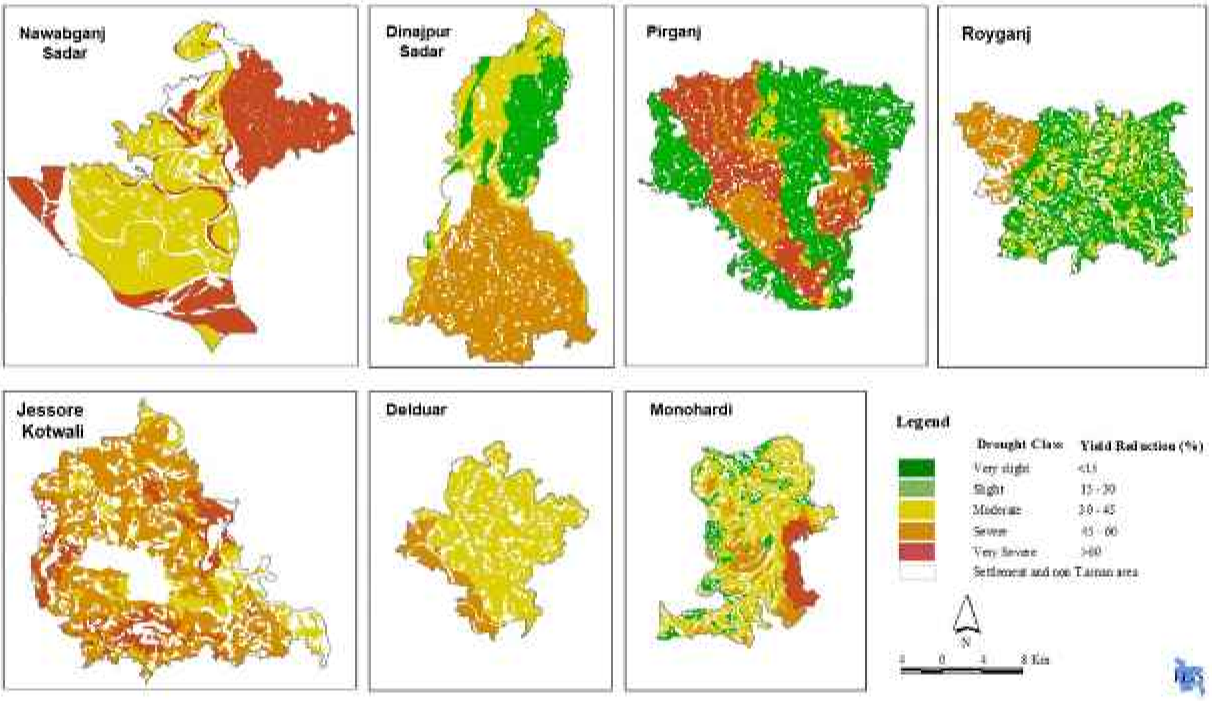
Net irrigation requirement: Wheat crop



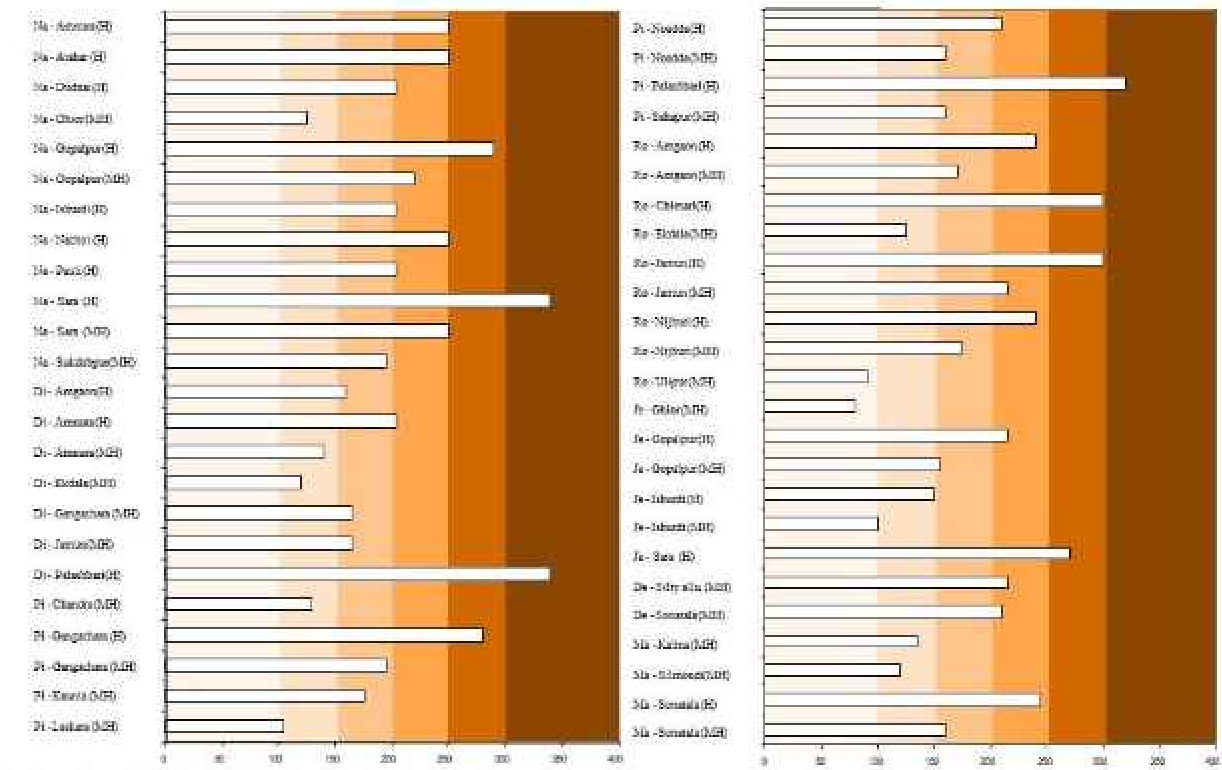
Net Irrigation Requirement Map for Wheat



Drought Classification for Wheat

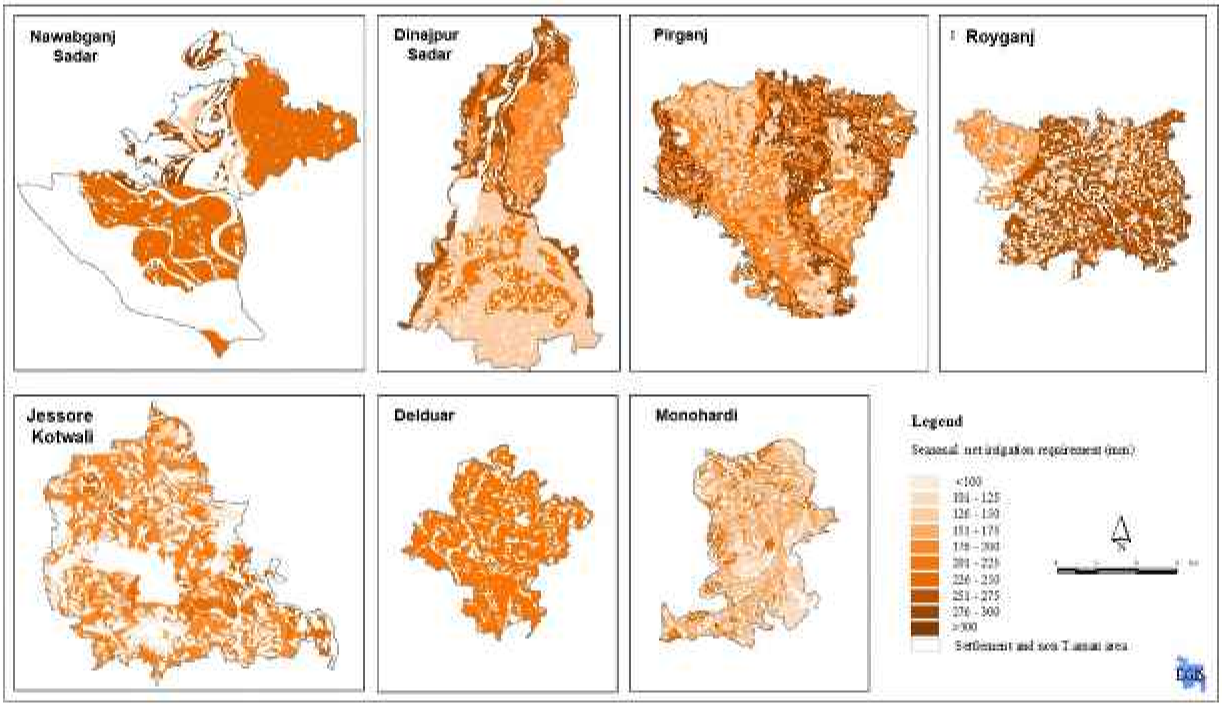


Net irrigation requirement: T Aman crop

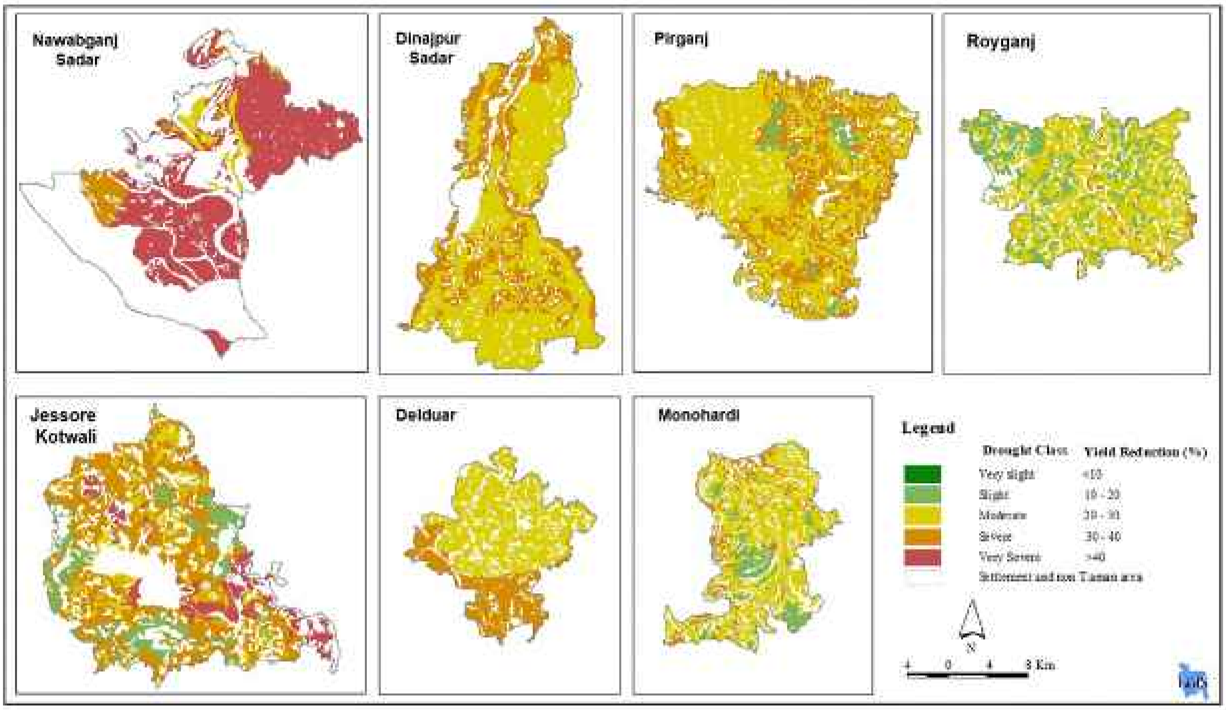


Na - Nawabganj sadar , Di - Dinajpur sadar , Pi - Pirganj , Ro - Royganj , Je - Jessore , De - Delduar , Mo - Monohardi

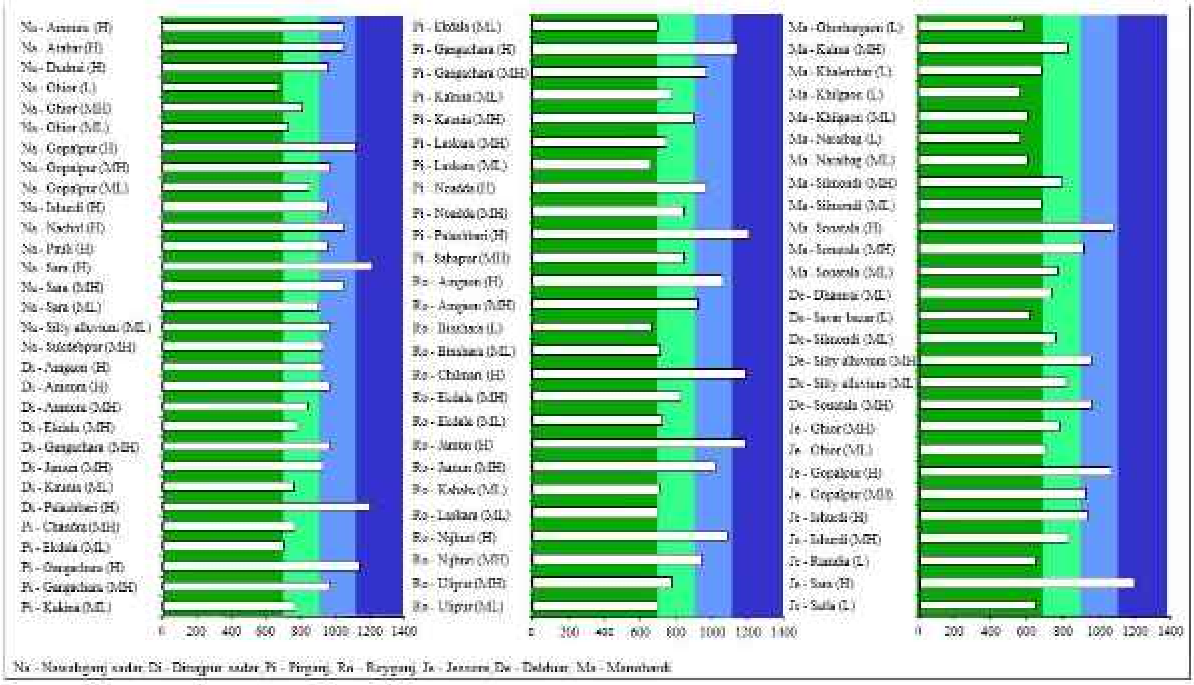
Net Irrigation Requirement Map for T Aman



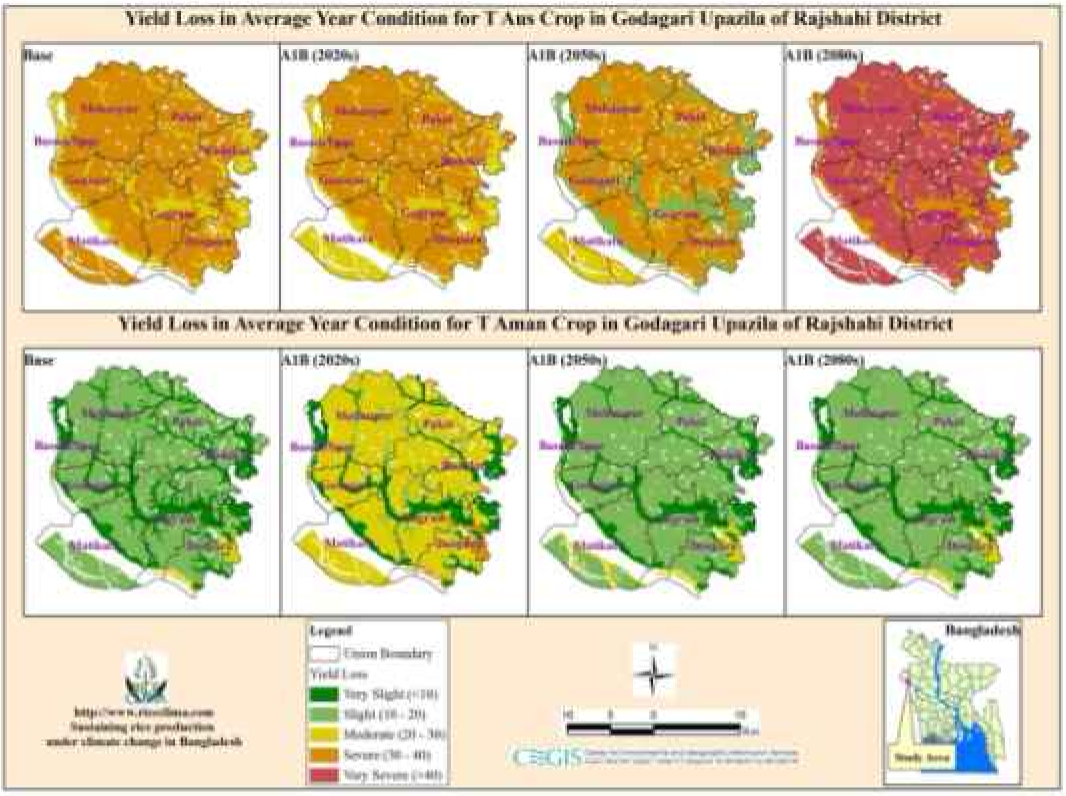
Drought Classification for T Aman



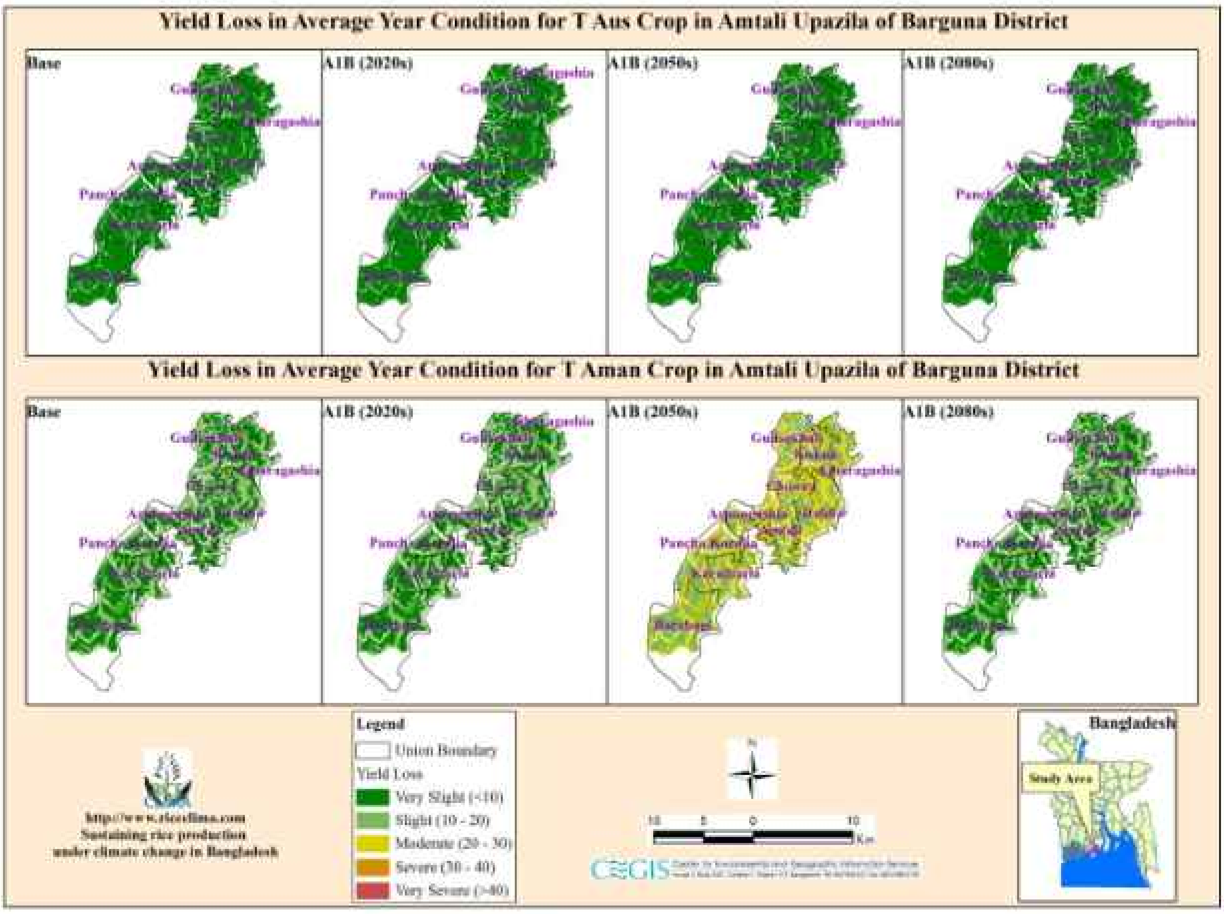
Net irrigation requirement: Boro crop



Net Irrigation Requirement Map for Boro



Saline Prone Study Area Yield Loss-T Aus and T Aman Crop



Irrigation Water Demand

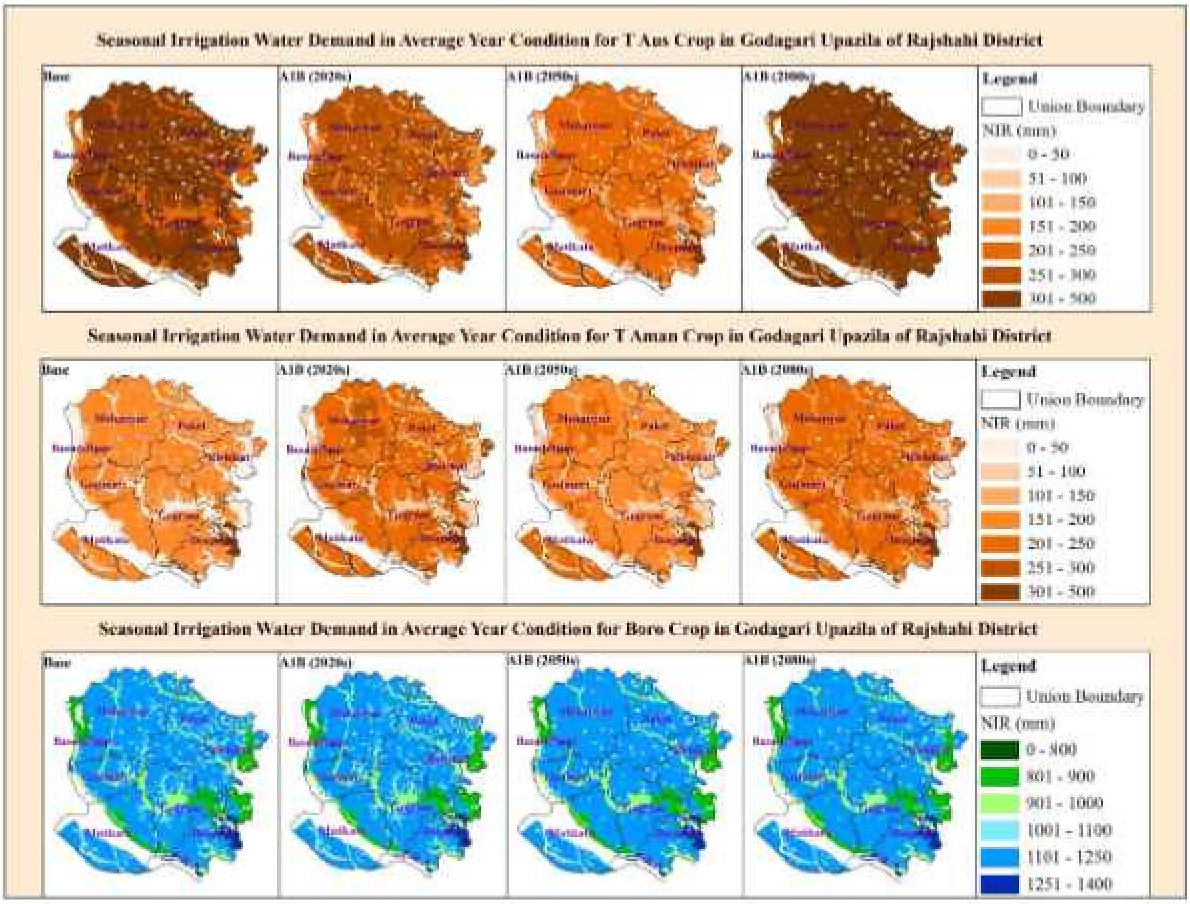
Drought prone study areas

Crop Name	Base Year NIR (mm)	Change of NIR (mm) from base situation		
		2020s	2050s	2080s
T Aus	310-350	-(60 to 70)	-(75 to 90)	+(50 to 70)
T Aman	140-180	+(60 to 70)	+(35 to 40)	+(65 to 75)
Boro	1030-1120	+(20 to 40)	+(20 to 60)	+(30 to 70)

Saline prone study areas

Crop Name	Base Year NIR (mm)	Change of NIR (mm) from base situation		
		2020s	2050s	2080s
T Aus	100-120	-(60 to 80)	-(25 to 40)	-(5 to 10)
T Aman	80-125	+(20 to 30)	+(30 to 40)	+(20 to 25)
Boro	830-880	+(10 to 20)	+(10 to 30)	+(35 to 40)

Drought Prone Study Area: Irrigation Water Demand –T Aus, T Aman and Boro crop



Frontier Technologies in Irrigation & water Management: Tools, Techniques and Applications

Dr. Saad Hasan
Chairman, Nodes Digital Limited &
Associate Professor, United International University
saad@nodesdigitalbd.com

Introduction

Efficient water management and irrigation are crucial for sustaining agriculture, especially in regions where water resources are limited or variable. With the advancement of frontier technologies, the methods used for irrigation and water management have become more efficient, precise, and sustainable. These innovations include smart systems, remote sensing, IoT (Internet of Things), artificial intelligence (AI), and data analytics, all of which have transformed the landscape of water use in agriculture. Irrigation requirement for crop production is the highest water demand sector in Bangladesh accounting for about 86% of water used. Bangladesh is considered as one of the most vulnerable countries due to climate change and water related impacts will likely be the most critical. According to IPCC, due to climate change and increasing demand for water, about **25%** of the population will live with water scarcity by 2050.

Existing research pointed out that developed countries are more active in introducing frontier technology in agriculture (e.g., in commercial wine in France, maize in Northern Italy, cotton irrigation in the USA, and rice in Japan). Technology evolution in these countries is based on smart agriculture machinery systems and it aims to generate "big data" to increase production efficiency. Even in Bangladesh, we at Nodes Digital are trialing and IoT and AI based technologies to reduce irrigation.

Tools and Techniques in Modern Irrigation

Smart Irrigation Systems

Smart irrigation systems use sensors and weather data to automate irrigation processes. These systems optimize the application of water, ensuring crops get the right amount at the right time.

Weather-based Controllers: These systems adjust irrigation schedules based on real-time weather data to avoid overwatering or under-watering.

Soil Moisture Sensors: Embedded in the soil, these sensors measure the moisture content, helping to ensure that irrigation occurs only when needed.

Flow Meters: Used to measure water flow rates, flow meters help in identifying water usage patterns and detecting leaks in the irrigation system.

Remote Sensing

Remote sensing technologies like satellites, drones, and unmanned aerial vehicles (UAVs) offer valuable data for efficient water management.

Satellite Imaging: Satellites can monitor large agricultural areas, providing real-time data on soil moisture levels, crop health, and water stress.

Drone Technology: Drones equipped with multispectral and hyperspectral cameras can map large agricultural fields with high precision, giving farmers detailed insights into soil health and water usage patterns.

Internet of Things (IoT)

IoT-based Irrigation Systems: IoT-enabled systems can monitor weather conditions, soil moisture, and crop needs. These systems automate irrigation decisions based on data collected from sensors and weather forecasts.

Smart Pumps and Valves: IoT-based pumps and valves allow for automated, real-time control of water flow to specific areas, reducing water wastage.

Artificial Intelligence and Machine Learning

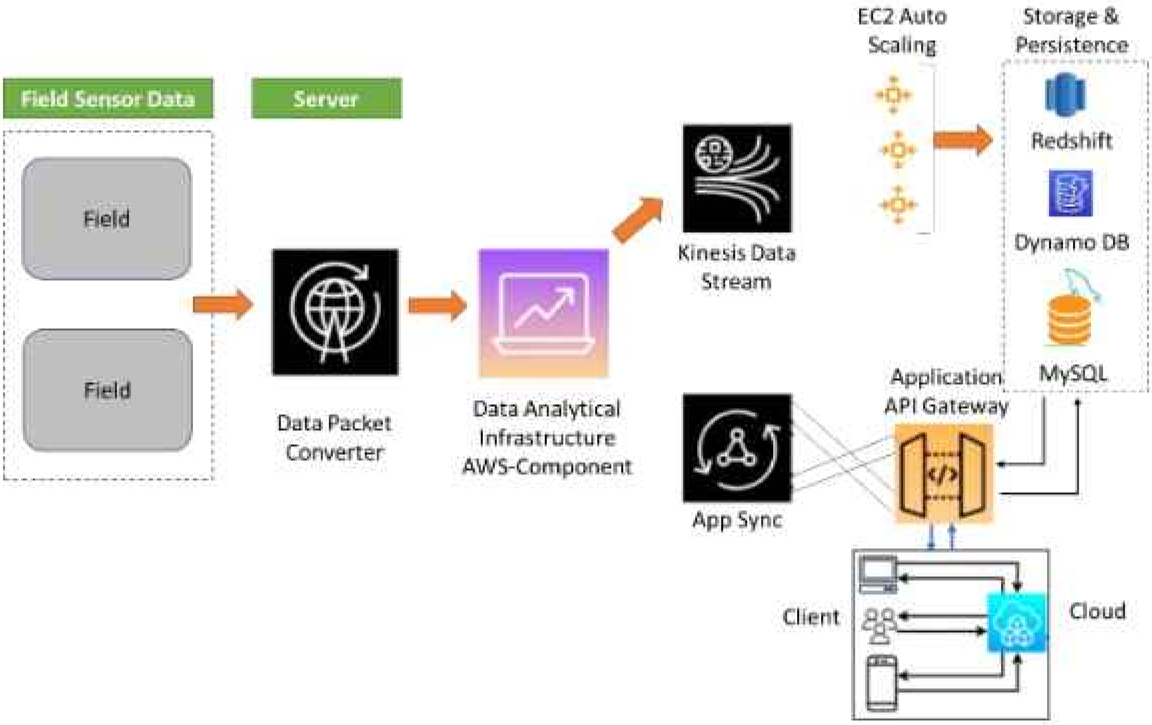
AI and machine learning algorithms analyze large volumes of data to forecast crop water requirements, detect inefficiencies, and improve water management.

Predictive Analytics: AI models analyze historical data to predict future water needs, optimizing irrigation schedules based on expected weather conditions and crop growth stages.

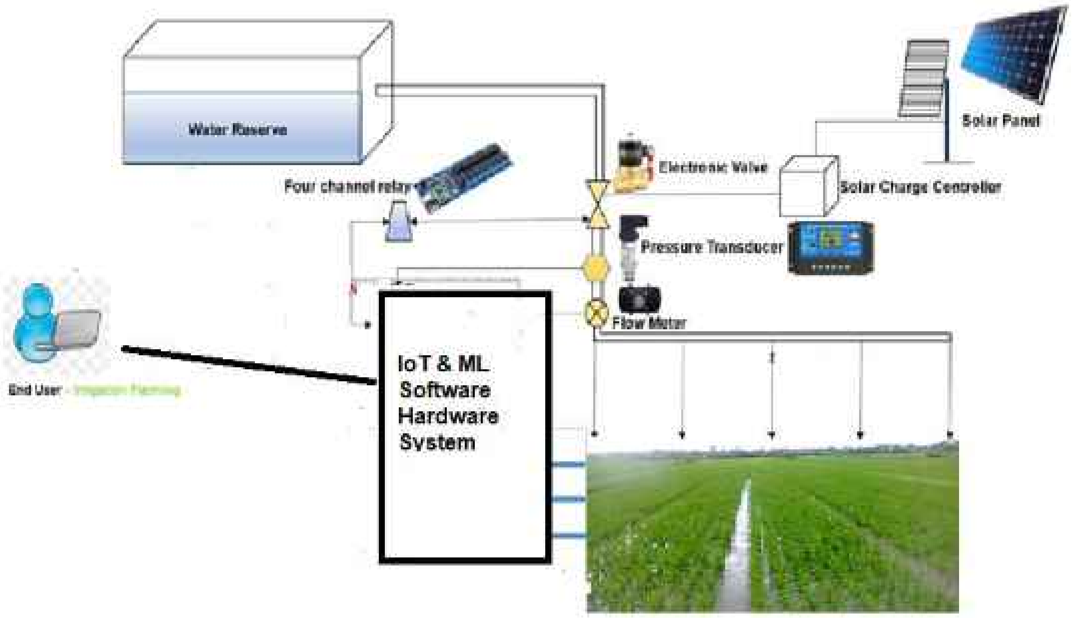
Crop Water Stress Detection: AI systems can assess crop health and detect early signs of water stress using image recognition and machine learning algorithms.

Cloud Computing

A key component of IoT based precision agriculture is "Cloud Computing" which refers to the delivery of computing services—including servers, storage, databases, networking, software, analytics, and intelligence—over the Internet ("the cloud") to offer faster innovation, flexible resources, and economies of scale. The architecture of the IoT based PA software system include developing Cassandra or Kafka data pipeline, where data can be streamed/sent from IoT sensors and stored in cloud (online) storage/servers. Multiple Application Programming Interface(s) APIs to receive data from sensors, retrieve data from cloud storage/server by Machine Learning Programs, human users, and to push data to mobile application have been developed and tested.



The ML and IoT based system including cloud computing can be incorporated to automate surface irrigation system. The irrigation subsystem can operate automatously based on the instructions from the ML



-

Case Study 1: Remote Sensing for Precision Irrigation in the California Central Valley

Overview

The California Central Valley, one of the most productive agricultural regions in the world, faces persistent water scarcity issues. With a combination of drought cycles, over-extraction of groundwater, and high agricultural demand, efficient water management is critical. To address this, farmers and agricultural agencies have begun utilizing remote sensing technologies, such as satellite imaging and drone surveys, to improve irrigation practices, conserve water, and optimize crop yields.

Technologies Employed

Satellite Imaging

Satellites equipped with multi-spectral and thermal infrared sensors were used to monitor large areas of farmland. The data collected helps in assessing soil moisture levels, crop health, and identifying areas where irrigation is either insufficient or excessive.

The *Landsat* series and *Sentinel-2* satellites are commonly used for these purposes, offering high-resolution imagery for crop monitoring, with a frequency of revisit ranging from a few days to a few weeks.

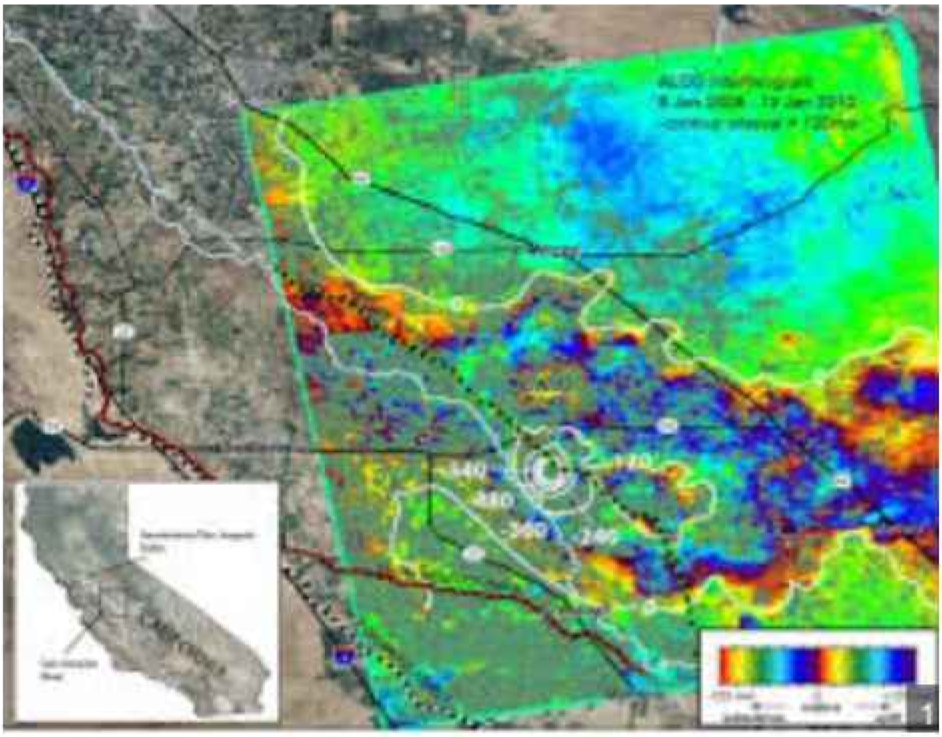
Drones for High-Resolution Data Collection

Drones equipped with multispectral cameras were used for more localized and precise monitoring. Drones provided real-time, high-resolution data that enabled farmers to observe conditions at the individual crop level. In particular, the use of near-infrared (NIR) sensors allowed for the creation of vegetation indices, which were critical in assessing plant stress, including water deficiency.

IoT Sensors Integration

Ground-based IoT sensors were integrated with remote sensing data, helping to provide more granular soil moisture readings. These sensors were placed in the soil and provided real-time data to complement the satellite and drone data. This integration allowed farmers to correlate aerial and ground-level data for even more accurate irrigation decisions.

NDVI based on drone image



Heat map based on satellite image

Implementation Process

Data Collection and Analysis

The first step was to gather imagery from satellites and drones over the fields. The satellites provided a broad overview of large agricultural areas, while drones were used to focus on specific fields or problem areas. These images were analyzed to identify areas with varying degrees of water stress, which was determined by analyzing vegetation indices, like the Normalized Difference Vegetation Index (NDVI). Thermal infrared data from satellites allowed the team to identify heat stress and soil moisture conditions, which gave further insights into water deficiencies.

Irrigation Scheduling Optimization

With the data collected, an irrigation scheduling system was developed to automatically adjust irrigation schedules. Areas that were identified as water-stressed through remote sensing data received additional water, while areas with sufficient moisture were excluded from irrigation cycles. This was done by integrating remote sensing data into precision irrigation systems. For instance, automated irrigation systems were linked with sensors in the field to adjust irrigation based on the most up-to-date imagery from drones and satellites.

Monitoring and Adjustment

After implementing the optimized irrigation system, the fields were continuously monitored with periodic drone flights and satellite passes. If any inconsistencies or new signs of crop water stress were identified, adjustments were made to the irrigation schedules. Regular data updates allowed farmers to track crop performance and water consumption patterns throughout the growing season, improving the accuracy of future irrigation decisions.

Outcomes and Benefits

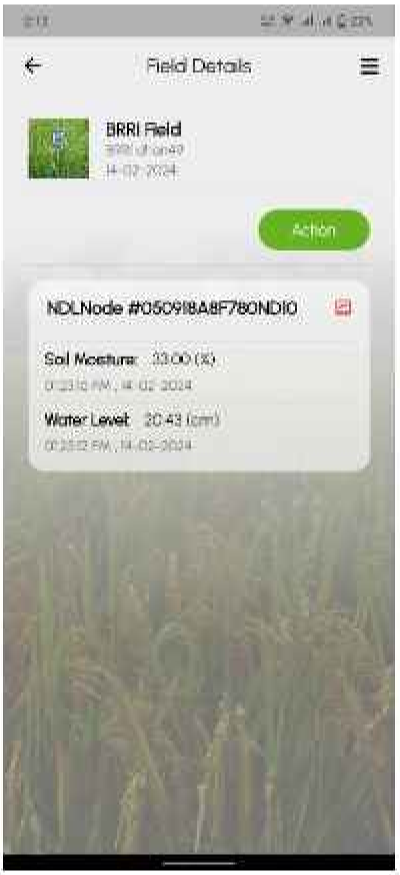
The case study in California's Central Valley illustrates the effectiveness of remote sensing technologies in optimizing water use in agriculture. By integrating satellite and drone imagery, along with IoT sensors, farmers were able to enhance irrigation scheduling, conserve water, and increase crop yields. This case highlights the potential of remote sensing to address the challenges of water management in regions facing water scarcity and provides a model for other agricultural areas around the world to adopt similar technologies for sustainable farming practices.

The success of this project demonstrates that when combined with modern data analytics and precision irrigation systems, remote sensing can play a transformative role in making water management more efficient, cost-effective, and sustainable.

Case Study 2: Implementation of Internet of Things (IoT) based smart AWD system called e-Irrigation in Bangladesh

Nodes Digital developed an Internet of Things (IoT) based smart AWD system called e-Irrigation .The system consists of two parts, the first part is IoT-based AWD irrigation system for rice production in Bangladesh using different sensors like Ultrasonic sensor and soil moisture sensor, and mobile app. The ultrasonic sensor measures the water level in field and sends the data to cloud based servers. These data are processed to deliver a action related to water requirement through an user-friendly mobile app. Therefore, it provides the smart solution to water crisis as well as provides an automated system through which farmers can control the large farm area located at different locations by using their mobile for enhancing water productivity as well as in reducing the extra manpower efforts, and water requirement.

Field Implementation of e-Irrigation system



Mobile Application to monitor Field data

Conclusion

The integration of frontier technologies like IoT, AI, machine learning, drones, and satellite imaging is revolutionizing irrigation and water management practices. These innovations allow for more precise, efficient, and sustainable use of water resources, which is critical in ensuring global food security, especially in water-scarce regions. However, overcoming challenges related to cost, accessibility, and infrastructure will be essential to unlocking the full potential of these technologies. As these technologies evolve, their role in achieving sustainable agriculture and managing water resources will only grow in importance.

Water Savings and Climate-Smart Irrigation Technologies for Rice: Research and Development Perspective

Dr. Md. Mahbubul Alam
PSO & Head, IWM Division,
BRRI, Gazipur

Introduction

Rice has played a critical role in feeding a larger portion of the population in the growing world, since it was domesticated 7000 years BP in Meghalaya- Assam areas of India and the mountain regions of Southeast Asia and Southwest China (Swaminathan, 1984). As per FAO statistics during the period of 1961–2018, rice area and production have increased from 115 M ha to167 M ha and 215 MT to 782 MT, respectively (Fig. 1). Rice is cultivated in 118 countries in the world and out of 167 MT ha in world's rice producing area, 146 M ha area is in Asia which accounts for 705 MT of production, *i.e.,* 91 per cent of World rice production (FAO, 2019). Asia contributes to nearly 90 per cent of the world's rice production and 9 out of top 10 rice producing and consuming countries are located in Asia (Fig. 2).

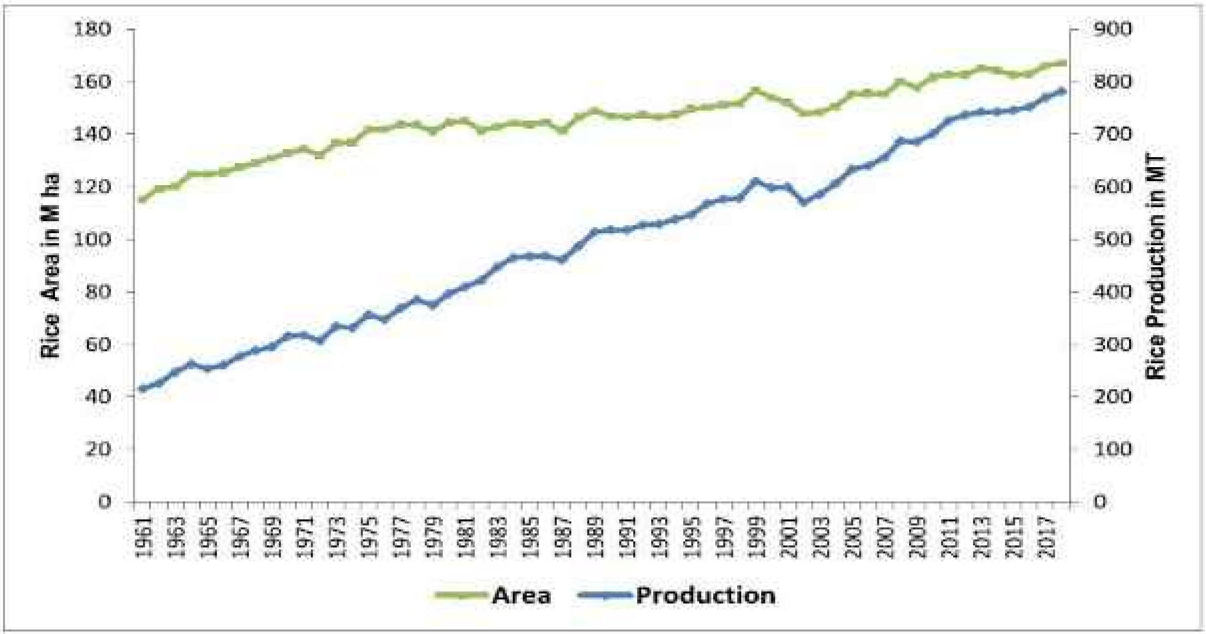


Fig. 1. Global rice area and production (Source: FAO, 2019)

Water scarcity is a serious threat to food security for millions of people, particularly in the arid and semi-arid regions (Singh et al., 2006). At the global level, water consumption for agriculture is forecasted to increase by 584 km^3 during the period of 2000–2025, while world population is expected to grow from 6.18 billion in 2000 to 7.9 billion in 2025 (Shiklomanov, 2000). Molden et al. (2007) estimated agricultural water withdrawal from natural systems to be 2664 km^3, which constitutes 70 % of water withdrawn for human requirements. They also estimated evapotranspiration from agricultural land to be 7130 km^3, which is projected to increase by 60–90 % by 2050 if water productivity cannot be increased. Improving water productivity in agriculture will be crucial to reduce the need for additional water in irrigated systems, and is a critical response to addressing water scarcity. Inclusive knowledge of fresh water usage and crop production systems is essential for water managers and policy makers to improve water management in areas with low water productivity (Immerzeel et al., 2008). Water productivity expresses the value or benefit derived from the usage of water and includes essential aspects of water management (Molden and Sakthivadivel, 1999; Molden et al., 2001a; Droogers and Bastiaanssen, 2002; Kijne et al., 2003; Singh et al., 2006). Its analysis can provide insights into means to improve overall agricultural water management (Abdullaev and Molden, 2004).

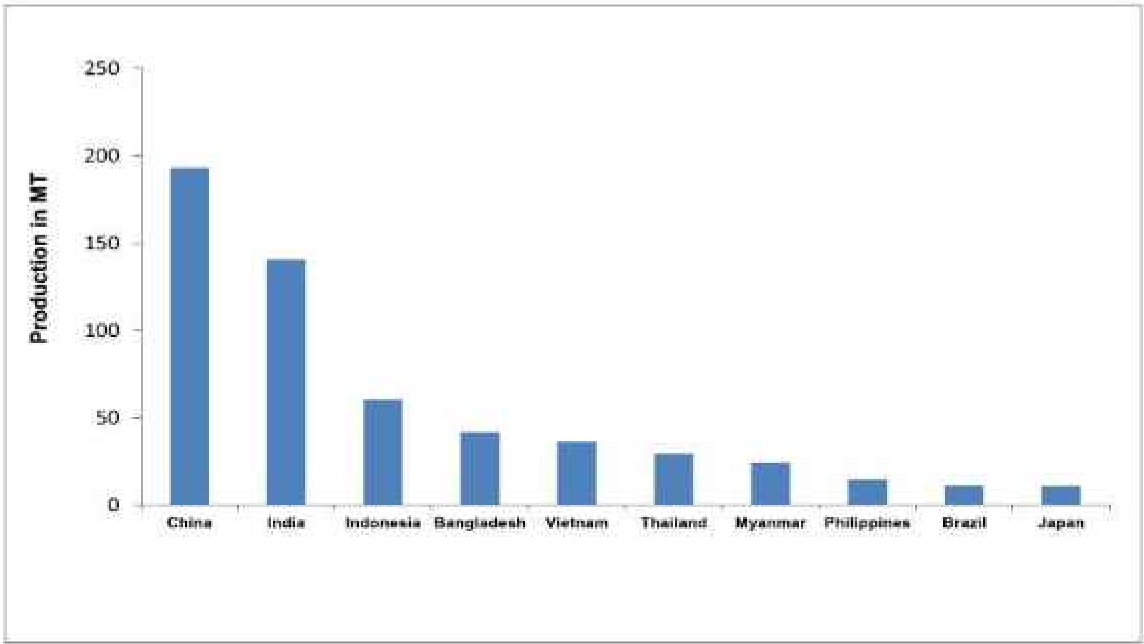


Fig. 2. Top ten rice producing countries of the world (Source: FAO, 2019)

Rice is the predominant crop in three main crop-growing seasons: Kharif-1 (March–June), Kharif-2 (July–October) and Rabi (November–February) in Bangladesh. Three types of rice – Aus in Kharif-I, Aman in Kharif-II, and Boro in Rabi season – are cultivated. Both Aus and Aman rice, cultivated in monsoon (May–October), are mostly rainfed and often partially irrigated. Due to risk of floods and other natural disasters, such as cyclones during the monsoon, the dry season is the most productive, risk-free and diversified cropping season in the country. Consequently, Boro rice is the major irrigated crop in the dry season that currently contributes 55–60 % of the country's total rice production (Mainuddin et al., 2019). The total irrigated area has increased from 1.52 Mha in 1983 (18 % of the net cultivable area, NCA) to 5.59 Mha in 2020 (65 % of the NCA) (BADC, 2021) due to tremendous increase in shallow tubewells (STWs) and deep tubewells (DTWs) for extracting groundwater. The number of STW increased from 93 thousand to 1.40 million and that of DTW from 14,000 to 37,007 during the same period. Approximately 77 % of the area is now irrigated by groundwater and only 27 % is irrigated by surface water (BADC, 2021).

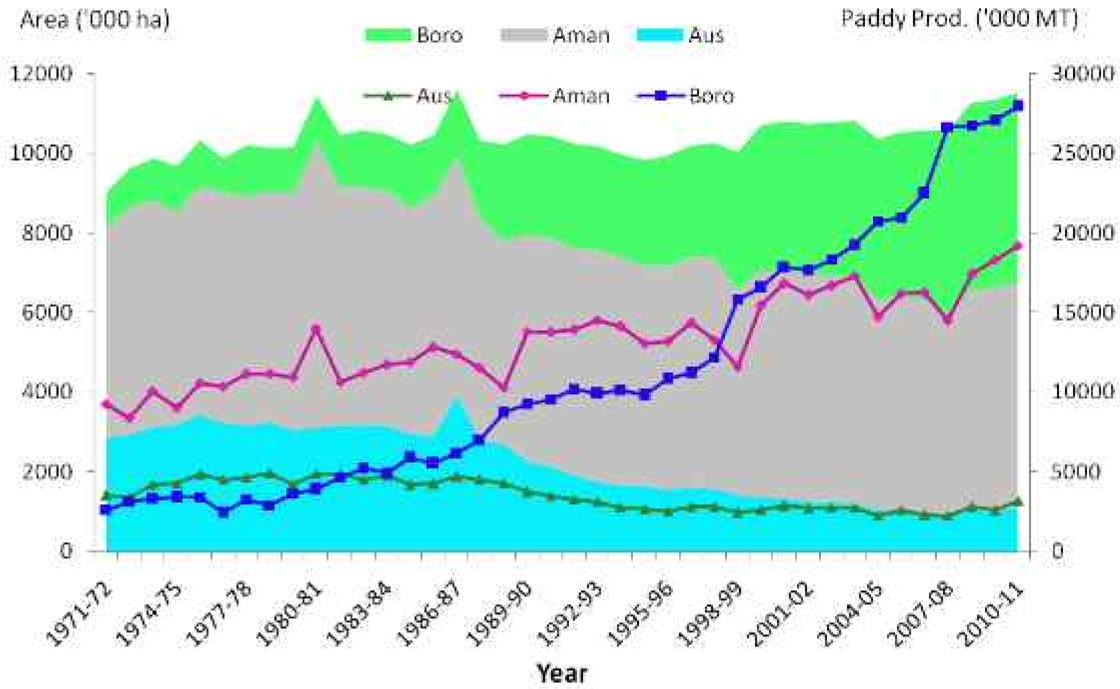


Fig. 3. Rice season-wise area coverage and production in Bangladesh.

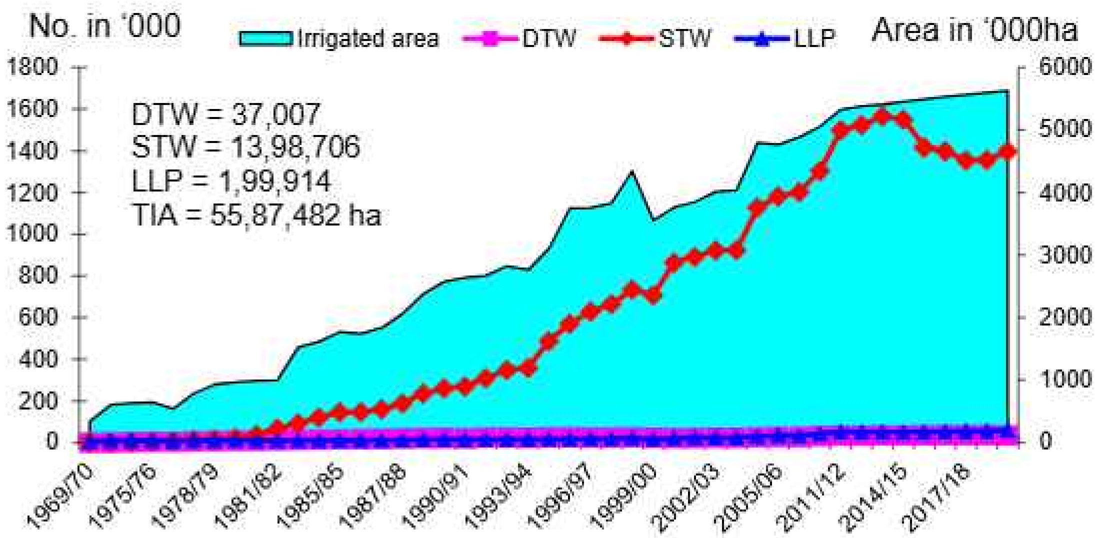


Fig. 4. Irrigated area and irrigation device used in Bangladesh.

Water requirement of rice

Seasonal water use in rice is quantified by including the quantity of water used towards preparation of land and the water lost from the agro ecosystem because of crop evapo transpiration (evaporation and transpiration) and other losses (seepage and percolation) during crop growth. Fig. 5 shows a distinctive cross-section of a puddled rice plot in a vertical manner and it is evident that the top layer (0–10 cm) is holding the water after irrigation and second layer of 10–20 cm will be muddy in nature because of fluffy pan of soil formed by puddling action over the years of rice cultivation and finally the third layer of undisturbed subsoil (Fig. 5).

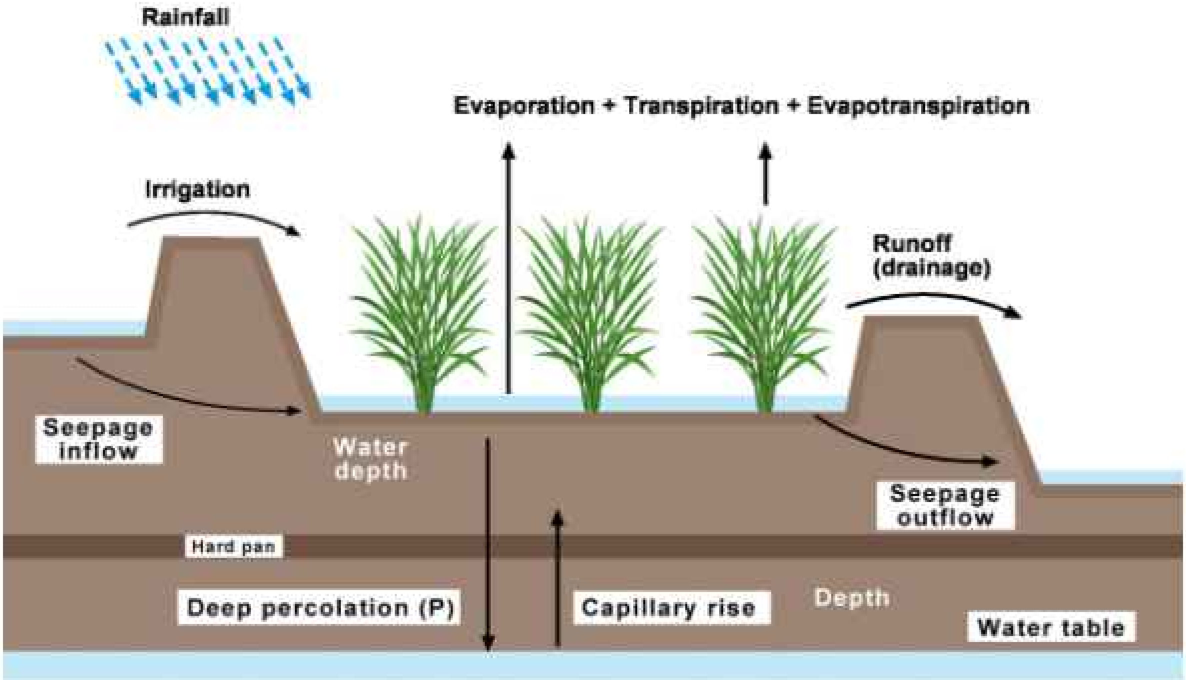


Fig. 5. Water balance component in irrigated rice cultivation.

Critical stages of water requirement in rice

Active tillering (AT), panicle initiation (PI), booting, heading and flowering stages of rice are considered to be the critical stages of water requirement. Rice is exceptionally sensitive to water shortages, and hence the interval for irrigation must not go beyond the specific time during these critical stages since the deficit of water will happen in the plant if transpiration exceeds uptake. Impact of shortage of water on rice growth characteristics and yield attributes, depends on the growth stage of the crop in which the water shortage is observed.

In rice cultivation, farmers generally prefer to keep standing water on the land. But IRRI-BRRI research shows that it is possible to cultivate rice successfully without continuous standing water on the ground. However, the need for water varies at different stages of the growth of rice plants. The water requirement of different stages of growth of rice plants is given below:

Table 1. Water Requirement of Rice at different growth stages

Growth Stages of Rice	Irrigation Requirement (mm)	Percentage (%)
Seedbed	50-60	5
Land Preparation	200-250	20
Transplanting to PI	400-550	40
PI to Flowering	400-450	30
Flowering to Ripening	100-150	5
Total	1200-1460	100

Climate Change & its impacts

Rice is the staple food crop of Bangladesh and any reduction in rice production systems due to climate change and depleting water resources would seriously hamper the food security. IPCC (Inter Governmental Panel on Climate Change) and a few other global studies projected the negative impacts of climate change and global warming on crop production to the tune of 10–40% reduction in crop yields in India by 2080–2100 (IPCC, 2007). ETc and requirement for irrigation in paddy at different simulations of increasing temperature using CROPWAT showed a rise in the irrigation water requirement by 0.6, 1.4, 2.5 and 3.7%, respectively, for the increase in temperature of 0.5,1.0, 2.0 and 3.0 ◦C (Surendran et al., 2014).

Climate change is a long-term change in the average weather patterns that have come to define Earth's local, regional and global climates. These changes have a broad range of observed effects that are synonymous with the terms of climate change. The cause of current climate change is largely human activity, like burning fossil fuels, like natural gas, oil, and coal. Burning these materials releases greenhouse gases and increases the temperatures commonly referred to as global warming. Climate change increase the extremities like flood, drought, salinity intrusion, sea level rise etc.

Climate Smart Agriculture?

Climate-smart agriculture (CSA) is an integrated approach to managing landscapes—cropland, livestock, forests and fisheries—that addresses the interlinked challenges of food security and accelerating climate change.

CSA aims to simultaneously achieve three outcomes:

1. **Increased productivity:** Produce more and better food to improve nutrition security and boost incomes.
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.

What is Climate Smart Water Management Technology?

Climate smart water management is fundamental for the development and management of water resources for sustainable food production

Climate smart water management have 3 pillars: 1. Mitigation, 2. Adaptation and 3. Improving Livelihood by food security

Mitigation is reducing the negative impacts of traditional agricultural practices to our soils, our water supply and atmosphere. Adaptation is imagination and science working together to make adjustments in agricultural practices to changing environmental conditions and uncertainty. Food security not only means growing more food but more nutritional food. It also means improving of the smallholder livelihoods farming communities of the developing world. The basis of all CSA is the climate smart water management. We have to support the inclusion of climate smart water management approach at all levels, from farm to national policies and legislations.

Climate Smart Irrigation (CSI) includes both analogue and digital irrigation technologies and practices to tackle two main objectives: (a) sustainably enhance agricultural productivity, water productivity, and rural farm incomes to build community and farm-level resilience and climate change, and (b) enable adaptation, mitigation and resilience to climate change across different scales through irrigation technologies and water resources management (Goap et al. 2018). CSI technologies can use localized data to allow farmers, water managers, and regulators to make improved irrigation management decisions (Taneja et al. 2019).

Water saving technologies

Water scarcity by now is an adamant problem in many parts of the world due to increase in greenhouse gases (GHG) and frequent occurrence of weather extreme events. The UN estimates that about 1/3rd of the total population in the world live in regions that is experiencing severe water scarcity and approximately 1.3 billion people are still don't have access to safe water. Shortage of water is especially evident in the rice bowls of the world, especially in China and India, because there were lot of demands from other sectors as well, prompting conflicts between different sectors (Jiang et al. 2021).

Therefore, the main challenge is to formulate novel technologies and rice production systems that would help to have sustainable and climate resilient rice farming with minimum seasonal water input to combat the declining water availability. Various "water saving technologies" are available or are being continuously developed to help farmers to manage up with low quantity of water in irrigated environments (Humphreys et al., 1996; Tuong and Bouman, 2003). Two types of water losses is encountered with rice production. One in irrigation water conveyance or distribution loss another is field scale loss.

Water conveyance or distribution technology

For overcoming losses of water in the minor irrigation systems, different improved water distribution systems are used for efficient water distribution and proper use of that costly input for crop production. The different improved distribution systems are:

1. **Improved Earthen Channels:** It can be made with clay and soil mixture with rice husk. It is compacted up to a certain limit for compaction and leak-proof. It is a low-cost channel and made with local materials to prevent excessive seepage and percolation losses.
2. **Lined Channels:** Earthen channels are lined with impervious materials to prevent excessive seepage and percolation losses and growth of weeds in channels. A large portion of water harnessed at a high cost, through the canal irrigation network or through wells and pumps, is lost by seepage from unlined conveyance systems comprising of the main canal, branches, distributaries, water courses and field channels. In impermeable soils like sand and sandy loam, the losses in earth channels may be as high as 20 to 40% of the water delivered to the channel. The loss in the field distribution system is even more significant in areas irrigated by wells as the unit cost of developing the resource is high. Lining of water courses will provide nearly equal distribution of

water amongst all the farmers in the cultivable command area. Lining will reduce the labor cost in maintaining the water course. It also almost eliminates water logging caused by seepage in water courses. More land will be available for cultivation since the cross-sectional area of the channel required to carry a given discharge through a lined channel is considerably less than the unlined channel.

a) **Brick lining:** It is made by brick and cement mortar, provided virtually water-proof channel lining and mainly use in minor irrigation system. It is susceptible to damage by trampling by livestock, insects, weed growth and erosion by high velocity flows. It obstructs the tillage equipment and livestock movement in the field level.
b) **Precast lining:** Precast concrete is a term applied to concrete units that are manufactured at a central place hauled to the job site. Their low cost and operating advantages make them particularly suitable for handling for comparatively low discharges. Precast concrete sections may be made in semi-circular or U-sections. The area of land occupied by the channel is greatly reduced when precast concrete sections are used since side embankments are unnecessary.

3. **Buried Pipe Distribution System:** An underground pipeline water distribution system consists of buried pipes for conveying water to different points on the farm and allied structures required for the efficient functioning of the system. The system offers many advantages over open channels in water conveyance and distribution. Since the pipes are laid underground, cultivation can be done above the pipeline; no culverts or other structures are required. Open channels often take 2-4% of the land area out of cultivation, which is saved by adopting the underground water distribution system. The pipelines do not interfere with farming operations. When properly installed, they have long life and low maintenance costs. They are essentially leak-proof. Their placement below ground level prevents damage to pipes and eliminates water loss by operation.
4. **PVC and Plastic pipe:** All of the advantages of the buried pipe water distribution system are also applicable to the PVC and plastic pipe water distribution system. It is not necessary to install the PVC and plastic pipe system on a permanent basis. The pipeline system is essentially water tight with almost no conveyance and evaporation loss during transmission. There is a considerable amount of water savings, which reduces pumping cost. The PVC and plastic pipe method of water distribution system requires a less investment than an unlined or lined open channel and buried pipe system. This method is usable with buried pipe system or from the tubewell outlet directly (Bentum *et al.*, 1995). PVC and plastic pipe method of water distribution system is especially important in Rabi crops and T. Aman season for supplemental irrigation because most of the earthen channels are not in usable condition after rainy season.

Field-scale water management technology

Most of these water saving technologies will attempt to minimize the other losses occurring *via* seepage, percolation and evaporation etc. without taxing the rice plants and thereby increasing the water productivity per quantum of rice yield produced (Belder et al., 2003). More than a few strategies are already available to reduce water requirements of rice, such as SSC - saturated soil culture, AWD-alternate wetting and drying (Li, 2001; Tabbal et al., 2002; Sriphirom et al., 2020), ground-cover systems (Lin et al., 2003a, 2003b), aerobic rice

(Bouman, 2003; Mandal et al., 2010, 2013), SRI-system of rice intensification (SRI) (Stoop et al., 2002; Materu et al., 2018), raised beds (Singh et al., 2003), etc. In addition, identification of rice varieties through conventional breeding for tolerating water stress, selection of varieties through molecular markers, and employing advanced molecular/biotechnological tools for water-limited conditions are the areas of current research focus.

In general, flooded water has a higher rate of evaporation than water evaporated from moist soil alone. Evaporative water loss can be reduced by reducing the duration of flooding the paddy field with water input (Bouman et al., 2007; Tuong et al., 2004). Water saving technologies of rice cultivation systems such as bed planting, AWD irrigation, aerobic culture, GCRPS and SRI are also very effective in this regard. Strategies and options that will enhance the water use efficiency and rice are discussed in the following section.

1. Reducing turnaround time and direct seeding

The main principle behind this technique is minimizing the time gap between initial land preparation and transplanting, which will reduce particular sluice to have uniformity, proper scheduling of irrigation water, adoption of appropriate delivery systems, etc. Dry sowing may be promoted in all possible areas to make the best use of Southwest monsoon. Studies indicate that the transplanting method of paddy cultivation, which is labour intensive and costly, could be replaced with direct-seeding without reduction in crop productivity, as the yield recorded from the transplanting, direct seeding by broadcasting, and line-seeding were of 6091 kg ha^{-1}, 5848 kg ha^{-1} and 6061 kg ha^{-1}, respectively (Johnkutty et al., 2002).

In a study on dry seeded rice, water productivity was significantly higher than the wet seeded and transplanted rice. It also showed that intermittent irrigation resulted in reduction of irrigation water use considerably (27–37%) compared with flooded rice cultivation (Jaffar Basha and Sarma, 2017). Water use was reduced by 35–57% for DSR - dry seeded rice than the submerged field (Singh et al., 2003; Sharma et al., 2003). DSR resulted in higher yield than the flooded field and water saving was to the tune of 20%, in farmers participatory action research program (FPARP) in India while the reported yield increase was not observed in experimental plots (Gupta et al., 2003).

2. Saturated soil culture

In saturated soil culture (SSC), seepage and percolation flows could be minimized by keeping closer to saturation, which will reduce the hydraulic head of the stagnant (ponded) water. In saturated soil culture practice, irrigation will be done in such a way that till it reaches 1 cm depth of ponded water and next irrigation will be scheduled after a day of the disappearance of ponded water (DADPW). Bouman and Tuong reviewed more than 30 experiments on the SSC studies carried out in different parts of the world, and found that the quantity of water required for cultivation of rice, decreased by 23% (range: 5–50%) from the entirely submerged or flooded field as control, however yield reduction was non-significant (Bouman and Tuong, 2001).

3. Alternate wetting and drying

Alternate Wetting and Drying (AWD) is a popular water-saving technique used in various parts of the rice growing areas in the world in recent years. AWD is a method of irrigation, in which, duration between each irrigation will be increased, till the soil become drier followed by full irrigation in the form of flooding (Cabangon et al., 2001). In other words, irrigation will be given after a few days of the disappearance of ponded water. Water saved in the AWD is to the tune of 13–16% (53–87 mm), compared to the flooded conditions and this results in significantly higher water productivity than the flooded fields/submerged regime (Belder et al., 2003). Few studies showed an increase in the productivity of rice under AWD (Zhang and Song, 1989), however, many of the research results reported a reduction in yield. Currently in China, AWD is considered as water saving technology and been largely adopted and became a common practice in most of the lowland rice cultivation areas (Li and Barker, 2004). It is also generally a farmer adopted practice in Northwest India. AWD in combination with biochar application resulted in irrigation water saving, reduction in CH4 emission, SOC stock increase and at the same time without significantly affecting the yield and farmers income (Sriphirom et al., 2020).

4. Aerobic rice

Puddling is practice of land preparation in rice mainly for different purposes such as stagnation of water (flooded condition) by compacting the surface soil and minimizing the percolation losses, control of weeds, levelling the field and easiness of transplanting etc. There is a perception that puddling reduces the percolation losses, however, there are only few studies which quantified and in some of the studies it was found that there was no reduction in the total quantity of water used for rice cultivation (Tabbal et al., 2002; Tuong et al., 2004).

Aerobic rice is a novel rice production agro ecosystem, in which specific rice genotypes which are adapted for aerobic conditions are cultivated in well drained soils without flooding similar to dryland conditions where other cereals such as wheat and maize are also grown with economic and judicious use of water (Bouman et al., 2007). Ultimate objective of aerobic rice is cultivating the rice with less water and producing more *i. e* with highly economic water use. Under this system of rice cultivation, the idea of having the entire field under flooded condition is totally avoided altogether, rather than attempting to reduce quantity of water input in lowland paddy fields (Bouman and Tuong, 2001). This technological system of aerobic rice eradicates the process of puddling and continuous flooding, and offers a promising alternative water management system that will reduce huge quantity of total water use and ultimately increasing the water productivity *i.e.* quantity of water used for producing a kg of rice. It has been reported that saving of water to the tune of 73% and 56% in preparation of land and for the entire crop growth period (Farooq et al., 2009).

Several studies reported that yield under this technological intervention may lower by 20–30% than the flooded conditions with HYVs, however the yield is almost twice the yield of traditional upland cultivation and having a yield between 4.5 and 6.5 t ha^{-1}. On an average total water use was reduced by 60% than that of flooded rice cultivation with 1.5–2.0 times higher water productivity, resulting in higher economic water productivity. Advantage of aerobic rice is that there is a possibility of mechanization of planting, weeding etc. and hence the requirement of labour was less. Even though, yield increase was reported, care should be taken, before large scale adoption of this technology i.e. suitable aerobic rice cultivar, best management practice etc. needs to be explored.

5. System of rice intensification

System of Rice Intensification (SRI) as an innovative rice cultivation was evolved in Madagascar during late 1980s and early 1990s. These SRI techniques allow the resource poor farmers to realize a paddy yield to the tune of 15 t ha^{-1}. Besides, SRI is possible in low fertile soils, with minimum inputs, and without depending much on external inputs at the same time with less quantity of irrigation water (Stoop et al., 2002; Uphoff and Randriamiharisoa, 2002).

Typical SRI practices are single younger seedlings of 8 to 12-days-old seedlings with root tip down will be transplanted by adopting a wider spacing of 25 × 25 cm or more wider on a square pattern. In SRI system, weeds will be controlled with the help of cono-weeder/or a rotating hoe. This will assist in removal of weeds and also prompt, proper aeration in soil. Other important practices are application of compost or farm yard manure/organic manure to maintain the soil organic matter and irrigate the field as and when required, especially during the vegetative phase (Thakur, 2018).

SRI techniques results in significant changes in phenotypic structure, by altering the plant spacing and age and it has a direct correlation on yield components and yield of rice under this type of cultivation. In SRI, water requirement will be reduced by 50%, and yield also increases by double than that of traditional (conventional) rice cultivation and did not require any additional external inputs (Uphoff and Randriamiharisoa, 2002). Still, the adoption of SRI technology is very hard to many farmers, because it needs higher manpower (Moser and Barett, 2003). SRI method of cultivation results in a higher yield of any rice cultivars and that may be possibly due to the introduction of high yielding hybrid varieties (Thakur, 2018). Crop and Irrigation water productivity is higher under SRI and these things will compensate the farmers for the additional expenditure incurred towards labour charges and it will enhance the profitability of agriculture (labour, capital, land and water). Water use was reduced by 50%, without affecting the grain yield of rice in the SRI system (Thiyagarajan et al., 2003).

6. Ground-Cover Rice Production Systems (GCRPS)

Ground -Cover Rice Production Systems (GCRPS) is a system of growing rice with mulching using straw/plastic film/bio plastic film is being in use in China as early as 1990 and this is mainly done to enhance the plant growth by the increasing the soil temperature in cooler climates. In GCRPS, plastic film mulching (PFM) is used in lowland rice cultivation and the soil will be with soil temperature and moisture, ideal for rice cultivation. Nevertheless, the quantity of water used was 60–85% lower than the conventional flooded system without affecting the rice productivity (Huang et al., 1999). However, some researchers reported substantial reduction in yield under such conditions (Castillo et al., 1992; Farooq et al., 2009).

7. Raised beds

In Australia, in the late 1970s, these technologies by using raised beds were initiated for the production of crops in the clayey soils (Maynard, 1991) and similar technology was adopted in 1990s for irrigating wheat in the IGP (Indo-Gangetic plains), where rice–wheat cropping system is the dominant one. Raised bed techniques can save water by 12–60% in the case of DSR (direct-seeded rice) and transplanted rice on raised beds, with similar or lower yields for control (Balasubramanian et al., 2003; Gupta et al., 2003). They reported that yield loss (low yield under raised beds) was mainly due to the competition from weeds, nematode infestation, improper sowing in raised beds and micronutrient (*e.g.*, iron, zinc) deficiencies etc.

8. Other management practices

There are several other management practices, which can considerably save the water use in rice cultivation. With respect to the land preparation period, there are several options viz., levelling of the land, proper tillage, field channel lining, proper bund preparation etc. will help to reduce the quantity of water used. For example, in the case of land levelling, advanced techniques such as laser land levelling helps to level the field without any kind of depressions/undulations and that will ultimately reduce the irrigation time and also reduces losses through evaporation and percolation (Humphreys et al., 1996).

A few studies suggest that mulching with plastic/organic (straw) in rice resulted in 20–90% of water saving and maximum was reported under aerobic rice than that of the anaerobic rice (Lin et al., 2003a, 2003b). These huge water savings might be due to the reduction in evaporation and percolation losses, which used to happen in continuously flooded systems.

Conclusions and recommendations

The cultivation of rice has reached 11.56 M ha area and the majority of which are cultivated under persistent flooding conditions (BBS, 2021). The global food demands and extreme weather events are likely to reduce crop yield including rice production which in turn threatening food security. It has been reported that around 20% of irrigated areas in rice are estimated to suffer from 'physical water scarcity' by 2025. Other than this, there are several restraints involved with rice cultivation, namely a huge water demand for land preparation (puddling) and retaining continuous flooding, pest and diseases and higher labour inputs have made it less remunerative for many farmers, especially for small and marginal farmers. Water is one of the main resources, which has many interlinked connectivity with many sets of emerging problems, which needs to be addressed and managed for achieving the sustainable development goals and cleaner production systems.

From various water saving technologies discussed, site-specific right technology need to be advocated as per the agroecological environment, soil health and landform conditions to optimize the water productivity and crop yield potential. A brief overview of the available approaches in water saving technologies is presented below:

- ♣ The efficiency of water use depends on the choice of a variety of crops and cropping system, application of farm yard manure (FYM)/compost or green manures, uniform scheduling the cultivation operations for each paddy fields under a particular sluice, proper scheduling of irrigation and adoption of appropriate delivery systems.

- Dry sowing needs promoting in all possible areas to make efficient use of Southwest monsoon.
- Short and medium duration rice varieties can be cultivated.
- The cropping pattern has to be adjusted for efficient water used
- During land preparation, there are different options to save water viz., levelling of land, field channels lining, proper tillage, preparation of bunds by proper plastering, plugging of rat holes.
- Establishment of rice crop can be optimized to tackle water scarcity by direct sowing (seeding), which in turn reduce the turnaround time between crops and could make an efficient use of rain water during monsoon.
- Irrigation water distribution system should be improved for reducing conveyance loss.
- Four alternative management practices *viz.,* saturated soil culture (SSC), alternate wetting and drying (AWD), system of rice intensification (SRI) and aerobic rice can be recommended to farmers during the crop growth based on the site-specific needs to save irrigation water.
- Water driven crop models such as Aquacrop has a wide applicability in different locations under varying climatic and spatio-temporal settings for deriving crop water requirement, irrigation scheduling and its management, hence more research focus needs to be given on such water driven crop models.

Water Savings and Climate-Smart Irrigation Technologies for Non-Rice: Research and Development Perspective

Dr. Md. Anower Hossain
CSO & Head, Irrigation and Water Management Division
Bangladesh Agricultural Research Institute, Joydebpur, Gazipur 1701
Email: manower1970@gmail.com

Bangladesh is considered to be one of the most vulnerable countries to climate change. This is due to its unique geographic location, dominance of floodplains and low elevation from the sea. There would be drastic changes in rainfall patterns in the warmer climate and Bangladesh may experience 5-6% increase of rainfall by 2030, which may create frequent big and prolonged floods. In contrary, the country is facing drought in the northwestern region, which affects agriculture, food production, water resources and human health. The moderately drought affected areas will be turned into severely drought prone areas within next 20-30 years (IPCC 2007a). Though the groundwater dominates the total irrigated area, its sustainability is at risk in terms of quantity in the northwest region (Simonovic 1997; Shahid 2011) through over extraction of this resources. Different studies have documented that groundwater table has been declined by at least 10 meters during the last 14 years (Ali et al. 2012; Shahid & Hazarika 2010) in some areas of the Barind tract of northwest region. This substantial declination of groundwater level during the last decade causing threat to the sustainability of water use for irrigation in this region and impacting upon other sectors as well (Jahan et al. 2010). Frequent shortage of water has had impacts that can be ranged as economic, social and environmental (Islam et al. 2014). If this over-utilization continues, it may result in its exhaustion after few years that may have serious impact on the agriculture-based economy of the country. So, emphasis should be given on the sustainability of this valuable resources.

Although maximizing crop production through greater expansion of irrigated lands is a basic requirement, sustainable utilization of country's limited water resources is also a major concern. The key challenges are now to increase agricultural productivity without deteriorating the groundwater resources (Shahid & Hazarika 2010). This is possible only if safe extraction of groundwater resources, the irrigation water is utilized judicially by implementing apposite irrigation methods, and practicing water saving cropping patterns simultaneously. Policy level interventions are also needed to achieve sustainable use of groundwater for irrigation through adaptation of effective measures by the farmers aiming to achieve food security and ecological balance.

Ingress of salinity is an additional major problem in southern part of Bangladesh. Significant part of the coastal area is already facing problems related to salinity intrusion which will be pronounced further under warmer climate. In Bangladesh, over thirty percent of the net cultivable area is in the coastal region. Out of 2.86 million hectares of the coastal and off-shore areas, about 1.05 million hectares are affected by different degrees of salinity, which constitute about 52.8 percent of the net cultivable area in 93 upazillas of 18 districts (SRDI, 2010). Enhanced salinity in the locality has affected water, soils, agriculture, vegetation, mangrove, fisheries and livelihoods of the communities and households. Coastal agriculture, among others, is key vulnerable area and therefore need new approaches and technologies to deal with existing and future salinity problems in the coastal area.

Inefficient management of irrigation systems and threat of climate change will make Bangladesh agriculture more vulnerable, and crop production may be more challenging and costly in future. Global climate changes will certainly affect Bangladesh and the country is already facing its consequences. Cost of irrigation due to the effects of climate change may further increase and will require better water management. Climatic change situation may influence land and crop productivity and resources use pattern. Therefore, water management for enhancing crop production under climate change will be required for better utilization of land and water resources of the country. Water availability environment of the country makes water management a critical issue (Ghani, 2005), especially for about two to two and half months (Mid February to April). During this period of the year, water table goes below suction limit, arsenic concentration exceeds the safe limit, soil salinity in coastal area increases beyond crop tolerance level and surface water sources especially smaller rivers and low-lying areas (beels) become dry. Therefore, comprehensive plans and implementation methods should be practiced to address water management issues. Sustainable agricultural development and improved livelihood will only be possible if land and water resources of the country are used judiciously taking advantages of improved climate smart technologies available in the country or adapted from abroad after adaptive trials.

Impacts of Climate Change on Crop Agriculture

- **Soil salinity** (sea level rise, ingress of saline and brackish water, increased land inundation, infiltration of salt water in the soil)
- **Drough**t (changes in rainfall pattern, increase and changes of temperature and evaporation)
- **Crop survival** (less crop yield due to temperature and humidity changes, moisture stress, increased pest and disease infestation)
- **Irrigation water use** (increased crop ET due to hot weather, reduced rainfall and groundwater availability)
- **Fresh water availability** (low river flow, increased evapotranspiration, saline water intrusion into groundwater, excess groundwater abstraction, etc)
- **Natural disasters like, cyclones, tornadoes, floods etc**. (frequent occurrence of natural disaster causing greater loss to the properties and lives)

Possible Impacts on Water Resources due to Climate Change

♣ Change in hydrologic cycle
- Increase in water vapor
- Change in precipitation pattern
    - Intensity and extremes
    - Melting of ice and snow cover
    - Changes in soil moisture and runoff

♣ Increase in risk of flooding and drought
♣ Increase in stream flow as snow melts; then in the long run, flow will decrease
♣ Current water management practice not robust enough

Major Constraints for Agricultural Development in Drought Prone Areas
The major agricultural constraints identified in the drought areas are as follows:

Availability of ground water- In north western region, groundwater plays a decisive role in crop production. The ratio of groundwater to surface water use is much higher in northwestern districts of Bangladesh compared to other parts of the country. This causes substantial declination of groundwater level during the last decade causing threat to the sustainability of water use for irrigation in this region and impacting upon other sectors as well.

Availability of surface water - Global climate change effects reduced water flow in major rivers. In addition, upstream water diversion by India has made the situation worse. All the rivers and canals become dry during the dry season and make the people completely dependent on groundwater.

Water intensive crop cultivation- Water demand for agriculture has increased manifold due to cultivation of water intensive crops especially boro rice. The majority of farmers are still dependent on growing water intensive crops.

Irrational irrigation management-Most of the farmers do not follow the proper irrigation schedule for crops due to lack of proper knowledge. In most cases they apply more irrigation than needed to meet up the crop requirements. Poor maintenance of existing infrastructure and irrational use of water are causes for low irrigation efficiency.

Adoption of modern technologies/non-availability of modern technology- A few waters saving irrigation technologies like AWD for rice, AFI for row crops, drip irrigation for orchards and high value crops are available, but their rate of adoption by the farmers are still negligible. A successful intervention regarding the introduction of crop water saving technologies and the changes in the water charging system may change behavioral attitudes of farmers in adopting irrigation technologies.

Increased temperature

Past and present climate trends and variability in Bangladesh are generally characterized by increasing surface air temperature which is more pronounced during winter (October-February) than summer. Over the past few decades, there has been a significant increase in both maximum and minimum temperature during the pre-monsoon (March to May) and monsoon season months. As every crop has a temperature range for their vegetative and reproductive growth, hence with the temperature falling/exceeding range, crop production faces constraints. Extreme heat will slow growth and also increase moisture loss. Extremely hot and cold soil temperature can also hamper crop growth. Besides, increasing temperature will require more irrigation demand for lowering canopy temperature.

Untimely rainfall and prolonged drought

This region is characterized by low annual rainfall compared to other parts of the country with uneven distribution and wide variation over the year. The HBT does not have a stable ecosystem and farming is vulnerable to interruption because of: a) absence of large water bodies, b) sparse vegetation, c) low and erratic rainfall with limited resources of groundwater and d) high temperature in summer. Rainfed agriculture in the High Barind Tract is extremely difficult. The main constraint to crop production is draught due to erratic and low rainfall from October. The long term mean annual rainfall is 1200 ± 300 mm. The maximum temperature reaches as high as 45°C in May and the minimum falls to as low as 6°C in January. Moisture depletion starts from October and in December, no residual moisture is normally available for crop emergence, a situation that continues up to April.

Major Constraints for Agricultural Development in Saline Areas

The agricultural development in the coastal saline belt is constrained by various physical, chemical and social factors. In general, the major agricultural constraints identified that impede development are as follows:

Soil and water salinity -It is the most dominant limiting factor, especially during the dry season A substantial area of land is tidally affected by saline water. Appropriate management practice for crop production in this area is not available.

Soil Fertility -Fertility status of most saline soils ranges from low to very low in respect to organic matter content, nitrogen, phosphorus and micronutrients like zinc and copper.

Availability of irrigation water- In coastal area, there is little scope of ground water exploration. Canal water Scarcity of quality irrigation water during dry season limits cultivation of boro rice and rabi (winter) crops, and aus cultivation during kharif-1 (March-July) season.

Untimely rainfall and prolonged flood - Variability of rainfall, uncertain dates of onset and recession of seasonal floods and risk of drought restrict cultivation of aus and aman rice. Uncertain rainfall delays sowing/transplanting and flood damages aus and aman crops. Heavy monsoon rainfall causes delay in transplanting of aman and sometimes flash floods wash away the standing crop. Prolonged floods would tend to delay in cultivation of rabi crops, resulting in significant loss of crops yield.

Natural disasters- Coastal area is exposed to threat of hazards resulting from a number of natural disasters like cyclone Sidr, Aila etc. Higher discharge and low drainage capacity, in combination with increased backwater effects, would increase the frequency of such devastating cyclone/floods under climate change scenarios.

Lack of salt tolerant crop variety - Narrow technological and germplasm bases for salt tolerant crops limit crop choices. On the other hand, due to extensive cultivation of a particular cultivar of crop year after year makes the crop susceptible to pests and diseases attack. Pests and diseases like hispa, leaf-hopper and tungro virus are prevalent in the region and extensive damage is caused by these almost every year.

Poor drainage condition- Perennial water-logging due to inadequate drainage and faulty operation of sluice gate facilities restricts potential land use of the low lands within the poldered areas.

Extension programs- Lack of appropriate extension programs for diffusion of modern technologies. Extension personal trained in saline soil management is also inadequate. This lacking retarded adoption of HYV technologies.

Land ownership pattern -Most of the farmers are landless and sharecropper. Big land ownership and unfavorable land tenure system and dominance of absentee farmers discourage adoption of modern technologies.

Socio economic condition - Poor socio-economic conditions of the farmers

Communication- Poor communication and remote marketing facilities also retard agricultural development of the region.

What is saline soil?

Soil containing soluble salts in such quantities that they interfere with the growth of most crop plants. The electrical conductivity of the saturation extract is greater than 4 mmhos/cm at 25^0 C and the exchangeable sodium percentage is less than 15. The P^H reading of the saturated soil is less than 2.5. Salts exist in the soil as ions. When precipitation is insufficient and temperature is high (December-June), salts accumulate in the soil by leaching ions from soil profile that results salinity.

Causes of salinization

- Nature of soil, less precipitation
- Permanent water-logging, tidal flow/surge
- Excess groundwater abstraction
- High evaporation due to high temperature
- Vegetation
- Intrusion of saline water in non saline areas for shrimp culture etc.

Characterization of the saline soil

Degree of salinity	Extent of salinity (dS/m)
Non-saline	0 - 4.0
Slightly saline to low saline	4.1 - 8.0
Low saline to medium saline	8.1 - 12.0
Medium to high saline	12.1 - 16.0
High saline to very high saline	>16.0

Relative salt tolerance of some field crops

Highly sensitive ECe:<1.3 dS/m	Moderately sensitive ECe: <3.0 dS/m	Moderately tolerant ECe:<6.0 dS/m	Tolerant ECe:<10.0 dS/m
Apple	Grape	Guava	Date palm
Lemon	Broccoli	Grapes	Barley
Orange	Cabbage	Para grass	Cotton
Onion	Cauliflower	Spinach	Sugar beet
Carrot	maize	Rice (BRRI Dhan	Tobacco
Beans	Cucumber	23 and 47)	Safflower
Strawberry	Pumpkin	Sugarcane	
Groundnut	Radish	Mustard	
Chickpea	Spinach	Wheat	
Lentil	Flowers	Sesame	
Grass pea	Chilli	Soybean	
Rose, etc.	Gourds	Safflower	
	Tomato	Pearl millet	
	Watermelon		
	Squash		
	Sweet potato		
	Potato etc.		

Source: Hisar Agricultural University, India and SRDI

Existing cropping systems in saline areas

In saline area, three dominant farming systems are practiced: (1) Single or two rice crops per year, (2) rice – shrimp rotational farming, and (3) shrimp farming alone. The first farming system is common in areas with relatively high elevation and some distance from estuaries, having salinity control structures (salinity duration < 3 months). The second farming system is dominant in low-lying areas with salinity-control structures and saline water duration of up to 8 months. The last farming system is practiced in low-lying areas with saline water duration of more than 8 months, because of the proximity to estuaries and/or the lack of salinity-control structures. Implementing the first farming system, farmers have grown high-yielding rice varieties, while the second farming system is linked to traditional rice varieties, which are relatively tolerant to high water depth.

Transplanted Aman rice is the main crop in the coastal area. Farmers can not grow rabi crops due to soil and water salinity and lack of irrigation facilities during the dry season. But in Khulna areas, shrimp culture is also an important agro-practice in addition to T.aman cultivation. Generally, few farmers grow chilli, sweet patato, mugbean, soyabean, watermelon and some sorts of vegetable after the harvest of T. Aman in the saline areas.

Management practices for efficient use of high salinity water

- More frequent irrigation
- Selection of salt tolerant crops and varieties
- Use of extra water for leaching
- Conjunctive use of fresh and saline waters
- Growing crops with low water requirements
- Cultural practices

Improved Cultural Practices for Soil and Water Salinity Management

Planting systems of crops (Ridge and furrow, Bed and furrow) - Beds should be at least 30 cm high above the field level. Seeds or seedlings should be planted on raised beds so that the upward movement of salts through capillary movement will be slowed down. The best planting position is on the shoulders of the double-row bed.

Mulching -If possible, straw mulch should be used to conserve soil moisture as well as to reduce the upward movement of soluble salts. Mulching can considerably help leach soluble salts, reduce ESP and obtain higher yields of tolerant crops. Increasing depth of mulch results in increased and deeper leaching of salts and significant improvement in the yield of the following rice crop.

Irrigation systems (Drip and furrow) - Drip irrigation can reduce the root zone salinity of the row crops. Factors that affect root zone soil salinity includes the salinity of irrigation water, the amount of water applied and the soil's hydraulic characteristics. Near the drip emitter, soil salinity will be the least and will reflect the salinity of irrigation water. Soil salinity increases with the distance from the emitter so that relatively large values can be detected near the periphery of the wetted pattern.

Continuous cropping - Fallowing encourages upward movement of salts. So, it is advisable to crop the land all the time, if possible. Continuous cropping, particularly when rice is one of the crops in the sequence, improves the soil, reducing ESP with time to a gradually increasing depth.

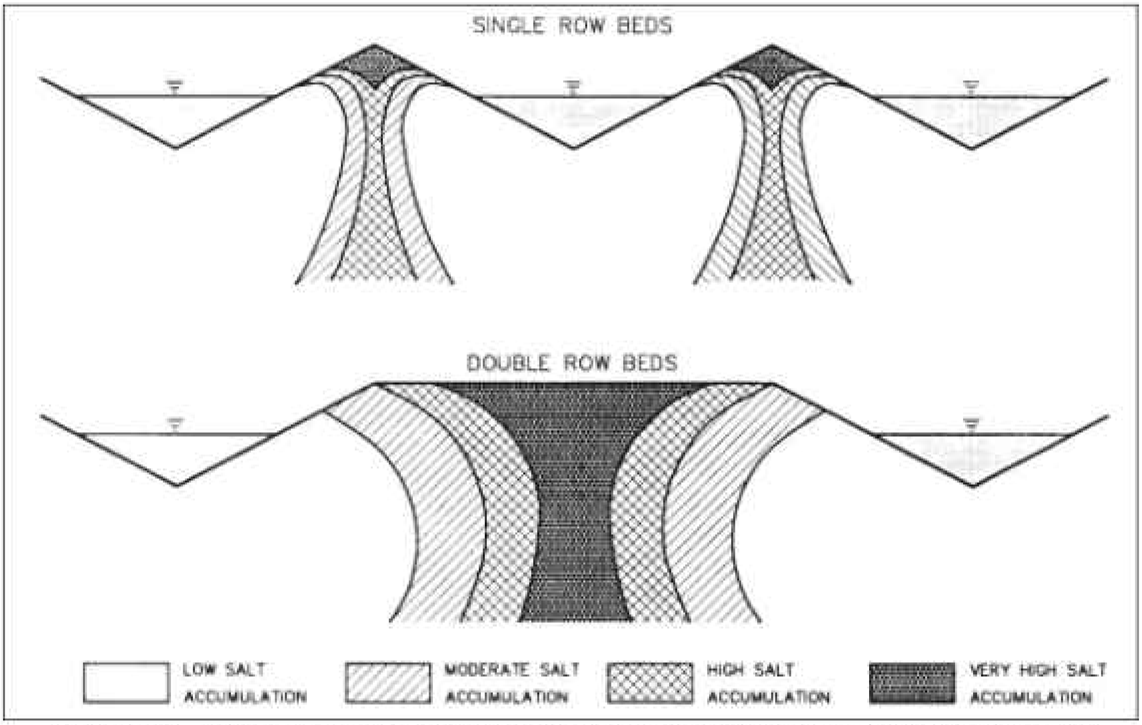


Figure 1a. Single-row versus double-row beds showing areas of salt accumulation following a heavy irrigation with saline water.

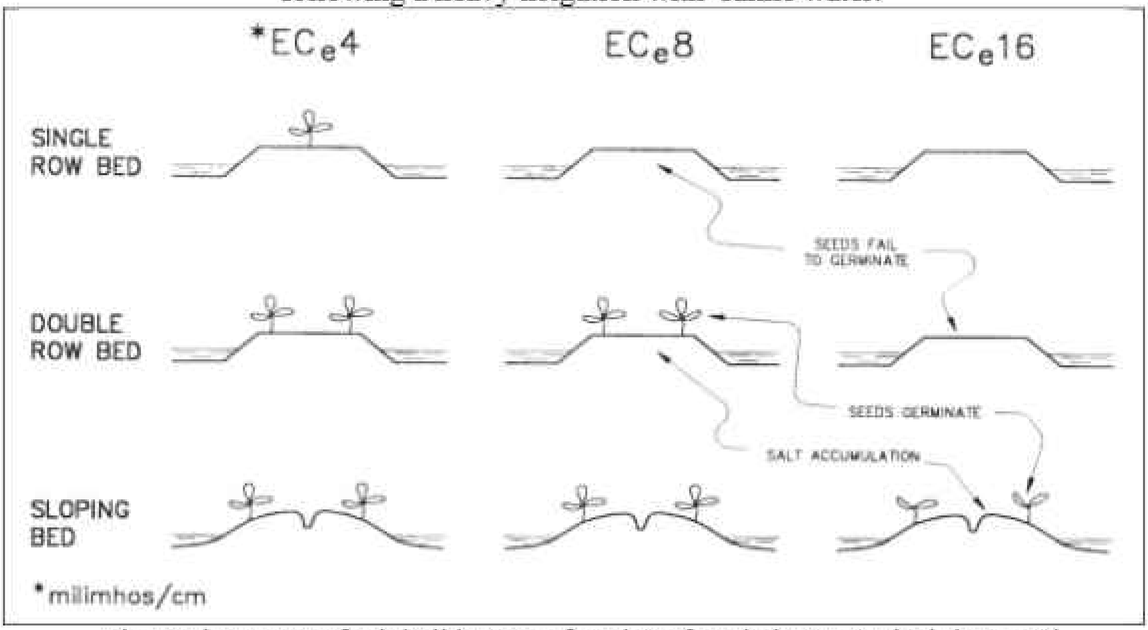


Figure 1b. Pattern of salt build-up as a function of seed placement, bed shape and irrigation water quality.

Some Water-Efficient Irrigation Technologies for Climate Smart Agriculture

A. Crop Production with Deficit Irrigation Technique

In water scarce situation, DI strategy is a way of maximizing water use efficiency (WUE) for higher yields per unit of irrigation water applied. In DI strategy, the crop is exposed to a certain level of water stress either during a particular growth period or throughout the whole growing season, without significant reduction in yields. In this technique, irrigation is applied to avoid water deficits at critical growth stages of crops or irrigation is avoid at growth stages that are not/less sensitive to water stress. Thus, deficit irrigation techniques can alleviate the negative impact of decreasing water availability on farm economic results by using more efficiently this resource.

In this strategy, wheat is irrigated two times-one at CRI stage and other at flowering stage. Maize is irrigated at early vegetative, flowering and grain filling stages. Only one irrigation at pre-flowering stage can produce a good yield. Groundnut should be irrigated at vegetative and flowering stages. Potato is irrigated at stolonization and at bulking stages. Sunflower is suggested for irrigating three times at vegetative, pre-flowering and heading stages up to 80% of field capacity, or two times at vegetative and heading stages.




B. Bed and furrow irrigation to wheat

A study in Gazipur with wheat (variety: Shatabdi) shown that the optimal bed size should be 40 cm followed by 30 cm furrow width. Over 20% water could be saved in bed and furrow method compared to that of normal flood irrigation. It is very simple to design and irrigate the wheat fields. Bed plantation allows plants to get adequate air and light for physiological growth.

C. Cultivation of wheat planted on raised bed using optimum water and fertilizers

Based on the results obtained from the study, irrigation scheduling based on sensitive growth stages was found better than the schedules based on cumulative pan irrigation in respect of grain yield and water productivity. Grain yield also decreased with the decreasing rate of the recommended fertilizers doses. So farmers are suggested to apply irrigation as per water sensitive growth stages of wheat with optimum fertilizer dose.

D. Water use in conservation tillage for wheat cultivation

The research results support some conclusions. Firstly, raised bed method might be preferable in respect of yield and water use. Secondly, although a comparatively lower yield were obtained using the other methods (PTOS, strip tillage and no tillage methods), need less tillage operation and there by cost effective. So with respect to the availability of PTOS and strip tillage machines, farmers can effectively use these methods for wheat.




E. Alternate furrow irrigation (AFI) for row crops

In this system, irrigation water is applied to alternate furrows and in-between furrow is kept dry. Dry furrows are irrigated in next irrigation event, while previously irrigated furrow remains dry. This irrigation method is suitable for row crops like tomato, brinjal, maize, etc. About 35-40% water can be saved with almost no loss in yield.

F. AWD for rice

Studies were conducted at Rajshahi, Dinajpur and Chittagong regions. Applying irrigation using AWD (Alternate wetting and drying) technique at 20 cm below ground surface was found more effective for irrigated rice cultivation.

- AWD can be started after 15 days of transplanting
- When the ponded water is dropped to 20 cm below the soil surface, irrigation should be applied to re-flood the field with 5 cm of ponded water.
- From one week before to one week after flowering, ponded water should always be kept at 5 cm depth.
- After flowering, during grain filling and ripening, the water level can drop again to 20 cm below the surface before re-irrigation.
- When many weeds are present, AWD can be stopped for 2-3 weeks until weeds have been suppressed.
- Apply urea fertilizer preferably on the dry soil just before irrigation.

G. Drip irrigation for production of vegetable crops

Drip irrigation system, a relatively new technology in Bangladesh, is getting popularity among large farmers for growing vegetable crops. It is sometimes called trickle irrigation and involves dripping water onto the soil at very low rates (2-4 litres/hour) from a system of small diameter plastic pipes fitted with outlets called emitters or drippers. Drip irrigation system is used to irrigate row crops and orchard. In this system, water is applied close to plants so that only part of the soil in which the roots grow is wetted. With drip irrigation system, water applications are more frequent (usually every 1-3 days) than with other methods and this provides a very favorable high moisture regime in the soil in which plants can flourish.

Fertigation in tomato and brinjal

Both irrigation and fertilization are used more efficiently. This method helps to reduce loss of irrigation water and fertilizers, and increase yield. Drip irrigation is applied at 2-3 days interval for 15 to 25 minutes depending on crop types and crop evapotranspiration. Irrigation at 2 days interval is the best practice. But irrigation at 3 days interval yields the best if the crops are mulched. Yield obtained under this method was about 70-75 t/ha for brinjal and 90-95 t/ha for tomato. This was about 28 - 31% increase over traditional irrigation system. Balanced dose of micro-nutrients i.e., $B_{15}Zn_{20}Mg_{20}$ is very essential along with $N_{100}P_2O_{5\text{-}100}K_{100}$ for quality tomato production. Nearly 60% and 38% of MP and 50%

of irrigation water was saved by this method. Incremental benefit cost ratio for brinjal ranged from 2.40 to 2.50 while it was about 7.0 for tomato production.

Summer tomato cultivation by fertigation

Summer tomato cultivation under drip irrigation was found very much profitable. BARI Hybrid Tomato-4 produces 30.0-35.0 t/ha of fruits in summer (June – Sept.) under poly shed with fertigation system. Nearly 28-32% increased summer tomato yield can be obtained by fertigation system over traditional system. The benefit cost ration (BCR) was found to be 4.22. Medium and large farmers can use this technology. It can create employment opportunity for rural people during the lean period.

Capsicum production by fertigation in controlled condition

Controlling night temperature within 15^0C to 17^0C in poly house, capsicum can be successfully grown by fertigation. Both water and fertilizer use efficiency in fertigation system is higher than any other methods. Thus it can save water and fertilizer. About 15-16 t/ha of capsicum can be produced by fertigation system which is about 40-45% more than the yield obtained under traditional method of irrigation. Fertigation system can save about 45-48% of irrigation water and about 35-40% of urea and MOP fertilizer. This system helps controlling bacterial wilt disease. Benefit-cost ratio under this method was about 5:1

Strawberry production by fertigation

Strawberry can be profitably grown by fertigation system. Yield obtained under this system was about 16 t/ha which was about 40% higher than tradition method. The potential yield can be realized if drip irrigation is applied at 2 days interval with a moderate fertilizer dose of $N_{75}P_{45}K_{75}S_{25}$ kg/ha. This system can save about 46% of irrigation water and about 50-55% of urea and 25% of MOP fertilizer. Benefit-cost ratio under this method was about 8:1. About 15-18 lakh taka/ha can be earned by cultivating strawberry with fertigation system.

H. Sprinkler Irrigation

Sprinkler irrigation is a very new introduction in the arena of irrigation system of Bangladesh. It is a method of applying irrigation water through a system of pipes usually by pumping. It is then sprayed into the air through sprinklers so that it breaks up into small water drops which fall to the ground similar to rainfall. Though sprinklers are more costly to purchase and operate than surface systems, farmers may achieve higher yield with higher net return and BCR with sprinkler irrigation, provided the systems are operated and maintained correctly.

i) Cultivation of onion by sprinkler irrigation

Sprinkler irrigation at 7 days interval with 120 ETc is most suitable for onion production. Compared to surface irrigation method, bulb yield of onion can be increased by about 60-65%. As much as 19.0 t/ha bulb yield was obtained by cultivating onion (BARI Piaj-1) using this system. Benefit-cost ratio of 2.83 supports well the economic feasibility of sprinkler irrigation system.

ii) Cultivation of garlic by sprinkler irrigation

Sprinkler irrigation at 10 days interval with 80% ET_0 was found most suitable for garlic production. Compared to surface irrigation method, bulb yield of garlic can be increased by about 15-20% with water saving of about 8-10%. Benefit-cost ratio was about 2.0.

F. Water Logging and Salinity/Wastewater Management

i) Water logging effect on sesame:

Late vegetative and flowering stages are very sensitive to water logging. More than 65% yield may be decreased with a continuous logging of 36 hours at vegetative and flowering stages. Even a continuous logging of only 12 hours may decrease the yield (33- 35%) reasonably. So, standing water should be drained out as early as possible to avoid probable yield loss.

ii) Water logging effect on chilli

Yield reduction of chilli is directly proportional to the water logging duration (24, 48 and 72 hours). Whatever might be the duration of water logging, flowering stage is more sensitive to water logging. Yield reduction ranged from 43 - 82% with minimum for 24 hours and maximum for 72 hours water logging. Vegetative stage is less sensitive to water logging.

iii) Integrated salinity management techniques

Farmers in the saline areas can grow high value horticultural crops like tomato, chili, okra, watermelon, pumpkin, etc. using drip irrigation in raised bed with mulch. Some high value crops like tomato, chili, watermelon, and cucumber perform well in the saline areas in raised beds with mulch and drip irrigation conditions. Drip irrigation in raised bed with mulch is an integrated way to reduce soil salinity substantially (for example, 10 dS/m to 4.5 dS/m) to make soil environment favorable for crop growth. The crops are planted on 30 cm raised bed. Then straw or polyethylene mulch is applied after plant establishment. Irrigation is applied through drip system at 2 days interval for 15 to 25 minutes depending on crop types and crop evapotranspiration. The technology has found technically feasible and economically viable for saline areas (ie, BCR is about 2.0 to 4.7). In this technique, crops can be grown in comparatively high saline soil.

iii) Urban wastewater for crop production

In the advent of water scarcity, urban wastewater as an alternate source of irrigation water can alleviate the problems of local water shortages, reduce the pressure on fresh water sources and protect the local environment. Some research findings on the use of wastewater for irrigating upland crops like wheat, maize, potato and vegetables reveal that urban wastewater can be a reliable source of irrigation in dry prone areas of Bangladesh. Irrigation with wastewater increases crop yields, and reduces the need for costly fertilizer inputs, thereby reduces the production cost of the farmers. It can save not only about 20 -25% fertilizer, but it also improves physicochemical properties of soil which are helpful for next cropping. A well-planned use of urban wastewater can thus contribute to food security by increasing food production in the peri-urban areas.

Conjunctive Use of Saline and Fresh Water for Crop Cultivation in Saline Area

- In this method, saline water is mixed with fresh water for irrigating crops at their seedling and vegetative stages
- At the later stages saline water alone or blend with freshwater is used for irrigation
- Blending of saline water with fresh water at ratio of 1:1 is enough to reduce the water salinity to crop tolerance

- Groundwater with a salinity of 2.8-4.3 dS/m is a good source to exploit for irrigation at the initial stages of crops.
- Available canal water with salinity level of 4.6 - 6.4 dS/m can be utilized for wheat irrigation at the mid and latter growth stages with 6-8% of yield loss.
- Farmers will get more opportunity to grow wheat in fallow and water scarce areas

G. Water Management in Hilly Areas

Perennial charas, rivers, rain water, etc. can be used successfully in hilly areas as a source of irrigation water by constructing necessary water control structures like small dams/dykes/diversion box and reservoirs. Rain water can be harvested during the rainy season and preserved through the construction of cross dam in between two hills across the water ways. Water from such small scale reservoir can be used in dry season to irrigate horticultural and field crops in winter months for good harvest.

Gravity flow irrigation is possible to irrigate hill valley by raising the water level of Chharas through construction of dam, dyke, etc. Besides, pipe and gate valve can be set in a reservoir dam in such a way that it permits the controlled use of water by opening and closing of gate valve. As water is stored at upstream of the valley, the potential energy of reservoir water is enough to make gravity flow to the lower valley land. If flow rates of charas are very low then a reservoir can be made adjacent to the chara to collect this chara water and then LLP is used to irrigate crop land. Due to the availability of irrigation water there has been a shift of cropping pattern from wheat and forage crops to vegetable crops.

Conclusions

The scope of further irrigation development to meet food requirements in the coming years is, however, severely constrained by decreasing water resources and growing competition for clean water. Serious water shortages are developing as existing water resources reach full exploitation. The great challenge for the coming decade will therefore be the task of increasing food production with less water, particularly in areas with limited water and land resources. The aim of this division is to develop water-efficient irrigation technologies and provide further information on the way crops react to irrigation water, leading to practical guidelines to assist extension workers, farmers and decision makers in minimizing water use for optimal crop production under changing climate.

Sustainable Irrigation and Water management for Haor, Hill Tracts and Coastal Region: Field Application

Eng. Muhammad Bodiul Alam
Chief Engineer (Minor Irrigation)
BADC, Dhaka

What is Sustainable Water Development?

Sustainable water management means using water in a way that meets current, ecological, social, and economic needs without compromising the ability to meet those needs in the future.

What is Sustainable Development of Groundwater Resources?

Groundwater sustainability is the development and use of groundwater resources to meet current and future beneficial uses without causing unacceptable environmental or socioeconomic consequences.

Example: Keeping the water running while brushing your teeth or shaving, wastes about 4-5 gallons of water on average. That's roughly what a family in Africa uses in an entire day. Instead, you could plug the sink while shaving and turn the faucet off until it's time to wash.

Principles of Sustainable Groundwater Management

A. Groundwater Recharge
  1. Natural recharge processes
  2. Artificial recharge methods

B. Monitoring and Assessment
  1. Regular groundwater level monitoring
  2. Water quality assessment

What are the problems with groundwater management?

Although groundwater is often relatively well protected from pollution, poor management has resulted in negative impacts such as declining aquifer heads, groundwater quality deterioration, lower crop yields, ecosystem degradation, and in some cases, land subsidence and seawater intrusion.

Challenges in Groundwater Management

- Over-Extraction, Consequences of excessive pumping
- Increased energy costs for pumping
- Depletion of aquifers

How is groundwater management sustainable?

1. Preventing contamination of groundwater (GW), which causes the groundwater water supply to not be able to be used as resource of fresh drinking water.
2. Limiting use of GW so that natural regeneration of contaminated groundwater can takes place.

What are the groundwater resources in Bangladesh?

Groundwater in Bangladesh occurs at a very shallow depth where the recent river-borne sediments form prolific aquifers in the floodplains. In the higher terraces, the Barind and Madhupur tracts, the Pleistocene Dupi Tila sands act as aquifers. In the hilly areas, the Pliocene Tipam sands serve as aquifers.

Groundwater Resources Development in Bangladesh

The groundwater resource is one of the key factors in making the country self-sufficient in food production. Groundwater-irrigated agriculture plays an important role in poverty alleviation and has greatly increased food production. The need for conjunctive use of surface and groundwater are highlighted in the National Water Policy (NWPo, 1999). This policy has established a linkage between water resources and the rural livelihood and ultimately the link to poverty alleviation. The country's GDP is highly dependent on the development of water resources in general. Trends indicate that farmers are becoming increasingly productive as a result of enhanced access to irrigation through groundwater (BMDA, 2000). For groundwater irrigation, the prime source of power energy for lifting water is fossil fuel (diesel or petrol) and electricity. Hence the linkage between the energy for lifting groundwater and irrigation economics is also very important.

Benefits of Groundwater Use for Agricultural Irrigation

Groundwater is a 'very popular commodity' with farmers (Shah et al, 2007) since it:

- is usually found close to the point-of-use (often only a well's depth away)
- can be developed quickly at low capital cost by individual private investment
- is available directly on-demand for crop needs.

What is the importance of groundwater for irrigation in Bangladesh?

Groundwater is a lifeline for agriculture in Bangladesh, supporting crop cultivation throughout the year. Essential during the dry season when surface water availability is limited. Bangladesh has made impressive progress in agriculture sector and has almost become self-sufficient in food grain production. This is a tremendous achievement owing to its small territory and huge population and this was achieved through agricultural mechanization and modernization. Irrigation is one of the leading inputs has direct influence to increase yield, food grains production and plays vital role for ensuring food security in Bangladesh. Various technologies have been used for irrigating crops which have contributed to rapid expansion of irrigated area.

Groundwater covered 77 percent of total irrigated area and major (62%) extractions occurred through Shallow Tube Wells (STWs). Boro rice, an irrigated crop, consumed 73 percent of the total crop irrigation and contributed to a greater extent in total rice production in Bangladesh. Boro rice alone contributed to 55 percent of total food grain.

History of Irrigation in Bangladesh

Bangladesh Agricultural Development Corporation (BADC) introduced shallow tubewells (STW) as irrigation equipment for the first time in 1968. Later in 1973 deep tubewell (DTW) irrigation started. In Bangladesh, the pumps used in irrigation are classified as shallow tubewell (STW), deep-set shallow tubewell (DSTW), very deep set shallow tubewell (VDSTW), and deep tubewell (DTW). The STW, DSTW and VDSTW are scientifically termed as suction mode pumps and DTW as force mode pump. Generally, the water pumps used for irrigation are selected on the basis of the depth of water table. The distance between the pump base and the depth of water table dictates whether the pump would be a force mode or a suction mode type i.e., whether it would be STW or DSTW or VDSTW or DTW of low, medium or high head. Basically, suction mode pump cannot operate economically in areas where water table goes below 7.6 m (25ft.) from pump base. According to BADC (2020), in boro season of 2019, a total of 1398706 shallow tubewells, 37007deep tubewells, 199914 low lift and floating pumps (for lifting surface water), and 3684 other equipment were used for irrigation all over Bangladesh.

Sustainable Development of Groundwater Resources for Irrigated Agriculture

The sustainable development of groundwater resources for irrigated agriculture is crucial for ensuring long-term food security, economic stability, and environmental health. Here are some key points highlighting the significance of sustainable groundwater development in the context of irrigated agriculture:

Water Security: Groundwater serves as a reliable and resilient source of water for irrigated agriculture. By managing groundwater resources sustainably, farmers can reduce their dependence on unpredictable rainfall patterns and surface water availability, ensuring a more secure water supply for their crops.

Drought Resilience: Groundwater can act as a buffer during periods of drought or low precipitation. Well-managed aquifers can provide a continuous and stable water supply even when surface water sources are scarce, helping to mitigate the impact of climate variability on agricultural production.

Increased Crop Yields: Adequate and sustainable groundwater use allows farmers to optimize irrigation practices, ensuring that crops receive the necessary amount of water throughout their growth cycles. This can lead to increased crop yields and improved overall agricultural productivity.

Economic Stability: Sustainable groundwater development contributes to the economic stability of farming communities. Reliable access to water enables farmers to plan and invest in their agricultural activities with confidence, fostering economic growth and reducing the vulnerability of rural economies.

Environmental Conservation: Over-extraction of groundwater can lead to environmental degradation, such as land subsidence and the depletion of ecosystems dependent on groundwater. Sustainable groundwater management helps maintain a balance, preventing adverse environmental impacts and preserving biodiversity.

Social Equity: Fair and equitable distribution of groundwater resources is essential for preventing social conflicts over water access. Sustainable management practices promote community involvement, stakeholder engagement, and the implementation of policies that consider the needs of all users, including small-scale farmers.

Energy Efficiency: Groundwater pumping for irrigation often requires energy. Sustainable practices involve optimizing energy use through efficient irrigation technologies, reducing the carbon footprint associated with agricultural water extraction, and promoting the use of renewable energy sources.

Regulatory Frameworks: Establishing and enforcing effective regulatory frameworks for groundwater use is crucial for sustainable development. This includes monitoring and controlling extraction rates, implementing recharge programs, and setting limits to prevent over-exploitation of aquifers.

Research and Innovation: Investing in research and innovation is key to developing new technologies and practices that enhance the sustainable use of groundwater in agriculture. This includes improved irrigation techniques, crop varieties that are more water-efficient, and advanced monitoring tools for aquifer health.

Climate Change Adaptation: Climate change brings increased uncertainty in weather patterns, making sustainable groundwater management even more critical. Developing adaptive strategies, such as promoting water-saving technologies and efficient irrigation practices, can help agriculture become more resilient to the impacts of climate change.

In conclusion, the sustainable development of groundwater resources for irrigated agriculture is essential for achieving a balance between meeting current agricultural needs and ensuring the availability of water resources for future generations. It involves a holistic approach that considers environmental, social, and economic aspects to create a resilient and productive agricultural system.

Best Practices for Sustainable Groundwater Use in Irrigation

A. Efficient Irrigation Techniques
  1. Drip irrigation
    a. Precision water application to plant roots.
    b. Reduces water wastage and enhances efficiency.
  2. Precision agriculture methods
    a. Sensor-based technology for optimal resource use.
    b. Variable rate irrigation systems.

B. Crop Selection
  1. Choosing crops adapted to local water conditions
    a. Drought-tolerant crop varieties.
    b. Matching crops to available water resources.
  2. Crop rotation strategies
    a. Minimizes water demand for specific crops.
    b. Enhances soil health and fertility.

C. Water Conservation Measures
  1. Soil moisture management
    a. Mulching to retain soil moisture.
    b. Avoiding over-irrigation through soil moisture sensors.
  2. Mulching and cover cropping
    a. Reducing evaporation from the soil surface.
    b. Improving soil structure and water retention.

Future Trends and Innovations

A. Emerging Technologies

1. Remote sensing for monitoring
    a. Satellite and drone technology for data collection.
    b. Advanced modeling for predictive analysis.
2. Smart irrigation systems
    a. Sensor-based irrigation scheduling.
    b. Integration with weather forecasts for precise water application.

B. Research and Development

1. Advances in groundwater recharge techniques
    a. Innovative methods for artificial recharge.
    b. Sustainable use of stormwater for recharge.
2. Sustainable agricultural practices
    a. Development of climate-resilient crop varieties.
    b. Integration of agroecological principles.

Integrated Water Resources Management (IWRM)

A. Coordinated Approach

1. Balancing water use across sectors
    a. Coordinated planning between agriculture, industry, and urban areas.
    b. Consideration of environmental water needs.
2. Synergy between surface water and groundwater management
    a. Integrated planning for both water sources.
    b. Understanding the interconnectedness of surface and groundwater.

B. Climate Resilience

1. Adapting to changing climate patterns
    a. Developing climate-resilient crop varieties.
    b. Anticipating and planning for changing precipitation patterns.
2. Mitigating the impact of extreme weather events
    a. Building resilient infrastructure.
    b. Emergency preparedness and response plans.

Policy for Sustainable Groundwater Management Irrigated Agriculture in Bangladesh:

According to The Ground Water Management Ordinance, 1985 (XXXVII of 1985) the minimum distance between two wells would be:

a. 2500 feet between two DTWs b. 1700 feet between a DTW and a STW
c. 800 feet between two STWs

The minimum distance between two wells would be:

Capacity	2 cusec	1.50 cusec	1.00 cusec	0.50 cusec
2.00 cusecs	800 meter	690 meter	600 meter	500 meter
1.50 cusec	690 meter	630 meter	540 meter	415 meter
1.00 cusec	600 meter	540 meter	450 meter	350 meter

Fig: Deep tube well scheme and buried pipe irrigation channel.

Fig: Rubber Dam (For storing water)

Fig: Hydraulic Elevated Dam built to impound surface water for irrigation, flood control etc.

Fig: Artesian Well (AW) (reduce water loss by providing irrigation)

Fig: Floating Pump (surface water use for irrigation)

Fig: Sprinkler irrigation

Fig: Drip Irrigation

Fig: Poly shade

Fig: Dug well (Rain water is harvesting and storing in dug well by a funnel)

In some part of the country irrigation carried out by gravity flow through major irrigation projects.

Solar Irrigation Pumps

Sustainable Irrigation and water Management in Char, Barind and Drought-prone Areas

Dr. Md. Iquebal Hossain
Superintending Engineer, BMDA

Water is the most valuable gift of nature

- A "Single" Resource– has no substitute
- A Limited Resource
- A Scarce Resource
- Has Social, Economic, and Environmental Value

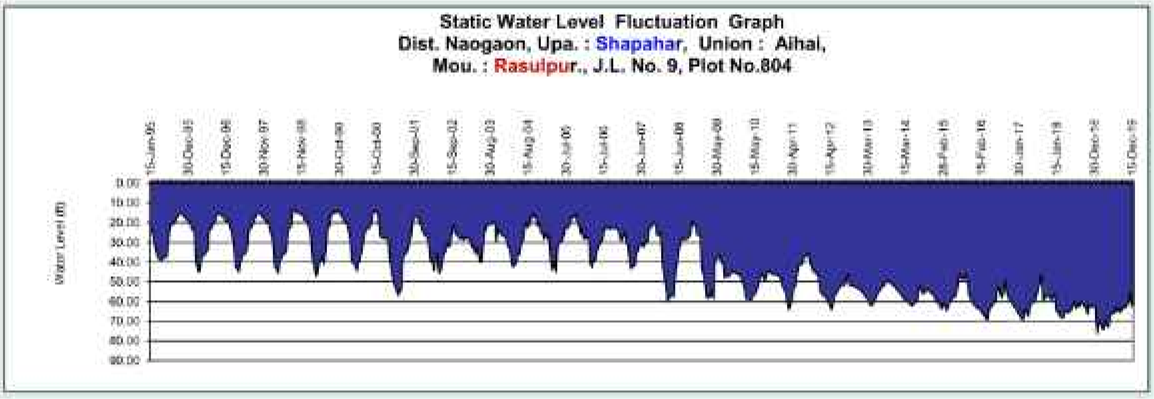
World's water Resources

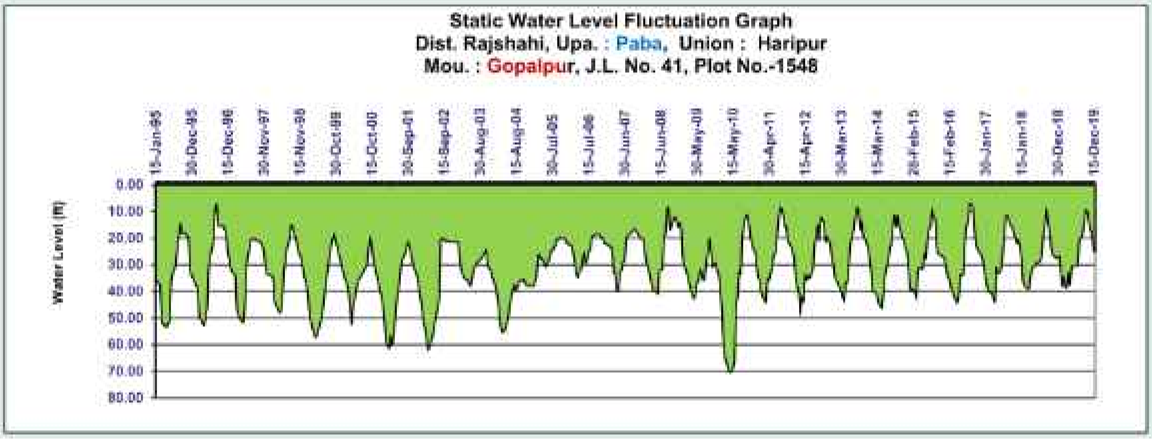
The estimated total world's water	:	$1.36X10^5$ M ha-m
Of this global water, Salt (saline) water (in ocean)	:	97.2%
Fresh water available on the planet earth	:	2.8%
Out of 2.8% of fresh water		
Available surface water	:	2.2%
Groundwater	:	0.6%
Out of this 2.2% of surface water		
Fresh water in glaciers and icecaps	:	2.15%
Only available in lakes and streams	:	0.01%
In other forms	:	0.04%
Out of this 0.6% of stored ground water		
It can be extracted economically with the present drilling technology	:	0.25% (only)

About Barind Tract

The Barind Tract is characterized by its undulated, terrace-like landscape and a distinct agro-climatic profile that sets it apart from other regions of Bangladesh. It receives significantly less rainfall—averaging about 1,400 mm annually, well below the national average of 2,500 mm—and experiences widely variations in temperatures ranging from 4°C to 44°C round the year. The region is underlain by a thick top clay layer, over 15 meters deep, which severely restricts natural groundwater recharge. Surface water sources are scarce, making groundwater the primary source for irrigation, drinking, domestic, and other uses. However, groundwater levels are in a declining trend, especially in the high Barind area, which has been identified as a climate-vulnerable hotspot under the Bangladesh Delta Plan 2100. During the dry season, groundwater also flows out of the aquifer system into rivers such as the Ganges and Mohanonda, contributing to base flow losses estimated at 21.5 million cubic meters (IWM, 2006; 2012). The region's climate is notably hotter and drier than most parts of the country, with sparse tree cover and frequent soil cracking due to moisture stress. Traditionally, the area supports only a single crop cycle with rain-fed T-Aman rice, and insufficient or untimely rainfall often disrupts crop production. Post-harvest, the fields serve as grazing land for cattle. The Barind Tract has long been underprivileged and underdeveloped, with poor socio-economic conditions prevailing among its residents.

Trend of Groundwater level





Irrigation scenario

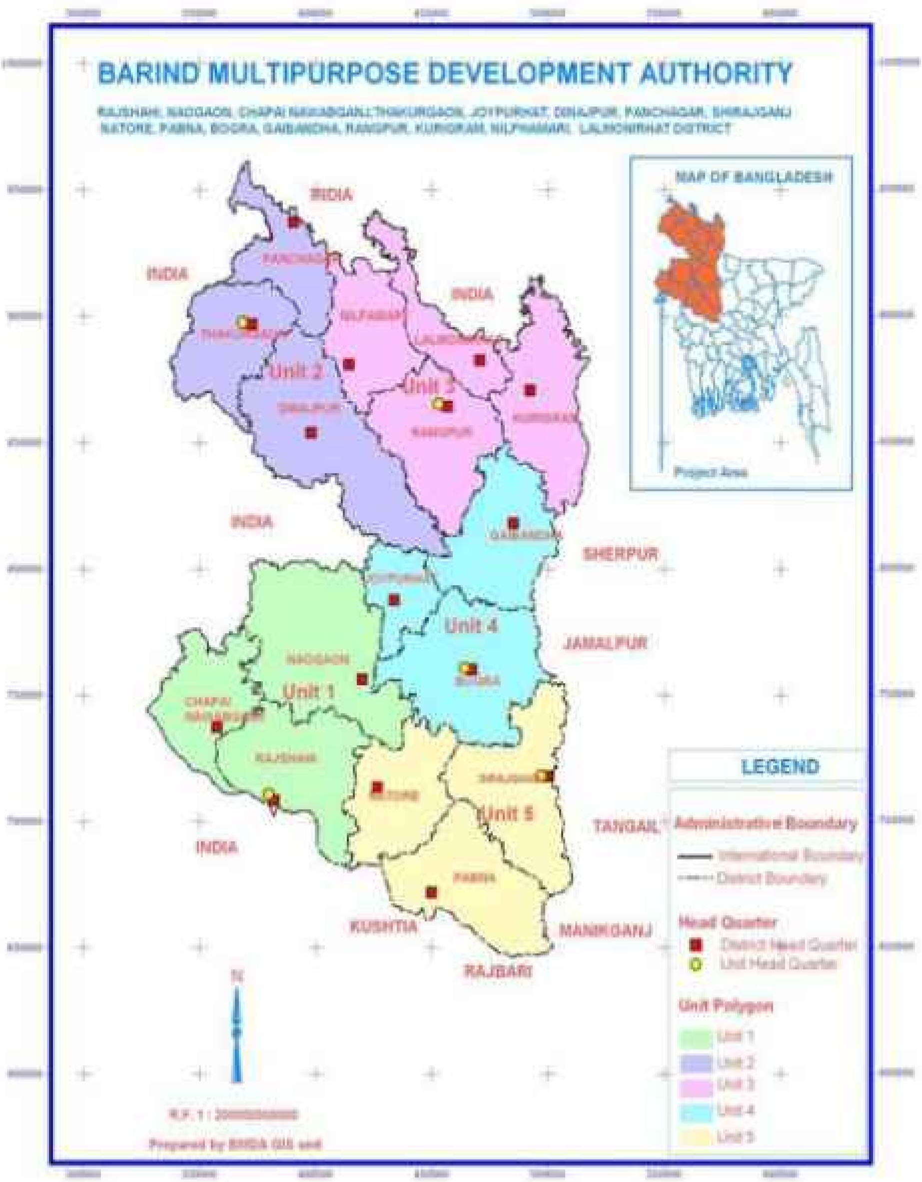
In Bangladesh:

- Total area : 1,47,56,885 ha
- Net Cultivated area : 80,82,398 ha
- Total irrigated area : 57,48,534 ha (71% of net cultivated area)
- Surface water irrigation: 15,97,944 ha (27.80%) Groundwater irrigation: 41,50,590 ha (72.20%)

In Barind Area:

- Surface water irrigation: 54,915 ha (9.94%)
- Groundwater irrigation: 4,97,668 ha (90.06%)

Jurisdiction of BMDA



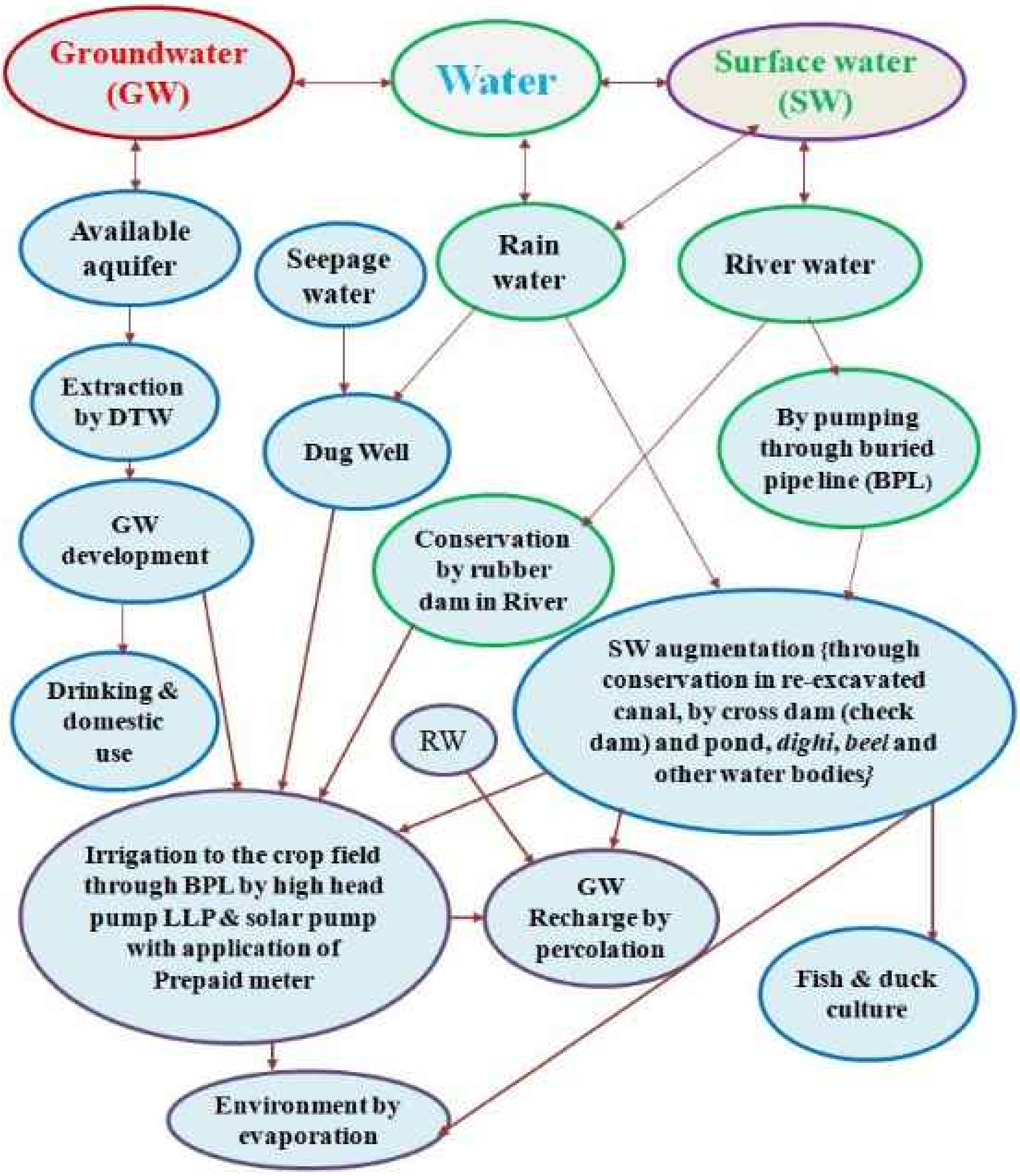
Vision & Mision of BMDA

Vision

Development of agriculture & environment in Barind Area.

Mision

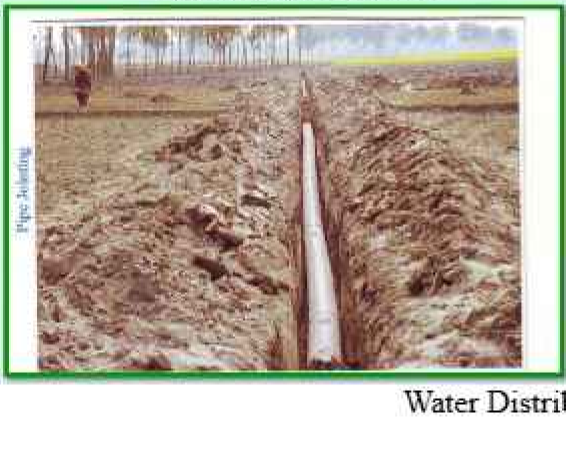
Expansion of irrigation area & cultivable land through establishment of irrigation infrastructure; Quality seed production & marketing facilities (Feeder Road) and environmental (Afforestation) development by plantation.



Groundwater Irrigation (extraction by DTW)

Earthen Surface Channel

Brick lined Surface Channel



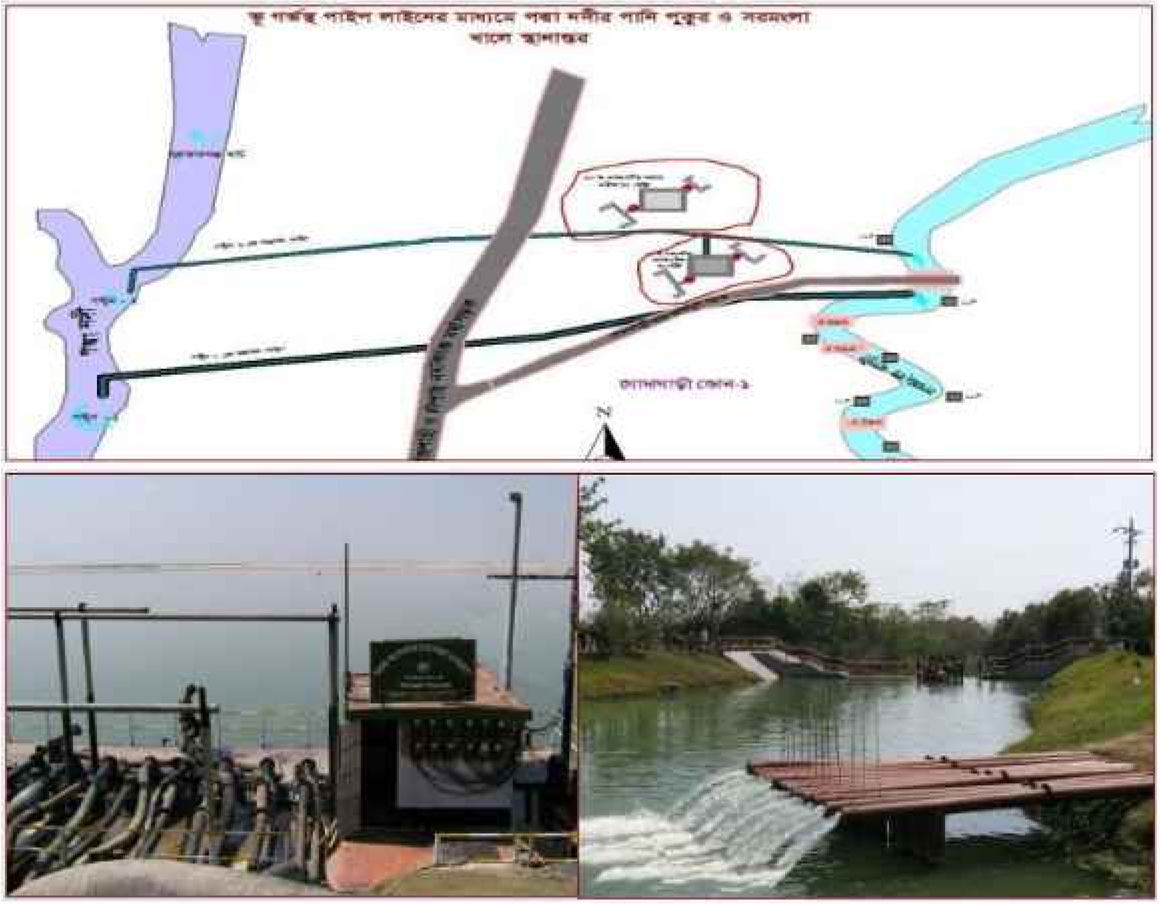
Water Distribution System

Drinking water supply to the rural people (from irrigation DTW)

Surface water Irrigation (by cross dam/check dam at the re-excavated khari/canal)

Surface water Irrigation (using Solar energy driven LLP)

Surface water Irrigation (Water from re-excavated dighi)



Surface water Irrigation in double lifting way (Water supply from Padma River to Sarmongla canal trhough 3.5 km under ground pipe line)

Surface water Irrigation (Water from river to the re-excavated canal)

Surface water Irrigation (By rubber dam at the Barnai river, Puthia

Removing of water logging, Sonakuri Beel, Pirganj, Thakurgaon

Dug well for severe water stressed area

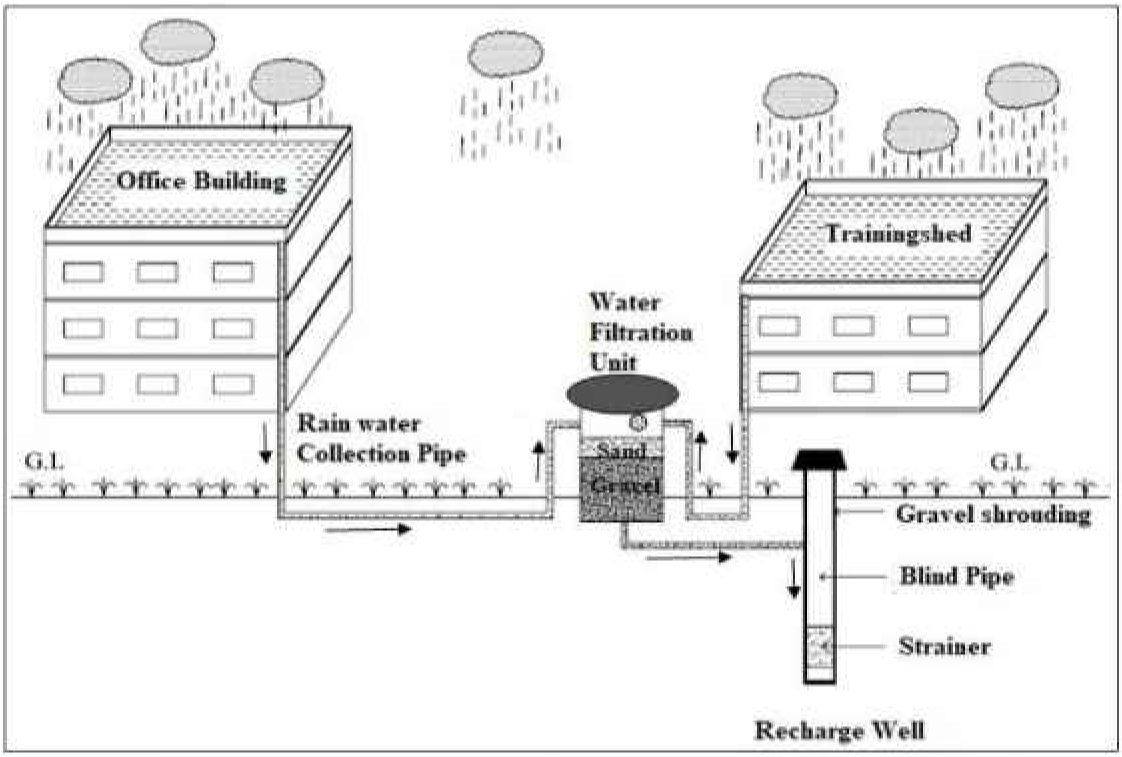
Sprinkler irrigation at Tea garden, Mathafata,Tentulia, Panchagar

Drip irrigation at Shahapania, Godagari, Rajshahi

Irrigation at Char land area, Palashbari (Jamunasshari river side)

Irrigation at Char land area, Jadurchar (Zinjiram river side)Kurigram Irrigation at Char land area, Jadrchar (Zinjiram river side) Kurigram sadar, Kurigram

Irrigation water management system



(a) Office Building, Training Shed and FU with RW

(b) Filtration Unit (FU) with Recharge Well (RW)

MAR application at BMDA Mohonpur office campus (using rooftop rain water)



Achievement of BMDA: At a Glance

Achievements of BMDA at a glance	(Upto June, 2024)
Installation /Rehabilitation/Activation of DTW	15824
Irrigation Water Distribution System (Buried Pipe)(Km.)	16076
LLP driven by Electricity (Nos.)	556
LLP driven by solar energy	420
Re-excavation of Canals (km.)	2560
Construction of Cross dam /Check dam (Nos.)	779
Pontoon for irrigation (Nos.)	11
Re-excavation of Derelict Ponds (Nos.)	4276
Solar powered Dug Well (Nos.)	640
Drinking water supply from irrigation DTW (Nos.)	1715
Utilization of Irrigation equipment in 2023-24 (Nos.)	DTW 15538 & LLP 891
Irrigated area in 2023-2024 (Lakh Hec)	Aus-0.811, Amon-3.596, Robi-5.946
Cropping Intencity (in CA, berore project- 117%)	230%

Planning and Designing Climate-Smart Irrigation Projects

Dr. Md. Aminul Haque
Chief Scientific Officer (Water Resources)
WARPO, Dhaka
Email: maminul05@yahoo.com

Agriculture in the country is characterized by subsistence production systems largely dominated by small and marginal farmers, yet a significant shift towards commercial farming with high value crops, fisheries and animal products has been evident in recent years. Given its abundant water resources, rice production under irrigated conditions is the top contributor to agricultural GHG emissions in Bangladesh. In an effort to reduce these emissions and other environmental impacts, farmers are increasingly applying alternative wetting and drying (AWD) methods of irrigation, using deep placed briquetted urea fertilizer, moving to non-rice crops and incorporating straw stubbles in to rice paddies as an alternative to burning crop residues—the latter contributing to soil organic matter replenishment. The rapid evolution of technology, including innovations in the fields of mobile, big data, social media, and the Internet of Things (IoT), creates a new challenge for project management methods because the environmental requirements change. Several solutions are proposed in smart irrigation project.

Smart Irrigation is a method of using science and technology to solve water in irrigation. **Climate-smart irrigation** provides plants with the right amount of water according to soil type and weather conditions to save irrigation water. A key things that are essential for saving water, time and money. These include a smart controller, rain sensors and moisture sensors.

Benefits of the smart irrigation:

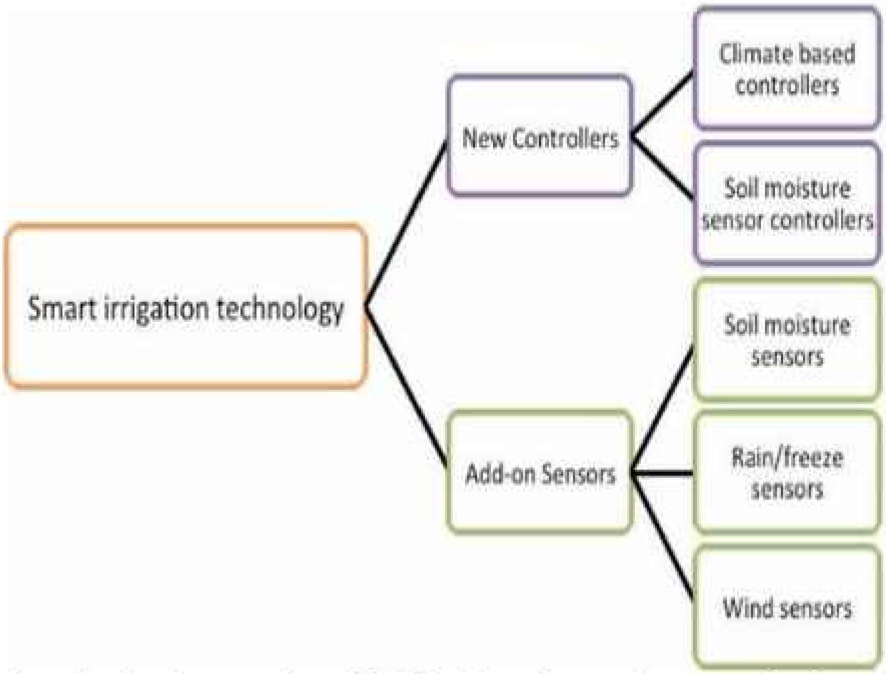
- **Water Conservation** - ensures plants get the right amount of water, leading to significant water savings.
- **Cost Saving** - low tariff periods ensuring substantial cost benefits to the user.
- **Improved Plant Health** - allow plants to receive water according to their specific needs. This ensures that the plants have adequate moisture, promotes healthier growth.
- **Increases Work Efficiency** - it can operate independently, saving farmers' time and effort.
- **Environmental Compatibility** - by reducing water use which can help reduce pressure on local water sources which is critical for areas prone to drought and water scarcity.
- **Remote Control and Monitoring** - via mobile apps or web interfaces
- **Integration With Weather Data** - can integrate real-time weather data and adjust irrigation schedules based on rainfall, humidity, temperature and other environmental factors.

- **Customization and Flexibility** - offers a high degree of customization. Users can customize watering schedules.

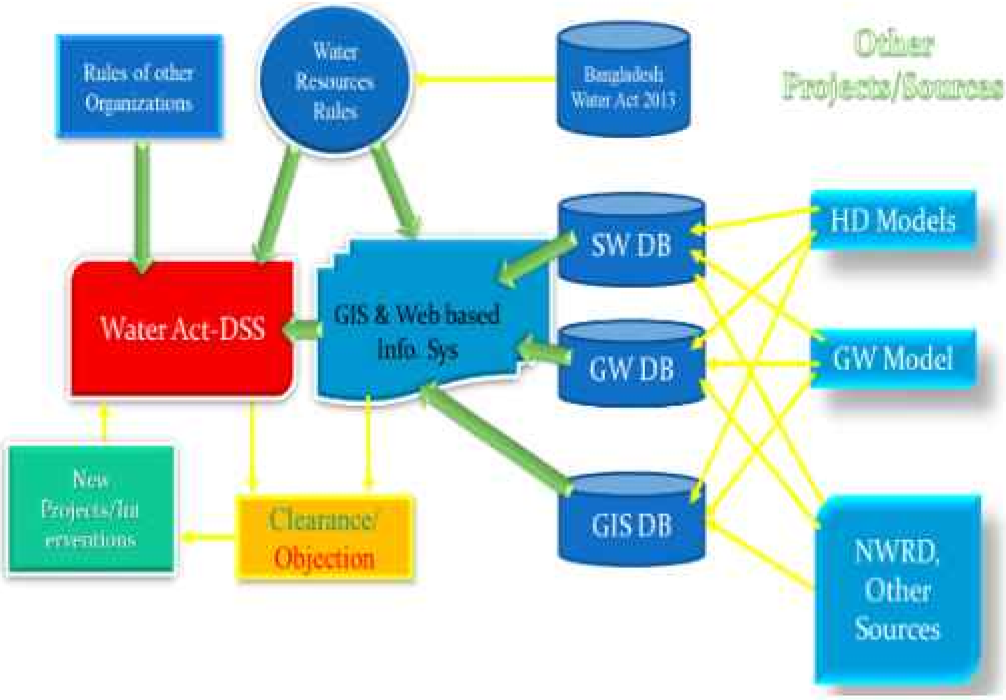
Planning Instruments for Smart Irrigation:

Climate-Smart Irrigation Design

- Smart irrigation system, which include data acquisition, irrigation control, wireless communication, data processing and fault detection features.
- Weather and Environment Analytics, Smart Schedules and Notification System



With regards to the implementation of IoT devices, the used communication technologies could be considered as a vital and imperative point to attain successful operations. The main technologies that are used in IoT for irrigation could be classified into two categories. One could be regarded as the devices that function as nodes and lead to forward or transmit small data amount at short distances along with having low consumption of energy. Consequently, the other devices are the ones that have the ability to transmit huge amounts of data over long distances, having high-energy consumption. There are various benefits associated with IoT systems in irrigation and some of them could be considered as overall water consumption reduction, high cost-efficiency, high performance efficiency, lesser energy consumption, lesser wastage of crops, and more. Development of Architecture of Smart Water Resources Information System is shown below:



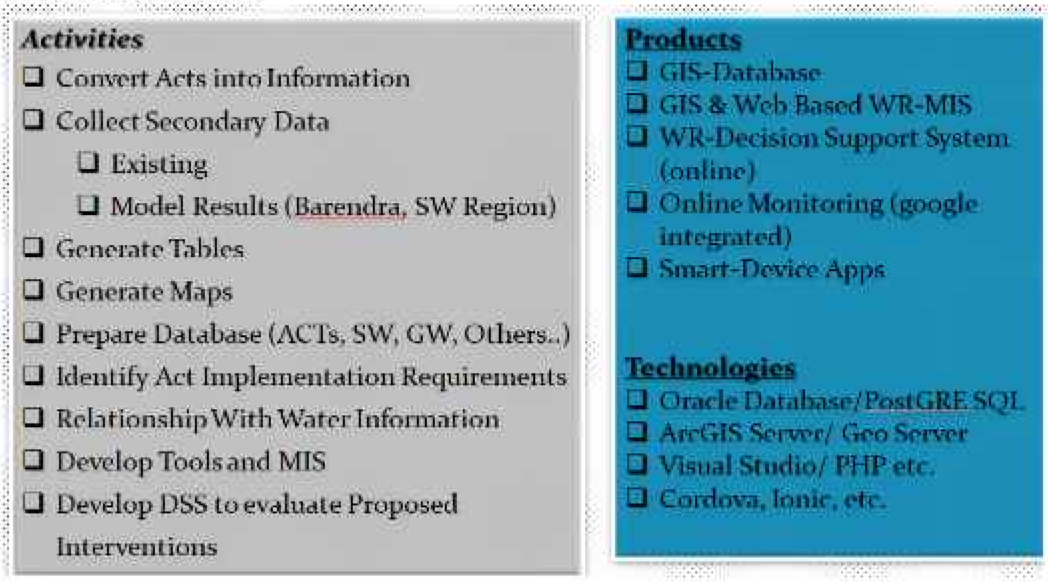
Smart Solutions for Data Acquisition, Process for SW and GW

- Water level (GW and SW) data acquisition from gauge stations across the country through SMS using Smart-Devices;
- Automatic data storage and View on Web;
- Smart Phone based Complain and Response System

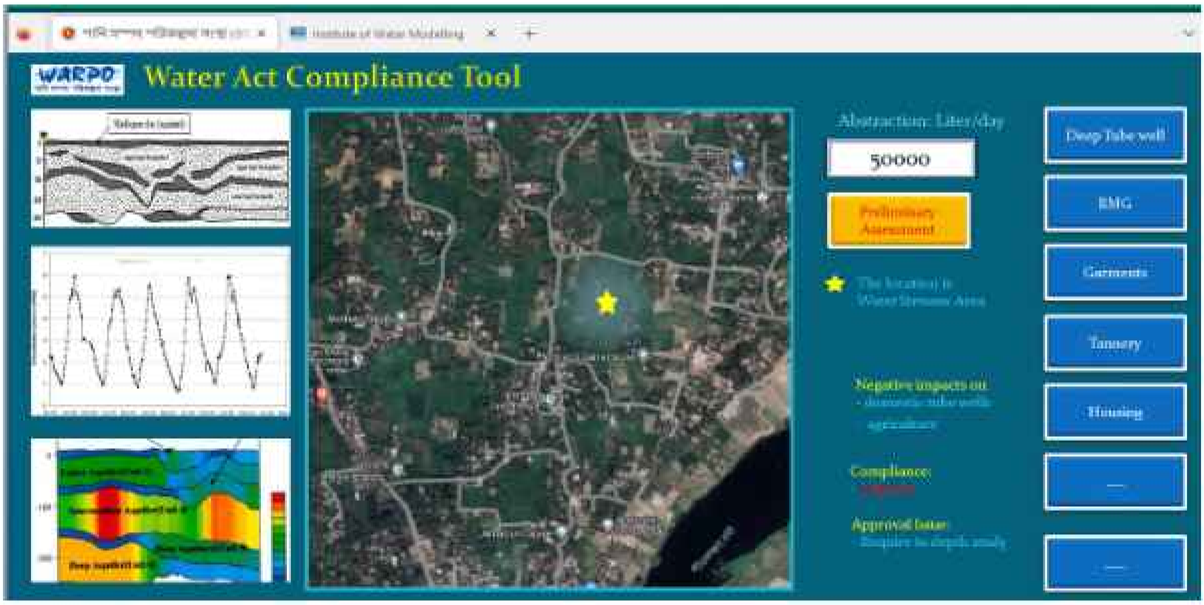
The first step for the implementation of a smart irrigation system for farm automation is laying the wireless sensor network field in which each node is inter connected by Wi-Fi module and lays data over a common server, from where an automated python script can keep polling the data and then send alert/start signal for the required operation. The first step towards establishing an automatic irrigation system is collecting data through various sensors attached throughout the field.

Water Act-DSS

Activities and Products



Water Act Compliance Tool



Final Products:

- Water Act DB; SW, GW and other DB
- Smart-WRIS: An MIS backed by SW & GW DB, GIS maps
    - Will produce status reports
    - View, Query database and maps
    - Water Act Implementation DSS backed by Water Act-2013 DB, MIS and other DBs
    - Facilitate decision making for Clearance/Objections
    - Implementation of Water Acts
    - integrated development, management, abstraction, distribution, use, protection and conservation
- Digital Online System of WARPO contributing towards *"Smart Bangladesh"*