CSRD
CLIMATE SERVICES FOR RESILIENT DEVELOPMENT

CLIMATE SERVICES FOR RESILIENT DEVELOPMENT IN SOUTH ASIA

Annual Report: January to December 2019

— *Strategic alignment* —

CGIAR
RESEARCH PROGRAM ON Climate Change, Agriculture and Food Security
CCAFS

Grant Summary Information

Project name:

Climate Services for Resilient Development (CSRD) in South Asia

Implementing Partner Name:

International Maize and Wheat Improvement Center (CIMMYT)

CGIAR Research Program:

CSRD is mapped to Climate Change, Agriculture and Food Security (CCAFS)

USAID Washington Grant Amount:

$3,000,000

Project Duration:
November 30, 2016 to May 31, 2019[1], with a no-cost extension until December 31, 2019.

Report Period:
Annual Report: January to December 2019 (Final Project Report)

Has this project been granted a no-cost extension (NCE)?

Yes. An NCE was granted from May 31, 2019 to December 31, 2019.

Submitted to:

Dr. Pete Epanchin
Climate Adaptation Specialist
Global Climate Change Office. Bureau for Economic Growth, Education and Environment (E3) USAID. Washington, D.C.

Principal Investigator / Project Director:

Dr. Timothy J. Krupnik (t.krupnik@cgiar.org)
Project Leader, CSRD, Senior Scientist and Systems Agronomist, CIMMYT

Mailing address:

CIMMYT International House 10/B. Road 53. Gulshan-2. Dhaka, 1213, Bangladesh

Contributors and citation:

Krupnik, T.J., Hussain, S.G., Montes, C., Schulthess, U., Siddiquee, A.A., Rahman, M.S., Khan, M.S.H., Salam, M.U., Ferdnandes, J.M.C., Khanam, F., Miah, A.A., Hasan, M.A., Kamal, M., Hossain, K., Haque, A., Kurishi, K.A., Rokon, G.M., Uddin, S., Billah, M.M., Tasnim, T. 2018. Climate Services for Resilient Development in South Asia. Mid-term Report, January – December 2019 (End project report). International Maize and Wheat Improvement Center (CIMMYT). Dhaka, Bangladesh.

[1] Please refer to the section 'Has this project been granted a no-cost extension (NCE)?' for further details.

Cover photos: Timothy J. Krupnik (Top), Elizabeth Gawthrop (bottom). In the top photos, farmers in Khulna discuss their interest in weather services. In the bottom, Dr. Nachiketa Acharya from IRI leads discussions at BMD on the components of probabilistic forecasting.

Project website: Click here.

Contents

Grant Summary Information ii

Contents iv

Tables vi

Figures vii

Photos x

Abbreviations xii

Executive summary xiv

Introduction 1
  Background 1
  Overview of the CSRD consortium in South Asia 1
  CSRD's theory of change and strategic pillars in South Asia 4

Objective 1: Impact-based national-scale decision tool platforms to support the Bangladesh Meteorological Department's Sector 3 agro-meteorology track 5
  Sub-Objective 1.1. Agricultural climactic information framework improved 5
  Sub-Objective 1.2. Climate services capacity development 23
  Sub-Objective 1.3: Development of forecast products, impact assessments and decision support tools for agriculture, fisheries and/or livestock 24

Objective 2: Collaborative development and refinement of South Asian regional-scale agro-climate decision support tools, services, and products 47
  Sub–Objective 2.1: Support to facilitate the development and refinement of regional decision support decision support tools, services and products 47

Objective 3: Coordination with CSRD partners in-country to ensure progress on the work streams under the CSRD South Asia and Bangladesh working group 61
  Sub-Objective 3.1. Coordination of Bangladesh CSRD partners 61
  Sub-Objective 3.2. Policy maker, agro-metrological services, extension, and farmer awareness of agro-meteorological forecasts and decision support tool platforms for agriculture increased 63

Implementation challenges 69

Annexes 70

Annex 1: Key Staff and Core Partner Designations 70

Annex 2: Project subcontractors and key partners' designations 77

Annex 3: Monitoring, Evaluation and Learning Plan 82

Annex 4: In-kind letters of support from partners 75

Annex 5: Success stories and communication pieces produced during CSRD 81

Annex 6: Links to other communications and news and pieces about CSRD 97

Annex 7: Agvisely: Methodology and approach used to generate automated and location-specific agricultural climate information services for farmers in Bangladesh 101

Annex 8: Draft Paper on Regional Climatological Analysis of Wheat Blast Disease Risks .. 121

Tables

Table 2.1: Results of the switching regression model using the hindcast experiment data for wheat farmers in Bangladesh and Bihar, 2017/18.. 19

Table 2.2: Details of the completed Agvisely trainings... 38

Table A7.1: Phenological windows of field crops in Bangladesh with estimates of the number of days required for each stage[1] and temperature thresholds. *n*[2] indicates the number of study observations included to calculate thresholds. 105

Table A7.2: Criteria for rainfall intensity used approved by the Bangladesh Meteorological Department... 107

Table A8.1: List of parameters in the wheat phenology model. 128

Figures

Figure 1.1: CSRD in South Asia's strategic pillars upon which its research, development and partnership activities were based 4

Figure 2.1: The draft PICSA field manual in English (the Bangla version was completed in early 2020) 8

Figure 2.2: Individual level impacts of PICSA training as communicated in FGDs with PICSA female farmer trainees........ 11

Figure 2.3: Household level impacts of PICSA training as communicated in FGDs with PICSA male farmer trainees........ 11

Figure 2.4: Community level impacts of PICSA training as communicated at FGDs with male and female trainees 12

Figure 2.5: A model hindcast sheet used during hindcast experiments to show farmers previous weather information in graphical form. Farmers then mapped their previous season's crop management practices to the dates in the graph and discussed how they may have changed management practices if they had had access to the weather information. The data from such exercises helps identify the most relevant types of climate information and crop management practices and the focus of climate services and agricultural extension programs........ 17

Figure 2.6: Sampled farmers' willingness to use climate services for altering agricultural operations captured by hindcast experiment........ 18

Figure 2.7: Depiction of the 'decision frame' on planting dates of farmers in Bihar, India. Note: the relative size of circles indicates number of farmers who responded affirmatively or negatively to questions. Numbers shown on the diagram are the sample sizes. 20

Figure 2.8: Depiction of 'decision frame' on planting dates of wheat farmers in Bihar, India. Note: the relative size of circles indicates number of farmers who responded affirmatively or negatively to questions. Numbers shown on the diagram are sample sizes. 21

Figure 2.9: Monsoon onset (a) and withdrawal (b) in Bangladesh (1981-2017). (c) Time series of country-averaged monsoon onset and withdrawal. Notes: shaded area is the spatial standard deviation and all values are expressed in pentads. Data source: Climate Hazards Group InfraRed Precipitation with Station product (CHIRPS v2)........ 25

Figure 2.10: a and b: Maps of maximum Pearson correlation index between ENSO and monsoon onset and withdrawal for clusters. c and d: the month (1-6 previous months) of highest correlation displayed in a and b........ 26

Figure 2.11: Maps of (a) accumulated precipitation until the second week of June 2017 and (b) corresponding anomalies. 27

Figure 2.12: Maps of local monthly anomalies in precipitation during the 2018 monsoon in Bangladesh in relation to the long-term (1981–2018) mean. Data from CHIRPS v2........ 28

Figure 2.13: Inter-annual average number of dry spells during 1951-2005 monsoon seasons – (a) APHRODITE and (b) multi-model CMIP5 averages and (c) difference between (b) and (a)........ 30

Figure 2.14: Difference between number of dry spells in future projections and historical CMIP5 multi-model average simulations for three future periods and two RCP scenarios. . 31

Figure 2.15: (a) The number of annual heavy rainfall events (1981–2017) and (b) linear trends. Note: p and n denote number of stations with positive and negative trends respectively 32

Figure 2.16: Rainfall amount (1999-2018) corresponding to the 95% during June-September, and accumulated precipitation for events above the percentile 95%. 33

Figure 2.17: An infographic describing how Agvisely works. A short video on Agvisely can also be found here. 36

Figure 2.18: Screenshot of a of the interactive agricultural climate services app Agvisely that includes BMD sub-district forecasts and provides location-specific agronomic management advisories for smallholder rice, wheat, maize, lentils and potato farmers on avoiding damaging heat, cold, dry spells, and heavy rainfall events. 37

Figure 2.19: The locations of three PANI experimental sites and percentage of water used for irrigation derived from ground water. 41

Figure 2.20: A 20 March 2019 aerial view of the PANI maize experiment planted in Dinajpur in winter 2018/19. Upper map shows the effect of the three irrigation treatments on the canopy temperatures of maize. The lower map is a red-green-blue (RGB) image of these plots 42

Figure 2.21: Main components of PANI irrigation scheduling advisory system: Server with database that runs a soil water balance model using weather data, crop management info and vegetation status measured by farmers by taking RGB photos with a smartphone app. 43

Figure 3.1: Regional seasonal outlook based on the condition in April 2019 produced on 7 May 2019 and its comparison with observed data in Nepal 48

Figure 3.2: Conditions interface of the National Agriculture Drought Watch 49

Figure 3.3: Seasonal assessment interface of the National Drought Watch, Bangladesh 50

Figure 3.4: Elements and processes of the SALDAS system for producing drought data products 52

Figure 3.5: Comparison of predicted and observed severity of Stemphylium blight disease of lentils at 5 calibration locations (3 in Bangladesh, 2 in Nepal) and across all locations. Predictions used the best set of the Stempedia model's parameters worked out from calibration. Vertical bars denote 95% confidence intervals 55

Figure 3.6: Comparison of predicted (circles) and observed (line) severity of Stemphylium blight disease of lentils. Predictions based on calibrated Stempedia model 56

Figure 3.7: Comparison of predicted and observed severity of Stemphylium blight on lentils at 5 tested locations (3 in Bangladesh, 2 in Nepal). Predictions based on calibrated Stempedia model. Vertical bars denote 95% confidence intervals 56

Figure 3.8: Predicted severity of Stemphylium blight disease of lentils at 5 tested locations (3 in Bangladesh, 2 in Nepal) at farmers' sowing time in 2017/18 and 2018/19 seasons. Predictions were based on the calibrated Stempedia model. 57

Figure 3.9: Modelling the incidence of Stemphylium blight on lentils in Bangladesh under current thermal regimes (C: 1981-2005), and three future periods (F1: 2006-2039, F2: 2040-2059 and F3: 2070-95) 57

Figure A7.1: Methodological process used during systematic literature review to identify peer-reviewed papers from which data were extracted to determining rice, wheat and maize stress thresholds. Numbers in parentheses indicate the number of papers identified or retained. ... 104

Figure A7.2: The architecture of Agvisely showing how forecast model outputs are integrated with climate stress thresholds for different crops depending on likely phenological stages during forecast periods to generate climate-smart crop management advisories. ... 109

Figure A8.1: The shape of temperature response curve obtained by Equation (1) using parameters for wheat blast (explained the text) ... 123

Figure A8.2: Map of what sowing dates (day of the year DOY) for winter wheat in Asia MapSPAM wheat mask. ... 125

Figure A8.3: Spatial pattern of the inter-annual average number of potential infections in Asia. Black *dot* symbols represent grid cells with presence of wheat. P99th is the 99% percentile. ... 129

Figure A8.4: As in Figure A8.3 but for inter-annual standard deviation ... 129

Figure A8.5: (a) Boxplots of spatial distribution of the inter-annual average number of potential wheat blast infections. (b) Boxplots of temporal distribution of country averaged number of potential infections. For each boxplot, the central mark shows the median and the edges are the 25th and 75th percentiles; dashed lines extend to the most extreme values not considered outliers, and outliers are plotted individually (x sign) ... 130

Figure A8.6. Maps of inter-annual average (a) air temperature (°C) and (b) relative humidity (%) during the cold season. Black *dot* symbols represent the points of Figure A8.3 where wheat blast is present. ... 131

Figure A8.7. (a) Local correlation between the number of potential infections and ONI. (b) As in (a) but for number of potential infections and DMI. ... 132

Figure A8.8. (a) Composites of the difference between number potential infections for the positive and negative face of ONI (a) and DMI (b). ... 133

Photos

Photo 1.1: FGD with PICSA-trained male farmers in Durgapur Upazila, Rajshahi District (Anarul Haque) ... 9

Photo 1.2: FGD with PICSA-trained female farmers in Durgapur Upazila, Rajshahi District (Saleh Mohammad Shahriar) ... 9

Photo 1.3: Farmer Mijanur Rahman showing a weather forecast received through Facebook through his engagement with DAE and PICSA (SM Shahriar) ... 13

Photo 1.4: Closer view of the 5-day BMD weather forecast sent by DAE with assistance from CSRD (SM Shahriar) ... 14

Photo 1.5: SM Shahriar (Agricultural Development Officer, CIMMYT) interviewing PICSA trained farmer Anwar Hossain Babu in Durgapur Upazila, Rajshahi District (Anarul Haque) ... 15

Photo 1.6: PICSA trained female farmer Safia Begum drawing her participatory storyline explaining how, why and when she changed her vegetable cultivation practices influenced by her PICSA training (Fahmida Khanam) ... 15

Photo 1.7: The Agvisely launch workshop at Farmgate, Dhaka, 24 November 2019 ... 37

Photo 2.1: Farmers consider mung beans as an economically important crop in southern Bangladesh that also contributes to food and nutrition security, although extreme rainfall events threaten the crop and cause large losses in most years (CIMMYT) ... 39

Photo 2.2: Left to right: Prof. Mauricio Fernandes (UPF and EMBRAPA), Mr. Shamsuddin Ahmed, Director of BMD, Dr. Wais Kabir, Director of Krishi Gobeshona Foundation, and Dr. Israil Hossain, Director of BWMRI officially recognize and endorse use of the CSRD supported and meteorological forecast-driven early warning system for wheat blast in Dhaka on 5 December 2019 ... 44

Photo 2.3: IRI and BMD scientists working in April 2019 in Dhaka to improve the code generating 1 and 3 month forecasts using IRI's Climate Predictability Tool ... 46

Photo 2.4: An orientation workshop on Regional Drought Monitoring and Outlook System held in 2019 in Islamabad, Pakistan demonstrated the functions of the system and gathered feedback on its usability (ICIMOD) ... 48

Photo 2.5: *Stemphylium* disease survey enumerators for 2018/19 in Nepal after returning from hands-on field training, 20 November 2018 (Sagar Kafle) ... 54

Photo 2.6: Wheat blast is a potentially devastating fungal disease that causes bleaching of the crop and unfilled grain. It was found for the first time in Asia in 2016. Since then, project scientists worked to assess the interaction between the region's climate and potential for disease outbreaks in key wheat growing countries. (CIMMYT) ... 59

Photo 3.1: CIMMYT ODK lead Ashok Rai (far left) conducted an intensive training alongside Khaled Hossain (CIMMYT Research Associate) on ODK to accelerate observed data weather availability. Through the use of digital data collection tools, weather data become instantaneously available on a cloud server, reducing the time from data collection to when data can be used and analyzed by one to three months. ... 62

Photo 3.2: Mr. Shamsuddin Ahmed, Director of the Bangladesh Meteorological Department, addressing participants and facilitating a panel discussion with BACS Alumni at the 2019 5th Annual Gobeshona conference on Climate Knowledge in Dhaka, Bangladesh........................ 63

Photo 3.3: Enhancing National Climate Services (ENACTS) launch workshop, 27 June 2019 at BMD (BACS) 65

Photo 3.4: Staff from CIMMYT and WorldFish trained as enumerators on 12 November 2019 to survey farmers and fishermen using methods developed under CSRD as part of CaFFSA project 66

Photo 3.5: Trainees in a multi-day workshop organized by ICIMOD and CIMMYT through CSRD on the Principles and Application of GIS in Agriculture Planning and Decision Making, emphasizing climate information, at BARC Dhaka in May 2019.. 67

Photo 3.6: Josh Klein, U.S. Senate Foreign Relations Committee (left) visited CSRD field activities in Bangladesh on 18 March 2019. Dr. Timothy J. Krupnik, Senior Scientist and Systems Agronomist, and CSRD in South Asia Project Leader (Right) explained how CSRD partners with extension services in Bangladesh to deliver climate services to smallholder farmers.. 67

Abbreviations

ACI	Advanced Chemical Industries Ltd
AEO	agricultural extension officer
APHRODITE	Asian Precipitation - Highly-Resolved Observational Data Integration Towards Evaluation
BACS	Bangladesh Academy for Climate Services
BARC	Bangladesh Agricultural Research Council
BARI	Bangladesh Agriculture Research Institute
BAU	Bihar Agricultural University
BIID	Bangladesh Institute of ICT in Development
BMD	Bangladesh Meteorological Department
BMR	Bangladesh Map Room
BRAC	*formerly* Bangladesh Rehabilitation Assistance Committee
BWCSRP	Bangladesh Weather and Climate Services Regional Project
BWMRI	Bangladesh Wheat and Maize Research Institute
CaFFSA	Capacitating Farmers and Fishers to Manage Climate Risks in South Asia
CCAFS	Climate Change Agriculture and Food Security
CEGIS	Center for Environmental and Geographic Information Systems
CGIAR	*formerly* the Consultative Group for International Agricultural Research
CHIRP	Climate Hazard Group InfraRed Precipitation
CHIRPS	Climate Hazard Group InfraRed Precipitation by Satellite
CIMMYT	International Maize and Wheat Improvement Center
CMIP	Coupled Model Intercomparison Project
CNRS	French National Centre for Scientific Research
CPT	Climate Predictability Tool
CSISA	Cereal Systems Initiative for South Asia
CSRD	Climate Services for Resilient Development
DAE	Department of Agricultural Extension
DAP	diammonium phosphate
DAS	days after sowing
DEW	disease establishment window
DSSAT	Decision Support System for Technology Transfer
DST	decision support tool
ENACTS	Enhancing National Climate Services
ENSO	El Niño-Southern Oscillation
ESRI	formerly the Environmental Systems Research Institute
EWS	early warning system
FGD	focus group discussion
FOREWARN	Forecast-based Warning, Analysis and Response Network
FTE	full time equivalency
GDAS	Global Data Assimilation System
GIS	Geographic Information Systems
HKH	Hindu Kush Himalaya
ICCCAD	International Center for Climate Change and Development
ICIMOD	International Center for Integrated Mountain Development
ICT	information and communication technology
INAFI	Asia International Network of Alternative Financial Institutions Asia

IRI	International Research Institute for Climate and Society
IUB	Independent University of Bangladesh
IVR	interactive voice response
IWM	Institute of Water Modeling
LDAS	Land Data Assimilation System
MERRA	Modern-Era Retrospective analysis for Research and Applications
MoT	Magnaporthe Oryzae Triticum
Mt	metric tonnes
NARC	Nepal Agricultural Research Council
NASA LIS	NASA land Information System
NASA	National Aeronautics and Space Administration
NGLRP	National Grain Legume Research Program
NMME	North American Multi Model Ensemble
PANI	Program for Advanced Numerical Irrigation
PERSIANN	Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks
PICSA	Participatory Integrated Climate Services for Agriculture
RCP	Representative Concentration Pathway
RGB	red-green-blue
RH	relative humidity
S2S	Seasonal to Sub-Seasonal
SAAO	Sub-Assistant Agricultural Officer
SAARC	South Asian Association for Regional Cooperation
SALDAS	South Asia Land Data Assimilation System
SERVIR-HKH	SERVIR-Hindu Kush Himalaya
NMME	National Multi-Model Ensemble
SST	sea-surface temperature
TK	taka
TRMM	Tropical Rainfall Measuring Mission
UAO	Upazila agricultural offices
UPF	University of Passo Fundo
URI	University of Rhode Island
USAID	United States Agency for International Development
WaterApps	Water Information Services for Peri-urban Agriculture
WRF	Weather Research and Forecasting Model
WUR	Wageningen University and Research

Executive summary

Climate Services for Resilient Development (CSRD) is a global partnership that is aligned with the Global Framework for Climate Services. It works to link climate science, data streams, decision support tools, and training with decision-makers in developing countries. CSRD is led by the United States Government and is supported by the UK Government's Department for International Development (DFID), the UK Meteorological Office, ESRI, Google, the Inter-American Development Bank, the Asian Development Bank, and the American Red Cross. Led by the International Maize and Wheat Improvement Center (CIMMYT), the CSRD initiative in South Asia ran from November 2016 to December 2020 with partners to conduct applied research and facilitate the use of climate information to reduce risk for smallholder farmers.

This report details activities of the CSRD project in South Asia during whole of 2019, throughout to the end of the year, which marks the end of the project[2]. Notable highlights include the following:

- In partnership with the Bangladesh Meteorological Department (BMD) and Department of Agricultural Extension (DAE), CSRD established Agvisely, interactive, map-based agro-meteorological bulletin and an accompanying mobile phone app that provides numerical weather forecasting model predictions with easy-to-understand crop-specific management advisories. Agvisely is an automatic climate service advisory system for Bangladesh's major field crops in Bangladesh. A database of climate information service advisories covers the different phenological stages of eight crops. Each stage has specific threshold temperature and rainfall threshold above or below which crop stresses occur. Agvisely contains advisories for these stages that are to be triggered for different values of temperature and rainfall that may arise within the following five day periods. In addition to providing real-time crop advisories depending on the next five day weather forecast, Agvisely provides temperature and rainfall forecasts for each of Bangladesh's 491 sub-districts. This makes it the highest resolution forecast now available in Bangladesh.
- On December 5, 2019, BMD, DAE, and the Bangladesh Wheat and Maize Research Institute all endorsed use of the numerical weather forecast driven Wheat Blast disease early warning system. This system,– which can be found at www.beattheblastews.net – also provides automated, customized and location-specific disease management advisories as a function of the forecast model outputs supplied by BMD. Over 800 extension officers in Bangladesh are now receiving alerts by email 5 days in advance if their designated working areas were predicted to be at risk of a wheat blast outbreak. Each extension officer in Bangladesh is responsible for between 2,000–5,000 farmers. This underscores the potential to reach farmers with relevant climate information services in the form of wheat blast disease outbreak warnings and advisories now that the government has endorsed use of the early warning system.
- As a result of BMD's engagement with CSRD and the International Research Institute for Climate and Society (IRI), BMD is now regularly running the scripts generating monthly and three-monthly precipitation forecasts are now shown on BMD's website. Links for

[2] All previous five CSRD reports and additional publications can be found on the project website.

the monthly and seasonal precipitation forecasts can be found here and here. Completion and integration of these forecasts in BMD's website signals that CSRD was successful in achieving one of its primary goals to begin the use of sub-seasonal and seasonal forecasts in Bangladesh.

- Bangladesh's Department of Agricultural Extension (DAE) continued to expand their use of Participatory Integrated Climate Services for Agriculture (PICSA) training approaches to increase farmers' knowledge of climate and meteorology, and their relation to crop and farm management practices. A customized PICSA manual for Bangladesh was completed during the reporting period, as well as an effectiveness study that was used to advise DAE on methods they can used to improve the impact of PICSA after CSRD ended in December of 2019. In addition, DAE took strong steps towards integration of PICSA in their regular institutional programs, with pro-active steps taken to generate additional funding for PICSA after CSRD closes.
- CSRD scientists completed a set of novel 'hindcast experiments' in Bangladesh, Nepal, and India to examine the ways in which farmers may or may not act on climate information to improve crop management. 600 farmers took part in the participatory study, which indicated that farmers were able to make a series of strategic choices on crop management – with emphasis on nutrient management and irrigation timing improvements – with the supply of forecast information. However, climate information alone is not enough to condition behavioural change among farmers. Such information needs to be complemented with adequate quality inputs of seed supply, access to finance, and the availability of labor, farm machinery, irrigation water and post-harvest storage facilities as part of integrated development programming. Based on learnings from CSRD, two other research programs operational in Bangladesh – one led by Wageningen University and the other led by WorldFish – are now using this method in their climate services projects.
- The CSRD project completed a series of detailed analyses to develop . Agriculturally relevant climatological analysis and improved extended-range forecasts and outlooks for Bangladesh, with the resulting code turned over to the BMD for further use. Key areas of analysis included studies to improve the prediction of monsoon onset and withdrawal, prediction using ENSO data, mapping the seasonal progression of the monsoon and deviations from historical normal, monthly anomalies in precipitation, and mapping of dry spells within the monsoon (both historically and with future climate predictions to 2095).
- At a regional level, CSRD's engagement with the International Centre for Mountain Research and Development (ICIMO has resulted in additional improvements in sub-seasonal to seasonal meteorological forecasts to more accurately monitor of hydrological states, most notably drought. A non-validated and preliminary drought monitoring portal was completed during the course of the CSRD project, with resulting seasonal outputs from this work found at http://tethys.icimod.org/apps/sldasdataforecast/. In addition, a comprehensive resource book was published by the South Asian Association for Regional Cooperation Agriculture Centre, CIMMYT and ICIMOD, with support from CSRD.
- The productivity of lentils (*Lens culinaris*) in South Asia is severely affected by diseases, many of which are related to prevailing weather conditions. Developed through CSRD,

the Stempedia forecasting model has great potential as a weather-driven tool for forecasting the occurrence of *Stemphylium* blight. Work during the reporting period resulted in successful calibration and validation of the model. Confidence in the model is now sufficiently acceptable that it can be utilized for Nepal and Bangladesh. Based on the work of CSRD, the model will be trialed for pilot use in the 2020-2021 lentil production season in both countries.

- CSRD's work in capacity building continued during the reporting period. Notable outcomes included the provision of tools such as Agvisely and the wheat blast early warning system to governmental partners. The World Bank funded Bangladesh Weather and Climate Services Regional Project (BWCSRP) for example now features CSRD's decision support tools on governmental partners linked to the project. CSRD continued also to support the Bangladesh Academy for Climate Services, while also deepening capacity development within BMD by establishing an electronic, internet tablet based reporting system for weather station data collection. The latter two interventions continue to sustain after the CSRD project, again indicative of the activity's success.

Introduction

Background

Climate Services for Resilient Development (CSRD) is a global partnership that connects climate science, data streams, decision support tools, and training to decision-makers in developing countries. CSRD addresses the climate challenges faced by smallholder farmers in South Asia. The partnership is led by the United States Government and supported by the UK Government Department for International Development (DFID), the UK Meteorological Office, ESRI, Google, the Inter-American Development Bank, the Asian Development Bank, and the American Red Cross.

The CSRD in South Asia initiative[3] ran from November 2016 to December 2019 and was led by the International Maize and Wheat Improvement Center (CIMMYT) and funded by USAID. The consortium worked to increase resilience to climate change in South Asia by creating and making available timely and useful climate data, information, tools and services. These activities aligned with the Global Framework for Climate Services and the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).

CSRD activities in South Asia had three core objectives:

1. Impact-based national-scale decision tool platforms to support the Bangladesh Meteorological Department's (BMD) Sector 3 agro-meteorology track.
2. The collaborative development and refinement of South Asian regional scale agro-climate decision support tools, services and products.
3. Coordination with CSRD partners in-country to ensure progress on the work streams under the CSRD South Asia and Bangladesh working group.

Overview of the CSRD consortium in South Asia

In South Asia, the CSRD consortium focused primarily on Bangladesh (in alignment with Objective 1 as described above), with a secondary emphasis on Nepal and India (supporting Objective 2), and overall capacity development and awareness raising efforts across countries (Objective 3). To improve the usefulness and agricultural relevance of climate information and weather forecasts, the consortium developed strong science partnerships, and moved research into action and impact. The overarching goal was to develop and sustain the capacity development of agricultural climate services in the region. Throughout its duration, the consortium benefited from valuable inputs and guidance from USAID and its multi-partner CSRD Steering Committee.

CSRD in Bangladesh

Bangladesh is a core focal country for CSRD (see Objective 1). The two strategic partners in Bangladesh were the Bangladesh Meteorological Department (BMD) and the Department of Agricultural Extension (DAE) of

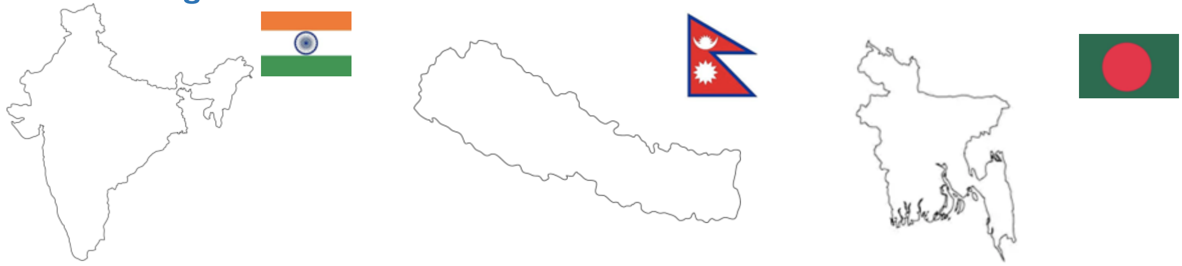
[3] Also referred to as 'CSRD in South Asia' and 'the consortium' in this report.

the government of Bangladesh (under the ministries of defence and agriculture). BMD was the principal national organization mandated to sustain the country's network of surface and air observatories, radar and satellite stations and geomagnetic and seismological observatories. It is also the main provider of climate information and forecasts to the general public. The DAE has more than 14,000 grassroots level extension agents, known as sub-assistant agricultural officers (SAAOs). These SAAOs are the first and primary point of contact and technical assistance for most Bangladeshi farmers, and are an important conduit of information from Bangladesh's technical and research departments to farmers and other stakeholders.

Both DAE and BMD enabled CSRD to develop partnerships to embed climate services in relevant regional institutes that will continue beyond CSRD. In this light, both organizations are also involved in the World Bank-funded Weather and Climate Services Regional Project for Bangladesh and make use of CSRD's technical and capacity development products in this and associated initiatives. By engaging with these agencies, CSRD developed country-driven decision support tools (DSTs) and climate-related agricultural management advisories for farmers to minimize climate and weather impacts on crop production, which in turn have increased farmers' resilience to climate risks. To promote the reach of relevant information to farmers, CSRD's dissemination strategy combined the use of DAE's extension network and information technology tools.

The Bangladesh Agricultural Research Institute (BARI) was another important CSRD partner. BARI is Bangladesh's most prolific and multi-crop research institute. It conducts breeding and research on pulses, oilseeds, vegetables, fruits, and other crops and research on soil and crop management, irrigation, disease and pest management, farm machinery and socioeconomic issues. In collaboration with CSRD, BARI works on evaluating the PANI (Program for Advanced Numerical Irrigation) app and decision support system (as developed by CIMMYT), which helps farmers schedule irrigation based on assessing crop groundcover, evapotranspiration demand, and BMD's weather-forecasts. CSRD also supported the Bangladesh Maize and Wheat Research Institute (BMWRI) to implement a wheat blast (*Magnaporthe oryzae* pathotype *Triticum*) disease risk early warning system (EWS) for farmers at the national (Objective 1) and regional (Objective 2) levels.

South Asia regional collaboration:



The International Center for Integrated Mountain Development (ICIMOD), which manages the USAID funded SERVIR-Hindu Kush Himalaya (HKH) initiative, was another core CSRD partner. Aligned with the SERVIR-HKH activities, CSRD brought knowledge and support to boost ICIMOD's efforts to develop a remote-sensing drought monitoring and forecasting system for South Asia (under CSRD Objective 2). This work complemented additional efforts led by SERVIR-HKH on monitoring drought in Afghanistan, Pakistan, Nepal and Bangladesh. Through linkages with ICIMOD and the SERVIR-HKH initiative, CSRD collaborated with the Bangladesh Agricultural Research Council (BARC), which is the apex body of the National Agricultural Research System (NARS) in Bangladesh. Leveraging learning from Afghanistan, Pakistan, and Nepal, CSRD worked with BARC to improve the capacity of national scientists to anticipate and respond to drought episodes. To achieve this goal, and in support of Objective 2, BARC was sub-contracted by ICIMOD and made responsible for implementing a new national center for drought monitoring and forecasting at ICIMOD's headquarters in Kathmandu. Additionally, CSRD provided computer facilities and technical back-stopping for BARC to promote use of the results of CSRD's work on drought and to provide access to equipment and online modern drought monitoring tools.

CSRD in South Asia developed several informal yet crucial partnerships. The partnership with the Nepal Agricultural Research Council (NARC) developed weather-forecast based models and warning systems for *Stemphylium* lentil disease. Another important partnership was developed with the International Center for Climate Change and Development (ICCCAD) at the Independent University in Bangladesh (IUB) from early 2018. ICCCAD contributed to the founding of the Bangladesh Academy for Climate Services (BACS) alongside the International Research Institute for Climate and Society (IRI) and CIMMYT through CSRD (see Objective 3 write-up). The academy is increases the awareness of and coordination between organizations involved in providing climate information through educational programs, training and exchange meetings.

International collaboration

CSRD also maintained international collaborations with several advanced research institutes and universities. CSRD and the University of Reading collaborated to provide training and technical back-stopping to DAE's implementation of PICSA (Participatory Integrated Climate Services for Agriculture) in five Bangladeshi districts under Objective I. To scale-up PICSA implementation efforts, CSRD forged a partnership with Wageningen University's (WUR) Water Information Services for Peri-urban Agriculture (WaterApps) project. In addition, the University of Passo Fundo (UPF), Brazil collaborated with CSRD scientists to implement a weather forecast-based early warning system for wheat blast disease in Bangladesh (Objective 1). Both WaterApps and UPF collaborated with CSRD on an entirely in-kind basis. The University of Rhode Island (URI) was another CSRD in South Asia partner that collaborated on analyzing climate data and developing the PANI algorithm in the early stages of the consortium.

This report

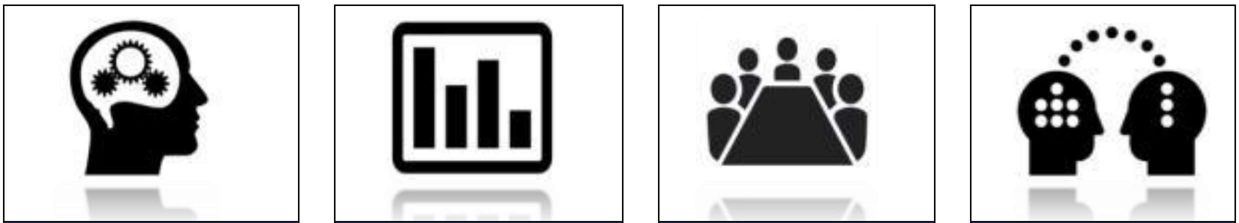
This report summarizes and updates readers on CSRD activities from January to December 2019. Previous project reports are on the project website.

Annex 1 presents information on CSRD team members across the associated organizations in South Asia while CSRD's formal sub-contractors are described in Annex 2. Annex 3 provides a detailed account of project monitoring and evaluation procedures from 2016–2019. Annex

4 details the in-kind funding support leveraged from partners from June 2019 to December 2019 with details of previous in-kind funding allotments available in previous CSRD semi-annual and annual reports. Annex 5 presents communication and success stories generated by the project over its three years while Annex 6 presents media reports on CSRD activities across the same period. Annexes 7 and 8 present the methods used to develop Agvisely and regional wheat blast analyses.

CSRD's theory of change and strategic pillars in South Asia

CSRD's theory of change rests on four strategic pillars (Figure 1.1) and is discussed in detail in the 2017 and 2018 annual reports. All CSRD activities supported one or more of these pillars as described in the Action and Learning Framework sections at the end of each activity results write-up in this report.



Pillar 1	Pillar 2	Pillar 3	Pillar 4
Create the solution space	**Use quality data, products, and tools**	**Build capacities and platforms**	**Build Knowledge**
Establish a problem-focus, engage key stakeholders, and create a platform for sustained communication and collaboration. Build synergies among relevant programs.	Provide decision-makers access to useful and available information and technology. Develop tailored products and services responsive to specific needs.	Support the use of targeted climate science products and services. Promote sustainability, scalability, and replicability in climate information services.	Identify and promote good practices among the global climate services community. Support research efforts and innovation to increase the effectiveness of climate services.

Figure 1.1: CSRD in South Asia's strategic pillars upon which its research, development and partnership activities were based

Objective 1: Impact-based national-scale decision tool platforms to support the Bangladesh Meteorological Department's Sector 3 agro-meteorology track[4]

Sub-Objective 1.1. Agricultural climactic information framework improved

Background – No matter how precise and useful forecasts are, most South Asian farmers are unfamiliar with using meteorological and climate information to inform the management of their farms. CSRD worked to increase the use of climate information as a service to farmers in the shape of forecasts, early warning systems and management advisories. This required building farmers' capacity to better understand the implications, usefulness and use of climate information.

Activities under CSRD in South Asia Sub-Objective 1.1 focused on improving South Asian farmers' ability to use climate and weather information to plan and conduct their livelihood activities. Much of this work involved coordination and partnership with the Department of Agricultural Extension (DAE) and the Bangladesh Meteorological Department (BMD) in Bangladesh, and enabling front-line agricultural extension agents to understand and explain climate information services so that farmers can reduce risk in their farming systems.

Despite the availability of weather forecasts, most farmers rely on indigenous knowledge and intuition to make agricultural decisions. This is mainly due to their lack of understanding of meteorological and climate information, a situation that in turn reduces their potential to make use of practices that can contribute to resilience. Climate services can enable farmers to comprehend the importance of meteorological and climate information in crop and farm management decision-making.

Activity 1.1.1 Updating agro-meteorological information for major food and income staples in Bangladesh using farmer decision making frameworks

Under Activity 1.1.1, CSRD in South Asia carried out research to understand how farmers use climate and weather information to conceptualize and plan their livelihoods. This also involved using this information to improve the ways in which climate and agricultural science-based advisories can be translated into easily understandable language, tailored to needs, and extended to farmers in a timely way. Further work emphasized participatory processes and capacity development efforts working with Bangladesh's Department of Agricultural Extension and partners on how to better partner with farmers to improve their strategic decision making on their livelihoods and farm management.

[4] Each of the products described in this report refers to the key research and science product outcomes developed through CSRD.

Product 1. Crop-specific farmer decision-making frameworks and extension training to improve the quality and usefulness of agro-meteorological forecasts

Expanding the use of PICSA

2017 conference – A South and Southeast Asia Regional Technical and Learning Exchange conference was held by CSRD from 17–19 September 2017. At this forum, Dr. Peter Dorward of the University of Reading gave an overview of the large recent growth of climate services and said it was time to take stock of how climate services research and practices should be developed in the future. He introduced the concept of Participatory Integrated Climate Services for Agriculture (PICSA), which is a successful systems approach that is farmer-focused and practical, based on partnerships between farmers, government and non-government agencies to encourage farmers to understand climate and plan their livelihood/farming activities (see Box 2.1). Lessons from the application of PICSA in Africa were presented and discussed in terms of their relevance to South and Southeast Asia. Building on this work, CSRD entered into partnership with the University of Reading, DAE and BMD to pilot and expand the use of PICSA in Bangladesh.

Box 2.1: The PICSA approach

PICSA is a new approach to extension and climate information services developed by Dr. Peter Dorward and colleagues at the University of Reading, UK. The PICSA approach enables farmers to make informed decisions based on accurate, location-specific climate and weather information, and locally relevant crop, livestock and livelihood options. Considering farming and livelihood options in the context of climate is crucial for good farm decision making. The PICSA approach is designed with field staff in mind and provides smallholder farmers with improved resources and information.

PICSA uses historical climate records, participatory decision-making tools and forecasts to help farmers identify and better plan livelihood options that are suited to local climates and their circumstances. It was first implemented in 2016 in West African with farmers in Senegal and Mali. At the end of the growing season, 97% of the Senegalese and 76% of Malian farmer respondents had found the approach 'very useful'.

The key components of PICSA are as follows:

- Providing and considering climate and weather information with farmers, including historical records and forecasts.
- The joint analysis by field staff and farmers of information on crop, livelihood and livestock options and associated risks.
- A set of participatory tools that enable farmers to use climate and weather information in planning and decision making.

This approach enables farmers to make strategic plans before cropping seasons based on their improved knowledge of local climate features. Moreover, PICSA stimulates farmers to consider and then implement the innovations of (i) changing the timing of activities such as sowing dates, (ii) implementing soil and water management practices, (iii) selecting different crop varieties, (iv) fertilizer management and (v) adapting farm management plans to their available resources. There is good potential for farmer-to-farmer extension to scale-up the use of the approach, which is of great interest given the current context of limited extension services.

Training trainers – Partnering with the University of Reading, in 2018 CSRD translated the PICSA training manual into the Bangla language and engaged the Bangladesh Meteorological Department (BMD) and the Department of Agricultural Extension (DAE) to pilot PICSA in five districts across Bangladesh. In 2018, ten DAE cadre officers were trained by CSRD and University of Reading as master trainers on the PICSA approach. Subsequently, in late 2018 and before the winter crop season, these master trainers, guided by CSRD and the University of Reading, trained 40 DAE field extension agents (SAAOs).

Training of farmers – During the reporting period in 2019, the trained SAAOs trained 500 farmers (20% women) at 20 PICSA farmer field schools. The farmer participants subsequently took part in weekly discussion meetings and learning sessions on how to interpret and make use of historical and forecasted climate information to improve farm and livelihood decision-making. Following the completion of the pre-winter rabi season PICSA trainings (October–November 2018) in the five districts, the DAE began regularly receiving customized 5-day, location-specific forecasts derived from BMD's Weather Research and Forecasting Model (WRF) which passed on to the PICSA piloting villages. This information continued to be supplied to May 2019, and then again during the summer monsoon rice season from July to November 2019.

PICSA manual – In 2018/19, CSRD supported the translation of the general PICSA manual into the Bangla language. In this reporting period the University of Reading finalized the contextualized PICSA Manual for Bangladesh, which reflects PICSA as piloted in Bangladesh (Figure 2.1). The new manual is designed for trained extension staff to use as a reference on applying the PICSA approach.

Effectiveness study – In collaboration with Wageningen University's WaterApps project and the University of Reading, in summer 2019 a post-season monitoring and evaluation study was conducted to assess the effectiveness of PICSA and identify if and how it had caused farmers in the five districts to modify their crop management decision making and income-generating activities in response to the pre-season trainings and receipt of the 5-day forecasts and management advisories. A qualitative and quantitative evaluation was carried out led by the University of Reading with financial support from the WaterApps project and coordination by CSRD.

The steps of the study included (i) training survey and focus group enumerators, (ii) the holding of focus group discussions and (c) a quantitative survey, as reported below:

Survey training – Two 2-day trainings at the BRAC Learning Center, Dinajpur in the 7–11 July 2019 period prepared six enumerators and four supervisors for carrying out the surveys. The trainings comprised classroom and field-based instruction including on using the Open Data Kit (ODK) to conduct quantitative surveys. The six trained enumerators were students from Khulna University, Patuakhali Agricultural University and Hajee Mohammad Danesh Science and Technology University, who were experienced in conducting household level surveys using tablets.

The training on qualitative surveying was attended by two male students (a PhD researcher from Wageningen University and a CIMMYT research assistant) and one female CIMMYT research assistant). This training (and FGDs with PICSA trained farmers in 5 districts) were facilitated by Dr. Samuel Poskitt from the University of Reading.

FGDs – As part of the qualitative study, (3–18 September 2019), CSRD held six focus group discussions (FGDs) with PICSA-trained farmers in Barishal, Khulna, Patuakhali and Rajshahi districts. Time constraints meant that FGDs could not be carried out in Dinajpur district. There was one FGD each with male and female farmers in each of the three districts with up to three farmers in each FGD amounting to a total of 25 participants (12 female, 13 male). The participants were randomly selected from the initial analysis of the quantitative data collected using ODK to represent both male and female farmers who had made changes as a result of PICSA and those who had not.

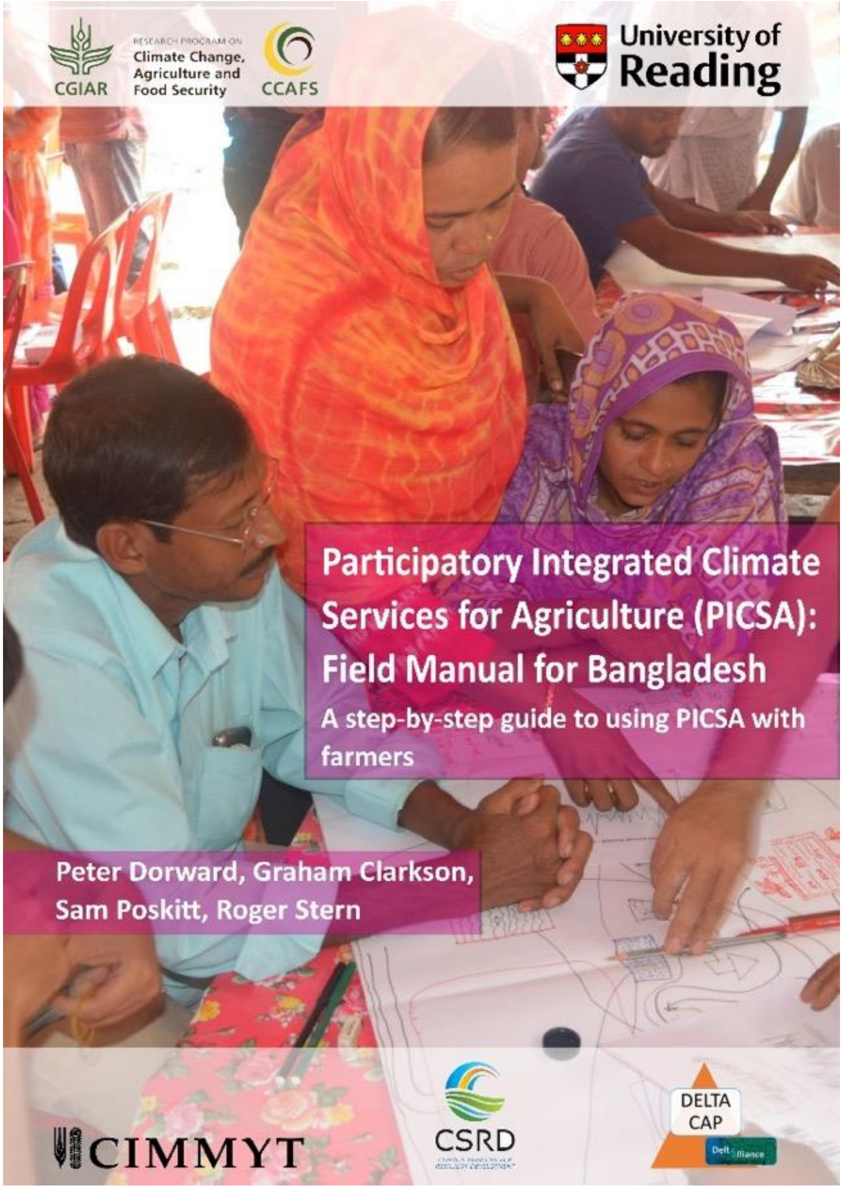


Figure 2.1: The draft PICSA field manual in English (the Bangla version was completed in early 2020)

The FGDs mainly addressed open-ended questions that encouraged farmers to share their reflections and experiences of PICSA on the following topics:

- Farmers' participation in the training and understanding of the steps of PICSA
- Perceptions and experiences of PICSA
- Details of any changes made as a result of the PICSA training
- The impacts of changes resulting from PICSA at the household, individual and community levels
- The steps they plan to take to continue getting benefits from the positive effects

- What could be improved about the PICSA training
- What can help farmers access climate information themselves.

FGD findings – The main findings from the FGDs, which were carried out as part of the qualitative study, were as follows:

- The PICSA trainings for farmers involved getting farmers to draw maps of their farms and associated livelihood options, as described in previous CSRD report reports. FGD respondents said that on the first day of their day PICSA trainings, most participants were nervous about drawing their allocation maps. However, with guidance from SAAOs and educated farmers most participants had become more confident and managed to draw their maps.
- The FGDs reported that male and female farmers were intensively involved in all PICSA activities, including designing crop calendars, resource allocation mapping, participatory farm budgeting, and learning how to interpret and use climate data for decision making.
- The male farmers said that female farmers only have limited knowledge of agricultural operations as they mostly only go to the fields at harvesting and post-harvesting times while men attend all operations. The FGD results indicated that trainees had learnt from male farmers about each step of crop cultivation during their participation in the regular PICSA trainings, mainly from preparing crop calendars and budgeting. The male farmers said they had learnt about taking care of chickens, ducks and other livestock from the female farmers. They said they had enjoyed sharing information during PICSA activities and the friendly atmosphere at the trainings.
- The trained farmers said they had gained knowledge at the trainings about resource allocation, farm budgeting, improved and new varieties of crops, new agronomic management, ideal seedbed establishment for boro rice, how to protect crops from heavy rainfall using field drainage and how to protect seedlings from very cold weather. Most of them said they were sharing this knowledge with non-trained farmers in their communities.

Photo 1.1: FGD with PICSA-trained male farmers in Durgapur Upazila, Rajshahi District (Anarul Haque)

Photo 1.2: FGD with PICSA-trained female farmers in Durgapur Upazila, Rajshahi District (Saleh Mohammad Shahriar)

In addition, the FGDs revealed the following about the impact of the trainings in three of the districts:

- Many farmers changed their farming practices as a result of what they learned from the PICSA trainings. For example, farmers in Patuakhali District said they had expanded mung bean cultivation. In Barishal District, they got higher yield from boro rice by doing ideal seedbed establishment. These farmers got weather information as per their needs from SAAOs, mobile apps and the internet.
- Most surveyed farmers had participated in other trainings on agriculture cultivation and agronomic management from DAE. These PICSA-trained farmers are very active and some have good relationships with SAAOs.
- Some trained male farmers hadn't subsequently made any direct changes to their agricultural or livestock management practices, mainly because they had already selected crops and the activities for the 2018/19 winter rabi season and didn't have enough funds to make any such changes. According to male farmers in Rajshahi, the PICSA training started just before the rabi season and also, they were more interested in fish farming and cultivating betel leaves, which were not discussed in detail in the training. Since they didn't get any new knowledge about betel leaf cultivation and controlling pests on betel leaves, they didn't change any of their activities after PICSA training. They, however, said that there had been some indirect effects of the training including increased awareness about weather forecasts and plant nourishment, increased knowledge about livestock farming and fisheries, and increased self-confidence.
- Some trained female farmers had made some changes inspired by the PICSA training, mostly motivated by the resource allocation mapping. They had started growing winter and summer vegetables in their homestead gardens for home consumption meaning that they didn't need to buy vegetable from outside which saved them money. One young female farmer from Rajshahi had started a small poultry farm with help from her father and was paying her college tuition and transport costs by selling eggs and chickens.
- The young male trained PICSA farmers said they faced difficulties sharing their new knowledge with senior and more experienced local farmers. They said that non-trained senior farmers felt they knew more than them because of their years of experience.

Figures 2.2, 2.3 and 2.4 show the compiled individual, household and community level effects diagrams drawn by farmers at the Barishal, Patuakhali and Rajshahi district FGDs.

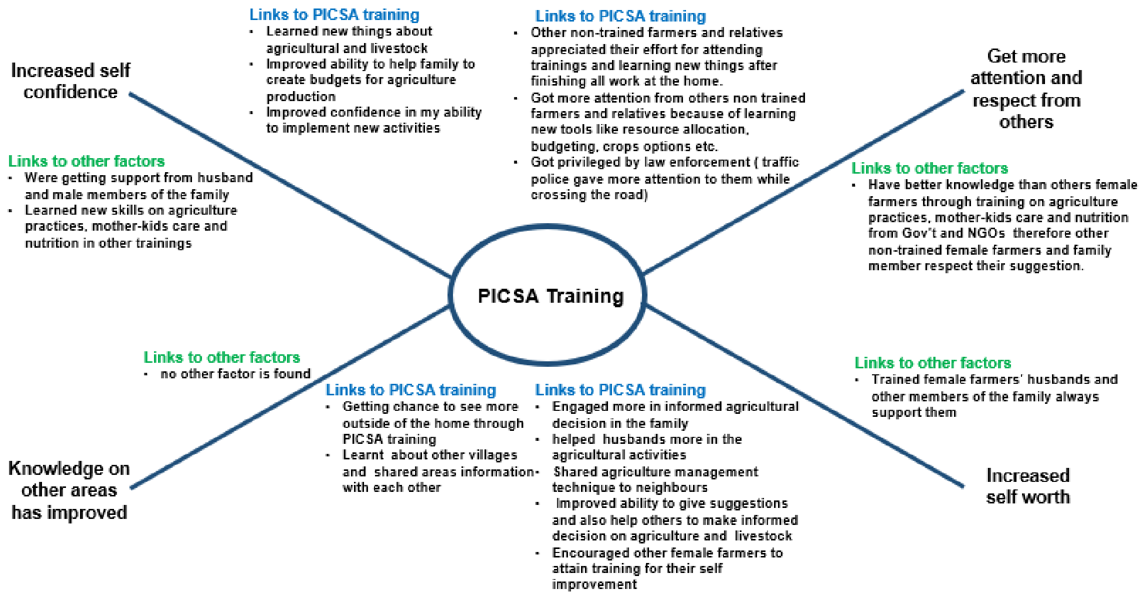


Figure 2.2: Individual level impacts of PICSA training as communicated in FGDs with PICSA female farmer trainees

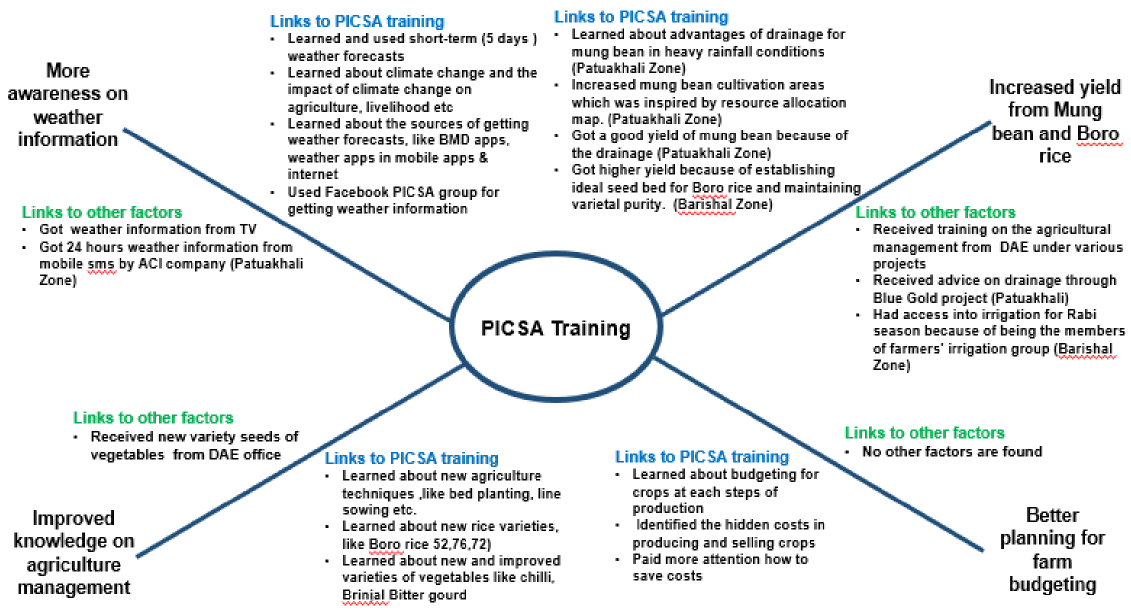


Figure 2.3: Household level impacts of PICSA training as communicated in FGDs with PICSA male farmer trainees

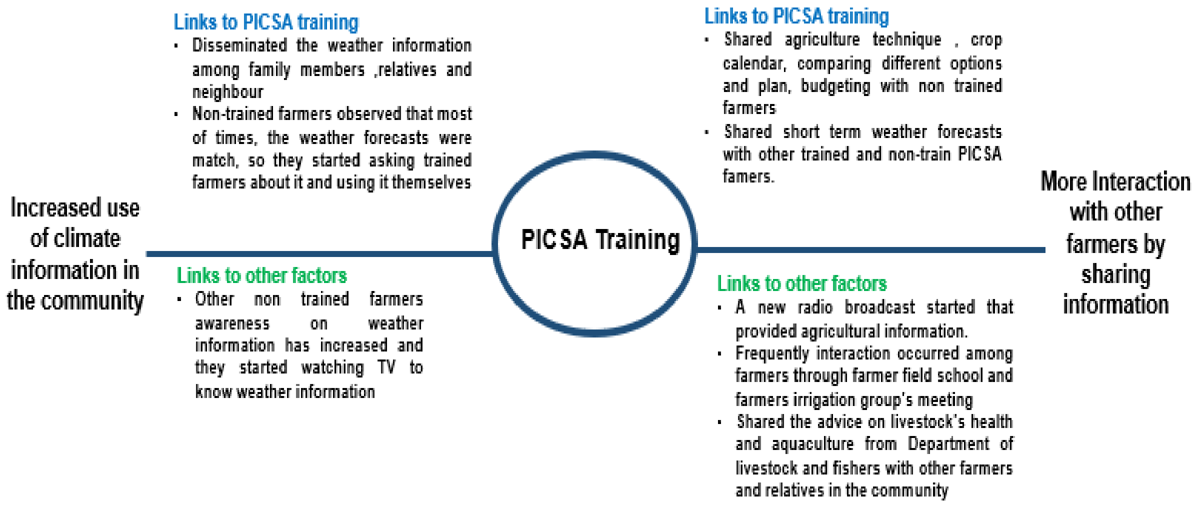


Figure 2.4: Community level impacts of PICSA training as communicated at FGDs with male and female trainees

PICSA training tools – According to the farmers who took part in the FGDs, both male and female trainees had easily understood about resource allocation, budgeting, crop calendars and options. They had found the classes on historical climate graphs and the probabilities of weather and climate parameters the most difficult things to understand. At the first class, they learnt about the definition of weather and climate, climate change, the reasons for climate change and its impact on agriculture and livelihoods. In the second class, they saw historical climate graphs and did probability calculations, which were very new to them. A problem they faced was that the information was presented in English months and did not show the local rabi, kharif 1 and kharif 2 seasons, which hindered their interpretation of the graphs. Also, the farmers couldn't take the graphs home and didn't do the probabilities calculation with their family members, meaning most of them didn't retain this knowledge.

The farmer participants said that the following things needed improving in the PICSA trainings:

a) They should start at least one month before the cropping season to enable decision making for the upcoming season.
b) All trainees should be provided with the PICSA training manual, training materials with historical graphs, and the drawings to take home.
c) All trained farmers should be asked to redo the exercises at home with their families and present them at future training sessions. This would, for example, include making crop calendars and resource allocation maps, and planning how to modify agricultural and livelihood activities using climate information.
d) The historical graphs should be presented in Bangla months.
e) The beginning and end months of the boro, kharif 1 and kharif 2 seasons should be shown on the graphs using the Bangla months.
f) A short video or photos about measurement of rainfall should be presented at trainings to help participants understand what e.g. 100 mm or 500 mm of rainfall looks like and what light, heavy and very heavy rainfall BMD forecasts mean. Comparison of rainfall

volumes to common household cooking vessels, etc. were suggested as solution for this.

g) DAE officers should do follow up meetings or visits after the training is finished and the season ends to collect feedback from farmer trainees.

h) In the last winter boro rice season, each PICSA training was four hours long without any break and without refreshments. A break with refreshments should be included.

Sources of weather forecasts – The PICSA farmer training explained about the Bangladesh Meteorological Department (BMD), its 5 day forecasts, the toll free 1090 number for weather information and why BMD cannot provide forecasts at the sub-sub district level. CSRD's studies found that most trainee farmers and their family members' had subsequently increased their awareness about weather forecasts. Before their engagement with PICSA and CSRD, they mostly got information on the weather from television, with those who didn't have TVs going to their local market or tea stall watch to the news. The female trained farmers also watched TV or listened to the radio for information on the weather more frequently than before. Kulsum Begum, a PICSA trained farmer from Babuganj Upazila, Barishal district reported how her elder son had said:

"Mom, since getting the training, you are frequently watching the weather news!"

The farmers received 5 day weather forecasts at the PICSA trainings; but afterwards most of them didn't receive such forecasts regularly from their SAAOs. They only received forecasts from SAAOs (by mobile phone or personal visits) when a calamity threatened. The farmers also said that whenever they needed weather information, they called SAAOs and most times, the provided forecasts were accurate.

Photo 1.3: Farmer Mijanur Rahman showing a weather forecast received through Facebook through his engagement with DAE and PICSA (SM Shahriar)

Farmers get smart with Facebook – The CSRD PICSA training follow-up studies found that some trainee farmers received weather forecasts from Facebook where DAE in consultation with CSRD and BMD regularly posted 5 day forecasts in Bangla on the five PICSA district SAAOs' Facebook groups. The SAAOs have added lead and young farmers who have smart phones and Facebook accounts to their Facebook groups to provide them with direct access to forecasts that they can in turn pass on to other local farmers. According to the SAAOs, previously, sub-district agricultural offices (UAOs) and agricultural extension officers (AEOs) received weather forecasts from DAE's Dhaka office by email to pass on to SAAOs, which meant that SAAOs received the information only 2–3 days after it was sent from Dhaka. SAAOs and farmers now get these forecasts instantly directly from the PICSA Facebook groups.

Some lead and young farmers with smart phones were using mobile weather apps or the internet to access forecasts for sharing with other farmers. Only a few male farmers in the FGDs had called 1090 for a forecast:

"It was a general weather forecast for the country, but it matched what happened" – male farmers of Bokhtiyarpur village, Durgapur Upazila, Rajshahi.

Surprisingly, some male farmers who took part in PICSA and the follow-up focus groups at Bokhtiyarpur village in Durgapur Upazila, Rajshahi explained that they hadn't checked the weather information during and after the 2018/19 rabi season as there were no threatening climate risks and they had just guessed the likely conditions from their experience. According to the farmers in Rajshahi, the last boro season (2018/19) was a good weather year for farmers but a bad year for selling rice as rice only fetched a very low price.

On the other hand, the female farmers at Par Chowpukuria village in Durgapur Upazila, Rajshahi, said that their interest in weather forecasts had increased as most of the time the weather matched the forecasts. Whenever they needed weather information, they asked their neighbor who was PICSA trained to check the forecast on the internet.

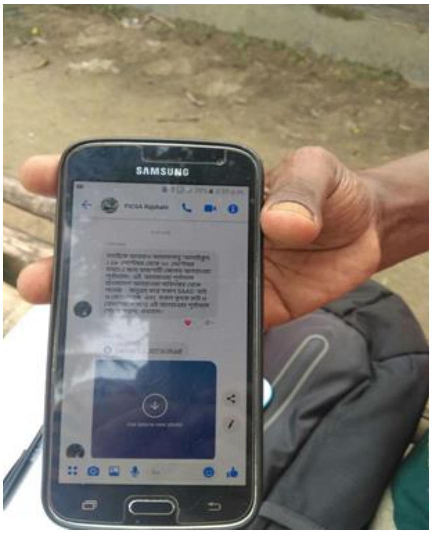


Photo 1.4: Closer view of the 5-day BMD weather forecast sent by DAE with assistance from CSRD (SM Shahriar)

Preferred sources of information – The trained farmers who had participated in the PICSA activities expressed their preferred sources of weather information:

- Many disliked the inaccuracy of forecasts that were not location-specific and expressed their need for improved weather information for their areas.
- Most trained farmers preferred voice message weather forecasts.
- A few literate farmers preferred both voice messages and mobile SMSs in Bangla script on their mobiles.

Sustaining impact – According to the PICSA trained farmers who participated in follow-up FGDs, the following things need to be sustained:

- PICSA-trained farmers need to practice that they learned and teach their family members about the PICSA tools.
- The farmers need to build their interest about new agronomic management technologies and increase their awareness about weather forecasts and agronomic management to manage higher yields.
- Most farmers need funding to adopt new options such as fattening beef cows, goat farming and fisheries. They need zero or low interest loans. The farmers asked for a

PICSA-related project where they could get financial support for expanding their farming.

- DAE should provide more PICSA or agriculture-related training for farmers for them to learn continuously.
- DAE officers should do follow-up meetings or visits after training finishes and the season ends to get feedback from trainees and keep the trainees on track.
- Farmers' family members should be involved in the training so they can learn and help the farmers on their farms as some trained farmers couldn't convince or communicate the PICSA methodologies to their family members.
- The farmers in Rajshahi needed more land for growing crops. Many farmers there had switched to fish farming and were using the land for this and so did not have enough land for growing crops.
- The Rajshahi farmers were interested in fish farming and cultivating betel leaves and to learn more about these subjects including pest and disease control during the PICSA training.

Photo 1.5: SM Shahriar (Agricultural Development Officer, CIMMYT) interviewing PICSA trained farmer Anwar Hossain Babu in Durgapur Upazila, Rajshahi District (Anarul Haque)

Photo 1.6: PICSA trained female farmer Safia Begum drawing her participatory storyline explaining how, why and when she changed her vegetable cultivation practices influenced by her PICSA training (Fahmida Khanam)

Quantitative survey – A survey was first piloted from 13–28 July 2019 on a sample of 50 PICSA-trained farmers (25 male, 25 female) from each of the five districts (Barishal, Rajshahi, Dinajpur, Khulna and Patuakhali). The full survey was then carried out in in September–October 2019 using Android tablets provided by CSRD and ODK questionnaires designed by the University of Reading. The survey was administered using ODK by trained enumerators after the pilot testing of the questionnaire with farmers in Dinajpur in the early second half of 2019 and after the rabi season had ended and the farmers had harvested their crops. The survey was based on a questionnaire used to evaluate PICSA in other countries. It asked 280 farmers (61% men, 39% women) who had been trained on PICSA before the 2018/19 rabi season about their:

- experiences of the training and its effects on their planning, decision-making and attitudes to farming; and
- responses and especially any changes they had subsequently made to their farming

practices.

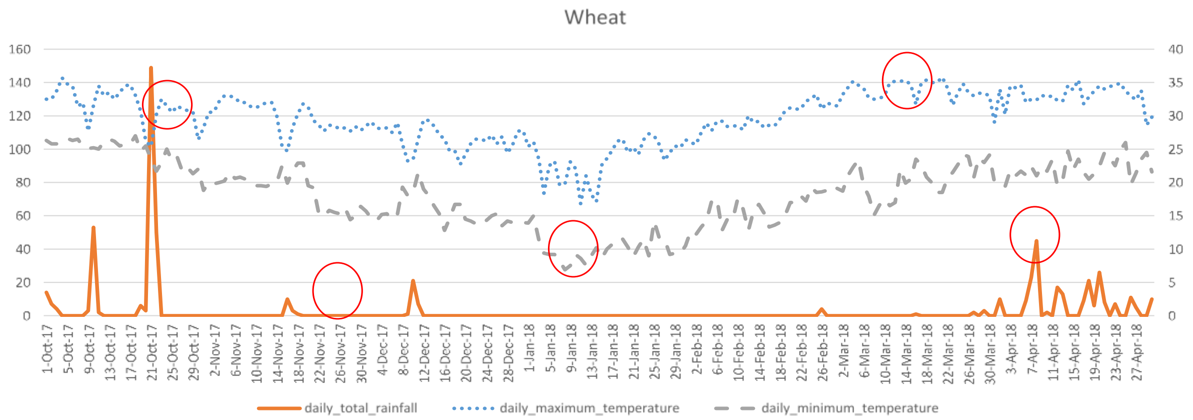
The respondents reported that their training on and application of PICSA had had a positive influence:

- 98% said they felt more confident in planning and decision-making, whilst 87% thought they were better able to cope with bad cropping years caused by the weather.
- 72% thought their food security had increased, and 86% thought their incomes had increased following the PICSA training.
- 90% of respondents had made changes following the training with 80% making crop changes, 52% livestock management changes, and 9% other livelihood changes.
- The most popular specific changes were trying new crops (44%) and changing livestock management practices (32%). These farmers had tried a diverse range of new crops to the extent that the most popular selection on the survey was 'other.' The most common livestock management changes involved supplementary feeding and using vet services for cattle.
- The next most common types of changes tried out were 'changing crop/land management' (25%) and changing the number of irrigations (24%), especially reducing them.
- Farmers' responses to the open-ended questions regarding the impact of the changes indicated that they had mostly increased yields and income from farming.
- 92% of the respondents said they had shared information about PICSA with other local farmers.

Applied research to inform development partners how to align climate services with farmers' decision-making priorities

Usefulness of climate services – The availability of seasonal and short-term weather forecasts and agro-advisories should enable farmers to handle the year-to-year variability of weather and improve their farm profits. The economic value of a climate service can be defined as the monetary equivalent potential outcome if the users have access to and acted upon the advice provided by the service. Knowledge of the decisions farmers make in relation to key weather variables (e.g.: maximum and minimum temperature and rainfall) are needed to understand this value.

Hindcast experiments – CSRD implemented research to examine the ways in which farmers may or may not act on climate information services using an innovative 'hindcast' experiment framework in early 2019. More than 600 farmers across India, Nepal and Bangladesh were presented with weather data of the past year and asked if and how they would have changed their crop management practices if they had been given access to forecasts with a lead time of 5 days. The research focused on understanding the economic benefits of using climate services for decision making in agriculture and to justify investments in climate services for farmers. A systematic method was developed to evaluate the impact of short term-climate advisories. The hindcast approach allows researchers to interact with farmers and discuss hypothetical scenarios regarding if and how they might change their crop management practices with access to climate information to condition their decision making.



Wheat (Mark the Planting date (P) , irrigations (I) , fertilizer applications,(F), Weeding (W) , Harvesting (H) on the above date line

October 2017 (Aasshin 15 Kartik 14)	November 2017 (Kartik 15 to Augrahayon 14)	December 2017 (Augrahayon 15 to Poush 16)	January (Poush 17 to Magh 17)	February (Magh 18 to Falgun 16)	March (Falgun 17 to Chaitra 17)	April (18 Chaitra to 18 Boisakh)

Modified operations using forecast

Tick the feasible operations in presence of 5 day forecast

Postpone sowing **irrigation due to dry spell** **irrigation (low temp)** **irrigation (high temp)** **harvesting quickly**

Figure 2.5: A model hindcast sheet used during hindcast experiments to show farmers previous weather information in graphical form. Farmers then mapped their previous season's crop management practices to the dates in the graph and discussed how they may have changed management practices if they had had access to the weather information. The data from such exercises helps identify the most relevant types of climate information and crop management practices and the focus of climate services and agricultural extension programs.

The method involved presenting farmers with daily data of key weather variables on line graphs including maximum and minimum temperature and rainfall for the past cropping seasons (Figure 2.5). The researchers then asked the farmers to mark their crop husbandry decisions (planting, irrigating, weeding, fertilizing, harvesting etc.) on the date lines and identify decisions they would have altered if they had been provided with 5 day forecasts.

A random selection of villages were sampled within 10 km radius of meteorological stations in the study locations in each country to ensure accuracy of the data presented to farmers. The actual inputs used like fertilizers, irrigations, weeding, and yields obtained by the farmers were collected separately.

Results – The results show that the farmers were very willing to change farming practices such as sowing dates, irrigation (related to at critical temperature thresholds) and harvesting times (related to knowing if they knew about untimely rainfall that could damage crops) (Figure 2.6).

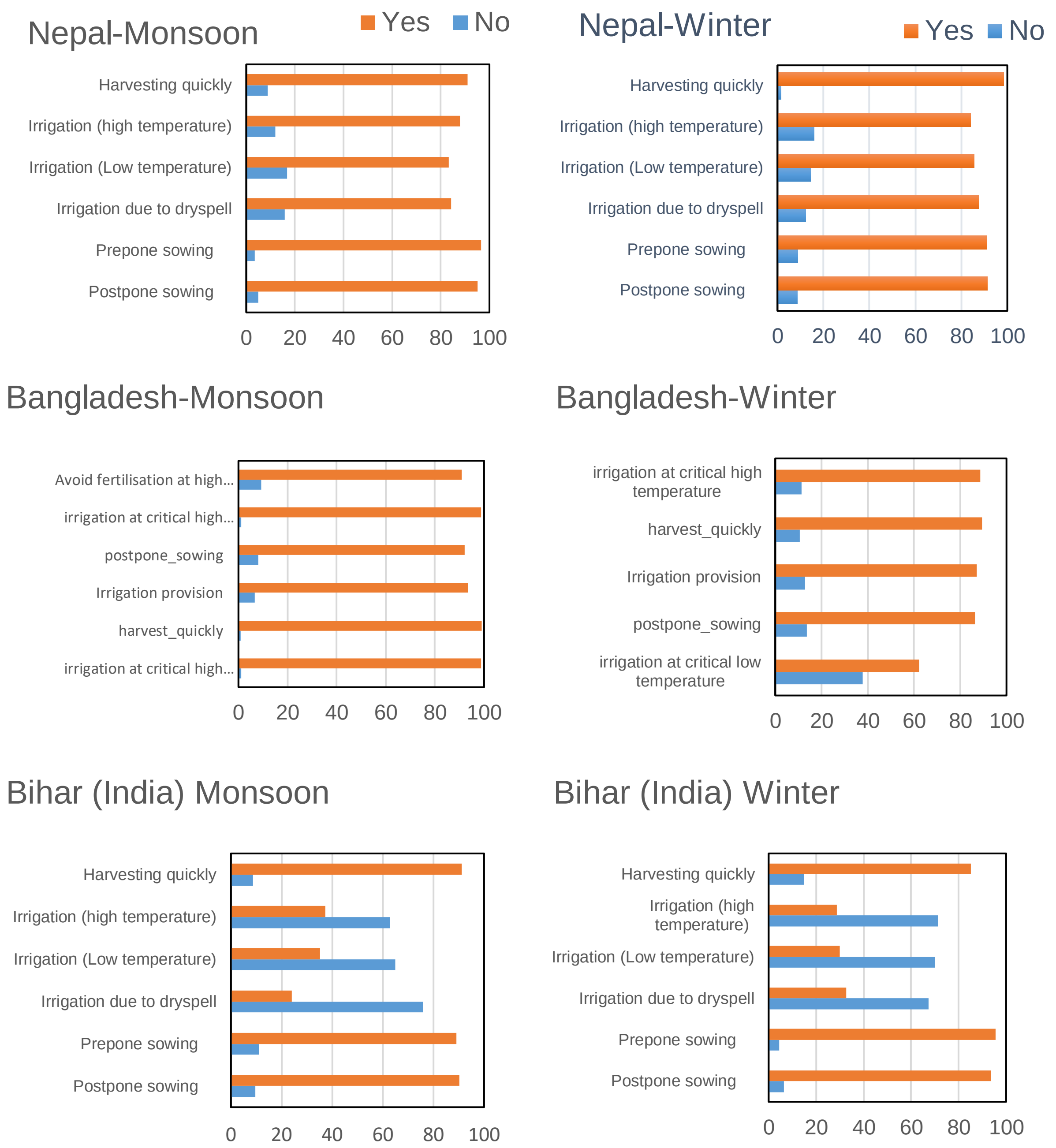


Figure 2.6: Sampled farmers' willingness to use climate services for altering agricultural operations captured by hindcast experiment

Potential chances in yield as a result of farmers' hypothetical modification of crop management practices in the hindcast experiments – A statistical approach was taken to create 'what if' scenarios to capture potential changes in yield that would have happened if farmers had altered their operations within the lead period (five days) of the forecasts. In the case of winter wheat, farmers indicated that they would have changed their planting dates, that they would have irrigated on extremely hot days, and that they would have harnessed earlier before damaging rainfall events. The benefits of taking such decisions were analyzed using statistical models. The factors that may hinder forecast-based decision making were also identified.

Farmers' actual decisions taken in in the winter 2017-18 season were compared to a location-specific 'ideal' decision set (planting date, irrigation at critical temperature thresholds and harvesting before rainfall events as advised by extension services). The deviations of actual farmers' decisions from the 'ideal' were used to construct a composite index. Using the index, the dataset was divided into two regimes (far from ideal [Regime 1] and near to ideal [Regime 2]) and counterfactuals were generated using a switching regression model. The results of the endogenous switching regression model using the hindcast experiment data for wheat farming in Bihar (India) and Bangladesh are given in Table 2.1.

Table 2.1: Results of the switching regression model using the hindcast experiment data for wheat farmers in Bangladesh and Bihar, 2017/18

Variables	Bangladesh		Bihar	
	Coefficient	Standard error	Coefficient	Standard error
Regime 1				
Deviation from critical planting date	-13.27**	6.36	-6.2	24.28
Deviation of irrigation from date crossing critical temperature limit	-0.0087	0.0058	-22.17	18.24
Deviation from date of rainfall during harvest period	-2.23	10.2	17.89	22.8
DAP fertilizer application	-6.3	3.7	1.0	2.11
Urea fertilizer application	2.53**	1.17	9.00**	2.1
Potash fertilizer application	42.49**	4.57	-6.26	12.4
Constant	499.22	371.62	2,077*	1,137
Regime 2				
Deviation from critical planting date	-0.69	3.78	27.2	25.58
Deviation of irrigation from date crossing critical temperature limit	-0.01639**	0.0058	-16.26	20.81
Deviation from date of rainfall during harvest period	15.15**	4.7	117.33**	39.04
DAP fertilizer application	-5.88	3.71	-1.3	2.4
Urea fertilizer application	7.12**	2.1	3.6**	1.1
Potash fertilizer application	15.15	4.74	1.9	0.21
Constant	32.75	145.38	4601**	2192

The simulations using estimated regression regimes showed potential wheat yield gains of 15% in Bangladesh and theoretically more than 60% in Bihar if farmers switch to the ideal weather sensitive practices of Regime 2 (near to ideal) by following climate sensitive decision-making based on weather forecast agro-advisories. The case of Bihar shows the possibility of larger gains by changing planting dates and avoiding heat stress as well as harvest period losses. A similar strategy would also lead to moderate yield gains in Bangladesh.

This research work also explored other factors that affect farmers' decision making on when to plant, which is a key variable determining yield, especially for wheat. The results show that the factors varied significantly in India, Nepal and Bangladesh. Figures 2.7 and 2.8 show the major results for rice and wheat farmers. The differentiation of these two crops is important, as it permits tailored and crop-specific advising to extension officers working with each type of crop farmer:

- The hindcast experiment clearly indicated that decisions by farmer's groups had a major influence on their interest in modification of planting times in Bihar but not in Bangladesh. This suggests that extension services in Bihar should likely emphasize increased awareness of climate information and the relation between climate, planting dates, and crop productivity in the future.
- Cash constraints can constrain planting dates in Bihar farmers while they were not a major concern in Bangladesh. As such, extension services and agricultural development programs may need to place additional focus on overcoming access to finance in Bihar as a pre-requisite for the successful adoption of climate services in agriculture.
- Drought spells were decisive on governing planting dates in both countries.

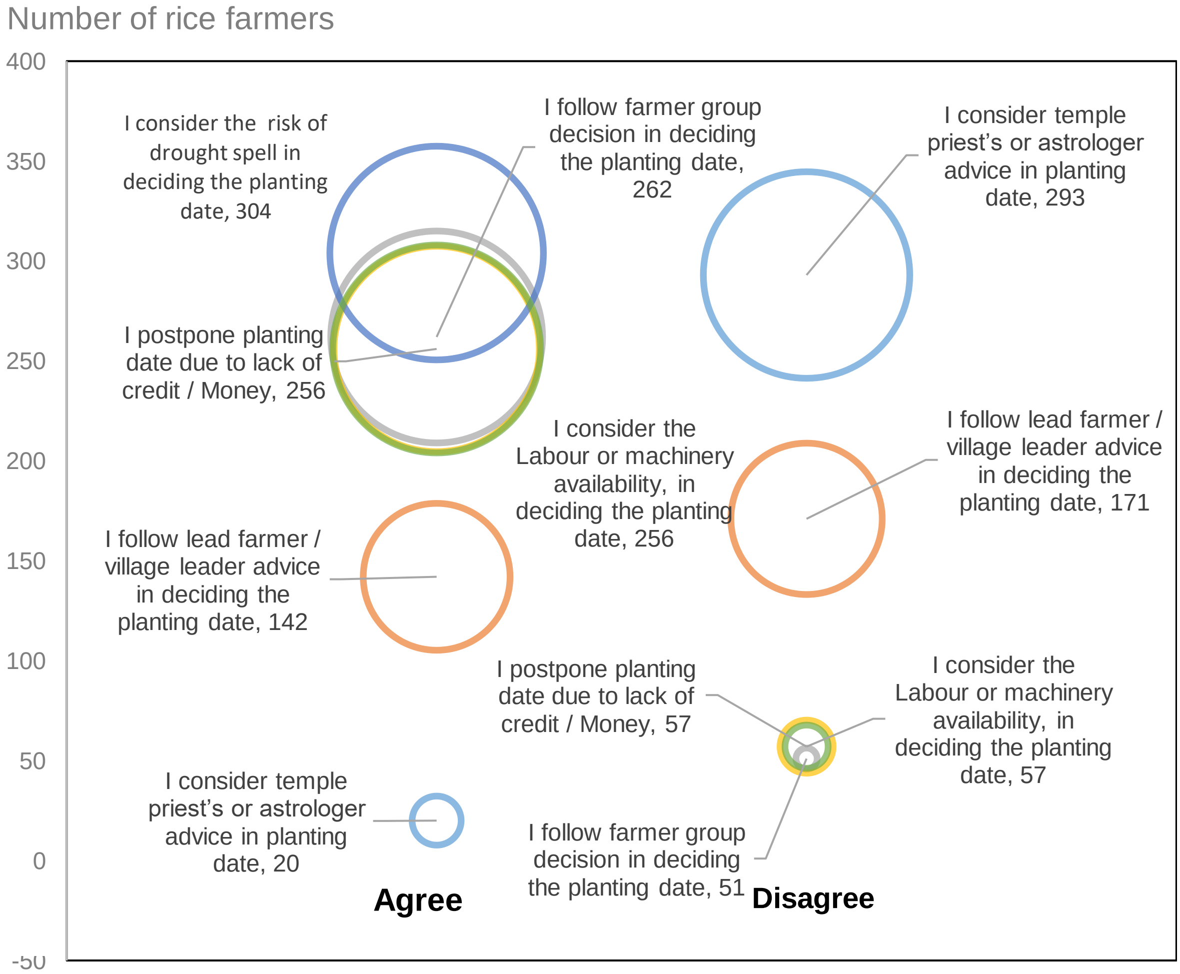


Figure 2.7: Depiction of the 'decision frame' on planting dates of farmers in Bihar, India. Note: the relative size of circles indicates number of farmers who responded affirmatively or negatively to questions. Numbers shown on the diagram are the sample sizes.

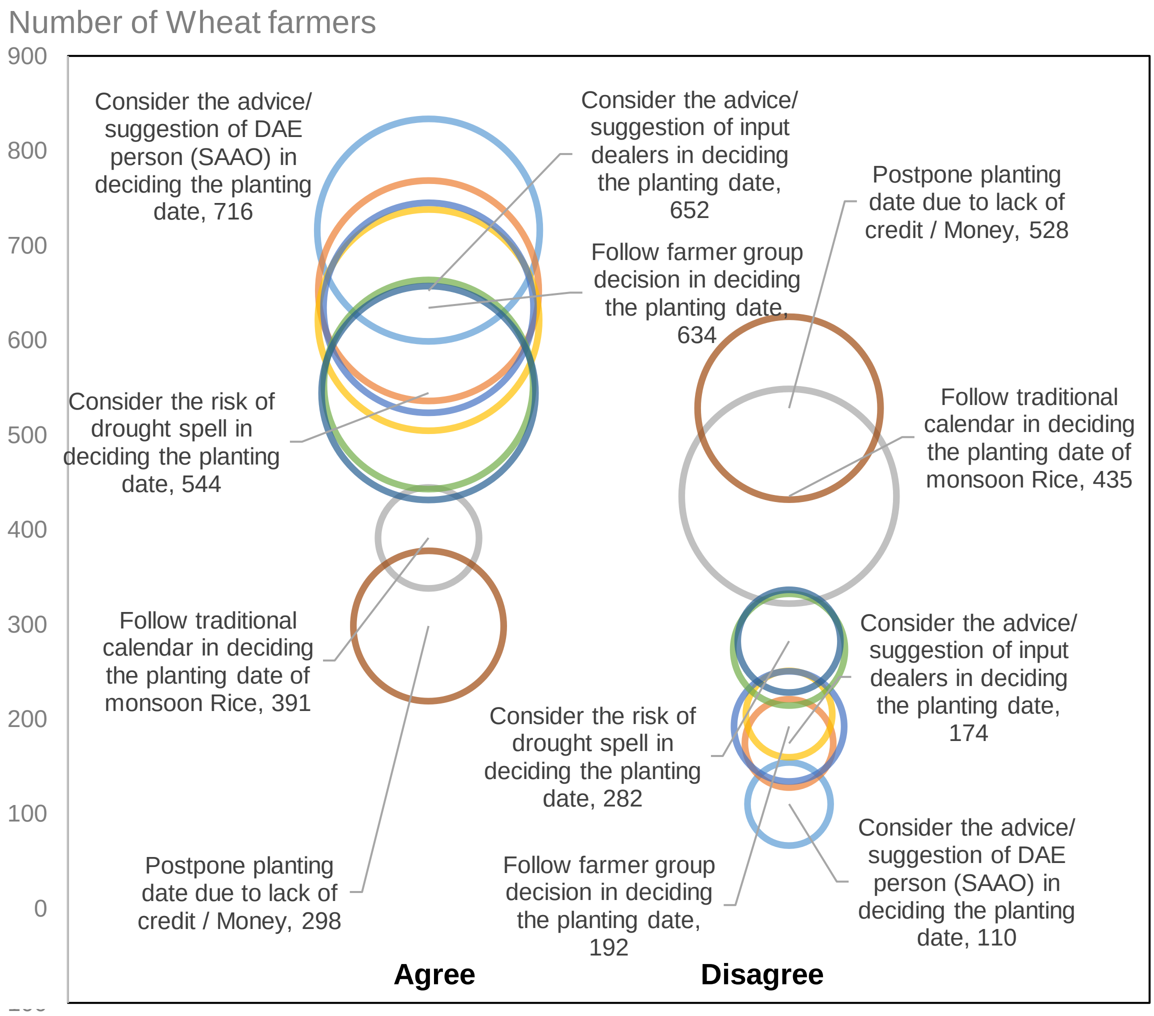


Figure 2.8: Depiction of 'decision frame' on planting dates of wheat farmers in Bihar, India. Note: the relative size of circles indicates number of farmers who responded affirmatively or negatively to questions. Numbers shown on the diagram are sample sizes.

These results show the largely untapped potential of climate services to help farmers avoid unsuitable planting dates and heat stress and harvest time rainfall damage to their crops and are therefore of great importance in South Asia. Note that the hindcast experiments did not evaluate disease forecasting, which would also have considerable economic benefits.

Farmers who participated in the hindcast experiments showed a high level of interest in accessing climate information services; while the *ex-ante* evaluation of farming practices indicated that these services can increase yields and income levels in South Asia. The provision of such services needs to be complemented with adequate quality inputs of seed supply, access to finance, and the availability of labor, farm machinery, irrigation water and post-harvest storage facilities. The results support further investment in climate services, which should improve social welfare and enhance food security.

Sustainability and exit strategy of CSRD in South Asia

The use of PICSA and hindcast experiments to inform agricultural extension in Bangladesh – CSRD's piloting of the PICSA approach to extension and climate information services in Bangladesh has gained popularity among the trained SAAOs and participating farmers. During the course of CSRD, 20 high-level DAE officers were trained as master trainers on PICSA. They then trained 40 SAAOs who subsequently trained 1,000 farmers in 40 communities in 20 upazilas of 11 districts of Bangladesh.

Bangladesh's DAE has expressed a strong interest in adopting PICSA and implementing PICSA activities as part of the organizations' core programming, and also in the World Bank funded 'Weather and Climate Services Regional Project for Bangladesh', which is led by DAE. In addition, the following are two decision support tools developed by CSRD that are now applied in DAE-led PICSA trainings (which are discussed later in this report):

- The Agvisely automated climate service advisory system for Bangladesh's major field crops helps extension agents and farmers increase the resilience of farming systems to climate risks.
- The early warning system for wheat blast disease was developed by CIMMYT in partnership with the Brazilian Agricultural Research Corporation (EMBRAPA), the University of Passo Fundo (UPF) and a number of international and national research and extension partners.

Officers and field level extension personnel have been trained as master trainers on the use of these two applications to communicate weather information and crop management advisories at least five days in advance. It is relevant to note here that these tools have been endorsed for institutional use by DAE and have become a core part of DAE's PICSA extension activities by providing location-specific information that can be used in trainings. DAE is regularly using PICSA in its farmer field school programming. And during 2019 CSRD supported DAE to seek continuing funding support for scaling out the PICSA approach:

- On 10 April 2019, DAE submitted a project proposal on 'Upscaling the PICSA approach and assessing its impacts on managing climate risk in Bangladesh' to the government's Krishi Gobeshona Foundation for funding support on. The proposal remains under consideration (approvals often take 12-14 months). If awarded, this will result in additional funding flexibility and additional support for DAE to continue developing the PICSA approach for three more years beyond CSRD until longer duration funding is in place.
- A concept paper for a PICSA project was resubmitted to Bangladesh's Ministry of Agriculture (MoA) in late 2019. The proposal was consistent with Articles 2.1 (Specific Objectives), 5.2 (Extension Methods), 5.5 (Agricultural Productivity) and 9 (Agricultural Mechanization) of the National Agricultural Policy, 2013.

If these efforts are fruitful then it is likely that the PICSA approach to providing climate services will play a sustained and vital role in combating climate related stresses and to enhance farmers' livelihoods.

Adoption of hindcast experimental approach by other climate services research initiatives – An additional hindcast survey is underway with the Capacitating Farmers and Fishers to Manage Climate Risks in South Asia project (CaFFSA) project supported by the CGIAR Research Program on Climate Change, Agriculture, and Food Security (CCAFS) aligned with CSRD that focuses on rice-fish and aquaculture systems. The adoption of this method and its application in aquaculture by WorldFish, one of CIMMYT's sister CGIAR centers, indicates the value and promise of this approach. Data are currently being analyzed from this survey.

In addition, the Water Apps project of Wageningen University is considering using the hindcast method for evaluating climate services provided to farmers.

By proving stand-alone products, protocols and methods, CSRD generated longer-lasting impacts as a pioneering project in agricultural climate services in South Asia.

Contribution of Activity 1.1.1 to CSRD's Action and Learning Framework

Pillar 1, Indicators 1.1 and 1.2, Pillar 2, Indicators 2.1 and 2.2, Pillar 3, Indicators 3.1, and 3.2, and Pillar 4, Indicator 4.1 (see Annex 3).

Sub-Objective 1.2. Climate services capacity development

Background – Sub-Objective 1.2 activities also concern technical improvements in climatological services, data acquisition and analysis, weather and seasonal climate forecasting skill improvements, and climatological research in Bangladesh.

Activity 1.2.1. Climate services capacity development in partnership with the International Research Institute for Climate and Society

Product 1. BMD agricultural climate services assessment

The BMD agricultural climate services assessment was completed on schedule in the third quarter of 2017. The assessment is provided as Annex 4 of the 2016/17 CSRD in South Asia Annual Report. Further details of work resulting from the assessment's recommendations are described in CSRD's 2018 semi-annual report.

Product 2. National scientist training and exchange, and CSRD planning with IRI

CSRD successfully facilitated a two-week science and training exchange hosted by IRI at Columbia University, at the Lamont-Doherty Earth Observatory campus in New York, USA in April 2017. Further details are in the 2016/17 CSRD in South Asia Annual Report.

Sustainability and exit strategy of CSRD in South Asia

Products 1 and 2 under Activity 1.2.1 were designed to provide essential training to BMD meteorologists and climatologists so they could participate more effectively in other Objective 1, 2 and 3 activities. As such, no formal exit strategy was designed as these products were parts of other activities.

Contribution of Activity 1.2.1 to CSRD's Action and Learning Framework:

Pillar 1, Indicator 1.1 and Pillar 4, Indicator 4.1 (see Annex 3).

Sub-Objective 1.3: Development of forecast products, impact assessments and decision support tools for agriculture, fisheries and/or livestock

Activity 1.3.1: Iterative development and refinement of decision-support platforms with improved agro-meteorological services visualization and communications tools

Background – In pre-CSRD project consultations, BMD requested technical support and collaboration on the three subjects detailed in this section of the report and that are a key component of 'Activity 1.3.1, the Sector 3 Agro-meteorology track'. The three subjects are

- The provision of GIS maps displaying climatic stresses
- Forecasts for irrigation management
- The development of impact based agro-forecast systems with an emphasis on developing crop-specific pest and disease models.

The following write-ups report the progress in the reporting period on the Activity 1.3.1 research topics and products:

- Agriculturally short- and extended-range forecasts graphically depicted as climatic stress risk maps for major cereals.
- An ITC platform for meteorologically integrated irrigation management services.
- Spatially explicit and meteorologically driven wheat blast *(Magnaporthe oryzae Triticum)* disease risk assessments for Bangladesh.

Product 1. Agriculturally relevant climatological analysis and improved extended-range forecasts and outlooks[5]

Using historical climate data to provide information on present and future climatic conditions

Deriving actionable climate information for crop planning from historical data

The climatic data and products produced by the Bangladesh Meteorological Department (BMD) are a valuable source of information for agriculture stakeholders. Effective institutional communication is an essential part of the climate information services development cycle. BMD–CSRD consultations prior to and at the beginning of the project identified many opportunities and activities to enhance climate information services for agriculture to build the resilience and adaptation capacities of Bangladeshi farming systems. This prioritized the analysis of BMD and other historical climate data to identify and characterize the major climate factors that influence agriculture in Bangladesh.

Background data – Between 2016 and 2019, BMD and IRI scientists generated databases of climate information to document climate variability as the first step in developing improved

[5] The initial USAID scope of work based on the 12 July 2016 consultation with BMD suggested focusing on developing 'Seven-day rainfall forecasts with 15-day accumulative rainfall outlooks' (Tasks i. ii.). At the start of the project, CSRD staff found that BMD was already generating seven-day rainfall forecasts using outputs from its Weather Research and Forecasting (WRF) model. Fifteen cumulative rainfall outlooks were relevant in the context of several other forecasting parameters that were identified during the BMD skills assessment. Importantly, these topics were more agriculturally relevant for farmers than generic 7 or 15-day accumulative rainfall outlooks. With the endorsement of BMD, CSRD therefore focused on these forecasting needs under this activity product now renamed 'Agriculturally relevant climatological analysis and improved extended-range forecasts and outlooks'.

climate information services for agriculture in Bangladesh. The main patterns, long-term trends and future projections of temperature and precipitation extremes were analyzed in terms of their implications for agriculture and the design of climate information services considering in-country variability. Regional features, such as the high seasonality associated with the monsoonal climate, were studied in the context of climate information services. This seasonality governs agriculture and crop productivity with, for example, summer aman rice and winter boro rice governed by the timing and amount of rain and associated air temperature and humidity. These efforts continued in 2019 to perfect the information products delivered by CSRD in consultation with BMD.

Prediction of onset and withdrawal – The onset of the rainy season is a major driver of Bangladeshi agriculture. During the reporting period, the features that govern its onset were examined and several approaches evaluated to apply to Bangladesh's agricultural context, including a tailored agronomic definition of the onset of the monsoon and the implementation of methods to assess the historical variability of the timing of the monsoon, future projections, and seasonal and sub-seasonal predictability:

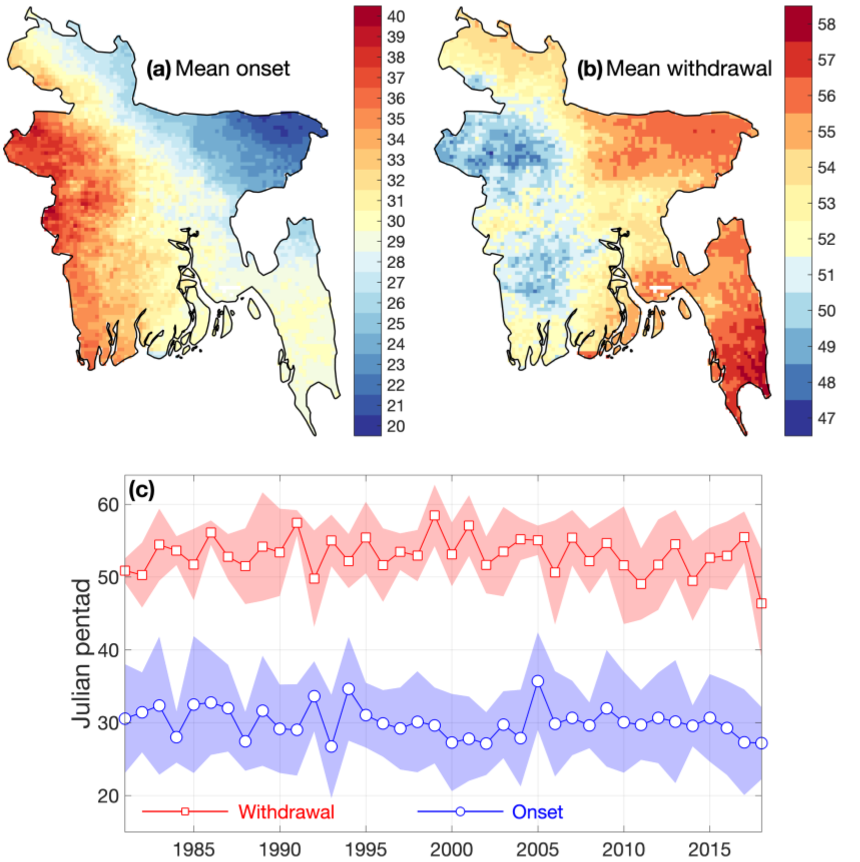


Figure 2.9: Monsoon onset (a) and withdrawal (b) in Bangladesh (1981-2017). (c) Time series of country-averaged monsoon onset and withdrawal. Notes: shaded area is the spatial standard deviation and all values are expressed in pentads. Data source: Climate Hazards Group InfraRed Precipitation with Station product (CHIRPS v2)

- The maps of monsoon onset and withdrawal at Figure 2.9 (a-b) show results obtained from the CSRD analysis of historical data. They show the southwestward propagation of the monsoon and the range in timing and the spatial variability. This analysis also shows that the withdrawal of the monsoon mainly follows a west-east gradient with a similar range of dates across the country.
- The time series of country-averaged dates shows significant inter-annual variability of about one month in monsoon onset and about two months for the withdrawal when considering extremely early and late years (Figure 2.9c).

Prediction using ENSO data – During the reporting period, CSRD scientists collaborated with BMD to examine the relationship between the timing of the monsoon and the El Niño-Southern Oscillation (ENSO) in consideration of potential intra-national variability. The observed correlation of the timing of the monsoon with an ENSO index for each preceding six months was calculated taking the climatological monsoon onset and withdrawal for statistically-derived homogeneous groups of dates as references, with highly correlated relationships identified and retained. Figure 2.10 shows the maximum correlations (1981-2018) and the corresponding months (lead time).

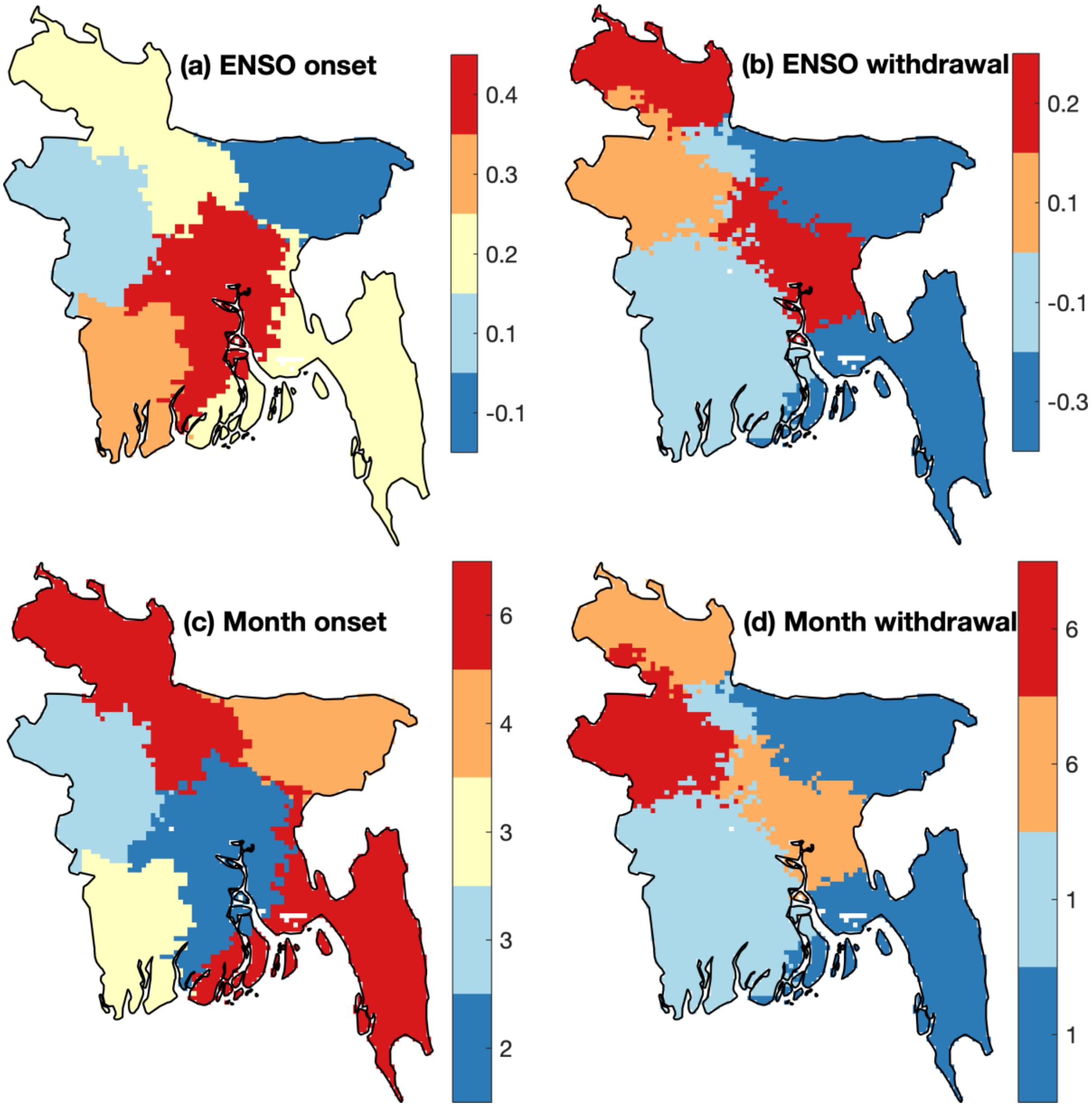


Figure 2.10: a and b: Maps of maximum Pearson correlation index between ENSO and monsoon onset and withdrawal for clusters. c and d: the month (1-6 previous months) of highest correlation displayed in a and b.

The analysis show negative correlations in the north east region (Sylhet) for the onset of the monsoon, and a maximum positive correlation for the onset in the center of the country. This suggests that the ENSO index can more accurately predict onset at the regional rather than the country level. These results suggest the possibility of the increasing predictive power of ENSO at the regional level, and a potential for statistical modeling for regional seasonal forecasting to inform stakeholders about the earlier or later than normal onset of monsoons. However, additional means of prediction need to be explored in order to implement operational products.

The information generated from the above activities have great potential to be used by BMD and other stakeholders. Continuous rainfall monitoring by BMD can be used to predict the onset of the monsoon while other data can be used in forecasting systems after the end of CSRD. In addition to the above activities, studies have been carried out to evaluate and demonstrate the use of tailored agronomic definitions of monsoon onset in agriculture using crop modeling. Outputs from this work can be found in a report completed in December 2019 on the utility of agronomic monsoon onset definitions for rainfed *Aman* rice in Bangladesh.

Mapping the seasonal progression of the monsoon and deviations from historical normal

Crop productivity in Bangladesh depends on the seasonality of the climate, particularly on precipitation for rainfed crops such as the summer monsoon aman rice crop as yields and management decisions are very dependent on the timing of the rainy season. The onset of the rainy season is thus crucial in the design and implementation of climate information services alongside considering the progression of precipitation of the current season in relation to climatology. CSRD implemented a methodology to generate data on seasonally accumulated precipitation using data from BMD's weather stations and high-resolution gridded data.

Accumulated precipitation maps – In the reporting period, maps were produced to ground truth accumulated rainfall. The maps in Figure 2.11 show the accumulated precipitation until July 2017 and deviation from the long-term average as an example.

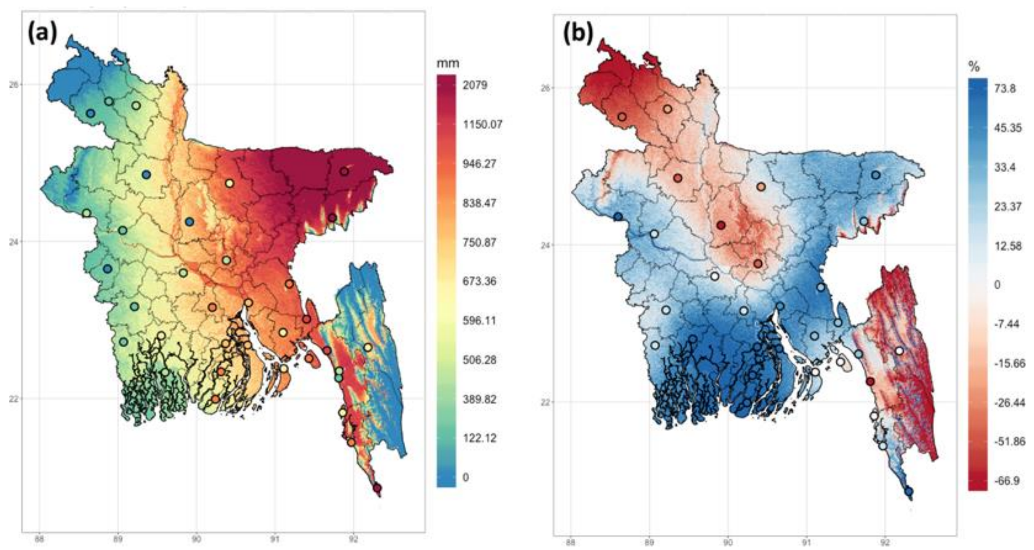


Figure 2.11: Maps of (a) accumulated precipitation until the second week of June 2017 and (b) corresponding anomalies.

Maps and analyses such as these can be useful for the regional within country planning of agricultural climate services by institutions such as DAE. For example, in this case, the pattern of accumulated precipitation is similar to the previously studied spatial distribution of total rainfall. However, in contrast, a large area in central and north Bangladesh experienced dry conditions that can reach more than 50% of rainfall deficit. Such information can be relevant for well-adapted rice varieties, for example ones that are robust to these climatic conditions.

Monthly anomalies in precipitation – During the reporting period, high-resolution gridded precipitation data was used to assess the seasonal evolution of rainfall in Bangladesh at different geographical scales using historical data. The maps shown in Figure 2.12 depict the gradual evolution of monthly total rainfall anomalies in Bangladesh from April to September 2018 in relation to the long-term (1981–2018) average.

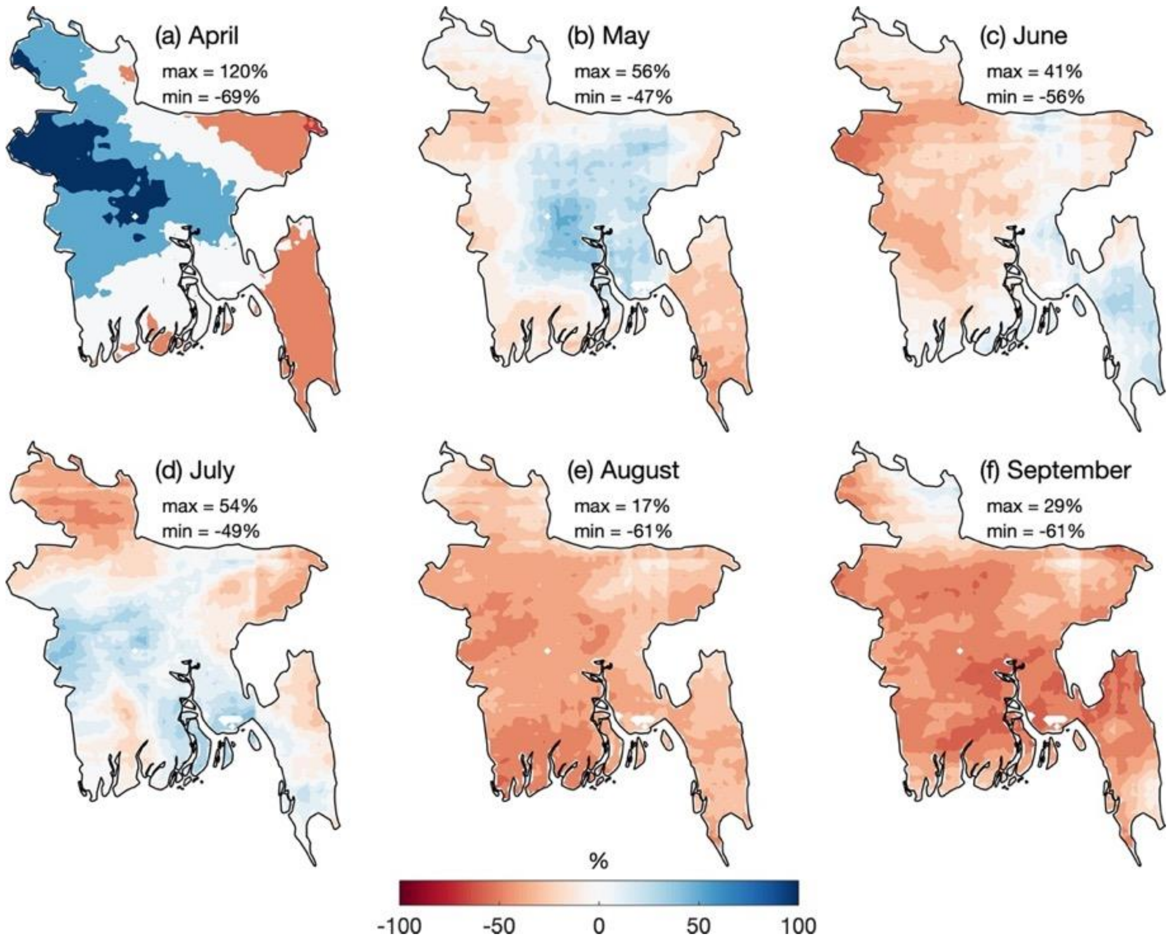


Figure 2.12: Maps of local monthly anomalies in precipitation during the 2018 monsoon in Bangladesh in relation to the long-term (1981–2018) mean. Data from CHIRPS v2

This example shows how the 2018 monsoon season began with large relative differences from the long-term average, which started to reduce as the season progressed, with an area of positive anomalies in the center of the country that reversed to negative in August and that remained until the end of the season when there were dominant negative anomalies, indicating a relatively dry 2018 monsoon. This analysis raises the question of whether it is possible to predict the occurrence of negative anomalies (i.e. less than average rainfall) at the end of the rainy season based on the historical analysis of precipitation data to generate local seasonal precipitation forecasting products. This kind of information would complement other more sophisticated products such as those that BMD is interested in developing.

Historical mapping of monsoon dry spells

Most of Bangladesh's precipitation occurs as intense summer monsoon rainfall. Monsoon dry spells (defined as five day periods with less than 1 mm rainfall) are, however, common and often significantly impact crops, especially as they are usually accompanied by high temperatures. Fluctuations between wet and significant dry conditions can stress crops and negatively impact agriculture and water resources. The forecasting of dry periods has been an important focus of CSRD's work on developing climate information services for Bangladesh.

A core research objective of CSRD since it began in 2016 involved documenting the long-term annual incidence of dry spells based on data from BMD weather stations and international organizations. The various products provide useful information for farmers, policy makers and DAE personnel to inform crop management. This information can inform the use of supplementary irrigation, seedbed establishment and transplanting dates, and land preparation to mitigate the impact of dry spells and also help identify the false onset of monsoon rains.

Results presented in CSRD's progress reports for 2017 and 2018 show that the number of dry spells in within the monsoon varied significantly across the country in a spatially coherent way associated with total seasonal rainfall, which opens up the possibility for improved regional forecasting. The results show a significant increasing trend in the number of dry spells for central Bangladesh and the whole country. However, these results need to be complemented with studies on the occurrence of wet spells to give a better idea about the sub-seasonal variability of precipitation.

Further studies were carried out during the reporting period to evaluate the representation of dry spells over longer periods considering historical and future projections. This is relevant for in-country regional planning and for evaluating current research and diagnostic tools over a geographical area that has not been well studied by the international community.

Using a widely accepted approach for evaluating results from climate models, during the reporting period the variability in dry spells in Bangladesh were evaluated for 1951 to 2005 and projected for 2006-2095 for future greenhouse gas trajectories defined using two RCP[6] scenarios (RCP 4.5 and RCP 8.5). Observation-based daily precipitation data from the APHRODITE product[7] were used for 1951 to 2005 and the 21 CMIP5[8] climate models belonging to the statistically downscaled and bias-corrected 0.25° × 0.25° spatial resolution NASA NEX-GDDP[9] product. Dry spells were defined as events of at least 5 consecutive days with precipitation anomalies exceeding one standard deviation of daily precipitation during June to September wet seasons.

6 Representative Concentration Pathway
7 APHRODITE = Asian Precipitation - Highly-Resolved Observational Data Integration Towards Evaluation
8 Coupled Model Intercomparison Project Phase 5
9 NASA Earth Exchange Global Daily Downscaled Projections

The map at Figure 2.13a shows the long-term climatology of dry spells obtained with the APHRODITE product, with magnitudes and patterns similar to those identified using other data sources and presented in previous reports (Figure 2.13a). In the second half of 2019, multiple precipitation-related assessments were performed for Bangladesh using APHRODITE data (including its validation). The goal of this work was to assess if these data sources could as a source of data with acceptable representativeness.

The other two maps in Figure 2.13 represent the multi-model evaluation of climate models:

- Figure 2.13b shows the ensemble climatology of dry spells for the same historical period using multiple model inputs.
- Figure 2.13c shows the difference between model results and observations.

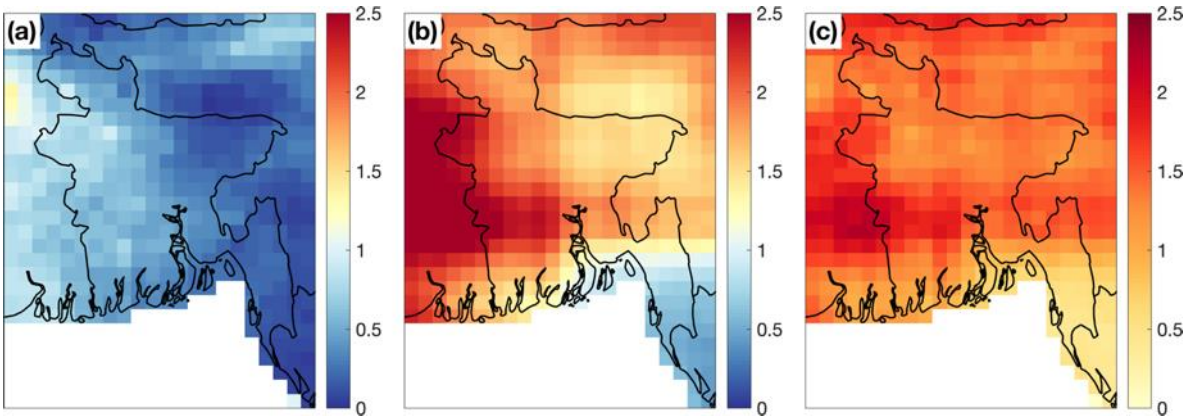


Figure 2.13: Inter-annual average number of dry spells during 1951-2005 monsoon seasons – (a) APHRODITE and (b) multi-model CMIP5 averages and (c) difference between (b) and (a).

These results suggest that the model ensemble tends to overestimate the number of dry spells in Bangladesh, probably associated with the difficulty of capturing sub seasonal features over regions where the dominant precipitation mechanism results from complex interactions. However, these results partly contradict CSRD's results on total precipitation, which that are more in line with the actual observations. As such, BMD has been advised that it may be necessary after the completion of the CSRD project to evaluate different models individually to identify which are most suitable for use in Bangladesh.

In addition, CSRD scientists examined the difference in the number of dry spells between three future periods (2006-2029, 2030-2069 and 2070-2095) for RCP45 and RCP85 projections and historical simulations were calculated (Figure 2.14).

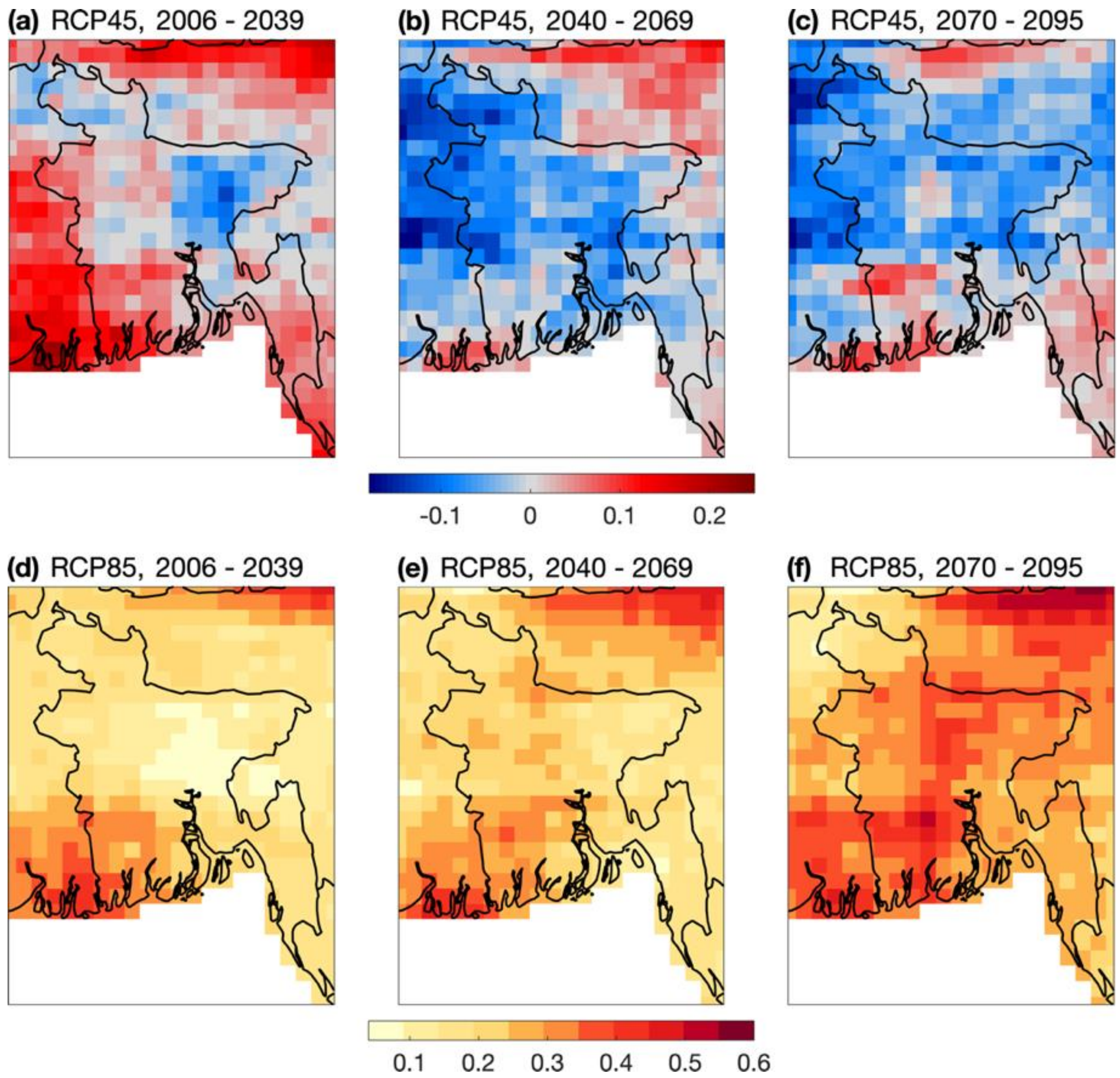


Figure 2.14: Difference between number of dry spells in future projections and historical CMIP5 multi-model average simulations for three future periods and two RCP scenarios.

The following results highlight the complexity of representing sub-seasonal events in Bangladesh:

- Only projection RCP85 shows a trend in the number of dry spells over the three periods, with an increasing number over time.
- Projection RCP45 shows both negative and positive anomalies in the number of dry spells for the three sub-periods.

In addition, the projections of precipitation show a slight increase in total precipitation, which is more pronounced in RCP85, and also increased variability, which is represented by an increase in the number of wet and dry spells, including more extreme events.

These results raise questions that need addressing to inform the design of targeted climate information services for Bangladesh.

Historical mapping of heavy rain events in the early pre-monsoon period

In Bangladesh, precipitation is the main climate variable that influences crop yields and management practices, and that regulates extreme high temperatures in the transition to the rainy season. Additionally, agriculture in Bangladesh is often affected by extreme precipitation events that damage crops, reduce farmers' incomes and impact food security.

CSRD early on identified the study of the long-term and spatial occurrence of heavy rainfall events as a priority concern for Bangladeshi agriculture to inform the development of climate information services for farmers. The analysis of the probability of heavy rainfall during the transition from the dry to the wet season (early pre-monsoon rainfall), and during the monsoon, were recognized as priorities in terms of their temporal and spatial variability, trends, multi-scale forecasting, and the possible use of satellite products for extended studies to generate useful information for planting, planning harvests, and fertilizer management, for multiple crops and especially for sensitive ones such as mung beans.

As example of CSRD's work in this field is the long-term statistical analysis of BMD historical data that was carried out in the reporting period. Figure 2.15a shows the results from the mapping of the annual number of heavy rainfall events between 1981 and 2017 using a 95% percentile of daily precipitation as a criterion, and corresponding linear trends.

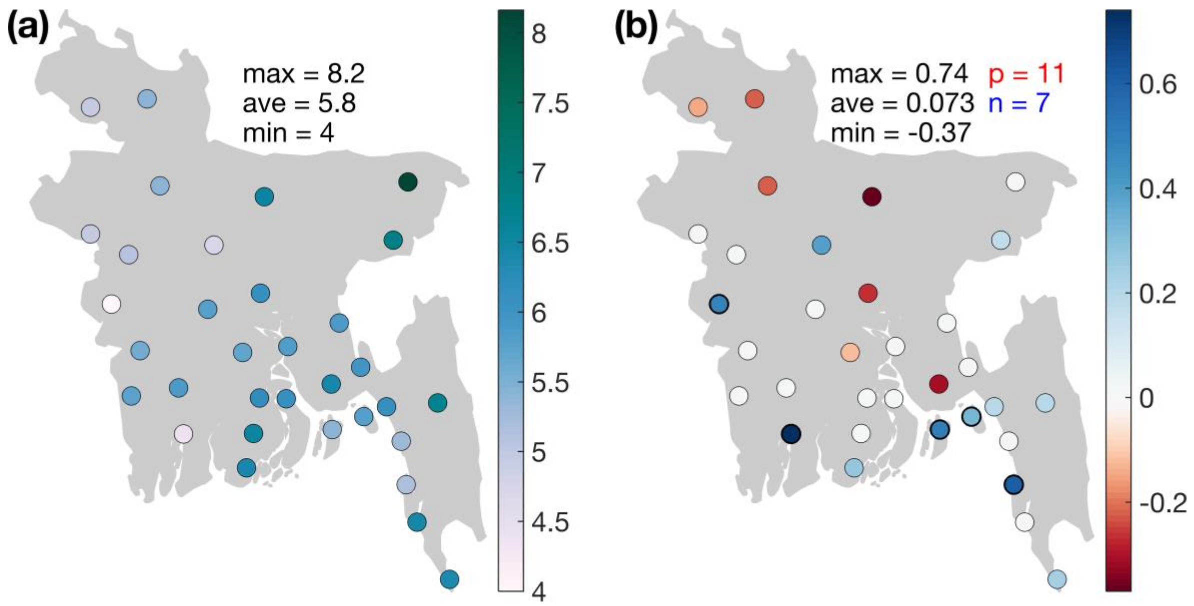


Figure 2.15: (a) The number of annual heavy rainfall events (1981–2017) and (b) linear trends. Note: p and n denote number of stations with positive and negative trends respectively

The improved understanding of the occurrence of heavy rainfall events can inform the development of climate information services for specific crops and regions, such as for mung beans in south Bangladesh. This crop, which is increasingly grown by small farmers, is very sensitive to heavy rainfall events at harvesting in the pre-monsoon period.

During the course of 2019, CSRD also collaborated with BMD developed a methodology to assess the occurrence of heavy rainfall events in Patuakhali, south Bangladesh, considering long-term statistical analysis, large-scale meteorological drivers and BMD weather forecasts. In addition, statistics about these events during the mung bean harvesting period were used to design and implement site-specific climate services for this crop considering rainfall monitoring and forecasting, and results from farmer-user surveys. BMD numerical forecasting data for the Patuakhali region were used to define extreme precipitation events in the context of mung bean cropping over this area. The threshold precipitation values and multiple short-term possible foreseen scenarios were defined to inform the implementation of an early warning system based on sending interactive voice response messages to farmers. More than 1,000 farmers received these messages in 2019, with >3,000 planned recipients farmers in 2020.

Figure 2.16 shows results obtained from the 2019 CSRD assessment of the performance of three satellite-derived daily precipitation products (CHIRPS, PERSIANN and TRMM) in terms of their representation of heavy rainfall events in Bangladesh.

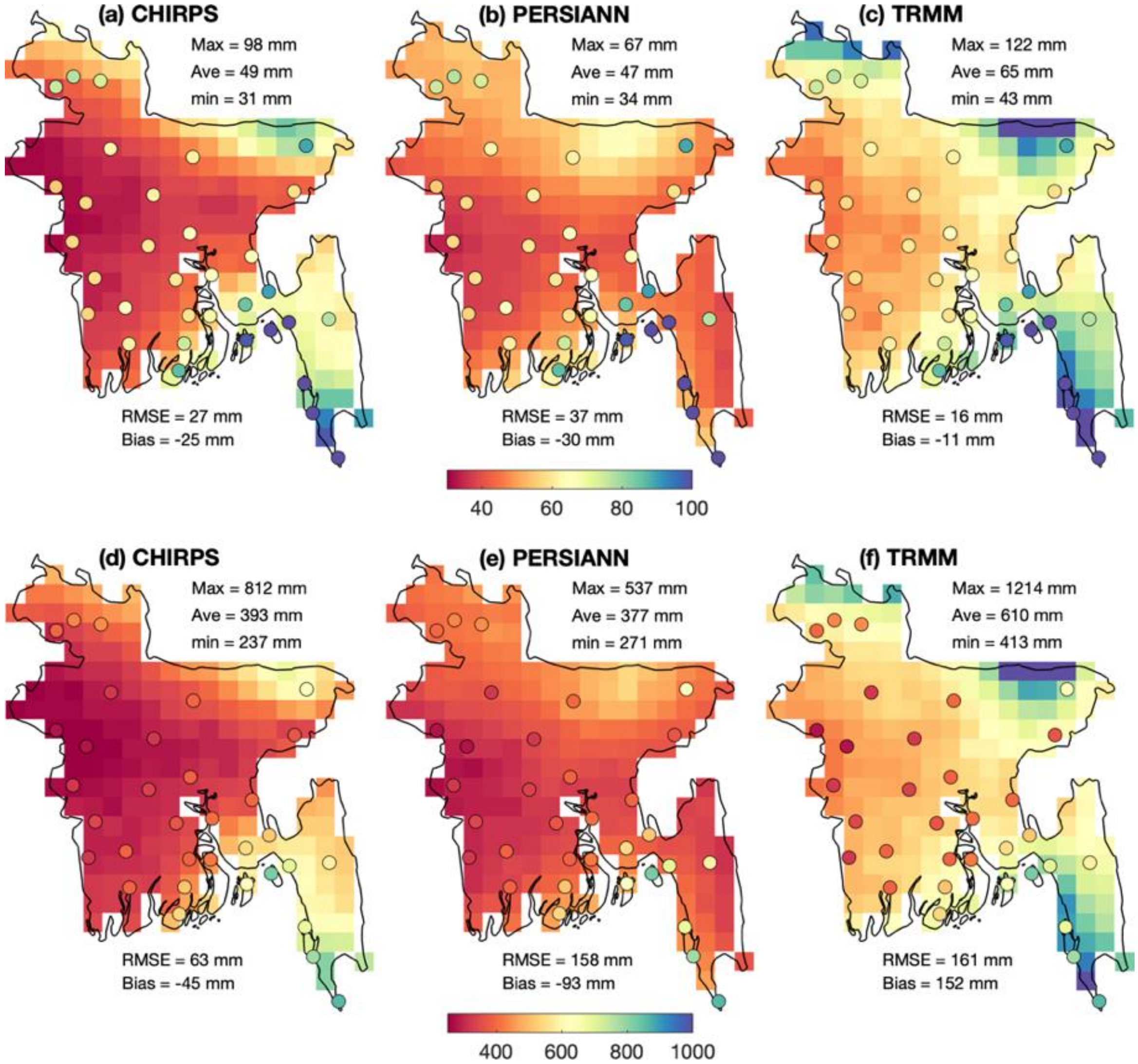


Figure 2.16: Rainfall amount (1999-2018) corresponding to the 95% during June-September, and accumulated precipitation for events above the percentile 95%.

The results presented below are an extension of the previous analyzes using weather station data. They show important differences in the accuracy of the products on capturing the magnitude of extreme precipitation events in relation to BMD stations, suggesting that this type of analysis is necessary when looking for the application of these products, even though they are widely used by weather services.

The heavy rainfall event mapping activities described above have direct applications for BMD and DAE. One is using satellite products to report the seasonal occurrence of extreme precipitation events by agricultural region. Moreover, further analysis can be done by merging gridded historical, high-resolution satellite data with rain gauge data. However, using these results to inform climate information services must be subject to the implementation and generation of new data and its correct translation and transfer to users. The results presented here are, however, preliminary and additional research probably to be carried out by BMD after the conclusion of the project.

In addition, the work conducted in 2019 indicates the potential of location-specific forecasting to inform climate information service-based solutions to problems associated with extreme precipitation events. However, its extension to and use in larger areas and periods of the year (e.g. other crops) may be difficult given the lack of high-resolution observation networks in Bangladesh. Previous CSRD work focused on analyzing these events using data from weather stations where magnitudes, occurrence and coherent regional patterns were identified. This information was useful to continue studies and applications in south Bangladesh for forecasting heavy rainfall events. However, the use of weather stations has limitations associated with their spatial coverage and data availability and quality. However, recently released high temporal and daily resolution, almost real time data, generated by international organizations such as the National Aeronautics and Space Administration (NASA) and the National Oceanic and Atmospheric Administration (NOAA), have great potential for monitoring extreme precipitation events and associated agricultural planning.

Sustainability and exit strategy of CSRD in South Asia

Code for the analytical products developed in Product 1 under Activity 1.2.1 of Sub-Objective 3.1 of CSRD have been provided to BMD to use in future climate analytical products and tools.

Product 2. The Agvisely climate services decision support and an advisory tool to avoid crop stress[10]

Background – BMD wants to improve the quality of its agro-meteorological forecasts. In 2017, it was envisaged that improved short-term and seasonal forecasts and the integration of the resulting information as crop-specific advisories would be deployed through CSRD partners. Other suggestions were made to improve BMD's weekly agro-meteorological bulletins. In response, CSRD began work with BMD and other partners, such as DAE, to develop improved, high spatial- and temporal-resolution forecasts and crop management advisories. The Agvisely.com climate services decision support and advisory tool to avoid crop stress responded to and achieves these objectives.

FGDs – In 2017, in the early months of the project, CSRD conducted focus group discussions with 68 farmers and 59 DAE sub-assistant agricultural officers (SAAOs) in Barisal, Bhola, Patuakhali, Rajshahi and Dinajpur Districts in Bangladesh. The coastal Barisal, Bhola, and Patuakhali Districts are climate-risk prone and experience more cyclonic activity in the pre- and post-monsoon seasons, while Rajshahi and Dinajpur are more drought-prone higher

[10] Note that this is a new product that resulted from CSRD's work that was not part of the original project work plan.

elevation regions. The FGDs elicited farmers' understanding of predominant climate and weather patterns, and their impact on agricultural decision making and crop productivity. Farmers' use of weather forecasts and their degree of trust in extended and seasonal forecasting were also explored, alongside preferences for how climate information can be graphically communicated to farmers. SAAO focus groups also examined the perceived use of extended range and seasonal forecasts for extension agents, while also exploring various media and methods for rapidly communicating climate information and advisories to farmers.

FGD results – The FGD results indicated that neither farmers nor SAAOs regularly used or had strong confidence in weather forecasts. Both groups pointed to lack of location-specific information as a barrier. Participants who had received forecast information said it was too geographically broad to be of use to their farm operations. The high degree of agronomic complexity and microclimates in Bangladesh were a common subject of discussion in the focus groups. However, the farmers and extension agents expressed an interest in high-intensity weather event forecasts such as of storms, heavy rainfall and hail that can damage crops. However, both groups had a generally poor understanding on the day-to-day effects on crop productivity of weather and less dramatic climatic events, such as high temperatures and cold. The farmer participants preferred 1–7 day forecasts and indicated that they had never heard of, nor were likely to trust longer-range forecasts. The SAAOs also preferred 1–7 day forecasts, but saw the value of seasonal forecasting so they could better assist farmers with pre-seasonal planning and crop selection. That said, both farmers and SAAOs may have had unrealistically high expectations of the accuracy of forecasts; both groups indicated that unless forecasts were at least regularly 80% accurate that the information was difficult to use for agricultural planning. Options for the graphical depiction of climate forecast information were also explored with farmers.

Response – CSRD has responded to the needs identified in the FGDs by developing an Agvisely, interactive, map-based agro-meteorological bulletin and an accompanying mobile phone app that provides numerical weather forecasting model predictions with easy-to-understand crop-specific management advisories. Crop productivity in Bangladesh is heavily influenced by the large variability in temperature and precipitation. Access to timely weather forecasts and crop management advisories would improve the resilience of Bangladesh's smallholder farmers to climate variability and extremes. But the data used to develop advisories must be scientifically valid and understandable and useful to farmers.

There are a range of temperatures within which plant growth is optimum at the different growth stages. When temperatures drop below or exceed the threshold then plant growth stops. The lowest temperature at which crop growth can occur is the minimum cardinal temperature while the maximum cardinal temperature is the temperature above which plant growth stops. Rice, wheat, maize, potato, pulses and other crops have optimum temperature ranges for their growth and development. This range varies by species and the phenology or growth, the developmental stages of crops and by cultivar. Crops growth is adversely affected when temperatures are too high or too low. Therefore, knowing the upper threshold and lower thresholds can be useful for advising farmers of ways to increase the resilience of their crops to climate extremes.

Scientists have developed complex crop growth models that relate precipitation and atmospheric, soil, and water temperatures to the growth rates of crop species and cultivars.

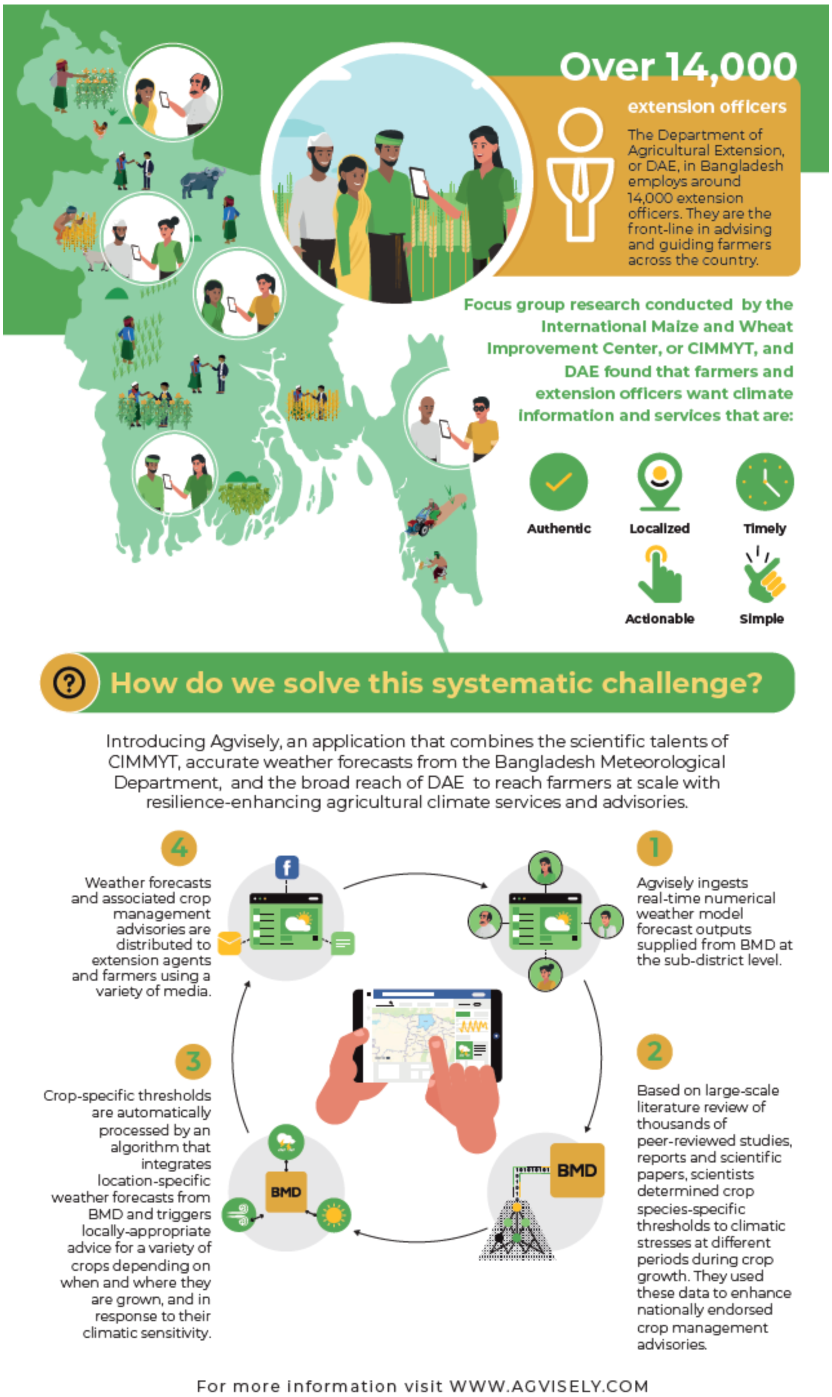


Figure 2.17: An infographic describing how Agvisely works. A short video on Agvisely can also be found here.

This understanding is useful for research, but less useful for developing useful and practical recommendations for farmers who grow a variety of crops across different locations that may be at different growth stages. In order to simplify and generalize advisories for very large groups of farmers – such as those in population-dense Bangladesh – the methods described below consider atmospheric thermal stress thresholds in reference to crop species but not particular varieties. CSRD has worked to provide rule of thumb recommendations for farmers on ways of overcoming thermal stress in their crops and to optimize irrigation while avoiding waterlogging.

Agvisely – CSRD led the development of the Agvisely automated climate service advisory system for Bangladesh's major field crops (Figure 2.17). The database of climate information service advisories for Bangladesh's major field crops, which is Agvisely's back-end, covers the different phenological stages of eight crops. Each stage has specific threshold temperature and rainfall values. Agvisely contains advisories for these stages that are to be triggered for different values of temperature and rainfall that may arise within the following five day periods (Figure 2.18).[11]

[11] The methodological procedures used in the development of Agvisely are given in Annex 7.

Photo 1.7: The Agvisely launch workshop at Farmgate, Dhaka, 24 November 2019

The system analyses Upazila level forecasts to assess whether or not extreme temperature and rainfall thresholds are likely to be exceeded or 'gone under' in the next five days, which triggers the sending out of advisories to application users on the web app, via SMS and email. The methodological approach behind Agvisely is given in Annex 7.

In this reporting period, Agvisely was officially adopted by BMD and DAE. It was subsequently launched at a workshop in Dhaka on 24 November 2019 and is now featured on BMD and DAE's websites, and is a widely-used tool to advice farmers on weather forecasts and responsive crop management advisories.

CSRD led development of Agvisely. The JavaScript framework React, Leaflet and other libraries were used for the front-end application, and the Java-based Spring framework for the back-end. The application is hosted on the Google Cloud Platform. Weekly meetings of CSRD staff with DAE and BMD were held to inform the development of the app. Several special sessions took place with sub-district level officers and SAAOs that helped make the application more user-friendly.

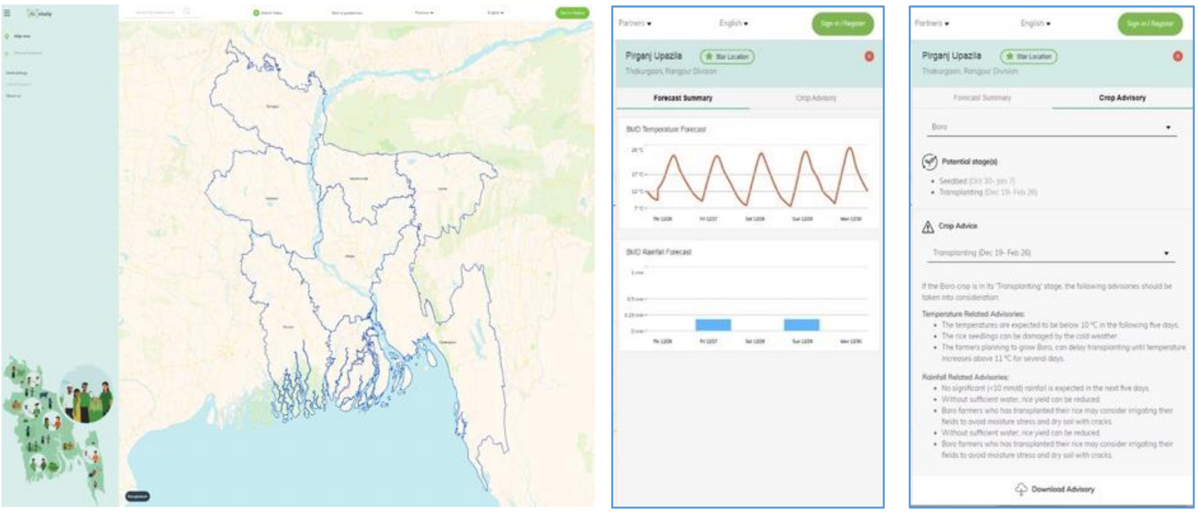


Figure 2.18: Screenshot of a of the interactive agricultural climate services app Agvisely that includes BMD sub-district forecasts and provides location-specific agronomic management advisories for smallholder rice, wheat, maize, lentils and potato farmers on avoiding damaging heat, cold, dry spells, and heavy rainfall events.

Agisely generates Upazila-wise (sub-district) specific advisories based on BMD weather forecasts. The advisories provide location-specific agronomic management advisories tailored to smallholder rice, wheat, maize, lentil and potato farmers on how to avoid crop-damaging extreme heat, cold, dry spells, and heavy rainfall events. SAAOs, who are the intended end users of this application, are then expected to pass this information on to farmers. Climate and weather specialists, experts on agriculture, and researchers are other potential users of the application.

Agvisely is open access. A link has been on the BMD and DAE websites and DAE's climate services portal, while links to these websites will be placed on the application for navigating back and forth.

Training – On 22 December 2019, ten CSRD staff were trained in Chaka as master trainers on the use and interpretation of the outputs of the Agvisely application. Before the end of 2019, DAE and CSRD subsequently trained 116 UAOs and AEOs from 58 sub-district agriculture offices on the use of Agvisely. DAE nominated one UAO and AEO from each sub-district . For the PICSA upazilas preference was given to officers involved in implementing PICSA. The trained UAOs and AEOs are due to train 20 SAAOs from their upazilas with 19 upazilas chosen for these trainings based on the intended users of these applications.

In total, over 1,000 front-line agricultural extension agents were trained (Table 2.2) and are now actively using Agvisely to guide their interactions and advice given to farmers throughout Bangladesh.

Table 2.2: Details of the completed Agvisely trainings

No.	Districts	Upazilas	Number of UAOs & AEOs trained	Number SAAOs trained in late December 2019 – early January 2020
1	Dinajpur	Birol, Dinajpur Sadar, Birganj	6	60
2	Thakurgaon	Thakurgaon Sadar, Baliadangi, Pirganj	6	60
3	Rangpur	Rangpur Sadar, Taraganj	4	40
4	Rajshahi	Durgapur, Charghat, Paba	6	60
5	Natore	Natore Sadar, Bagati Para, Lalpur	6	60
6	Pabna	Pabna Sadar, Ishurdi, Sujanagar Chatmohar	8	80
7	Faridpur	Faridpur Sadar, Madhukhali, Nagarkanda, Bhanga	8	80
8	Rajbari	Rajbari Sadar, Baliakand	4	40
9	Shariatpur	Shariatpur Sadar, Bhederganj, Goshairhat	6	60
10	Jashore	Jashore Sadar, Chaugachha, Jhikorgacha Avoynagar	8	80
11	Magura	Sreepur, Magura Sadar, Shalikha	6	60
12	Khulna	Batiaghata, Dumuria, Rupsa	6	60
13	Chuadanga	Chuadanga Sadar, Alamdanga, Damurhuda, Jiban Nagar	8	80
14	Meherpur	Meherpur Sadar, Gangni, Mujib Nagar	6	60
15	Jhenaidah	Jhenaidah Sada, Soilakupa, Kaliganj	6	60
16	Pirojpur	Mathbaria, Vandaria	4	40
17	Barishal	Gaurnadi, Babuganj, Wazirpur, Barisal Sadar	8	80
18	Bhola	Burhanuddin, Bhola Sadar	4	40
19	Patuakhali	Patuakhali Sadar, Kala Para, Dumki	6	60
Total	**19**	**58**	**116**	**1,160**

Each extension agent in Bangladesh is responsible for assisting between 2,000 and 5,000 farmers through networks of farmers' clubs. These clubs are now benefiting from climate information service advisories that are received daily by extension officers via email and SMS for their working areas.

Sustainability and exit strategy of CSRD in South Asia

The Agvisely system has been endorsed for official use by BMD and DAE, with trainings of government staff deployed in late 2020. BMD and DAE are expected to carry forward this product and scale-out its use in Bangladesh, although CIMMYT will continue to offer coaching and assistance through the USAID supported Cereal Systems Initiative for South Asia (CSISA) project.

Using historical data to determine heavy rainfall event damaging thresholds for mung bean and improving forecasts to provide emergency alerts so farmers can mitigate crop loss risks

Another important outcome of CSRD's work on extreme rainfall events in 2018 has been a complementary mini-project provided by Matt McDonald and the Embassy of the Kingdom of the Netherlands through the Blue Gold Innovation fund in Bangladesh in (2018-2020). Focusing on highly profitable but weather-risk prone mung bean production, the CIMMYT-led CSRD synergistic project developed farmer-friendly and demand-driven climate- and market-smart mung bean advisory dissemination systems. CSRD scientists provided in-kind support for this effort through CSRD, as it was aligned with the general objectives of CSRD and was suggested by BMD and DAE as a suitable outgrowth of CSRD's work. The Blue Gold Innovation project emphasizes activities with agricultural communities in polders in Patuakhali, although systems developed by the project can be applied to other crops and locations of relevance in coastal Bangladesh**.** Consortium partners include CIMMYT as the lead implementing agency, in addition to WUR, the DAE, and BMD, in addition to the Bangladesh Institute for ICTs in Development (BIID) private sector to assist in ICT development.

Photo 2.1: Farmers consider mung beans as an economically important crop in southern Bangladesh that also contributes to food and nutrition security, although extreme rainfall events threaten the crop and cause large losses in most years (CIMMYT)

Mung beans are an increasingly important crop in coastal Bangladesh. Farmers cultivate it between February and April as an opportunity crop that uses residual soil moisture to stimulate germination. Mung beans are however poorly adapted to high-rainfall environments, and farmers frequently lose their crop due to heavy rainfall events at harvesting time. Most importantly, harvesting is also prolonged for mung beans as the varieties grown in Bangladesh are not determinate, meaning that they flower for an extended period and set seed and pods over a period of several weeks. If heavy rainfall strikes in this period, pods can shatter and the crop can become waterlogged, resulting in considerable crop losses.

In response, CIMMYT has built on the climate services information developed through CSRD and worked with BMD and DAE to develop customized and location-specific heavy rainfall event forecasts five days in advance of the risk of occurrence. To achieve this goal, daily rainfall data provided by the BMD was used and the climatology of heavy rainfall events in Patuakhali performed for the period 1 March to 1 May. The days with rainfall higher than 1 mm where isolated and ranked to then apply a mathematical procedure to find the location where the fitted exponential curve 'turns' (the 'knee' point), as described above.

A daily threshold rainfall amount of 23 mm/day was identified and used to characterize heavy rainfall events (HREs), with a total of 181 events identified in 1981–2018. Using the new threshold, further research exploring how to predict heavy rainfall events was conducted and used to develop a system by which algorithms can be used to extract BMD's Weather Research and Forecasting Model (WRF) model outputs, examine them for heavy rainfall event risks, and print them as a text file that can be used by BIID to provide interactive voice response messages to farmers at risk of weather-induced mung bean losses.

Based on information generated from focus groups, farmers had indicated a strong preference for delivery of weather advisories related to mung bean through voice call or voice message. Accordingly, the project developed and implemented an interactive voice response (IVR) system that delivers custom rainfall risk and harvesting advisories to farmers in Patuakhali.

The system was piloted in the 2019 mung bean season. The IVR system was created by CIMMYT and BIID in consultation with DAE and BMD as an online platform that disseminates pre-recorded message combinations (170+ combinations professionally recorded in Bangla that are customized using an algorithm depending on location and forecasted rainfall severity). Between April – May of 2019 IVR messages were delivered to 1,373 farmers in three pilot locations in Patuakhali during the phenologically sensitive period at maturity and harvesting when mung beans are at risk of major damage. In addition to pushing call messages directly to farmers, they can also hear the IVR from their mobile phone from a free of cost call back number.

Major findings of the project's monitoring and evaluation of the 2019 mung bean season deployment of the IVR weather advisory alert service are as follows:

- The farmer respondents to telephone surveys grew mung beans a total of 51.67, or 31.16 to 164.66 ha in Betagi Sankipur and Choto Bighai unions in Patuakhali, and Gulishakhali union in Barguna districts.
- Farmers in project working areas who used IVR weather advisories to protect their mung beans from rainfall damage perceived they had saved 48–52% of their crops from damage and losses. This equates to 238–772 kg ha $_{-1}$ equivalent of mung bean yield, or USD 175–567 ha$_{-1}$ after accounting for partial costs.
- Actions taken by farmers to avoid rainfall-induced damage appear to have saved a total of 88–204 Mt of mung beans equating to a conservative estimate of USD 64,513–151,337, or

an average of USD 118,711.

Sustainability and exit strategy of CSRD in South Asia

A tailored business plan has been developed by CIMMYT and BIID. BIID as a private sector limited company plans to take forward the IVR system and offer it in 2020 to farmers on a limited fee-for-service basis. It is also exploring options for co-financing from major telephone service providers through their corporate responsibility schemes. BMD and CIMMYT will continue to transfer meteorological forecasts to BIID contingent on income generation for their company or co-support by telephone companies to sustain this service.

Product 3. Weather forecast based irrigation scheduling with PANI (Program for Advanced Numerical Irrigation)

The usually sparse winter rainfall in Bangladesh varies from year to year. Thus, farmers regularly irrigate not only their boro rice crops, but also their wheat and maize crops. BARI recommends that farmers irrigate:

- wheat crops three times a season: i) at crown root initiation 17-21 days after sowing (DAS); ii) at booting 45-50 DAS, and iii) at grain filling 70-75 DAS; and
- maize i) at the seedling stage 25-30 DAS, ii) vegetative stage 40-45 DAS, iii) silking 65-70 DAS and iv) at grain filling 95-100 DAS.

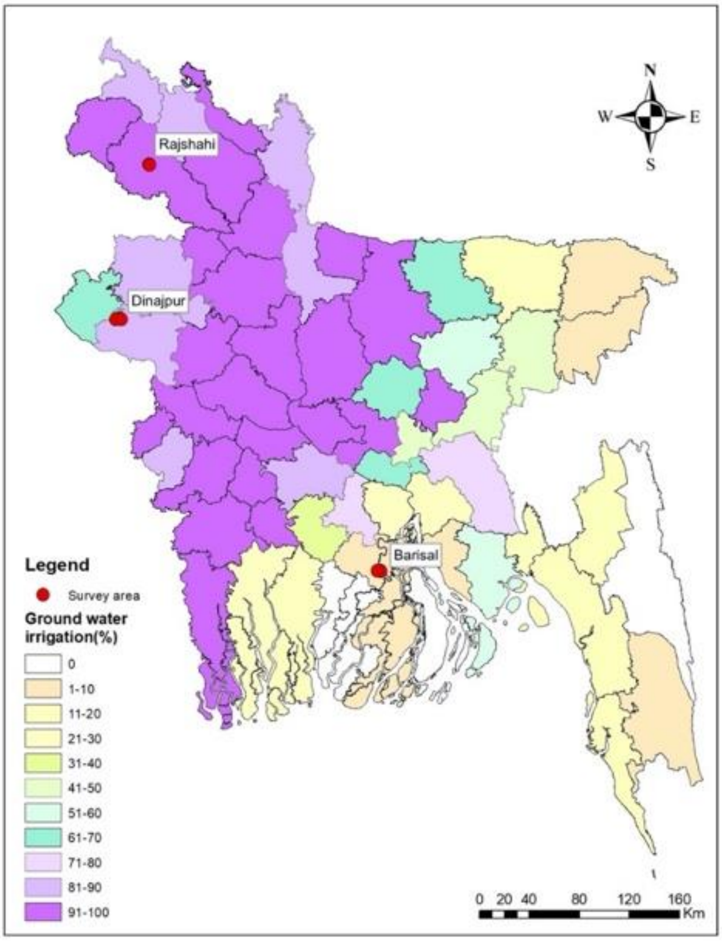


Figure 2.19: The locations of three PANI experimental sites and percentage of water used for irrigation derived from ground water.

Initial irrigation is optional for both crops. At each irrigation, the national crop management recommendations advise the application of water until soils are at field capacity. Especially in the south, the water table is close to the surface and can supply most crop water needs.[12]

[12] Schulthess, U., Ahmed, Z. U., Aravindakshan, S., Rokon, G. M., Kurishi, A. S. M. A., & Krupnik, T. J. (2019). Farming on the fringe: Shallow groundwater dynamics and irrigation scheduling for maize and wheat in Bangladesh's coastal delta. *Field Crops Research*, *239*, 135–148.

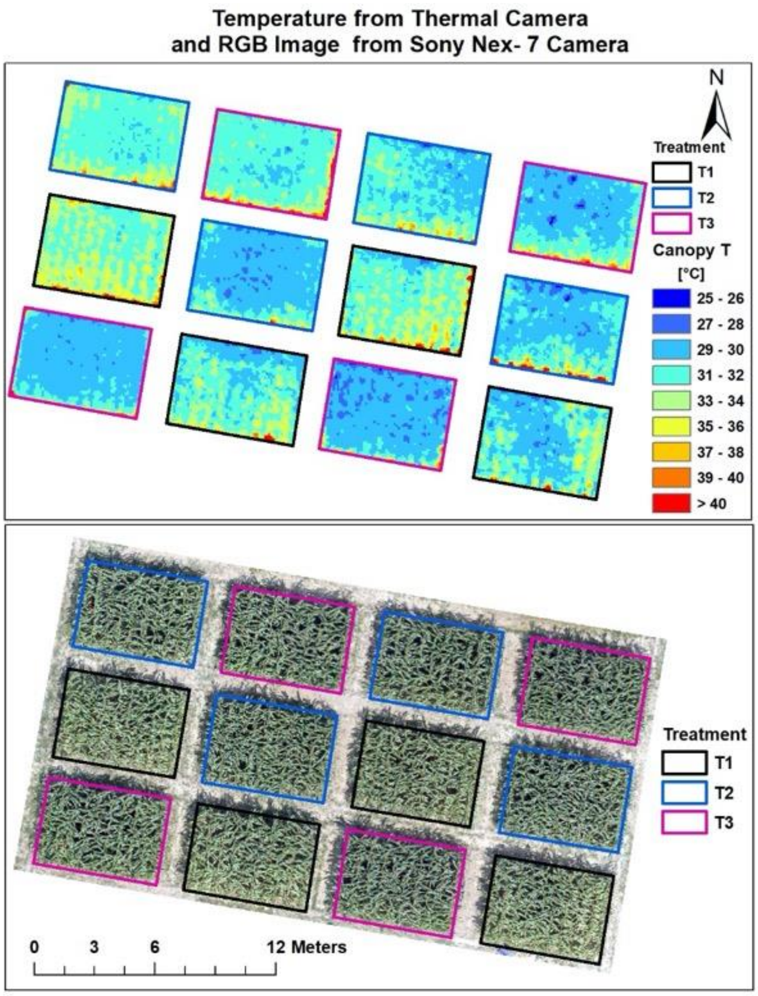


Figure 2.20: A 20 March 2019 aerial view of the PANI maize experiment planted in Dinajpur in winter 2018/19. Upper map shows the effect of the three irrigation treatments on the canopy temperatures of maize. The lower map is a red-green-blue (RGB) image of these plots

However, in the North West, especially in the Barind Tract, ground water levels are declining to more than 6m below the surface, which is the limit for operating suction pumps. The North-West is Bangladesh's main wheat production area, and it and the Jessore region in South-West Bangladesh are the main maize production areas. In both areas, irrigation predominantly uses ground water (Figure 2.19). Hence, the judicious management of irrigation is critical for the sustainable production of wheat and maize in Bangladesh and limiting the water footprint of these crops.

CSRD-run FGDs held at the start of the project showed that farmers perceive winter season rainfall to have become more erratic, dry periods longer and that rainfall intensity has increased. Hence, there is a need to generate more dynamic irrigation recommendations that take current and forecasted rainfall events into account.

In a previous Bill & Melinda Gates Foundation (BMGF) funded project, CIMMYT developed the irrigation scheduling app PANI for the southern Barisal division (Figure 2.20). The app estimates crop water use and the amount of plant-available soil moisture on a daily basis. It also calculates the capillary up-flow from the water table to the rooting zone. It takes into account actual and forecasted weather data and the ground cover of fields (percentage covered by green leaves seen from above) and previous irrigation applications. Weekly alerts are sent to farmers and irrigation service providers. PANI thus provides dynamic, field-specific irrigation advice.

To calibrate and validate PANI for Bangladesh's main wheat and maize production areas, in the 2018-2019 winter cropping season, the Bangladesh Agricultural Research Institute (BARI) conducted experiments for CSRD in Barisal, Rajshahi and Dinajpur on the three irrigation options of 1) dry treatment; 2) BARI recommendation and 3) PANI recommendations. The dry treatment tested whether PANI can also simulate low (dry) soil water conditions. The effects of the treatments are shown in Figure 2.20. The images, which were acquired by drone, showed that canopy temperatures were generally higher for the dry treatment (T1) than the well-irrigated ones.

The initial idea was to install PANI on a server at BMD to enable the training of BMD staff on maintaining PANI. However, frequent power failures and disruptions to internet services meant the server at BMD was unstable and unreliable hindering the validation of the PANI recommendations in real time. In trials conducted in the 2017/18 season, no differences in yield between the BARI and the dry (partially irrigated) treatments were observed for either crop. Sufficient rainfall in Barisal and Rajshahi, and proximity of the ground water level in all locations were responsible for this. CSRD thus shifted the experimental sites to new locations in the second year where water tables were lower. This resulted in significantly lower yields for the dry wheat treatment at all locations, whereas for maize, the dry treatments were also lower, although not significantly so.

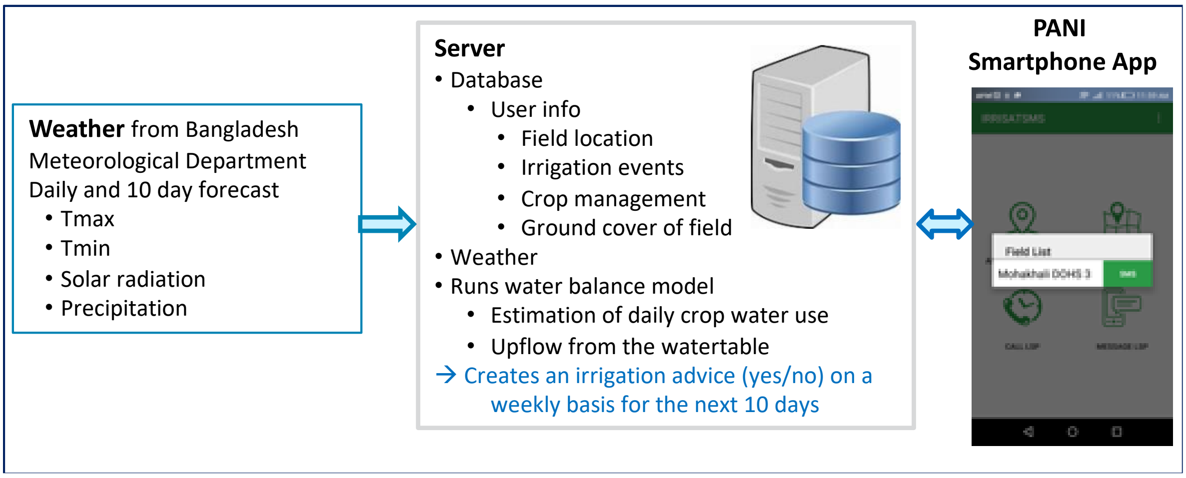


Figure 2.21: Main components of PANI irrigation scheduling advisory system: Server with database that runs a soil water balance model using weather data, crop management info and vegetation status measured by farmers by taking RGB photos with a smartphone app

Sustainability and exit strategy of CSRD in South Asia

As discussed above, CSRD now has solid data to validate PANI for Bangladesh's major maize and wheat production regions, a procedure that remains ongoing beyond the completion of the project. CSRD is preparing papers on the calibration and validation of PANI and analysis of the extent to which winter rainfall has changed in North and South-Western Bangladesh – Bangladesh's main wheat and maize growing areas. Significant rains in the 2017/18 and 2018/19 winter seasons resulted in almost similar yields for the dry and well-irrigated treatments. However, in years with drier winters, significant yield losses may well occur if crops are insufficiently irrigated. Scientists involved in CSRD are therefore still working to quantify the need for irrigation across years. The methodology being developed will serve as a blue print for similar studies in other regions where rainfall patterns are changing due to global warming, although it is unlikely that PANI will be advanced to the extension phase within Bangladesh beyond its use as a tool for researchers.

Product 3. Spatially explicit and meteorologically driven wheat blast (Magnaporthe oryzae Triticum) disease risk assessments for Bangladesh

Wheat blast is a devastating fungal disease that threatens food safety and security in the Americas and South Asia. First identified in Brazil in 1984, the disease is widespread in South American wheat fields, where it affected as much as 3 million hectares in the early 1990s. In 2016, it crossed the Atlantic Ocean, and Bangladesh suffered a severe outbreak. Crop diseases can often be predicted by a combination of environmental and climactic data, most notably by temperature regimes, precipitation, and relative humidity, all of which affect fungal spore development, release and infection. Starting in 2017, CSRD established a collaboration with scientists at the University of Passo Fundo (UPF) and EMBRAPA in Brazil, who developed a preliminary wheat blast predictive model driven by weather data. Plans were put in place to adapt the model to Bangladesh and test it at a large scale. CSRD released the validated model for use by DAE to advise farmers how to better and pro-actively manage the disease on December 5th, 2019.

As part of this collaboration, Professor Mauricio Fernandes and Felipe de Vargas from UPF visited Jashore, Bangladesh from 21 February to 5 March 2019. They delivered a lecture to the Bangladesh Wheat and Maize Research Institute (BWMRI) at a wheat blast training in Jashore, interacted with scientists and overviewed the progress of spore trapping and processing efforts and blast lesion microscopy. The training disseminated the basic techniques of identifying and culturing pathogens and field inoculation and disease scoring, and enabled the participants to share their experiences on combating the disease. Thirty five wheat scientists from China, India and Nepal as well as from BWMRI, DAE and CIMMYT in Bangladesh participated in the training. They made field visits to Meherpur to meet wheat farmers and survey for wheat blast.

During their stay in Bangladesh, the UPF scientists worked with the CSRD focal persons at BMD from 25-27 February 2019 to incorporate BMD generated WRF forecasts into the CSRD-developed wheat blast early warning system. In this regard Mr. Qamrul and or Bazlur Rashid from BMD worked with the visitors and have successfully incorporated the WRF forecasts into the early warning system. In addition, this early warning system has had benefits outside South Asia as the collaborating scientists have developed the same forecasting system for disease in Brazil.

Photo 2.2: Left to right: Prof. Mauricio Fernandes (UPF and EMBRAPA), Mr. Shamsuddin Ahmed, Director of BMD, Dr. Wais Kabir, Director of Krishi Gobeshona Foundation, and Dr. Israil Hossain, Director of BWMRI officially recognize and endorse use of the CSRD supported and meteorological forecast-driven early warning system for wheat blast in Dhaka on 5 December 2019.

During 2019, work continued to improve the wheat blast early warning system. The CSRD team collaborated remotely with the Brazilian scientists. Finally, in December 2019 Professor

Fernandes returned to Dhaka. A validation workshop was held on 5 December 2019 at the Bangladesh Agricultural Research Council. The system was officially accepted and adopted for use at the meeting by BWMRI, DAE, and BMD following intensive discussions on how the system and associated wheat blast advisories can be deployed to extension officers by email or SMS.

Sustainability and exit strategy of CSRD in South Asia

As described above, the wheat blast early warning system – which can be found at www.beattheblastews.net, has been formally endorsed by the key Ministry of Agriculture line agencies responsible for its endorsement. Once CSRD ended on 31 December 2019, the USAID supported CSISA project took on the responsibility of training master trainers within DAE to understand how to use and cascade-train field extension agents on the use of the wheat blast advisories provided by the early warning system. By February 2020, over 800 DAE field officer extension staff had been trained on use of the system and began receiving alerts by email 5 days in advance if their designated working areas were predicted to be at risk of a wheat blast outbreak.

Each extension officer in Bangladesh is responsible for between 2,000–5,000 farmers. This underscores the potential to reach farmers with relevant climate information services in the form of wheat blast disease outbreak warnings and advisories now that the government has endorsed use of the early warning system. This is one of CSRD's greatest successes. The impact of this work is expected to be long-lasting with CSISA contributing to the maintenance of the system and continued trainings planned for late 2020 (when the next wheat season begins) to enroll another 4,000 extension officers and lead farmers in the system and receive automatic advisories by email and/or SMS.

Contribution of Activity 1.3.1 to CSRD's Action and Learning Framework:

Pillar 2, Indicators 2.2 and 2.3, Pillar 3, Indicator 3.1 and Pillar 4, Indicator 4.1 (see Annex 3).

Activity 1.3.2: Agro-meteorological forecast service applications and systems for crops, fisheries and/or livestock developed and refined for medium term decision making co-developed and refined

Background – Activity 1.3.2 provided research and technical inputs for topics identified by USAID as important for climate services development in Bangladesh following its 2016 consultation with BMD and the Bangladesh Ministry of the Environment, Forest and Climate Change. Improvements to the analysis of historical climate data and short term and sub-seasonal forecasts are at the heart of these activities, the results of which are being included in BMD's agro-meteorological products and will be of use to DAE activities in the complementary World Bank funded Agro-Meteorological Systems Development project. See the below write-up on Sub-Objective 3.1 (coordination with Bangladesh partners) for further details on this collaboration.

Product 1. Improved seasonal forecasts and climatic stress maps developed and refined

Dr. Simon Mason of IRI visited Bangladesh from 14–19 April 2019 to follow up on the recommendations generated from the climate services assessment. During this period, he worked with BMD staff to complete the following tasks to improve the monthly and three-monthly forecasts using the Climate Predictability Tool (CPT) tool:

- Generating automated forecasts from customized scripts for the coming month and the coming three-month season using the previous month's observed sea-surface temperatures (SST).
- Generating automated forecasts for the coming month and the coming three-month season using the current month's National Multi-Model Ensemble (NMME) outputs.
- Generating automated forecasts for the coming target season using the previous month's observed sea-surface temperatures.
- Generating automated forecasts for the coming target season using the current month's NMME outputs.

The scripts were installed using a default configuration (i.e., SST and NMME predictor domains, NMME model combinations, etc.). Training was provided on how to customize these settings to optimize the forecast skill for each month forecasted. At the end of the CSRD project, BMD was in the process of regularly generating these outputs and discussing the results with IRI scientists affiliated with CSRD. When sufficient confidence is gained, BMD will be poised to implement CPT-based monthly and 3-monthy forecasts, and to report them as part of their ongoing weather services systems. CIMMYT staff are also working with BMD to identify ways that these approaches can be used in agricultural advisory services.

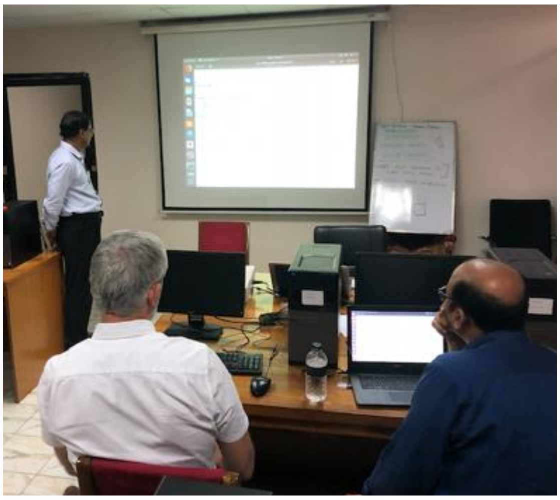


Photo 2.3: IRI and BMD scientists working in April 2019 in Dhaka to improve the code generating 1 and 3 month forecasts using IRI's Climate Predictability Tool.

Sustainability and exit strategy of CSRD in South Asia

BMD is now regularly running the scripts developed with IRI's support to CSRD. Monthly and three-monthly precipitation forecasts are now shown on BMD's website, indicating that this activity will be sustained after CSRD ends. Links for the monthly and seasonal precipitation forecasts can be found here and here. However, these products have yet to be validated and confirmation research is needed to match the forecasts with observed data. Nonetheless, the forecasts can be of considerable use.

Now the CSRD project has ended, the CSISA project is working with BMD to interpret the sub-seasonal and seasonal forecasts and guide DAE how this information can be used to advise farmers. At the time of writing, CSISA is in discussions with BMD and DAE on how the seasonal forecasts can be ingested into the Agvisely online climate information system for agriculture such that it can be used for guiding farmers on pre-season crop varietal choice and species.

Contribution of Activity 1.3.2 to CSRD's Action and Learning Framework:

Pillar 2, Indicators 2.2 and 2.3, Pillar 3, Indicator 3.1 and Pillar 4, Indicator 4.1 (see Annex 3).

Objective 2: Collaborative development and refinement of South Asian regional-scale agro-climate decision support tools, services, and products

Sub–Objective 2.1: Support to facilitate the development and refinement of regional decision support decision support tools, services and products

Activity 2.1.1: Coordination support for the International Centre for Integrated Mountain Development (ICIMOD) and partners on drought forecasting

Background – CIMMYT led the CSRD partnership in South Asia in coordination with an array of national and international partner organizations including the International Center for Mountain Research and Development (ICIMOD). Activity 2.1.1 added value to work already conducted by ICIMOD to add three research locations in Bangladesh to its regional efforts on drought monitoring under the SERVIR Hindu Kush Himalayan (HKH) project, and to support Asia region capacity development efforts on the use of earth observation data for monitoring drought.

Product 1. Ongoing support for ICIMOD and partners

The sub-seasonal to seasonal South Asia Land Data Assimilation System

Recent improvements in sub-seasonal to seasonal (S2S) meteorological forecasts and the growing power of earth observations are being used to initialize forecasts for the more accurate monitoring of hydrological states. With additional support from CSRD, a sub-seasonal to seasonal land data assimilation system (S2S-LDAS) was developed collaboratively with the NASA SERVIR program and end-users across Asia. This system applies advanced land surface modeling to optimize initial conditions, performed with the Noah-MultiParamiterization (NoahMP) model in the NASA Land Information System, using downscaled meteorological fields from the Global Data Assimilation System (GDAS) and Climate Hazards Group Infrared Precipitation (CHIRP) products. The NASA Goddard Earth Observing System Model's sub-seasonal to season (GEOS5-S2S) forecasts, downscaled using the NCAR General Analog Regression Downscaling (GARD) tool and quantile mapping, are then applied to drive hydrological forecasts to 6 month time horizons. The system is evaluated by comparing results with in-situ and satellite observations of water fluxes. The S2S-LDAS runs at ICIMOD to support drought monitoring and warnings.

In May 2019, the first S2S-LDAS seasonal drought forecast was produced for the 2019 monsoon and the results shared with meteorology and agriculture institutions including the Promoting Climate Resilient Agriculture (PPCR) in Nepal program's agriculture advisory team. Figure 3.1 shows the results of the seasonal outlook produced at the starting condition for the three monthly period of June-July-August and its comparison with observed conditions at the end of the season by Nepal's Department of Hydrology and Meteorology. The adequate match between predicted and observed conditions has helped win the confidence of users. Resulting seasonal outputs from this work can be found at http://tethys.icimod.org/apps/sldasdataforecast/.

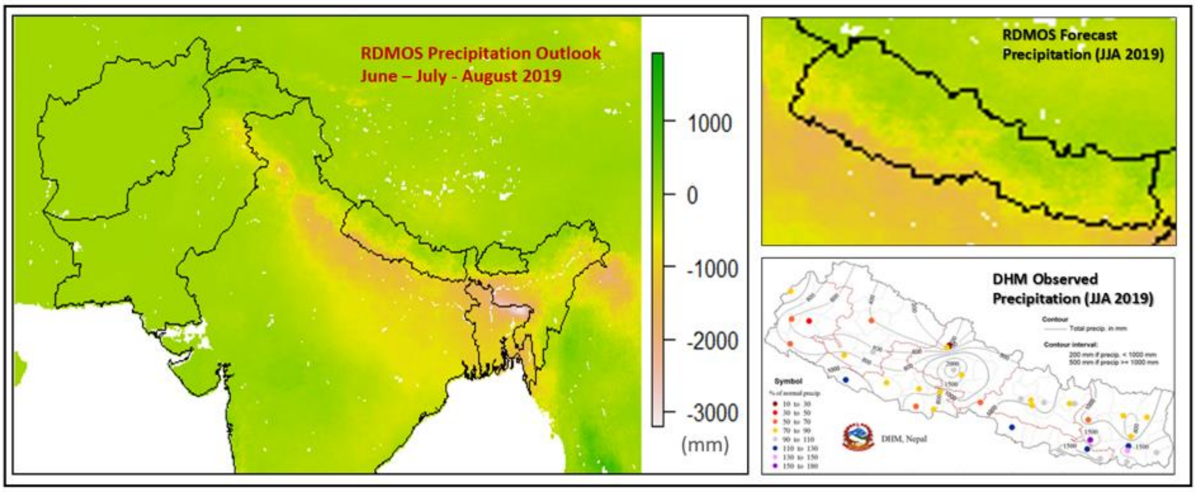


Figure 3.1: Regional seasonal outlook based on the condition in April 2019 produced on 7 May 2019 and its comparison with observed data in Nepal

Agricultural drought watch for South Asia: Data exploration and information portal launched

RDMOS – The Regional Drought Monitoring and Outlook System (RDMOS) application was launched on 29 July 2019 at a four day workshop to train agriculture and meteorology professionals on its use for monitoring and assessing drought in Islamabad, Pakistan.

Photo 2.4: An orientation workshop on Regional Drought Monitoring and Outlook System held in 2019 in Islamabad, Pakistan demonstrated the functions of the system and gathered feedback on its usability (ICIMOD)

Officials from SAARC member states attended the inauguration workshop, which was organized by the SAARC Agriculture Centre, ICIMOD, the Pakistan Agriculture Research Council (PARC), and the Pakistan Meteorological Department (PMD). The training was based on a comprehensive resource book produced by the SAARC Agriculture Centre, CIMMYT and ICIMOD. It was attended by 10 participants from Afghanistan, Bangladesh, Maldives, Nepal, Sri Lanka, and 25 participants from Pakistani agriculture and meteorology institutions.

Agricultural Drought Watch – As part of the support provided by CSRD to ICIMOD under Objective 2, work was undertaken to assist in two major components of the National Agriculture Drought Watch to develop real-time condition monitoring and seasonal assessments that are fully functional. Graphical representations of the web-based portals for the National Agriculture Drought Watch in Bangladesh are shown in Figure 3.2 and 3.3. The current conditions view is simplified to show real time conditions where administrative units can be selected to visualize maps and graphs related to rainfall, evapotranspiration, soil moisture and temperature.

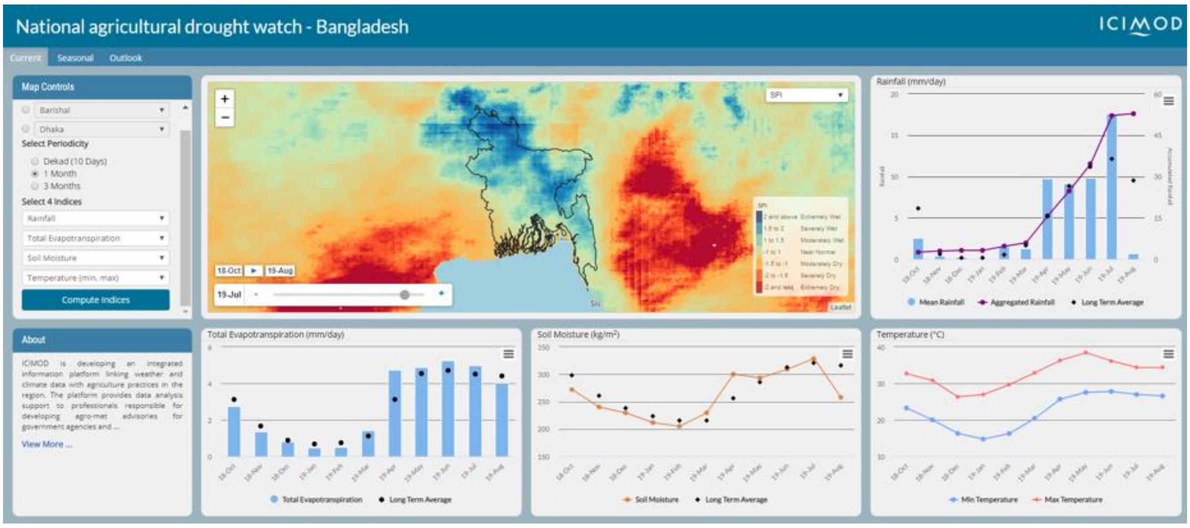


Figure 3.2: Conditions interface of the National Agriculture Drought Watch

The seasonal assessment window displays seasonally aggregated assessments where users chose the administrative boundary, time of assessment and periodicity according to the crop calendar. The bar graph represents aggregated assessment in terms of percentage of area under conditions between -2% to +2% based on standard anomaly calculations of rainfall, soil moisture, evapotranspiration and temperature.

All the calculations are limited to relevant agricultural areas to have specific assessments that are within major croplands of relevance. The percent of normal graph conversely represents conditions aggregated for entire selected administrative areas.

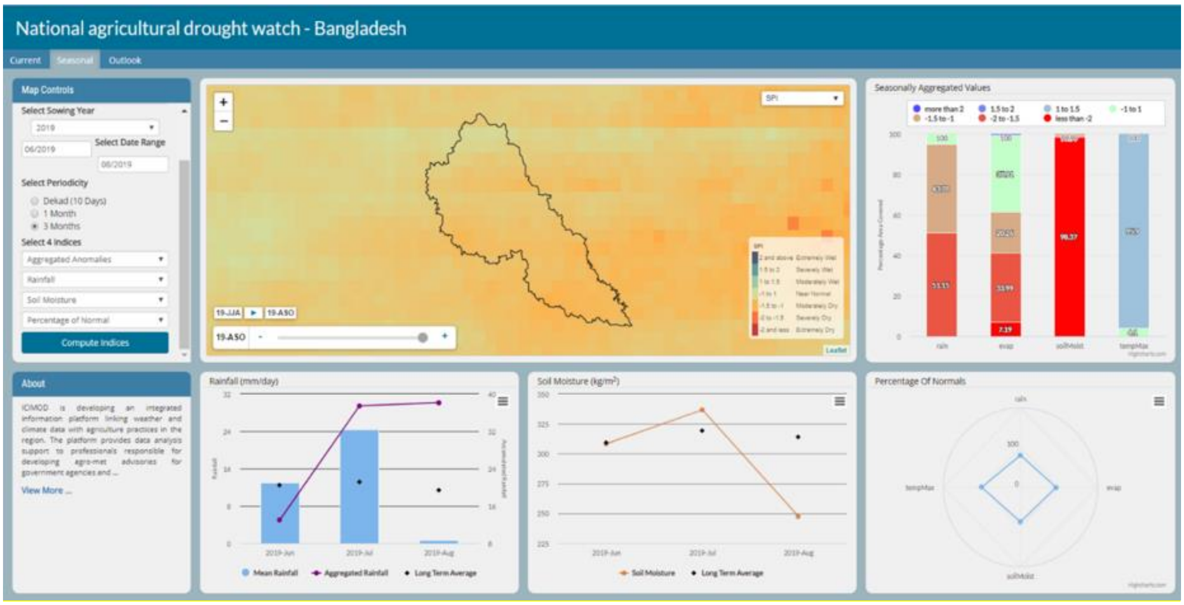


Figure 3.3: Seasonal assessment interface of the National Drought Watch, Bangladesh

Analysis of precipitation patterns to improve drought forecasting

South Asia is prone to drought:

- In Afghanistan, droughts caused estimated losses of 85% of rice and maize, 75% of wheat, 50% of potato and 60% of overall farm production between 1998 and 2005. Projected even drier conditions will cause yields to decline further for farmers who rely on rain-fed agriculture.
- The rainfall pattern in Pakistan varies across the country's long latitudinal extent with drought causing large crop losses.
- Droughts in Nepal cause losses of major crops, especially rice and potatoes.
- Bangladesh suffers crop losses due to droughts.

Drought mitigation measures need to be informed by long-term forecasting.

South Asia is characterized by considerable spatial and temporal variability in rainfall. Drought advisories therefore require a dense rain gauge network to capture precise precipitation information. However, there are too few ground monitoring stations in South Asia and the existing ones are unevenly distributed. This makes water resources assessment and drought prediction difficult, especially in mountainous regions such as the Himalayas, which has a limited rain gauge network.

Satellite based quantitative precipitation estimates are an attractive option for providing precipitation information for data scarce regions. Products include the long-term Climate Hazard Group InfraRed Precipitation Satellite (CHIRP/S), which provides rainfall estimates to enable the development of drought monitoring and early warning applications in data sparse regions. However, CHIRP/S data have some uncertainty, which can affect the accuracy of drought predictions.

In 2017 and continuing through to the end of 2019, CSRD in collaboration with ICIMOD began work to evaluate the spatiotemporal pattern of the long-term CHIRP/S across the eight major climate divisions of South Asia. This study compared monthly precipitation estimates from CHIRP, CHIRPS and APHRODITE with 130 rain gauges representing eight key climate divisions of Bangladesh, Nepal and Pakistan. Gridded observations using several statistical metrics between 1981 and 2012 were also utilized. The results showed:

- Climate Hazards Group datasets exhibiting better accuracy in warm seasons than winters (also due to CHIRPS's limited ability to detect frozen precipitation) with accuracy reducing along the elevational gradients and from wet to dry climate zones; and
- CHIRPS exhibiting better performance for areas that experience large amounts of precipitation as compared to arid and semi-arid areas.

Assembling the Land Data Assimilation System

NASA LIS – The NASA Land Information System (NASA LIS) is a widely used, open source land surface modeling and data assimilation infrastructure developed by the Hydrological Sciences Lab at NASA's Goddard Space Flight Center (GSFC). NASA LIS is intended to provide flexible high-resolution land surface modeling at the same spatial and temporal scales of remote sensing measurements.

LDAS – The Land Data Assimilation System (LDAS) is an instance of the Land Information System (LIS) land surface modeling software that has been configured for specific domains and purpose. LDAS merges observations with numerical models to estimate land surface states and fluxes. The guiding principle is that models and observations – including satellite observations and ground-based observations, provide valuable information for hydrology and water resource analysis. But each has significant limitations as models suffer from errors due to limitations in model structure, imperfect input datasets, and parameter uncertainty, while observational datasets are generally incomplete in space or time, capture only select aspects of the hydrologic cycle, have limited predictive potential, and are subject to their own measurement errors. Acknowledging the limitations while recognizing the tremendous information content in these observation systems and advanced land surface models, the LDAS merges models with observation datasets using statistical algorithms that weight inputs according to their relative uncertainty. In practice, this means that the LDAS uses the best available input data, including information on meteorology and landscape (e.g., soils, topography, land cover, etc.), applies these inputs to drive an ensemble of land surface model simulations, and then periodically applies update observations of modeled variables (e.g., soil moisture, snow cover) to nudge the model towards observed conditions.

South Asia LDAS – The South Asia Land Data Assimilation System (South Asia LDAS) is a collaborative modelling initiative that was supported by CSRD in 2019 and is representative of these efforts. It consists of a suite of advanced land surface models implemented at a 5 km horizontal resolution for fully distributed hydrological simulations across all South Asia. The system, which is built on the NASA LIS software platform, merges models with satellite data as remotely sensed observations are applied as meteorological forcing data (e.g., satellite-derived precipitation estimates), land surface parameters (e.g., land cover and vegetation fraction), and, in some instances, update observations in hydrological data assimilation (e.g., satellite-derived snow cover observations). SALDAS employs the Noah-MP land surface model at a 5 km resolution, with input meteorology from MERRA-2, GDAS, and Climate Hazards Group InfraRed Precipitation estimates (CHIRP) in monitoring mode as well as from downscaled Goddard Earth Observing System model (GEOS5v2) surface fields in forecast mode. SALDAS also includes the simulation of irrigation and groundwater withdrawal, including some data assimilation capabilities (Figure 3.4).

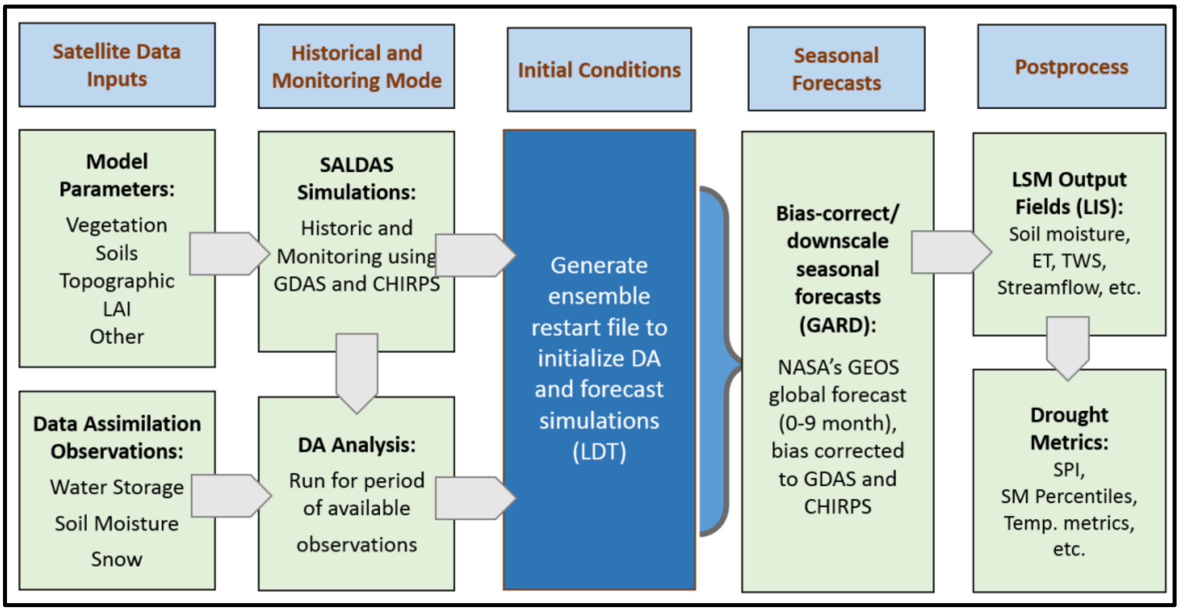


Figure 3.4: Elements and processes of the SALDAS system for producing drought data products

Sustainability and exit strategy of CSRD in South Asia

RDMOS was successfully deployed and tested in the second quarter of 2019. The first forecast was produced for the 2019 monsoon season with promising results that should promote the system's adoption. A comprehensive resource book on RDMOS was produced in July 2019 with CSRD authors. The book gives the theoretical background of RDMOS's drought monitoring and forecasting approach and practical examples from Afghanistan, Bangladesh, Nepal and Pakistan. Regional, national and on-the-job trainings were conducted in the third quarter of 2019 in Islamabad on drought monitoring and related monitoring approaches. In addition to assisting with the trainings held with CSRD support in Pakistan, the RDMOS resource book provides a guide for the trainings planned for 2020 and 2021 throughout South Asia.

Even with knowledge of agro-meteorology, agriculturalists often find it difficult to interpret complex climate and weather information. The National Agriculture Drought Watch application was developed under CSRD in consultation with users to facilitate such data analysis in a user-friendly format. The convenience of this system promotes its adoption for practical decision making. An orientation workshop on the app was held in the fourth quarter of 2019.

In 2020, the SERVIR HKH Programme will continue to facilitate the expanded use of the RMDOS and National Agriculture Drought Watch applications. The following activities are foreseen to build on the CSRD work:

- The deployment of the system at BARC and linking it to DAE's website
- Continuing end user-engagement to ensure use of the service in advisories

- The probabilistic visualization of ensemble forecasts in the RDMOS.

Contribution of Activity 2.1.1 to CSRD's Action and Learning Framework:

Pillar 1, Indicator 1.1, Pillar 2, Indicator 2.2, and Pillar 4, Indicator 4.1 (see Annex 3).

Activity 2.1.2. Regional learning platform for climactically refined decision support tools to support integrated disease management in lentils in smallholder farming systems

Background – The productivity of lentils (*Lens culinaris*) in South Asia is severely affected by diseases, many of which are related to prevailing weather conditions. Stemphylium blight, which is caused by *Stemphylium botryosum*, is a threat to lentil production and the livelihoods of many smallholder farmers in Bangladesh, India and Nepal. Lentils are a popular legume that are cooked as dhal that is typically eaten with rice and is an important part of nutrition-sensitive farming systems in South Asia.

Cloudiness, temperature, precipitation and relative humidity directly influence the incidence and severity of Stemphylium blight in lentils. However, the actual conditions that cause Stemphylium blight vary considerably between locations within growing seasons and between seasons within a location. This makes it challenging to develop climate services to support integrated disease management for lentils. While applying foliar fungicides can control the disease, uncertain weather forecasts challenge the rational application of fungicide. The application of too much fungicide negatively affects farmers' profits and has negative environmental consequences.

Since late 2017, CSRD has supported the development of a Stempedia disease forecasting model in response to the above issues. CSRD has supported the field testing and calibration of the model to forecast the regional and seasonal incidence of the disease in South Asia. Additional assistance was provided by the Cereal Systems Initiative for South Asia (CSISA) project supported by USAID/Washington in the 2018/19 lentil growing season. The goal of this work was to use weather forecasts to drive emergency warning systems to inform farmers when to effectively and efficiently apply foliar fungicide against the disease.

Product 1. Stempedia: Lentil Stemphylium blight disease forecasting systems in Bangladesh, Nepal, and India[13]

The Stempedia forecasting model has great potential as a weather-driven tool for forecasting the occurrence of *Stemphylium* blight. Large-scale field surveys were conducted in Bangladesh, India and Nepal during the 2017/18 and 2018/19 growing seasons of the incidence and severity of the disease. The 2017/18 data were used to calibrate the model while the 2018/19 data were used to validate it.

Field data collection – In both years, data on Stemphylium blight and other lentil diseases were collected from 480 farmers' lentil fields across:

- 32 fields in each of 5 sites (Jashore, Faridpur, Magura, Meherpur and Rajbari) in

[13] Note that this work stream replaced the 'Precision Nutrient Management' work stream in CSRD in South Asia's original scope of work. The change was agreed with USAID in quarter 3 of 2017 because of the potential for rapid model validation and impact in the context of integrated disease management across Nepal, India, and Bangladesh.

Bangladesh;

- 32 fields in each of 5 sites (Barh, Barhaiya, Masaurhi, Mokama and Paliganj) in Bihar, India; and
- 40 fields each in each of 4 sites (Banke, Bardiya, Kanchanpur and Kailali) in Nepal.

In 2017, CSRD developed a protocol and trained data collection personnel. In addition to scoring the occurrence of the disease three times per season, the surveys recorded phenology and other crop management practices, measured yields in each field and carried out household surveys to investigate crop management practices. While the field investigations in 2018/19 started smoothly, heavy rains in Nepal in the late growing season destroyed about 10% and partially destroyed another 10% of the sample lentil fields. Data collection was therefore completed in Nepal in only 120 of the planned 160 fields. In India, local scientists struggled to identify the symptom and confirm Stemphylium blight disease. The field work in Bangladesh went smoothly.

Photo 2.5: *Stemphylium* disease survey enumerators for 2018/19 in Nepal after returning from hands-on field training, 20 November 2018 (Sagar Kafle)

Weather data for calibration and validation – During the 2018/19 season CSRD calibrated the Stempedia model using the 2017/18 field data. Data on the maximum temperature, sunshine hours and relative humidity are needed to run the model. However, weather station observational data were not available for all 14 disease monitoring sites and 480 monitoring fields. In addition, the meteorological observation stations did not consistently collect data on sunshine hours, which is a crucial variable for weather-driven disease modelling. Delays in accessing and only accessing incomplete weather data hampered the calibration of the model.

The project could only access precisely measured weather data from a portion of field locations – at Jashore and Faridpur in Bangladesh from BMD and at Kailali and Banke in Nepal from Nepal's Meteorological Forecasting Division. CSRD also had one automated weather station installed in Meherpur in Bangladesh in 2017/18, which provided temperature, relative humidity and solar radiation, but not sunshine hours.

In response to the limited data availability, CSRD's scientists used algorithms from the literature to test the workability of the conversion between solar radiation and sunshine hours. As presented in CSRD's semi-annual report for January–June 2019, historical data was extracted from the same dataset for the Jashore site for solar radiation and sunshine hours data. The comparison showed a good match between the measured and converted sunshine hours (comparison period mean 6.71 versus 6.74, standard deviation 2.02 versus 2.26, R2 = 0.97). CSRD therefore used this algorithm to convert solar radiation into sunshine hours at Meherpur and applied similar procedures to other locations where missing variables challenged analysis. In the end data from the five sites of Jashore, Faridpur and Meherpur in Bangladesh and Banke and Kailali in Nepal were used to calibrate the model.

Calibration – The calibration of the model considered all its six parameters:

- potential disease establishment window (DEW)
- maximum lower daily temperature threshold for spore release
- maximum upper daily temperature threshold for spore release
- number of days a week of susceptible window for infection (PSW)
- threshold for relative humidity above which infection takes place (RH threshold)
- threshold daily sunshine hours below which it is favorable for spore release (SSH threshold).

During the second half of 2019, the model was run using the weather data from the sites for the two essential inputs specific to the observation fields of sowing date and date of 50% flowering in three combinations of each of the six parameters to identify the combination that most closely matched the observed data across the testing sites. The results showed that the DEW and RH parameters were insensitive or poorly sensitive to the onset of the disease and were thus discarded from further analysis.

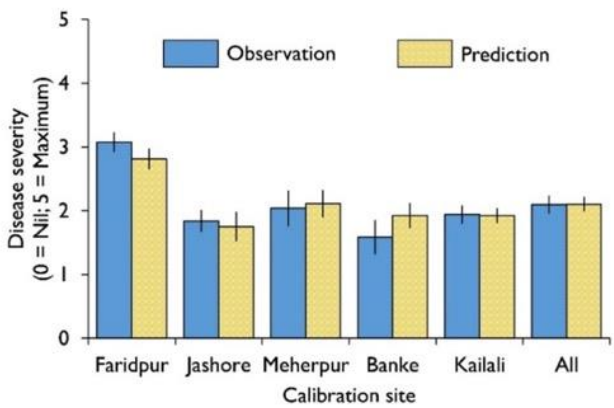


Figure 3.5: Comparison of predicted and observed severity of Stemphylium blight disease of lentils at 5 calibration locations (3 in Bangladesh, 2 in Nepal) and across all locations. Predictions used the best set of the Stempedia model's parameters worked out from calibration. Vertical bars denote 95% confidence intervals

The mean squared deviation was then applied to compare the observations and the model's predictions to estimate matches. The calibrated best set of the model's parameters significantly explained (at the $P<0.0001$ level) 70% of observed variation in disease severity at the five sites. On average the disease severity predicted by the calibrated best set of the model's parameters was similar (2.10±0.14) to the observations (2.10±0.11). In Bangladesh and Nepal the average disease severity predicted by the calibrated model was statistically similar to the observed disease severity (Figure 3.5).

Validation – The calibrated model was validated at the end of 2019 at the same five sites using 2018/19 field data. For this purpose, the model was run using site-specific weather data and the date of sowing and the date of 50% flowering specific to the observation fields. The predictions significantly explained (at the P<0.0001 level) 84% of observed variation of disease severity at the five sites (Figure 3.6). In several locations, however, the average disease severity predicted by the calibrated model was statistically similar (at the P>0.05 level) to observed disease severity (Figure 3.7). This indicates that the calibrated model adequately predicted field observation. The exception was Banke, Nepal where the prediction was significantly higher (at the P<0.05 level) than the observation. The model predicts potential disease risk by assuming the presence of the pathogen (inoculum) in the crop system (susceptible host and environment). It was most likely that there was only limited fungal inoculum at Banke.

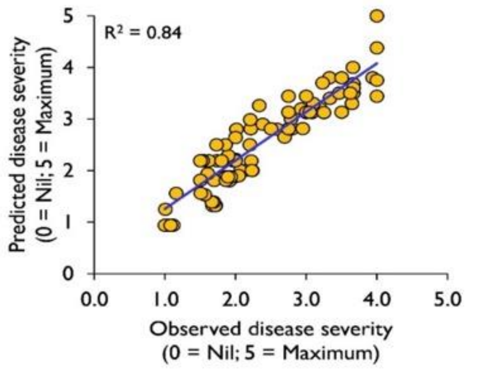


Figure 3.6: Comparison of predicted (circles) and observed (line) severity of Stemphylium blight disease of lentils. Predictions based on calibrated Stempedia model

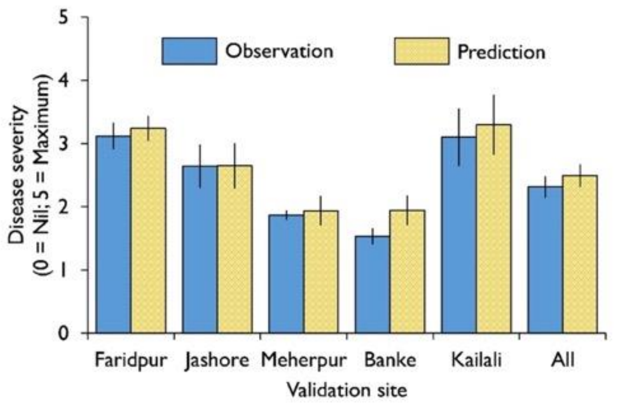


Figure 3.7: Comparison of predicted and observed severity of Stemphylium blight on lentils at 5 tested locations (3 in Bangladesh, 2 in Nepal). Predictions based on calibrated Stempedia model. Vertical bars denote 95% confidence intervals

Application – In late 2019, the calibrated and validated model was used to simulate scenarios of Stemphylium blight disease severity for lentils sown on different dates by the farmers in the 2017/18 and 2018/19 season at the five sites. The results clearly showed variation in disease severity between the sites and time of sowing both within and between seasons (Figure 3.8). This clearly indicates that the uncertainty of the occurrence of lentil Stemphylium blight disease within and between growing regions appears to be largely dictated by weather.

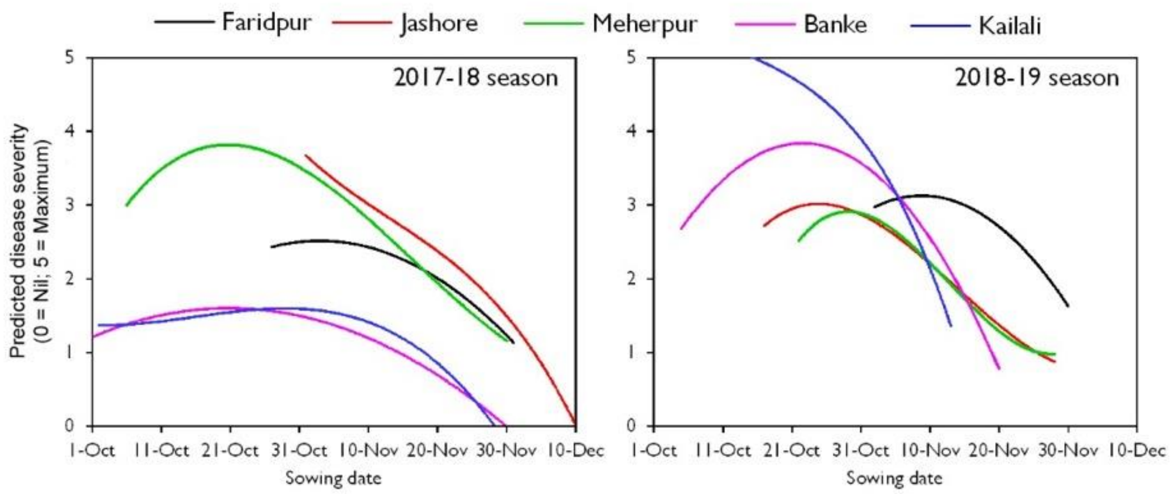


Figure 3.8: Predicted severity of Stemphylium blight disease of lentils at 5 tested locations (3 in Bangladesh, 2 in Nepal) at farmers' sowing time in 2017/18 and 2018/19 seasons. Predictions were based on the calibrated Stempedia model.

The risk of lentil Stemphylium blight disease was also predicted under future climate scenarios. The results (Figure 3.9) show the continued threat of the disease in the near and long term. These results have been published by the Krishi Gobeshona Foundation (KGF) in the book 'Climate Change and Bangladesh Agriculture: Adaptation and Mitigation Strategies'. The results strongly suggest that weather-forecast driven decision support models like Stempedia have a vital long-term role to play in rationalizing the use of foliar fungicide for managing crop diseases.

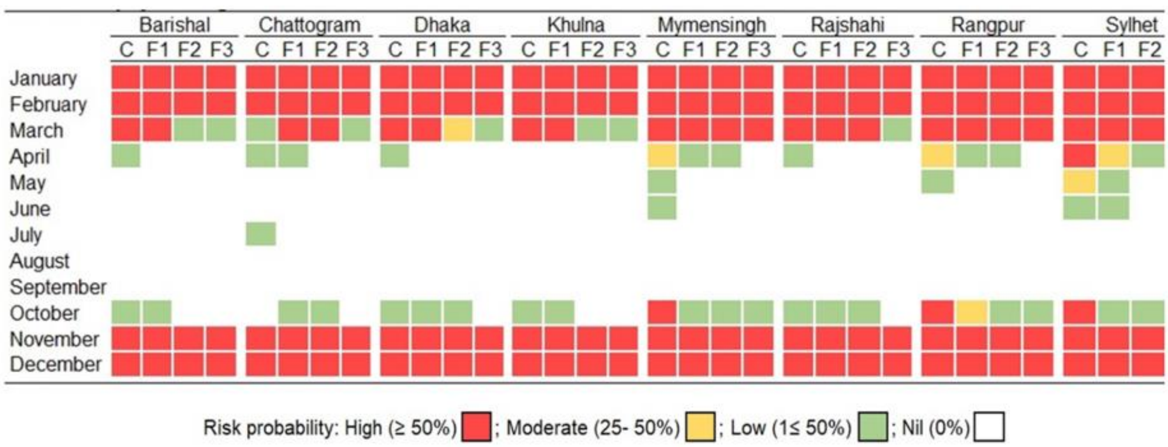


Figure 3.9: Modelling the incidence of Stemphylium blight on lentils in Bangladesh under current thermal regimes (C: 1981-2005), and three future periods (F1: 2006-2039, F2: 2040-2059 and F3: 2070-95).

Disseminating the modeling work – CSRD collaborating scientist Dr. Moin Salam presented the actions and future of Stempedia modeling work in South Asia to CIMMYT scientists in Dhaka, Bangladesh on 11 July 2019, and to a meeting of CSISA III project personnel from Bangladesh and Nepal scientists in Dhaka on 21 September 2019.

Progress – In 2019, CSRD completed its planned analysis of the 2017/18 and 2018/19 field data on lentil *Stemphylium* disease in Bangladesh, India and Nepal and the calibration and validation of the Stempedia model to use for forecasting the severity of the disease. However, due to staff changes and it taking longer than expected to calibrate and validate the model, the planned exploration of NASA POWER generated weather data did not progress as anticipated. Also, a paper based on the calibration and validation of Stempedia model is yet to be submitted for publication due to delays in completing the analysis.

Sustainability and exit strategy of CSRD in South Asia

Following the conclusion of CSRD, parts of the work on Stempedia are being continued under the CSISA project. This is part of CSRD's exit strategy as another season of work is needed to introduce the calibrated and validated Stempedia model into use by extension programs in South Asia. The following additional activities are being carried forward:

- A paper based on the calibration and validation of the Stempedia model will be completed and submitted to a reputed journal by mid-2020.
- Personnel involved in CSRD will present results of the Stempedia modeling work in mid-2020 at a workshop to BARC, DAE, NARC institutes, BMD, KGF and Bangladesh's Ministry of Agriculture. A similar workshop will be held in Nepal in the third quarter of 2020 involving NARC, NARC's National Grain Legume Research Program (NGLRP) and CIMMYT Nepal. Funding for the workshops is being sought from CSISA III.
- CSISA will support the dissemination of early warning advisories of the risk of *Stemphylium* blight disease to farmers, at least in Bangladesh and Nepal, from the 2020/21 cropping season. Advisory notes will be prepared in consultation with DAE staff in Bangladesh and NGRLP staff in Nepal. They will be communicated through DAE in Bangladesh via the newly developed BAMIS portal, which delivers 5-day agro-met advisories to farmers. Once Stempedia model-based advisories are fully operational (anticipated for the 2020/21 season), this system will be handed over to DAE. In the third and fourth quarters of 2020, CSISA will train DAE staff on operating the system. A similar entity to DAE does not exist in Nepal, but is likely to be established soon. In the meantime, the advisory will be channeled through NGRLP. In both countries, a farmers' survey will be conducted towards the end of the 2020/21 lentil season to assess the usefulness of the advisories and to explore issues to do with their use and application. Attempts will also be made to disseminate the advisories to agro-input dealers, who can pass on the advice to farmers on which fungicide to use and when to apply it to avert the occurrence of the disease.

Contribution of Activity 2.1.2 to CSRD's Action and Learning Framework:

Activity 2.1.2 work contributed to Pillar 2, Indicator 2.1, and Pillar 4, Indicator 4.1 (see Annex 3).

Activity 2.1.3. Application of historical, near-term, and future climate data applied to develop spatially explicit wheat blast (*Magnaporthe oryzae* Triticum) disease risk assessments for South Asia

Product 2: Climatically driven regional disease risk assessment for wheat blast (*Magnaporthe oryzae* Triticum)

Photo 2.6: Wheat blast is a potentially devastating fungal disease that causes bleaching of the crop and unfilled grain. It was found for the first time in Asia in 2016. Since then, project scientists worked to assess the interaction between the region's climate and potential for disease outbreaks in key wheat growing countries. (CIMMYT)

In addition to CSRD's activity to develop a wheat blast disease early warning system for Bangladesh, project scientists were also involved in modelling the risk of disease incidence and severity across all Asia. Work on this topic was presented in a detailed annex in the 2018 Semi-annual report. Since then, additional research has been completed to examine the climatic suitability for wheat blast disease at a large geographic scale – across the whole of Asia. A detailed description of this work is provided in Annex 8, and as such will not be discussed at length here.

Key research findings that resulted from this analysis include the following:

- The modeling results indicate considerable spatial variability in climatic suitability for the establishment of wheat blast in Asia. For wheat producing regions, far higher potential disease risk was observed in Bangladesh, Myanmar and some regions in India compared to other countries in the study.
- At the same time, these regions also have higher inter-annual variability of infection risk. On the other hand, wheat producing regions with temperatures and humidity below the threshold included in the model (described in detail in Annex 8) in China or India do not appear to be particularly prone to wheat blast establishment since the infection model applied in this work considers temperature and humidity thresholds to estimate the potential risk. However, the high inter-annual variability in temperature and humidity presented by these areas imply that in some years, conditions could be suitable for wheat blast. The latter results may be relevant when planning disease prevention actions through introducing new blast resistant or tolerant varieties, or early warning systems.

Sustainability and exit strategy of CSRD in South Asia

As of December 2019, project scientists are working to publish the climate suitability analysis for wheat blast in Asia. Following acceptance to a quality scientific journal, the data and codes developed for this work are expected to be made open access for use by other researchers. A webinar presenting the results of this work is also under consideration.

Contribution of Activity 2.1.3 to CSRD's Action and Learning Framework:

Pillar 2, Indicator 2.2, Pillar 4, Indicator 4.1 (see Annex 3).

Objective 3: Coordination with CSRD partners in-country to ensure progress on the work streams under the CSRD South Asia and Bangladesh working group

Sub-Objective 3.1. Coordination of Bangladesh CSRD partners

Background – CSRD supported a range of partners in Nepal, Bangladesh, and India through coordination, training opportunities, and networking across countries. This write-up highlights CSRD's work with its partners in 2019, emphasizing the second half of the year.

CSRD and synergies with the World Bank funded Bangladesh Weather and Climate Services Regional Project

Alongside CSRD, the World Bank has made an additional investment in Bangladesh through the Bangladesh Weather and Climate Services Regional Project (BWCSRP) that supports BMD, DAE and the Bangladesh Water Development Board (BWDB) with infrastructural support and technical capacity development. As described in the Objective 1 write-up, the DAE has taken on the PICSA activities that were piloted as part of CSRD. This indicates the sustainability of this intervention as DAE will continue to roll out PICSA trainings partly supported by BWSCRP. As the lead organization, DAE plans to continue to foster this work in the next two years with technical collaboration from CIMMYT-Bangladesh and the School of Agriculture, Policy and Development, University of Reading, UK.

In addition, DAE launched its Bangladesh Agro-Meteorological Information Portal in June 2019 through the World Bank funded Component C of the World Bank's larger investment in climate services for Bangladesh. Although CSRD cannot claim credit for the portal, it did play a strategic role in advising and coaching DAE and BMD staff on developing the portal, which was the subject of considerable discussion in many of CSRD regular project partner meetings in 2018 and 2019, and during DAE and BMD's visit to IRI in 2018. The CSRD decision support tool that provides sub-district level customized advisories for thermal and precipitation stresses in Bangladesh has been linked to DAE's portal.

Also:

- BMD now hosts the products developed by CSRD on its Agromet website, and as a co-founder will continue to provide support to BACS.
- To assure continuation of this work, CIMMYT signed an official memorandum of understanding with BMD for ongoing activity support in August 2019.

Bringing meteorological data collection into the digital age in Bangladesh

Prior to the CSRD project, most of the meteorological observation stations maintained by BMD relied on manual measurements. The personnel who maintain BMD's manual meteorological observation stations take manual observations of a range of variables including but not limited to air temperature, relative humidity, sunshine hours, soil temperature every three-hours. All of these observations were written down by hand by pencil on forms. These forms were typically kept at observing station offices for several months before they are would be sent to Dhaka for computer entry by BMD's Climate Division. This system results in significant time-lags and delays before observed data become available for analysis and use.

Photo 3.1: CIMMYT ODK lead Ashok Rai (far left) conducted an intensive training alongside Khaled Hossain (CIMMYT Research Associate) on ODK to accelerate observed data weather availability. Through the use of digital data collection tools, weather data become instantaneously available on a cloud server, reducing the time from data collection to when data can be used and analyzed by one to three months.

CSRD has enabled BMD to take a formidable step forward in accelerating its rate of data acquisition and making it available sooner to the public. Through CSRD, in January 2019, CIMMYT conducted an intensive residential training workshop on the use of Open Data Kit (ODK) for BMD staff from 20 meteorological station observatories in Bangladesh. The trainees came from BMD stations at Faridpur, Madaripur, Gopalgonj, Cox's Bazar, Teknaf, Rajshahi, Ishurdi, Bogura, Badalgachhi, Tarash, Rangpur, Dinajpur, Sayedpur Tetulia, Dimla, Rajarhat, Barishal, Patuakhali, Khepupara, and Bhola.

ODK is a research-community driven open-source software for collecting and managing data using digital tools like internet-enabled smartphones and tablets. It enables users to design survey or data collection instruments using Microsoft Excel. Survey results are imported into ODK and rendered in an easy to understand and visually guided survey format in HTML using open-source, researcher designed coding systems. When connected to the internet, data that are entered into tablets are sent to a cloud server where they are stored in a structured format for further use.

A complete list of data that are now available at regular 3-hourly or daily time intervals simply by logging on to the BMD-ODK cloud server include the following variables:

- Air temperature (°C)
- Relative humidity (%)
- Last 3 hours' rainfall (mm)
- Soil moisture at 5, 10, 20, 30, 50 cm soil depths (%)
- Soil temperature (°C) at 5, 10, 20, 30, 50 cm depths (%)
- Gust wind speed
- Wind direction
- Mean sea level pressure (hPa)
- Total amount of cloud (Octas
- Present weather conditions
- Past weather conditions.

Contribution of Sub-Objective 3.1 to CSRD's Action and Learning Framework: Pillar 2, Indicator 2.2 (see Annex 3).

Sub-Objective 3.2. Policy maker, agro-metrological services, extension, and farmer awareness of agro-meteorological forecasts and decision support tool platforms for agriculture increased

Background – This section details 2019 CSRD work to develop the capacity of national and regional partners on agricultural climate services.

Photo 3.2: Mr. Shamsuddin Ahmed, Director of the Bangladesh Meteorological Department, addressing participants and facilitating a panel discussion with BACS Alumni at the 2019 5th Annual Gobeshona conference on Climate Knowledge in Dhaka, Bangladesh.

The Bangladesh Academy for Climate Services (BACS)

Jointly founded by the International Center for Climate Change and Development (ICCCAD), the International Research Institute for Climate and Society (IRI) at Columbia University, Bangladesh Meteorological Department (BMD) and the International Maize and Wheat Improvement Center (CIMMYT) through CSRD, the Bangladesh Academy for Climate Services (BACS) was inaugurated in August 2018 at BMD. BACS has received in-kind and direct financial support through CSRD, and also from the Adapting Agriculture to Climate Today, for Tomorrow (ACToday) project (part of Columbia World Projects). The academy aims to embed climate thinking in decision-making processes and to close the gap between climate information providers and end users.

BACS offers three functions in support of climate services in Bangladesh:

- A convening role to open trans-sector and multi-stakeholder dialogue on climate services – defined as the production, translation, dissemination and use of climate and weather data to improve decision making), to identify existing initiatives, challenges and opportunities.
- To develop tailored certification short courses for students and early to mid-level professionals.
- To create graduate level curricula to train the next generation of weather, climate and sector experts with the skills needed to face the uncertainties of the coming decades.

As described in previous reports, BACS has received in-kind and direct financial support through CSRD, and also the Adapting Agriculture to Climate Today, for Tomorrow (ACToday) project, part of the Columbia University World Projects. BACS aims to embed climate thinking in decision-making processes and close the gap between climate information providers and end users, as described on the academy's website.

The highlights of BACS activities related to CSRD from the first half of 2019 included support for a session at the fifth Gobeshona Annual Conference on Climate Knowledge in Bangladesh, during which alumni who graduated from BACS's first Climate Services training program in October 2018 presented how they were applying what they learned. Graduates of the 2018 training included students from insurance companies, disaster response organizations, agricultural research, aquaculture management and universities.

Addressing Climate Risks in South Asia with ENACTS

In addition, BACS supported Columbia University's CSRD synergistic ACToday project to simultaneously improve the availability, access and use of climate information at a national level in Bangladesh. A workshop to launch the Enhancing National Climate Services (ENACTS) initiative was held on 27 June 2019 at BMD. It introduced ENACTS in Bangladesh to potential users in climate sensitive sectors, and demonstrated the new robust climate datasets. The datasets combine station data and satellite and reanalysis proxies providing more spatial coverage, as well as a new web interface, the Bangladesh Map Room (BMR). BMR provides access to an array of climate information products for Bangladesh. The workshop was organized under BACS, IRI at Columbia University, ICCCAD at the Independent University, Bangladesh (IUB), CIMMYT and BMD. This effort was funded by IRI's Adapting Agriculture to Climate Today, for Tomorrow (ACToday) project, co-developed with BMD, co-organized with ICCCAD and endorsed by BACS partners with additional financial support by CSRD. The training goal was to promote open access and usability of the ENACTS data and climate information products by partners and user communities.

The 73 participants came from organizations that use climate data comprising 38 from government and non-government agencies, 21 BMD personnel and 14 persons from IRI, ICCCAD and CIMMYT. Representatives from organizations working in:

- agriculture – BARC, DAE, BARI, and Oxfam
- aquaculture – CNRS, WorldFish, Department of Fisheries, CARITAS, CEGIS, World Bank
- insurance – ACI, Green Delta, Shadharon Bima, INAFI Asia, Syngenta, Win Miaki etc.
- disaster relief and natural resources management – Hellen Keller, Start Fund Bangladesh and IWM.

The workshop was inaugurated by the BMD director of BMD who introduced participants to ENACTS and its potential. He explained how:

- in generating the ENACTS dataset for rainfall and temperature, first the observed station data was put through rigorous quality control;
- the bias from satellite data was removed using observation data;
- using statistical techniques the bias adjusted gridded data was merged with station data to provide a more accurate dataset with coverage of every 5 km across Bangladesh;
- the rainfall time series (Jan 1981 to Aug 2018) was created by combining quality-controlled station observations with satellite rainfall estimates; and
- minimum and maximum temperature time series (January 1961 through 2018) were generated by combining quality-controlled station observations with downscaled climate

model reanalysis products.

Demonstration of this methodology was followed by discussions on the ENACTS dataset and products and their use. Participants also discussed how to make potential users aware of the initiative and how BMD deals with intermittent missing values. Group activities related to agriculture, aquaculture, insurance and disaster relief discussed the positive and negative aspects of ENACTS and their implications and discussed how to improve the Map Room.

Photo 3.3: Enhancing National Climate Services (ENACTS) launch workshop, 27 June 2019 at BMD (BACS)

Implementation of CSRD support to ICCCAD in BACS coordinator roles

The Bangladesh Academy for Climate Services is hosted at ICCCAD at the Independent University of Bangladesh, Dhaka. A sub-component of the Gobeshona network, BACS reports to the Gobeshona Steering Committee. In August 2019, CSRD provided a sub-grant to ICCCAD to develop tailored short certification courses for early to mid-level professionals in climate-sensitive sectors, with an initial focus on food security and nutrition, to address the needs of stakeholder organization. To streamline the activities of BACS, ICCCAD immediately appointed Prof. Mizan R. Khan as Coordinator and Tasfia Tasnim as deputy coordinator under a CIMMYT–ICCCAD contract funded by CSRD. CSRD continued to review and contribute to BACS activity progress and reports. A Google group was formed in mid-2019 to facilitate regular communication among BACS Executive Committee members with monthly Skype calls to discuss related activities.

Training dialogue – The second BACS Training Dialogue on Introduction to Climate Information Service for Aquaculture and Agriculture was held 27–31 October 2019 at BMD, Dhaka. CSRD supported reporting and session delivery. The ICCCAD team worked closely with IRI and other BACS partners to develop the training modules. At the same time a BACS alumni dinner discussion was held on 29 October 2019 as part of October 2018 training follow-up activities. The course was mainly designed for persons working in aquaculture value chains to improve their understanding of the use of climate services for aquaculture.

Capacitating Farmers and Fishers to Manage Climate Risks in South Asia (CaFFSA)

The CaFFSA project is developing, testing and delivering innovative climate services to 330,000 farm households in India and 150,000 fish-farming households in Bangladesh. The lead organization is the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in partnership with CIMMYT, WorldFish, The Earth Institute, Columbia University, Orissa University of Agriculture and Technology (OUAT), the Ministry of Earth Sciences (MoES, India) and BMD. Throughout 2019, CSRD supported CaFFSA to evaluate the value of weather information in rice-aquaculture systems in Bangladesh using the hindcast experiment methodology. CSRD also assisted WorldFish scientists involved with CaFFSA to develop a decision tree for climate-sensitive decisions in aquaculture and plans, which may later be included as part of the Agvisely map interface. Such actions enable climate services to reach an increased number of farmers and fishers directly and indirectly through DAE's and the Department of Fisheries' extension agents. These developments provide evidence of how CSRD has played a catalytic role in advancing climate information services in Bangladesh.

In 2019, the CaFFSA project organized the BACS training event, which was held in October 2019 with CSRD staff helping to deliver the course content. The lectures covered examples of crop advisory tools, disease modelling and early warning systems, problems in agricultural climate service design and delivery, farmer field schools for delivering climate information (PICSA) and the use of climate information. A separate session explained the development of an aquaculture decision tree for generating an aquaculture climate service based on examples from the CSRD project.

Photo 3.4: Staff from CIMMYT and WorldFish trained as enumerators on 12 November 2019 to survey farmers and fishermen using methods developed under CSRD as part of CaFFSA project

Other public interactions to support climate services in Bangladesh

Photo 3.5: Trainees in a multi-day workshop organized by ICIMOD and CIMMYT through CSRD on the Principles and Application of GIS in Agriculture Planning and Decision Making, emphasizing climate information, at BARC Dhaka in May 2019.

Through CSRD, ICIMOD and CIMMYT held a training workshop on the Principles and Application of GIS in Agriculture Planning and Decision Making at BARC in Dhaka, Bangladesh in the first week of May 2019. Nineteen professionals from nine agriculture-related institutions learned about the application of GIS in agricultural research and decision making, and especially on the use of spatial and climactic information in a GIS environment.

Josh Klein, Senior Professional Staff Member, Development, USAID, Energy and Environment, U.S. Senate Foreign Relations Committee visited CSRD activities in Jheneidah, Bangladesh on 18 March 2019. This visit was part of a larger mission to develop insight and check on the progress of USAID's activities in Bangladesh. During his half-day visit to meet farmers and scientists involved in CSRD, Mr. Klein learned about the project's collaboration with BMD, DAE and agricultural research institutes to develop weather-based early warning systems to mitigate wheat blast threats.

Photo 3.6: Josh Klein, U.S. Senate Foreign Relations Committee (left) visited CSRD field activities in Bangladesh on 18 March 2019. Dr. Timothy J. Krupnik, Senior Scientist and Systems Agronomist, and CSRD in South Asia Project Leader (Right) explained how CSRD partners with extension services in Bangladesh to deliver climate services to smallholder farmers.

On 20 March 2019, Dr. Timothy J. Krupnik, Senior Scientist and Systems Agronomist, and CSRD in South Asia Project Leader for CIMMYT, presented a paper at a meeting in Dhaka on "Scaling Climate-Smart Agriculture in Bangladesh: Practices, Policies and Institutions". The meeting was organized by the International Rice Research Institute (IRRI), CIMMYT, and the Bangladesh Rice Research Institute (BRRI), with support from the CGIAR Research Program CCAFS. Dr. Krupnik's presentation on 'Building agricultural resilience to climate stress requires a multi-faceted, multi-disciplinary approach' was accompanied by in-depth discussion on CSRD's work to support climate science and services in Bangladesh. A summary of the presentation and workshop outputs are available in an online report published by CCAFS.

Contribution of Sub-Objective 3.2 to CSRD's Action and Learning Framework:

Pillar 3, Indicator 3.1 (see Annex 3).

Implementation challenges

Aside from partial flooding in Nepal that hampered field work for lentil disease predictive modelling data collection efforts in early 2019, no significant implementation challenges were experienced during 2019.

During the reporting year, CSRD worked to hand over key CSRD products to government partners like BMD and DAE, and to implement and scale-out activities through association and synergies with the World Bank supported Agricultural Meteorology project in Bangladesh. This is especially the case for PICSA, which has been on-boarded as a core part of DAE's programming. Similarly, Agvisely and the Wheat Blast Early Warning System have been adopted by national partners and can continue to function without CSRD's direct influence. However, some additional source correction on these tools may be needed, which is now being supported by the USAID funded Cereal Systems Initiative for South Asia (CSISA) Phase III project (slated to continue to the end of 2021). This will permit relevant work streams to be grown to fuller completion, with the goal of implementing the use of science products by extension services and farmers in South Asia.

Annexes

Annex 1: Key Staff and Core Partner Designations

Name	Role	Institution	Address	Phone	Email	Comments
CIMMYT – BANGLADESH						
Dr. Timothy J. Krupnik	Systems Agronomist and CSRD Project Leader	CIMMYT	Dhaka, Bangladesh	+880-175-556-8938	t.krupnik@cgiar.org	55% FTE
T.S Amjath Babu	Agricultural Economist (Leading decision framework surveys)	CIMMYT	Dhaka, Bangladesh	+880 17 5550 7133	T.AMJATH@cgiar.org	50% FTE
Dr. Urs Christoph Schulthess	Senior Scientist Remote Sensing	CIMMYT	Dhaka, Bangladesh	+880-178-766- 9073	U.Schulthess@cgiar.org	15% FTE in-kind contribution
Dr. Carlo Montes	Agricultural Climatologist	CIMMYT	Dhaka, Bangladesh	--	c.motes@cgiar.org	145% FTE
Ms. Anne Laurie Pilat	Consultant	CIMMYT	Dhaka, Bangladesh	--	<A.PILAT@cgiar.org	25% FTE
Dr. Sk. Ghulam Hussain	Senior Consultant: Technical Coordination and partnership Management	CIMMYT	Dhaka, Bangladesh	+880- 171-5885608	sghussain.bd@gmail.com	100% FTE
Dr. Moin Salam	Senior Consultant: Lentil *Stemphylium* modeling and forecasting	CIMMYT	Dhaka, Bangladesh	+880-185-5871938	moinsalam1@gmail.com	50% FTE on consultancy basis
Mr. Ansar A Siddiquee Iqbal	Project Manager	CIMMYT	Dhaka, Bangladesh	+880-171-3044764	a.siddiquee@cgiar.org	25% FTE
Dr. Shafiq Islam	Jashore Hub Coordinator	CIMMYT	Jashore, Bangladesh	+880-171-145 1064	Shafiqul.Islam@cgiar.org	In-kind contributions to lentil disease model validation in Bangladesh through CSISA

Name	Role	Institution	Address	Phone	Email	Comments
Dr. Dinabandhu Pandit	Senior Technical Coordinator (CSISA)	CIMMYT	Faridpur, Bangladesh	+880-171-213 0599	d.pandit@cgiar.org	In-kind contributions to lentil disease model validation in Bangladesh through CSISA
Mr. Khaled Hossain	Research Associate	CIMMYT	Dhaka, Bangladesh	+880-171-7765505	m.k.hossain@cgiar.org	100% FTE
Mr. Mustafa Kamal	Research Associate	CIMMYT	Dhaka, Bangladesh	+880-171-7425006	m.kamal@cgiar.org	100% FTE
Mr. Md. Motasim Billah	Data Specialist	CIMMYT	Dhaka, Bangladesh	+880-182-4367257	--	100% FTE
Mr. Shahidul Haque Khan	Communication Specialist	CIMMYT	Dhaka, Bangladesh	+880-171-3330981	msh.khan@cgiar.org	25% FTE
Ms. Fahmida Khanam	Program Assistant	CIMMYT	Dhaka, Bangladesh	+880-171-3409446	Fahmida309@gmail.com	80% FTE
Mr. ASM Alanuzzaman Kurishi	Research Associate	CIMMYT	Dinajpur, Bangladesh	+880-171-5803856	a.kurishi@cgiar.org	75% FTE
Mr. Mani Krishna Adhikary	Agricultural Development Officer	CIMMYT	Dinajpur, Bangladesh	+880-171-2544706	m.adhikary@cgiar.org	100% FTE
Mr. Anarul Haque	Extension Agronomist	CIMMYT	Rajshahi, Bangladesh	+880-171-9546672	an.haque@cgiar.org	100% FTE
Mr. Md. Ashraful Alam	Technical Officer	CIMMYT	Dhaka, Bangladesh	+880-172-7022007	a.alam@cgiar.org	30% FTE
Mr. Golam Morshed Rokon	Agricultural Development Officer	CIMMYT	Barisal, Bangladesh	+880-171-9408321	g.rokon@cgiar.org	50% FTE
Ms. Sumona Shahrin	Consultant research associate	CIMMYT	Dhaka, Bangladesh	+880-187-5315084	sumonashahrin@yahoo.com	80% FTE
Md. Washiq Faisal	Consultant research associate	CIMMYT	Dhaka, Bangladesh	+880-174-0603385	faisal.washiq@gmail.com	50% FTE
CIMMYT - NEPAL						
Dr. Peter Craufurd	Country Representative	CIMMYT	Kathmandu, Nepal	+977 9808757832	P.Craufurd@cgiar.org	In-kind strategy guidance and contributions

Name	Role	Institution	Address	Phone	Email	Comments
CIMMYT - India						
Dr. R.K. Malik	System Agronomist and CSISA India Country Coordinator	CIMMYT	Patna, India	+977 9745060768	m.devkota@cgiar.org	In-kind contributions to lentil disease model validation in India through CSISA
Dr. Poonia SP	CSISA India Research Platform Coordinator		Patna, India	+91 8292525557	S.Poonia@cgiar.org	In-kind contributions to lentil disease model validation in India through CSISA
Dr. Tek Sapkota	Agricultural Systems and Climate Change	CIMMYT	New Delhi, India	--	T.Sapkota@cgiar.org	15% In-kind CCAFS contribution
CIMMYT - GLOBAL						
Dr. Bruno Gérard	Sustainable Intensification Program Director	CIMMYT	El Batan, Mexico	+52 (55) 5804 2004 ext. 2123	b.gerard@cgiar.org	3% FTE strategy and guidance
REGIONAL AND INTERNATIONAL PARTNERS						
International Center for Integrated Mountain Development (ICIMOD)						
Dr. Mir Abdul Matin	Theme Leader, Geospatial Solutions, Science and Data Lead (SERVIR-Hindukush Himalaya)	ICIMOD	Kathmandu, Nepal	+977-984-377-5633	mir.matin@icimod.org	ICIMOD focal point for CSRD in South Asia (In kind contribution)
Mr. Faisal Mueen Qamar	Remote Sensing Specialist Geospatial Solutions	ICIMOD	Kathmandu, Nepal	---	faisal.qamer@icimod.org	Lead analyst for CSRD in South Asia activities (25% FTE)
International Research Institute for Climate and Society (IRI, Columbia University)						
Dr. Simon J. Mason	Chief climate scientist	IRI	Palisades, NY, USA	+1-845-680-4514	simon@iri.columbia.edu	IRI focal point for CSRD in South Asia. 10.5% FTE
Dr. James Hansen	Senior Research Scientist CCAFS Theme Leader	IRI	Palisades, NY, USA	+1 (845) 680-4410	jhansen@iri.columbia.edu	5% FTE

Name	Role	Institution	Address	Phone	Email	Comments
Mr. John Furlow	Deputy Director for Humanitarian and International Development	IRI	Palisades, NY, USA	+1 (845) 680-4466	jfurlow@iri.columbia.edu	In-kind contribution through Columbia World program and ACToday
Dr. Eunjin Han	Associate Research Scientist: Crop modeling	IRI	Palisades, NY, USA	--	eunjin@iri.columbia.edu	8% FTE
Dr. Nachiketa Acharya	Post Doctorial Research Scientist: Sub-seasonal forecasts	IRI	Palisades, NY, USA	--	nachiketa@iri/columbia.edu	15% FTE
Dr. Colin Kelly	Associate Research Scientist: Temperature forecasting	IRI	Palisades, NY, USA	+1 (845) 680-4463	ckelly@iri.columbia.edu	8% FTE
Mélody Braun	Staff Associate	IRI	Palisades, NY, USA	--	m.braun@iri.columbia.edu	13% FTE
Ashley Curtis	Senior Staff Associate	IRI	Palisades, NY, USA	--	acurtis@iri.columbia.edu	13% FTE
Elizabeth Gawthrop	Science Communication Specialist	IRI	Palisades, NY, USA	--	gawthrop@iri.columbia.edu	4% FTE
Bangladesh Meteorological Department (BMD)						
Mr. Shamsuddin Ahmed	Director	BMD	Agargaon, Dhaka, Bangladesh	+ 880-2 891 4576	info@bmd.gov.bd	20% FTE
Mr. Md. Abdul Mannan	Meteorologist, Storm Warning Center	BMD	Agargaon, Dhaka, Bangladesh	+880-29135742	mannan_u2003@yahoo.co.in	20% FTE
Mr. S.M Quamrul Hassan	Meteorologist, Storm Warning Center	BMD	Agargaon, Dhaka, Bangladesh	+880-19162255449 +880-2 9135742	smquamrul77@yahoo.com, quamrul.hassan@bmd.gov.bd	20% FTE
Mr. Md. Bazlur Rashid	Meteorologist, Storm Warning Center	BMD	Agargaon, Dhaka, Bangladesh	+880-2 9135742	bazlur_rashid76@yahoo.com	20% FTE
Department of Agricultural Extension (DAE)						
Dr. Aziz Mazharul	Additional Deputy Director and Project Director, Agro-Meteorological Info. Services (DAE part)	DAE	Farmgate, Dhaka, Bangladesh	+880-2 9130928	azizdae@gmail.com	In-kind contribution through World Bank funded Agro-Meteorological Information Services project

Name	Role	Institution	Address	Phone	Email	Comments
Dr. M. Shahabuddin	Additional Director Planning & ICT management	DAE	Khamarbari, Farmgate, Dhaka, Bangladesh	+880-1742601461	shahabipm@gmail.com	20% FTE
Mrs. Rahana Sultana	Upazila Agriculture officer	DAE	Khamarbari, Farmgate, Dhaka, Bangladesh	+880-1715551091	rahanaplp@yahoo.com	20% FTE
Md. Fazlul Hoque	District Training Officer	DAE	Khamarbari, Barisal, Bangladesh	+880-172-8251836	f.hoq1542@gmail.com	In-kind contribution to administering district-based training work
Md. Monzurul Haque	District Training Officer	DAE	Khamarbari, Rajshahi, Bangladesh	+880-171-1224280	monzurul.aeo@gmail.com	In-kind contribution to administering district-based training work
Nikhil Chandra Biswas	District Training Officer	DAE	Khamarbari, Dinajpur, Bangladesh	+880-193-8826855	ncbiswasdae@gmail.com	In-kind contribution to administering district-based training work
Bangladesh Agricultural Research Institute (BARI)						
Md. Shariful Bin Akram	Scientific Officer	BARI	Wheat Research Centre, Dinajpur, Bangladesh	+880-1717-545797	sariful.santo@gmail.com	Time in-kind; sub-grant costs for experiments only
Md. Jakir Hossain	Scientific Officer	BARI	Regional Wheat Research Station, Shampur, Rajshahi, Bangladesh	+880-1710-375943	zakzubari@gmail.com	Time in-kind; sub-grant costs for experiments only
Shiek Shamsul Alam Kamar	Scientific Officer	BARI	Regional Agricultural Research Station, Rahmatpur, Barisal, Bangladesh	+88 01724-461414	alamkamar91@gmail.com	Time in-kind; sub-grant costs for experiments only

Name	Role	Institution	Address	Phone	Email	Comments
***Universidade de Passo Fundo* (UPF)**						
Dr. José Maurício Cunha Fernandes	Senior Scientist – Plant Epidemiology	UPF	Passo Fundo, RS, Brazil	--	mauricio.fernandes@embrapa.br	Time in-kind for scientific coordination
Mr. Felipe de Vargas	Computer scientist	UPF	Passo Fundo, RS, Brazil	--	119685@upf.br	100% FTE (wheat blast computer model coding)
University of Reading (UR)						
Dr. Peter Dorward	Professor, School of Agriculture, Policy and Development	University of Reading	Reading, UK.	+44 (0) 118 378 8492	p.t.dorward@reading.ac.uk	In-kind contribution
Dr. Samuel Poskitt	Post-Doctoral Scholar	University of Reading	Reading, UK	--	samuel.poskitt@reading.ac.uk	In-kind contribution
Dr Graham Clarkson	Senior Research Fellow, School of Agriculture, Policy and Development	University of Reading	Reading, UK	+44 (0) 118 378 5036	g.clarkson@reading.ac.uk	In-kind contribution
Bihar Agricultural University (BAU)						
Dr. Abhijeet Ghatak	Assistant Professor of Plant Pathology	BAU	Sabour, Bihar, India	--	ghatak11@gmail.com	In-kind contribution to lentil disease monitoring activities
Bangladesh Agricultural University (BAU)						
Dr. M.A. Farukh	Professor, Department of Environmental Science	BAU	Mymensingh-2202, Bangladesh	+880-1712-106603	--	In-kind contribution to lentil disease monitoring activities
Wageningen University: WaterApps project						
Dr. Saskia Werners	Assistant Professor of Adaptive Water Management	WUR	Wageningen University & Research Teams WSG - CALM PO Box 47, 6700 AA Wageningen, the Netherlands	+31 317 486442	saskia.werners@wur.nl	In-kind contribution to PICSA work

Name	Role	Institution	Address	Phone	Email	Comments
Mr. Uthpal Kumar	PhD Student	WUR	Wageningen University & Research Teams WSG - CALM PO Box 47, 6700 AA Wageningen, the Netherlands	--	uthpal.kumar@wur.nl	In-kind contribution to PICSA work
Nepal Agricultural Research Council (NARC)						
Dr. Rajendra Darai	Senior Scientist and Coordinator, Grain Legumes Research Program	BAU	Khajura, Banke, Nepal	--	Nglrp_khajura@narc.cov.np	In-kind contribution to lentil disease monitoring activities
International Centre for Climate Change and Development (ICCCAD)						
Dr. Saleemul Huq	Director	ICCCAD	House-27,Road 1, Block-A, Bashundhara R/A, Dhaka 1229	+880-177-9754662	saleemul.huq@iied.org	In-kind contribution to BACS
Dr. Feisal Rahman	Research Coordinator	ICCCAD	House-27,Road 1, Block-A, Bashundhara R/A, Dhaka 1229	+880-170-6849030	feisal1702@gmail.com	In-kind contribution to BACS)
Dr. Mizan R. Khan	Director ICCCAD and Coordinator of BACS	ICCCAD	House-27,Road 1, Block-A, Bashundhara R/A, Dhaka 1229	+880-171-3038306	mizan.khan@icccad.net	50% FTE (coordination for BACS)
Ms. Tasfia Tasnim	Research Officer ICCCAD and Assistant Coordinator of BACS	ICCCAD	House-27,Road 1, Block-A, Bashundhara R/A, Dhaka 1229	+880-193-0511433	tasfia.tasnim@icccad.net, tasfia2507@gmail.com	50% FTE coordination for BACS
Farah Anzum	Research Assistant	ICCCAD	House-27,Road 1, Block-A, Bashundhara R/A, Dhaka 1229	--	anzum.farah@gmail.com	100% FTE coordination for BACS

Annex 2: Project subcontractors and key partners' designations

Partner	Partnership Objective	Strategic Alignment	Leveraging Opportunity	Anticipated or committed funding (USD)	Objective & activity contributions (Core activity contributions)	Status of Partnership
Bangladesh Meteorological Department (BMD)	Integrative CSRD partner to produce and control the quality of climate information and forecasts. Iterative development of climate services frameworks and decision support tools.	Pillars 1, 2, 3, and 4	BMD is Bangladesh's lead agency for meteorological forecasting in Bangladesh and is interested to improve the quality of their ag-meteorological forecasts. Improvement of short-term and seasonal forecasts and integration of the resulting information as crop specific climate service advisories will be deployed through CSRD partners.	$68,459. Note that in agreement with BMD on November 13, 2018, the sub-grant amount was reduced to reflect BMD's largely in-kind and intellectual contribution to CSRD.	Sub-Objective 1.1., Activity 1.11., Sub-Objective 1.2, Activity 1.2.1., Sub-Objective 1.3: Activity 1.3.1 (all three sub-activities), Activity 1.3.2, Sub–Objective 2.1, Activity 2.1.1, Objective 3, Sub-Objective 3.1.	The sub-grant agreement between CIMMYT and BMD was signed on 29 August 2017 (Dated June 15, 2017) with full approval of the Ministry of Defense. Sub-grant copies are available for review upon request. The sub-grant amendment modifying the full amount that was completed on 13 November is also available on request.
Department of Agricultural Extension (DAE)	Iterative development of climate services frameworks and communication strategies. Extension and dissemination of agriculturally relevant meteorological information and advisories to farmers.	Pillars 1, 2, 3, and 4	DAE has over 14,000 field extension agents operating throughout Bangladesh. DAE also has capabilities in ICT tools for extension purposes. Second sub-grant was made to implement PICSA in ten more Upazilas.	$100,000 + $ 48,283	Sub-Objective 1.1., Activity 1.11., Sub-Objective 1.2, Activity 1.2.1., Sub-Objective 1.3: Activity 1.3.1 (all three sub-activities), Activity 1.3.2, Sub–Objective 2.1, Activity 2.1.1, Objective 3, Sub-Objective 3.1.	The Sub-grant agreement between CIMMYT and DAE has been signed on 16 October 2017. CIMMYT maintains a formal partnership MoU with the DAE, collaboration in CSRD has been initiated and is ongoing. Sub-grant copies are available for review upon request.
Bangladesh Agricultural Research Institute (BARI)	Validation and improvement of irrigation scheduling decision support	Pillars 1, 2, 3, and 4	BARI is Bangladesh's lead institute for research in non-rice crops, with significant	$30,000	Sub-Objective 1.3: Activity 1.3.1 (PANI and wheat blast activities)	The sub-grant agreement between CIMMYT and BMD has been signed on 8 August 2017 and is now

Partner	Partnership Objective	Strategic Alignment	Leveraging Opportunity	Anticipated or committed funding (USD)	Objective & activity contributions (Core activity contributions)	Status of Partnership
	tools (PANI). Collaborative research to develop and improve wheat blast forecasts and decision support systems.		technical capacity in irrigation and wheat related research.			under way. Sub-grant copies are available for review upon request. Please see report sections on PANI for more details. Sub-grant copies are available for review upon request.
International Research Institute for Climate and Society (IRI)	Skills assessments and advanced forecasting and agriculturally relevant climate services training for BMD and DAE, consistent technical backstopping and support.	Pillars 1, 2, 3, 4	Scientists at IRI have been collaborating with BMD for over four years. CSRD is leveraging this partnership provide consistent technical support and backstopping to BMD, and to develop improved climate services communications and extension strategies with DAE through IRI's contributions to CCAFS's Research Theme on Adaptation through Managing Climate Risk.	$300,000	Sub-Objective 1.1., Activity 1.11., Sub-Objective 1.2, Activity 1.2.1., Sub-Objective 1.3: Activity 1.3.1 (all three sub-activities), Activity 1.3.2, Objective 3, Sub-Objective 3.1.	The sub-grant agreement has been signed between IRI and CIMMYT on 31 August 2017. Sub-grant in near final stages of development, signatures and formalization expected by approximately the third week of May, 2017. Sub-grant copies are available for review upon request.
International Centre for Integrated Mountain Development (ICIMOD): Sub-grant 1	Collaborative development and refinement of South Asian regional-scale decision support tools, services, and products with emphasis on seasonal to sub-seasonal drought forecasts and integration with BARC1.	Pillars 1 and 4	Drought modelling downscaling at different resolutions and development of seasonal to sub-seasonal forecast of drought aligned with ongoing work in the SERVIR-Hindu Kush Himalaya (HKH) program	$195,000	Sub-Objective 1.1., Activity 1.11., Sub-Objective 1.2, Activity 1.2.1., Sub-Objective 1.3: Activity 1.3.1 (all three sub-activities), Activity 1.3.2, Objective 3, Sub-Objective 3.1.	The sub-contract agreement between CIMMYT and ICIMOD has been signed and completed on 1 May 2017. Sub-grant copies are available for review upon request.

Partner	Partnership Objective	Strategic Alignment	Leveraging Opportunity	Anticipated or committed funding (USD)	Objective & activity contributions (Core activity contributions)	Status of Partnership
International Centre for Integrated Mountain Development (ICIMOD): Sub-grant 2	Collaborative implementation of the October 8-10 2018 Regional Knowledge Forum on Drought held in Kathmandu.	Pillar 3	Awareness raising of climate services and earth observation data and tools to popularize drought monitoring and forecasting in collaboration with the SERVIR-Hindu Kush Himalaya (HKH) program	$25,000 (Completed)	Sub-Objective 3.2	The sub-contract agreement between CIMMYT and ICIMOD has been signed and completed on 14 September 2018. Sub-grant copies are available for review upon request.
Universidade de Passo Fundo (UPF)	Collaborative development and refinement of disease forecasting model and decision support system for wheat blast early warnings, supporting BARI	Pillars 2, 4	Establish a web-based application and decision support tool (DST) for in-season 5 and 10-day lead time forecasts to present the probabilistic risk of wheat blast infection Adapt a surveillance smartphone application to Bangladesh. Engage with CIMMYT's partners in Bangladesh to incorporate input and feedback on performance of the application DST detailed in Objective 1, and to assist in training and advising partners on use of the application DST	$15,000	Objective 1, Sub-Objective 1.3, Activity 1.3.1: (MoT forecasting) Objective 2, Sub–Objective 2., Activity 2.1.3.	A consultancy has been awarded to Mr. Felipe de Vargas of UPF for 11 months (total value of the consultancy is $15,000). This consultancy has been extended. Vargas is supervised by Dr. José Maurício Cunha Fernandes, Senior Scientist – Plant Epidemiology at UPF, and developer of the preliminary wheat blast forecasting model. The terms of reference for de Vargas are available upon request
University of Reading	Embed PICSA into DAE programming	Pillars 2, 3	• Identify the key opportunities for a locally adapted form of PICSA to enable farmers to make effective plans and decisions in the context of (a) existing farming and	Contract completed (value was $40,327).	Objective 1, Sub-Objective 1.3, Activity 1.3.2, Objective 3, Sub-Objective 3.2	Ongoing activities are in-kind.

Partner	Partnership Objective	Strategic Alignment	Leveraging Opportunity	Anticipated or committed funding (USD)	Objective & activity contributions (Core activity contributions)	Status of Partnership
			livelihood systems and (b) climate and related challenges • Provide technical support and training for the piloting of PICSA with DAE and other stakeholders • Develop recommendations for the wider roll out of PICSA in Bangladesh by DAE			
ICCCAD	BACS Coordination	Pillars 2, 3	• Coordination BACS executive committee and or advisory committee meetings regularly and prepare the meeting minutes. • Review the capacity building efforts on climate services in Bangladesh and help identify capacity gaps and develop tailored certification short courses for early- to mid-level professionals in climate-sensitive sectors, with an initial focus on food security and nutrition, to help address identified needs by various stakeholder organization.	Contract will be completed on (value is $30,000).	Objective 1, Sub-objective 1.2 Climate services capacity development	The sub-grant agreement has been made between ICCCAD and CIMMYT for the duration form July 01 2019 to June 30 2020. Sub-grant copies are available for review upon request.

Partner	Partnership Objective	Strategic Alignment	Leveraging Opportunity	Anticipated or committed funding (USD)	Objective & activity contributions (Core activity contributions)	Status of Partnership
			• Organize yearly BACS short course on various thematic issues of climate services. • Liaise with various Donor/Grants Making organizations and Stakeholder Organizations for inclusion as new members in BCAS committees and promote asset and fund generation. • Review BACS activity progress and reports periodically, and advise accordingly. • Represent BACS in national or international meetings. • Ensure participation of BACS in annual Gobeshona conference and having session on climate services.			

Annex 3: Monitoring, Evaluation and Learning Plan

Cumulative action and Learning Framework Report for January – December 2019

Climate Services for Resilient Development (CSRD)

Pillar	Indicator(s)	Milestones	Measurement method	Progress (Jan-Dec 2019)
Pillar 1: Create the solution space	**1.1.** Number of collaborative climate services development processes (e.g., working groups) established with identified problem focus and participation of key stakeholders.	• Collaboration among the CIMMYT-CSRD partners in an integrated way, including Bangladesh Meteorological Department (BMD), International Centre for Integrated Mountain Development (ICIMOD), Department of Agricultural Extension (DAE), International Research Institute for Climate and Society (IRI), the Bangladesh Agricultural Research Institute (BARI), Universidade de Passo Fundo (UPF), University of Rhode Island (URI), and University of Reading (UoR)	• Number of formal climate services working groups that have a clearly defined problem focus and participation of approved and designated stakeholders	**Achieved:** • Achievements listed below are for the January-December 2019 period. Readers are referred to the 2018 Annual Report for details of accomplishments from January 2018 to December 2018. • Eight periodic partner coordination meeting were held during January to December, 2019 where the focal persons from BMD and DAE and CSRD personnel took part. In these meetings the progress of work, constraints, and future work plans and responsibilities were discussed. • During the period from January to December 2019, eleven Skype meetings were held on PICSA implementation in Bangladesh. Meetings were participated by CIMMYT, University of Reading, WUR and DAE to discuss progress, planning of training and monitoring and evaluation of PICSA related activities. • Five BACS coordination meetings were held in the year of 2019 to discuss BACS governance, training programs, and launching of ENACTS in Bangladesh. Meetings were participated by CIMMYT, IRI, BMD and ICCCAD. One meeting was held between CIMMYT and IRI to discuss Dr. Simon Mason's visit to Bangladesh. Several meetings took place for organizing the 2nd BACS Training Dialogue on Introduction to Climate Services for Aquaculture and Agriculture. • Several meetings on GHG Mitigation Study were held to review the progress of crop, soil and livestock database development, data quality, data formatting and model run result sharing. The meetings were regularly participated by Ms. Fahmida Khanam Drs.

Pillar	Indicator(s)	Milestones	Measurement method	Progress (Jan-Dec 2019)
				Timothy Krupnik, Sk. Ghulam Hussain, Khaled Hossain, Tek Sapkota, and Gokul Prasad. • April 29, 2019, Monsoon Forum that starts from 29 April Dr. Hussain attended the meeting. Besides other participants and resource persons, he met with Dr. Anshul Agarawal, Senior Hydrologist of Regional Integrated Multi-Hazard Early Warning System in Thailand. Also met Francis Colledge, Senior Consultant, UK Met Office and discussed CSRD and climate service related activities being carried out in Bangladesh • On June 27, 2019 ENACTS was formally launched in Bangladesh. The Bangladesh Meteorological Department (BMD) is the first National Meteorological Service (NMS) in Asia to implement Enhancing National Climate Services (ENACTS), that focuses on the creation of reliable climate information that is suitable for national and local decision-making. ENACTS with IRI's technical support will allow BMD improve the availability, access and use of climate information at national level. • During Jan-Jun 2019, through ENACTS support two scientists from IRI provided training and worked with BD staff on organization and quality control of weather station data, install and review the ENACTS data for Bangladesh including regular updates, trouble-shooting system issues, etc. Their contributions are very useful and has enriched the knowledge and skill of the BMD staff.
		• Sub-grants awarded to CSRD partners awarded	• Signed documentation of sub-grant agreements or consultancies with eight CSRD partners (BMD, DAE, ICIMOD, IRI and BARI, UPF, URI).	**Achieved:** Achievements listed below are for the January-December 2019 period. Readers are referred to the 2018 Annual Report for details of accomplishments from January 2018 to December 2018. • All sub-grants with partners have been signed and are detailed in Annex 2 of this report.

Pillar	Indicator(s)	Milestones	Measurement method	Progress (Jan-Dec 2019)
				• BACS is hosted at the International Center for Climate Change and Development (ICCCAD) at the Independent University of Bangladesh (IUB) in Dhaka. It is created as a sub-component of the Gobeshona network, and as such will report progress to the Gobeshona Steering Committee and at each yearly Gobeshona conference. Following detailed discussions between ICCCAD and CIMMYT on behalf of CSRD and CSISA, it is agreed that CIMMYT through the CSRD project will provide support to ICCCAD for collaboration in the participatory development and institutional arrangements required to realize climate services for smallholder farmers in Bangladesh. A sub-grant was made through CSRD and CSISA to ICCCAD. As a partner, ICCCAD is developing tailored certification short courses for early- to mid-level professionals in climate-sensitive sectors, with an initial focus on food security and nutrition, to help address identified needs by various stakeholder organization. ICCCAD in consultation with CIMMYT has appointed a coordinator and an assistant coordinator on part-time basis, to assist coordinate BACS initiatives. • A second sub-grant was signed in August 2019 to DAE to implement PICSA in ten newly selected Upazilas of six districts. Forty SAAOs was trained as Master Trainer on PICSA. Now they are conducting Farmer Field Schools in twenty communities in ten selected Upazilas.
		• National scientist training, exchange, between CSRD partners and IRI	• Completion of at least 10 days of exchange training with DAE and BMD focal points at IRI at Columbia University.	**Achieved:** Achievements listed below are for the January-December 2019 period. Readers are referred to the 2018 Annual Report for details of accomplishments from January 2018 to December 2018. • Dr. Simon Mason of IRI visited Bangladesh during April 14 to 19, 2019. The main objectives of his visit were the installation and training on the operational

Pillar	Indicator(s)	Milestones	Measurement method	Progress (Jan-Dec 2019)
				seasonal forecasting system, and an introduction to the sub-seasonal forecasting. Systems have been set up using SSTs as predictors and NMME models as predictors. Both the new and the old version of CPT were used. It was expected that use the new version will produce a consolidated forecast as there is an automated system in place. Now the group working at BMD, with the collaboration of IRI, has generated one month (December 2019) and Seasonal forecast (three months) for DJF using PyCPT script and Latest version of CPT (16.2.4). These maps are available in BMD website under NextGEN_PyCPT Tab.
		• BMD and DAE knowledge and technical skill gaps identified	• Completion of BMD forecast and communication skill, and DAE communication skills completed	**Achieved:** • Achievements listed below are for the January-December 2019 period. Readers are referred to the 2018 Annual Report for details of accomplishments from January • Dr. Simon Mason of IRI came to Bangladesh on April 14 and stayed till April 19, 2019. During his stay he helped and trained BMD forecasters and meteorologists to install the updated automated version of CPT for seasonal forecasts. Operational system training was provided to the core focal point team to improve their knowledge of shell scripting. For the subseasonal forecasting, ten participants from BMD attended the training. • The automated shell scripts have been successfully installed at BMD. CSRD focal points are practicing to use the updated automated version of CPT for seasonal forecasts and also subseasonal forecasts. Although, there is an automated system in place, there is scope for development over the next few weeks and months. An introduction to the automated systems for forecasting has been completed for: (1)

Pillar	Indicator(s)	Milestones	Measurement method	Progress (Jan-Dec 2019)
				the next month (2) the next three months, and (3) the next target is cropping season. • Dr. Nachiketa Acharya of IRI visited BMD during 28 September to 3rd October 2019 to follow-up on Dr. Simon's training.
		• BMD, DAE, BARC, BARI, ICIMOD, IRI and other secondary partners' involvement in CSRD (supply of in-kind human resources, facilities, logistics)	• Letters of support from CSRD collaborating organizations clarifying in-kind partnerships and support	**Achieved:** • Achievements listed below are for the January-December 2019 period. Readers are referred to the 2018 Annual Report for details of accomplishments from January 2018 to December 2018. • CSRD has achieved in-kind staff time and logistics contributions to support agricultural climate services work from several organizations including IRI, UPF, BMD, DAE, and ICCCAD (See Annex 4 for further details). • BMD has provided office-space to CSRD staff in their headquarters in Dhaka, Bangladesh. The office has been furnished and officially opened since January of 2018 as a facility to support CSRD researchers and the Climate Services Academy. BMD is also providing venue and logistics for holding three trainings and also the launching of ENACTS. • BMD has provided venues for various training including the 2nd BACS Training Dialogue on Introduction to Climate Services for Aquaculture and Agriculture.
Pillar 2: Utilize quality data, products, and tools	**2.1.** Number of and type of information and technology resources identified and offered, or brokered, by CSRD to meet problem needs and support targeted climate services.	• Crop specific forecasting maps + management advisories refined and made publically available with ongoing refinement following user feedback	• Support to CSRD partners in developing regional and forecasting products and interfaces • Report on planning sessions to develop crop specific forecasting maps + management advisories	**Achieved:** • Achievements listed below are for the January-December 2019 period. Readers are referred to the 2018 Annual Report for details of accomplishments from January 2018 to December 2018. • Refinements in the crop specific forecasting maps + management advisories continued throughout first half of 2019.

Pillar	Indicator(s)	Milestones	Measurement method	Progress (Jan-Dec 2019)
			• Prototype crop specific forecasting maps + management advisories • Public launch of crop specific forecasting maps + management advisories • Refinements made in crop specific forecasting maps + management advisories	• An application has been developed for providing BMD's Meteorological Forecast based Agricultural Advisories by CIMMYT was presented to the relevant BMD and DAE representatives for their suggestions and comments. • On November 19, 2018, a meeting was held at the CSRD office at BMD with the Agro-meteorology Division, CSRD focal persons and the Director of BMD to share the prototype of agromet advisory related app developed by CIMMYT. • As per suggestion of BMD Director the Communication Engineer, Mr. M.A. Matin of BMD was met and it has been agreed that for housing the application a tab will be created in the BMD website which will be linked to server hosting the application. So that when a user clicks on the tab, he/she will be able to use the agromet advisory related app. • Currently, the entire client-side of the application (design and development) is also being developed by the 3CK. The initial deployment of the application took place in end of September 2019. For other climate variables and respective thresholds and any other new features to be added with the application will be decided later and additional design and script for those components will be required.
	2.2. Number of tailored products developed to support specific decisions	• Establishment of Program for Advanced Numerical Irrigation (PANI) prototype, subsequent field calibration experiments incorporating precipitation forecasts implemented with BARI	• Availability of PANI prototype application • Protocols for field experiments, and upload of resulting datasets to publicly available databases • Revised PANI prototype following CSRD partner and farmer evaluation.	**Achieved:** • All achievements detailed in this and previous reports

Pillar	Indicator(s)	Milestones	Measurement method	Progress (Jan-Dec 2019)
		• Agriculturally relevant climatology, extended-range and outlooks articulated as climactic stress risk maps generated	• Prototype availability of agriculturally relevant climatology, extended-range forecasts and outlooks articulated as climactic stress risk maps • Refinement of agriculturally relevant climatology, extended-range forecasts and outlooks articulated as climactic stress risk maps based on CSRD partner and farmer feedback • Formal establishment of agriculturally relevant climatology, extended-range forecasts and outlooks articulated as climactic stress risk maps on BMD website, with links from other CSRD partner websites	**Modifications:** Achievements listed below are for the January-December 2019 period. Readers are referred to the 2018 Annual Report for details of accomplishments from January 2018 to December 2018. • Initial USAID consultation with BMD in 2016 revealed an interest in developing seven-day precipitation forecasts with 15-day accumulative rainfall outlooks. Subsequent consultations with CSRD during the skills assessment and IRI trainings however resulted in new priorities being set that better reflect and respond to management decisions made by farmers and agricultural decision makers in the DAE and other relevant organizations. As such, the product from these activities has been renamed 'agriculturally relevant climatology, extended-range forecasts and outlooks'. These changes are detailed below and are under research and therefore in progress, with completion anticipated before Q2 of 2018. Key sub-products resulting from this work will include the following, which have been agreed on by CSRD partners: **Historical Monitoring** • Crop-specific thermal stress risk mapping • Monsoon progression: Seasonal accumulation • Monsoon progression: Deviation from the norm • Pseudo-monsoon onset • Monsoon dry spells (consecutive 5 d < 1 mm, monsoon seasonal scale) • Heavy rain events (moderately heavy and above, February-March) • Improved language, text, format for agricultural meteorological bulletin produced by BMD (note that this work is being used synergistically in the

Pillar	Indicator(s)	Milestones	Measurement method	Progress (Jan-Dec 2019)
				complementary CSMSM project in Patuakhali, Bangladesh. **Forecasts** • Crop-specific thermal stress risk mapping (extended range, < 14 day periods) • Heavy rain events (moderately heavy and above, 0-15 day forecasts in Feb-March) • Further details on progress are provided in Objective 1, Sub-Objective 1.3, Activity 1.3, Product 1.
		• Spatially explicit and meteorologically driven *Stemphylium* disease risk assessments model for South Asia (Replacement for previous Precision Nutrient Management work stream as agreed on with USAID)	• Preliminary model availability • Field protocols for model calibration in India, Bangladesh, and Nepal • Model converted to R code for integration into a formal DST • Refinement and improvement of model to improve suitability in India, Bangladesh, and Nepal	Achieved: Achievements listed below are for the January-December 2019 period. Readers are referred to the 2018 Annual Report for details of accomplishments from January 2018 to December 2018. • During January-June period, data collection, following the protocol described in previous reports, on the Stemphylium blight and other diseases for the growing season of 2018-19 was performed from 480 fields in Bangladesh, India and Nepal. Collected data are being processed for second-year's disease status analysis. These data will ultimately be used for validation of the calibrated model. Given that accessing weather data on time and space from national weather stations has been a great constraint to run model in order to provide climate-based disease forecasting. Therefore, utilization of NASA POWER generated weather data was explored whether that can be used in the forecasting system. Since the model uses sunshine hours data effort was made to convert solar radiation into sunshine hours using algorithms from literature. • Calibration of the 'Stempedia' model is being undertaken in several steps. Firstly, by running the model with single weather data-set at each of the five sties (from where weather data was available) for all the fields (176 in total) on such scenarios, the model,

Pillar	Indicator(s)	Milestones	Measurement method	Progress (Jan-Dec 2019)
				on average, underestimated the prediction (disease severity by model = 1.55 versus observation 2.21, r = 0.30). Secondly, by running the model with the same single weather data-set at each of the five sties (from where weather data was available) for the fields with more scrutinized flowering dates (73 in total); on such scenarios, the model's predictability greatly improved (disease severity by model = 2.19 versus observation 2.12, r = 0.62). Thirdly, running the model with changing parameter values; this work is ongoing and will be reported in the next phase. When completed, a better calibrated 'Stempedia' model for the region is expect.
		• Spatially explicit and meteorologically driven wheat blast (MoT) disease risk assessments model for Bangladesh and South Asia	• Coding for preliminary back-casting and forecasting models for MoT disease risk competed • Prototype of MoT forecasting DST completed • Refinement and public availability of MoT forecasting DST	**Achieved:** • Achievements listed below are for the January-December 2019 period. Readers are referred to the 2018 Annual Report for details of accomplishments from January 2018 to December 2018. • Professor Dr. Jose Mauricio Cunha Fernandes and Dr. Felipe Devargas from EMBRAPA, Passo Fundo, Brazil visited Bangladesh from the February 21st to March 05, 2019. During their stay in Bangladesh, Professor Mauricio and Dr. Felipe visited Jeshore to deliver lecture in wheat blast training in Jashore, interacted with scientists and overviewed the progress of spore trapping and processing efforts, blast lesion microscopy. The training was jointly organized by the International Maize and Wheat Improvement Center (CIMMYT), Bangladesh Wheat and Maize Research Institute (BWMRI), and the Department of Agricultural Extension (DAE) Bangladesh during 19-28 February, 2019 at Regional Agricultural Research Station, Jashore with financial support from the Australian Centre for International Agricultural Research (ACIAR), the CGIAR Research Program on Wheat (WHEAT), the Indian Council of Agricultural Research (ICAR), the Krishi Gobeshona Foundation

Pillar	Indicator(s)	Milestones	Measurement method	Progress (Jan-Dec 2019)
				(KGF) and the U.S. Agency for International Development (USAID). • During their stay in Bangladesh, Professor Mauricio and Dr. Felipe worked with the CSRD Focal persons of BMD from February 25-27, 2019 to incorporate BMD generated Weather Research and Forecasting (WRF) forecasts into Blast Model. In this regard Mr. Quamrul and or Bazlur Rashid to worked with the visitors and have successfully ingested the WRF forecasts to the model. Work at CIMMYT on DSSAT-NWheat model validation and Uploading the platform to the CIMMYT/BMD server. • Prof. Mauricio visited of Bangladesh from December 01to 07, 2019. On December 03, 2019 a high-level meeting took place with the Director BMD, Director (Field Services Wing) and Director (Plant Protection Wing) of DAE and to present wheat blast early warning system and discuss initial endorsement for wheat blast EWS roll-out in 2019/20 rabi season. This was also shared with the DG-BWMRI in the same day in the afternoon. • On December 05, 2019 CIMMYT organized the Validation Workshop and Training on Wheat Blast Early Warning System at the BARC Conference Room-1. Where Professor Maurício made a presentation on the Wheat Blast model and the Early Warning System. Among others the meeting was attended by Dr. Wais Kabir, Executive Director, Krishi Gobeshona Foundation (KGF); Mr. Shamsuddin Ahmed, Director, BMD; Dr. Dave Hodson, Principal Scientist, CIMMYT- Ethiopia; Mr. Chandi Das Kundu, Director, Field Services Wing, DAE; A Z M Sabbir Ibne Zahan, Director, Plant Protection Wing, DAE; Dr. Md. Israil Hossain, Director General, BWMRI. • The guest also highlighted the necessity of early warning systems for agriculture activities. The guests endorsed the work that has been done by CIMMYT

Pillar	Indicator(s)	Milestones	Measurement method	Progress (Jan-Dec 2019)
				and its partners. However, they opined that it needs more work and feedbacks from the users to make the system fully operational. • The EWS have been officially endorsed by DAE, BMD and BWMRI for linking to their websites on an experimental basis
		• Contributions to climate services products developed by other CSRD partners to support specific decisions	• Number of climate services products developed by other CSRD partners that the CSRD South Asia and Bangladesh group contributed to	**Achieved:** Achievements listed below are for the January-December 2019 period. Readers are referred to the 2018 Annual Report for details of accomplishments from January 2018 to December 2018. • The Fifth Gobeshona international conference was held in Dhaka during January 8-11, 2019 where the Bangladesh Climate Services Academy was presented and discussed in a Symposium on Climate Services in Bangladesh. • The Second BACS Training Dialogue on Introduction to Climate Information Service for Aquaculture and Agriculture was held during October 27-31, 2019 at the Bangladesh Meteorological Department. Under the project deliverable, CIMMYT and ICCCAD will host a session at the Gobeshona Conference on "Climate Services for Resilient Development in South Asia: Activities, outcomes, and impact" in January 2020. Planning for the session has been done in December 2019 in consultation with CIMMYT. BACS is Planning for the short course and identifying the potential group to be trained. In October, 2019, BACS's Second
	2.3. Number of people benefitting from CSRD activities.	• Quantification of people and agricultural land area benefitting from CSRD activities	• Number of people (disaggregated by gender) participating in research activities and/or applying technologies or management practices resulting from CSRD research products	**Achieved:** Achievements listed below are for the January-December2019 period. Readers are referred to the 2018 Annual Report for details of accomplishments from January 2018 to December 2018. • During April 16-20, 2019, twenty (15 male and 5 female) Cadre Officers of DAE (including ten new

Pillar	Indicator(s)	Milestones	Measurement method	Progress (Jan-Dec 2019)
			• Number of people (disaggregated by gender) trained resulting from the CSRD partnership • Number of hectares upon which farmers participating in research activities and/or applied technologies or management practices because of CSRD's research products	Upazilas from six new Districts) were trained by CSRD as PICSA Master Trainers in Khulna to facilitate future activities. Dr. Samuel Poskitt from the University of Reading was the main resource person. Mr. Tariful Newas Kabir, Meteorologist of BMD, provided technical support on weather forecast related subjects, while Mrs. Rahana Sultana of DAE and Ms Fahmida Khanam provided coordination and logistical support. • A mobile phone survey was conducted among 245 (192 male and 53 female) farmers involved in PICSA field schools in Barishal, Dinajpur, Khulna, Rajshahi, and Patuakhali during the 2018-2019 winter 'rabi' season in Bangladesh. The survey was conducted by CSRD staff from 26th March 2019 to 12th April 2019. Each farmer was asked several questions which included farmer's basic demographic information like age, sex, education, and marital status and also included close-ended questions about which steps or activity of PICSA farmers most appreciated or had difficulty understanding. They were also asked whether they received the BMD supplied short-term customized weather forecasts distributed through CSRD to DAE's Sub Assistant Agriculture Officers. The average the duration of phone interview was 13 minutes. Useful feedback form the farmers have been obtained that will help to improve future trainings and conduction of field schools. • The CSDR is currently engaged in developing two models to predict wheat blast and lentil Stemphylium blight diseases so that warning system for these diseases can be developed so that farmers can prevent crop loss from the damaging and risky weather that trigger these diseases. For calibration and validation of these models c weather data are required. A two-day training workshop on Open Data Kit (ODK) was organized by CSRD on Open Data Kit (ODK) during

Pillar	Indicator(s)	Milestones	Measurement method	Progress (Jan-Dec 2019)
				May 19 and 20, 2019 at BMD. Twenty-one (21) officials from 21selected weather stations attended program. The objective was to collect synoptic weather data in a timely and efficient manner. To facilitate data collection via ODK Android tablets were distributed among the participants. Mr. Ashok Rai was the main resource person from CIMMYT-Nepal, Mr. Khaled Hossain from CIMMYT-Bangladesh and Dr. M.A. Mannan from BMD facilitated the training. All logistic support was provided by BMD. • Seventy-two (72) participants (19 female and 53 male) from 39 government, NGO and INGO, Insurance companies, Universities attended the launching workshop. Presentations on Climate Services provided by BMD, Introduction to BMD's ENACTS Climate Datasets, Demonstration of BMD's online Climate Information Product (Maproom) were made by BMD and IRI resource persons. BMD maproom is accessible via http://datalibrary.bmd.gov.bd/
Pillar 3: Build capacities and platforms	**3.1.** Number of new capabilities to operate, deliver, or utilize climate services that are demonstrated.	• At least 150 DAE agents trained as trainers to extend use of PICSA and CSRD DSTs to DAE sub assistant agricultural officers (SAAOs).	• Training inventories and pre- and post-training test scores	**Achieved:** Achievements listed below are for the January-December 2019 period. Readers are referred to the 2018 Annual Report for details of accomplishments from January 2018 to December 2018. • Twenty Cadre officers of DAE (ten previously trained as PICSA ToT and ten new) have been trained as Master Trainer on PICSA during 16-20 April, 2019. Subsequently the trained Cadre Officers trained as Master Trainer in PICSA trained 40 SAAOs from selected from ten new upazilas were trained as ToT. • A second sub-grant was awarded to DAE basically for continuation of PICSA related activities in ten new upazilas during 2019-20 Rabi season. • 40 SAAOs from selected from ten new upazilas were trained as ToT and subsequently the trained SAAOs

Pillar	Indicator(s)	Milestones	Measurement method	Progress (Jan-Dec 2019)
				are conducting 20 PICSA farmer field schools in 20 communities in the selected new Upazilas. • In all 80 SAAOs from twenty Upazilas have been trained as ToT who are capable of training conducting PICSA farmer field schools.
		• At least 350 SAAOs subsequently trained in interpreting and communicating meteorological information effectively to farmers.	• Training inventories and pre- and post-training test scores	**Achieved:** • Achievements listed below are for the January-December 2019 period. Readers are referred to the 2018 Annual Report for details of accomplishments from January 2018 to December 2018. • In 2018-2019 eighty (80) SAAOs were trained. • The 80 trained SAAOs subsequently conducted 40 PICSA farmer field schools (FFS). In each farmer field school 25 farmers at 1:4 female: male ratio. In all 1000 farmers were inducted to PICSA.
	3.2. Number of efforts aimed at better understanding existing activities, new opportunities, and any limitations of climate services to achieve scale, replication or sustainability.	• Farmer decision making surveys	• Decision tree and/or choice experiment surveys deployed with farmers in CSRD field sites • Decision tree and/or choice experiment surveys data made publicly available on DATAVERSE following paper completion	**Achieved:** • The PICSA activities under CSRD project with selected 500 farmers in 5 districts in Bangladesh was completed in June 2019. To learn from the farmers experience and evaluate those farmers who were involved in the PICSA study CIMMYT will conduct the evaluation process. • Quantitative survey was conducted among randomly selected 280 farmers who participated in the PICSA field schools during 2018-19 Rabi season in four districts (Barishal, Patuakhali, Dinajpur and Patuakhali).. The survey was administered, using ODK, by enumerators who were trained by PICSA experts and tested the survey in a pilot with farmers in Dinajpur. The sample included 171 of men and 109 women. The results showed that the respondents considered PICSA to have a positive on their livelihoods. • CIMMYT conducted a more in-depth qualitative study with a subset of households purposively sampled from the quantitative survey respondents. A total of 12

Pillar	Indicator(s)	Milestones	Measurement method	Progress (Jan-Dec 2019)
				male and 13 female PICSA trained farmers in Barishal, Patuakhali and Rajshahi districts were interviewed. The qualitative survey in the Dinajpur district couldn't be done due to time constraints. For conducting the qualitative surveys, two CIMMYT research assistants (one male and one female) were trained by Dr. Samuel Poskitt, Postdoctoral Researcher on Agricultural Development and Climate Services from the University of Reading. CIMMYT research team is now summarizing the interview notes and the diagrams. By the end of December 2019, all the raw data including the notes and diagrams will be sent to the University of Reading for final analysis.
		• PANI business model study	• Geographically explicit business model study (quantitative and qualitative) articulating the conditions under which irrigation scheduling services are most feasible deployed in CSRD field sites	**Achieved:** Achievements listed below are for the January-December 2019 period. Readers are referred to the 2018 Annual Report for details of accomplishments from January 2018 to December 2018. • An literature review was completed to determine components for business model studies that were deployed and reported on in the [2018 semi-annual report]().
		• Number of people (disaggregated by gender) in CSRD partner organizations contributing towards, operating, or using climate services to improve agricultural decision making	• Participant observation, listing, and validation of collaborators at BMD, DAE, ICIMOD, IRI and UPF, and BARI contributing towards, operating, or using climate services to improve agricultural decision making	**Achieved:** Achievements listed below are for the January-December 2019 period. Readers are referred to the 2018 Annual Report for details of accomplishments from January 2018 to December 2018. • Seven DAE Cadre Officer (male) were trained as ToT on wheat blast protocol during February 2-4, 2019 in RARS Jashore. One SAAO briefing on wheat blast protocol was conducted in the respective 7 Upazilas. The trained SAAOs have collected data from their respective fields. Crop cut from 176 selected fields were also done. • A training workshop on "Principles and application of GIS in agriculture planning and decision making" was

Pillar	Indicator(s)	Milestones	Measurement method	Progress (Jan-Dec 2019)
				held during March 11-14, 2019 at the Bangladesh Agriculture Research Council (BARC). 19 (10 male and 9 female) participants from DAE, BARC, SRDI, BSMRAU, BJRI, SAU, BMD, BARI and BRRI attended the training. Eight Resource persons from ICIMOD, one each from CIMMYT and BARC conducted the training. • During April 16-20, 2019 Officers' Training of Trainers on PICSA for Aman season was held at CSS Ava Center, Khulna. Dr. Samuel Proskitt from University of Reading, UK and Mr. Tariful Newaz Kabir from BMD conducted the training for 20 (5 female and 15 male) DAE officers at UAO and AEO. • During April 29 to May 02, 2019 a training on IRI Climate Data Tools (CDT) and developing a method for integrating climate data was held under the auspices of ENACTS initiatives. The training was conducted by Dr. Asher Benjamin Siebert, Postdoctoral Research Scientist at IRI. Four (two male and two female) Meteorologist of BMD Ms. Nayma Baten, Ms. Shahnaz Sultana, Mr. A K M Nazmul Haque and Mr. Md. Aftab Uddin participated. • Under the same initiatives, a follow up training was held during June 9-27, 2019. The training was facilitated by Mr. Igor Yurievich Khomyakov of IRI. The training was attended by ten (two three female and seven male) officers of BMD. Both the trainings are very useful in data management. These training have enriched the knowledge of the BMD scientists.
Pillar 4: Build knowledge	**4.1.** Number of captured and shared lessons learned (e.g., case studies) pertaining to the policy, practice, and research of climate services development,	1. **Report:** Report on crop specific climate thresholds and farmer decision making framework for key food and income staples identifying ways to incorporate	• Availability of short report/case study/success story	**Achieved:** Achievements listed below are for the January-December 2019 period. Readers are referred to the 2018 Annual Report for details of accomplishments from January 2018 to December 2018. This details progress on a narrative report on crop-specific weather constraints and farmers' decision making processes with respect to crop management and weather in in Bangladesh has been made

Pillar	Indicator(s)	Milestones	Measurement method	Progress (Jan-Dec 2019)
	adoption, and maintenance.	meteorological information.		(See Objective 1, Sub-Objective 1.3, Activity 1.3.1, Product 1). • A systematic literature review has been completed as described in the 2018 semi-annual report. Crop specific climate thresholds continue to be refined for farmer decision making are being refined following CSRD partner feedback. Rather than develop a short report, information on how the thresholds are being used are being developed and was completed in the Q3 of 2019 as part of the methodological description of the improved BMD bulletin described in Objective 1, Sub-Objective 1.3:
		2. **Report:** Farmer decision making survey analysis. Information used to further refine packaging of climactic information presented by BMD and DAE.	• Availability of short report/case study/success story	**Achieved:** • An entirely new method to estimate potential economic value of weather forecasts termed "hindcast experiment" is developed. A choice experiment approach to understand the role of seasonal forecasts in crop choices is also being tested for the first time. It is expected that these methods will become a standard for similar assessments in future. • Achievements listed below are for the January-December 2019 period. Readers are referred to the 2018 Annual Report for details of accomplishments from January 2018 to December 2018. • The surveys on farmer decision making and climate information which included two experiments, 1) "a hindcast experiment" where past weather data is used to create a series of hypothetical short term forecasts for wheat and rice crops to understand possible farmer responses and constraints and 2) a "choice experiment" to understand farmers cropping system choices in response to seasonal forecasts are completed in selected districts in Bangladesh, Nepal and Bihar. • Understanding the value of short term forecast based agro-advisory using a climate sensitive decision frame

Pillar	Indicator(s)	Milestones	Measurement method	Progress (Jan-Dec 2019)
				of rice-wheat farmers in Nepal, India and Bangladesh is attempted here using a decision based analysis. Farmers are presented with the weather data of past year and asked for potential changes in decisions if the information was available to them with a lead time of 5 days. • The results show high untapped potential for climate services that potentially aims to reduce the effect of unsuitable planting dates, heat stress at critical temperature thresholds and harvest time damages. These three services can take bulk of the value that will be created for agro-advisories in south Asia. It is to be noted that hindcast experiments did not evaluate disease forecasts, which has obvious economic benefits. Farmers shows a high interest in accessing these services and ex-ante evaluation shows that they are indeed capable to increase yield and income levels in South Asia. The provision of services are only necessary condition to realize its value but not sufficient. It also needs supports from various fronts from seed supply, financial access, manual and machine labour availability, access to irrigation water and post-harvest storage structures. The results provide evidence to support further investment in climate services that can generate significant social welfare effects and lead to enhanced food security for households and the nations.
		3. **Report:** Potential for incorporation of maps and decision tools into existing decision support platforms (CARFT, LCAT, CPT, etc.).	• Availability of short report/case study/success story	**In progress:** • Report modified into submission of a peer-reviewed paper and available on request.

Pillar	Indicator(s)	Milestones	Measurement method	Progress (Jan-Dec 2019)
		4. **Report:** Business model appropriateness and results of PANI calibration experiments.	• Availability of short report/case study/success story	**Achieved:** • A short business model report is available upon request, and was detailed in the 2018 mid-year report.
		5. **Graphical report (Maps):** Use of historical gridded climatic data to evaluate the past frequency of occurrence of the climactic conditions conducive to wheat blast outbreak	• Availability of short report/case study/success story	**Achieved:** • This report is completed and available in Annex 4 of the 2018 Annual report.
		6. **Report:** STEMPEDIA: Lentil *Stemphylium* blight disease forecasting systems in Bangladesh, Nepal, and India	• Availability of short report/case study/success story	**Achieved:** • An initial report on 2017/18 lentil disease monitoring and model validation activities will be completed after by Q2 of 2019. • An initial report on model performance in Nepal, Bangladesh, India will be supplied after the CSRD project is completed in the last season of experimental evaluations. • This item is on schedule. Two reports are being prepared: (i) Full analysis of two years (2017-18 and 2018-19) of field data on lentil Stemphylium and other diseases in Bangladesh, India and Nepal; and (ii) a manuscript on calibrating, testing and applying Stempedia model under South Asian agro-environment aiming to publish in a reputed peer reviewed journal. • Regarding the first report, analysis of lentil Stemphylium and associated diseases of the collected data from 480 fields in the three countries during 2017-18 season have been completed. Data for 2018-19 season from the similar number of fields are being compiled and analyzed. This report will appear in the CSRD project completed report due in the end of 2019.

Pillar	Indicator(s)	Milestones	Measurement method	Progress (Jan-Dec 2019)
				• On the second report i.e. publishing a scientific paper, the Stempedia model is being calibrated with 2017-18 datasets. For this, a custom-made R-Program has been development. The aim is to explore the avenues of improvement of the model, as require, towards devolving a weather-based forecasting system on aiding farmers in deciding how much and when fungicide to use in economically managing the Stemphylium disease. The field data from 2017-18 season will be used to independently validate the model. We are targeting one of the four reputed journals to publish the paper: PLOS One, Phytopathology, USDopean Journal of Plant Pathology and Australasian Journal of Plant Pathology. The manuscript will be submitted in October 2019. • Given that accessing weather data on time and space from national weather stations has been a great constraint to run model in order to provide climate-based disease forecasting, we are exploring utilization of NASA POWER generated weather data that can be used in the forecasting system. A section of the reports will present this analysis.
		7. **Report:** BMD and DAE forecast and climate services assessment report	• Availability of short report/case study/success story	**Achieved:** • This report has been delivered. Please see the 2016-2017 Annual Report for the report, with implications discussed in the 2018 mid-year report.
		8. **Success story or Case study:** At least 10 CSRD case studies and success stories completed	• Availability of short report/case study/success story	**Achieved:** • During January-December 2019 three success stories related to CSRD were published. The story App decreases delays in data collection describes who to enhance the time-efficiency of daily weather database creation, CSRD delivered a training to officials on the Open Data Kit, a user-friendly app for easy data gathering and consolidation. The story titled "Bridging Gap between Theory and Reality" narrates about how the workshop participants were provided with a more in depth understanding of GIS and similar technologies

Pillar	Indicator(s)	Milestones	Measurement method	Progress (Jan-Dec 2019)
				as well as how to incorporate GIS into their respective fields of work. The third story was about "Building Resilience against Wheat Blast Disease through Collaborative Research and Action" that describes what are being done to fight the disease with help from national and international sources. • Three communications and news about CSRD were published during January-June 2019. These are Climate data matters By Tasfia Tasnim published in DhakaTribune (National Daily, Bangladesh), Stempedia Model: Fighting Blight in Lentil By M. Shahidul Haque Khan and Sultana Jahan published in CSISA website and a Photo story: Six Agricultural Innovations Combating Climate Change published in CIMMYT website.
		9. Scientific paper: Farmer decision making structures: What role is there for climate information in Bangladesh?	• Paper drafted and submitted to open-access, per review journal	**Achieved:** Surveys in Bangladesh, India and Nepal haven been completed. An additional survey to generate data to link the CaFFSA project on rice-fish and aquaculture systems, a complementary CCAFS project in Bangladesh in cooperation with WorldFish is also completed as a part of the exit strategy. The scientific article will be submitted in mid 2020 that will provided detailed results from hindcast experiment framework.
		10. Scientific paper: Opportunities and constraints for agricultural climate services in Bangladesh	• Paper drafted and submitted to open-access, per review journal	**In progress:** • This paper will be submitted by mid 2020 and is in progress.
		11. Scientific paper: Incorporating forecast information into irrigation scheduling services in Bangladesh	• Paper drafted and submitted to open-access, per review journal	**In progress:** • Paper under development, submission before 2020 ends.
		12. Scientific paper: Towards early warning	• Paper drafted and submitted to open-access, per review	**In progress:**

Pillar	Indicator(s)	Milestones	Measurement method	Progress (Jan-Dec 2019)
		systems for MoT in South Asia	journal (BARI, BMD, DAE, UPF)	• Anticipated submission before the completion of the CSRD project in 2019. • The paper titled 'Towards early warning systems for MoT in South Asia' is expected mid 2020/
		13. Scientific paper: Feasibility assessment of drought forecasting for agricultural climate services: A comparison of resolution scales (led by ICIMOD with BARC)	• Paper drafted and submitted to open-access, per review journal	**In progress:** • ICIMOD's analysis did not provide sufficient data for publication. Further analysis is underway in other projects.

Annex 4: In-kind letters of support from partners

International Centre for Climate Change and Development (ICCCAD)

Date: 19 December 2019

To

Timothy J. Krupnik
Systems Agronomist
Climate Services for Resilient Development in South Asia (CSRD) - Project Leader
Cereal Systems Initiative for South Asia (CSISA) - Bangladesh Country Coordinator
International Maize and Wheat Improvement Center (CIMMYT) | Sustainable Intensification Program
House 10/B. Road 53. Gulshan-2. Dhaka, 1213, Bangladesh

Subject: Involvement with in-kind support in the development initiative along with Climate Services for Resilient Development in South Asia (CSRD)

Dear Dr. Krupnik,

With this letter, I would like to confirm that International Centre for Climate Change and Development (ICCCAD) at Independent University, Bangladesh (IUB) has been involved with Climate Services for Resilient Development in South Asia (CSRD) Project since the January, 2018. Our 2 researchers along with me and our Deputy Director are involved with the Bangladesh Academy for Climate Services (BACS) as part of the CSRD activities.

From the mid of 2019 till the end of this year, we have participated actively in organizing the ENACTS launch workshop and 2nd BACS Short Course, staring from the planning to the report writing. Also, a small team from ICCCAD is closely involved with subgrant from CIMMYT.

Other than the above-mentioned activities, ICCCAD team with support from other BACS co-founders are planning to host a session in Gobeshona conference which will be held in January 2020. The team had several adhoc skype meetings in planning the sessions in Gobeshona6.

Considering the involvement of our researchers and the institutional policy and payment guideline, the in-kind contribution to CRSD has been estimated at USD 22,000 which is twenty-two thousand dollars.

We look forward to continuing our cooperation and support for the important CSRD work.

Thank you,

Saleemul Huq

Dr. Saleemul Huq
Director
International Centre for Climate Change and Development (ICCCAD)
at Independent University, Bangladesh (IUB)
House: 27, Road: 01, Block: A, Bashundhara R/A, Dhaka-1212
Email: saleemul.huq@iied.org

Secretariat : Plot – 16, Block-B, Aftabuddin Ahmed Road, Bashundhara R/A, Dhaka- 1212, Bangladesh
Tel- +88-02-840 1645-53, www.iub.edu.bd www.icccad.net

Research Office : House-27 (5th floor), Road-1, Block-A, Bashundhara R/A, Dhaka 1212, Bangladesh
Tel- 880-1760746401, 880-1779754662, E-Mail: saleemul.huq@iied.org

The International Research Institute for Climate and Society

November 15, 2019

Timothy J. Krupnik
Systems Agronomist
Climate Services for Resilient Development in South Asia (CSRD) - Project Leader
Cereal Systems Initiative for South Asia (CSISA) - Bangladesh Country Coordinator
International Maize and Wheat Improvement Center (CIMMYT) | Sustainable Intensification Program
House 10/B. Road 53. Gulshan-2. Dhaka, 1213, Bangladesh

Subject: Involvement with in-kind support in the development initiative along with Climate Services for Resilient Development in South Asia (CSRD)

Dear Dr. Krupnik,

With this letter, we would like to confirm that the International Research Institute for Climate and Society (IR), Columbia University has been involved with Climate Services for Resilient Development in South Asia (CSRD) Project since June 2017. Nine of our staff, including researchers, are involved with CSRD activities.

IRI's activity under CSRD includes technical backstopping, training and research for climate service development in Bangladesh. Considering the involvement of our staff and researchers and the institutional policy and payment guideline, the in-kind contribution to CRSD, specifically work done under other projects complementing and enhancing CSRD activities and outputs, has been estimated at $87,000 USD, or eighty-seven thousand dollars United States Dollars.

Thank you,

Ashley Curtis
Research Staff Associate
The Earth Institute, Columbia University, Lamont Campus
61 Route 9W, Monell Building
Palisades, NY 10964-8000 USA

The Earth Institute
Columbia University, Lamont Campus
61 Route 9W, Monell Building
Palisades, NY 10964-8000 USA

Phone: 1.845.680.4468
Fax: 1.845.680.4866

http://iri.columbia.edu

UPF
UNIVERSIDADE
DE PASSO FUNDO

Date: November 05, 2019
From: José Maurício C. Fernandes
Professor/Senior Researcher
Universidade de Passo Fundo
BR 285, São José| Passo Fundo/RS | CEP: 99052-900 Brazil

To: Timothy J. Krupnik
Systems Agronomist
Climate Services for Resilient Development in South Asia (CSRD) - Project Leader
Cereal Systems Initiative for South Asia (CSISA) - Bangladesh Country Coordinator
International Maize and Wheat Improvement Center (CIMMYT) | Sustainable Intensification Program
House 10/B. Road 53. Gulshan-2. Dhaka, 1213, Bangladesh

Subject: Involvement with in-kind support with the development initiative along with Climate Services for Resilient Development in South Asia (CSRD)

Dear Dr. Krupnik,

This letter is here to confirm that our organization the Universidade de Passo Fundo has been involved with CSRD project since the beginning 2017. Currently, three faculty members are engaged in the CSRD project. Considering the involvement of our faculty members the total yearly cost per institutional policy and payment guideline has been calculated as USD$ 10,000 (ten thousand US dollars).

Thank you,

José Maurício C. Fernandes
Professor/UPF/PPGCA

International Centre for Climate Change and Development (ICCCAD)

Date: 19 December 2019

To

Timothy J. Krupnik
Systems Agronomist
Climate Services for Resilient Development in South Asia (CSRD) - Project Leader
Cereal Systems Initiative for South Asia (CSISA) - Bangladesh Country Coordinator
International Maize and Wheat Improvement Center (CIMMYT) | Sustainable Intensification Program
House 10/B. Road 53. Gulshan-2. Dhaka, 1213, Bangladesh

Subject: Involvement with in-kind support in the development initiative along with Climate Services for Resilient Development in South Asia (CSRD)

Dear Dr. Krupnik,

With this letter, I would like to confirm that International Centre for Climate Change and Development (ICCCAD) at Independent University, Bangladesh (IUB) has been involved with Climate Services for Resilient Development in South Asia (CSRD) Project since the January, 2018. Our 2 researchers along with me and our Deputy Director are involved with the Bangladesh Academy for Climate Services (BACS) as part of the CSRD activities.

From the mid of 2019 till the end of this year, we have participated actively in organizing the ENACTS launch workshop and 2nd BACS Short Course, staring from the planning to the report writing. Also, a small team from ICCCAD is closely involved with subgrant from CIMMYT.

Other than the above-mentioned activities, ICCCAD team with support from other BACS co-founders are planning to host a session in Gobeshona conference which will be held in January 2020. The team had several adhoc skype meetings in planning the sessions in Gobeshona6.

Considering the involvement of our researchers and the institutional policy and payment guideline, the in-kind contribution to CRSD has been estimated at USD 22,000 which is twenty-two thousand dollars.

We look forward to continuing our cooperation and support for the important CSRD work.

Thank you,

Saleemul Huq

Dr. Saleemul Huq
Director
International Centre for Climate Change and Development (ICCCAD)
at Independent University, Bangladesh (IUB)
House: 27, Road: 01, Block: A, Bashundhara R/A, Dhaka-1212
Email: saleemul.huq@iied.org

Government of the People's Republic of Bangladesh
Bangladesh Meteorological Department
Meteorological Complex, Agargaon,
Dhaka-1207, Bangladesh.

Phone: + 88 02 9123838
Fax: + 88 02 8118230, 9103908
E-mail: info@bmd.gov.bd
Web: www.bmd.gov.bd

To
Timothy J. Krupnik
Senior Scientist and Systems Agronomist
Climate Services for Resilient Development in South Asia (CSRD) - Project Leader
Cereal Systems Initiative for South Asia (CSISA) - Bangladesh Country Coordinator
International Maize and Wheat Improvement Center (CIMMYT)
House 10/B, Road 53, Gulshan-2, Dhaka, 1213, Bangladesh

Subject: Involvement with in-kind support with the development initiative along with Climate Services for Resilient Development in South Asia (CSRD)

Dear Dr. Krupnik

This letter is here to confirm that our organization Bangladesh Meteorological Department has been involved with the USAID supported project "Climate Services for Resilient Development (CSRD)", and are working towards improving weather forecasting skills and providing better agro-meteorological weather forecasts since the beginning in 2017. Our four staff members are involved and spend 20% of their lime in this program. In addition, BMD has provided office space in the BMD campus for CSRD and are providing conference room, and other logistics support for organizing national level training, workshop, meeting, and seminar under this initiative.

Considering the involvement of our staff members and physical facilities and logistics provided, the value (in-kind) for the collaboration from January 2017 to end of December 2019 is estimated at BDT 1,500,000 (in word one million five hundred thousand taka) or USD 17,650.

Thanking you

26.12.19

Shamsuddin Ahmed
Director

গণপ্রজাতন্ত্রী বাংলাদেশ সরকার
কৃষি সম্প্রসারণ অধিদপ্তর
খামারবাড়ি, কৃষি খামার সড়ক, ঢাকা-১২১৫

Government of the People's Republic of Bangladesh
Department of Agricultural Extension
Khamarbari, Krishi Khamar Sarak, Dhaka-1215

To

ডি,ও,নং- 921 (6)

তারিখ ঃ 05/11/2019

Timothy J. Krupnik
Systems Agronomist
Climate Services for Resilient Development in South Asia (CSRD) - Project Leader
Cereal Systems Initiative for South Asia (CSISA) - Bangladesh Country Coordinator
International Maize and Wheat Improvement Center (CIMMYT) | Sustainable Intensification Program
House 10/B. Road 53. Gulshan-2. Dhaka, 1213, Bangladesh

Subject: Involvement with in-kind support in the development initiative along with Climate Services for Resilient Development in South Asia (CSRD)

Dear Dr. Krupnik,

Greetings from DAE with this letter, we would like to confirm that our organization Department of Agricultural Extension (DAE) has been involved with Climate Services for Resilient Development in South Asia (CSRD) Project since the July/2017. Our 05 officers 02 Secondary Technical Staffs are directly involved from DAE head quarter and field level officers & SAAOs are also involved with CSRD activities in the project areas as ten Upazilas of five districts in first sub grant also in new sub grant another10 Upazilas of new six districts of Bangladesh. This new sub grant of CSRD project will be implemented up to december/2019. We have spent 20% of our time for implementation of this project.

We have participated and facilitated implementation of field level all activities of CSRD project in respective Districts & Upazilas. Considering the involvement of our Department and the institutional policy and payment guideline the in-kind contribution to CSRD has been estimated at 39735 US$ (thirty nine thousand seven hundred thirty five US$).

We look forward to continue our cooperation with and support for the implementation of CSRD Project activities.

Thank you,

05/11/2019
(Dr. M Shahab Uddin)
Additional Director (Project Planning)
PPI & ICT Wing and CSRD Lead (DAE Part),
DAE, Khamarbari, Dhaka.
Phone;-02-55028201
E-mail:-shahabipm@gmail.com

Copy to:

1. Director, Field Service Wing, DAE, Khamarbari, Dhaka-1215.
2. Dr. Mazharul Aziz, Project Director, Agro-Meteorological Information Systems Development Project, Component-C of Bangladesh Weather and Climate Services Regional Project and Sub Focal Person for CSRD Project, Department of Agricultural Extension (DAE), Khamarbari, Farmgate, Dhaka-1215
3. Rahana Sultana, Agricultural Economist, Planning Project Implementation & ICT Wing and Sub Focal Person for CSRD Project, Department of Agricultural Extension (DAE), Khamarbari, Farmgate, Dhaka-1215
4. Sk. Ghulam Hussain PhD, Senior CSRD Partner and Technical Coordinator (CIMMYT-Bangladesh.
5. PS to Director General (DG), DAE, Khamarbari, Dhaka-1215.

Phone: Office: 9140850, 9140857, Fax No. 9111502 ফোনঃ ৯১৪০৮৫০, ৯১৪০৮৫৭, ফ্যাক্সঃ ৯১১১৫০২

Annex 5: Success stories and communication pieces produced during CSRD

Education to boost climate resilience:
Bangladesh Academy for Climate Services taking shape

On 21 March, 2018, fifty individuals from across 26 organizations came together to design an academy and learning umbrella for climate services in Bangladesh through a participatory and multi-stakeholder design workshop which took place at the Bangladesh Meteorological Department (BMD) in Dhaka, Bangladesh. The workshop was a joint initiative of the International Research Institute for Climate and Society (IRI), ICCCAD, CIMMYT and the CSRD in South Asia partnership. Supported by the United States Government and USAID.

Dr. Timothy J. Krupnik, International Maize and Wheat Improvement Centre's (CIMMYT) Systems Agronomist and Climate Services for Resilient Development (CSRD) in South Asia Project Leader, Ms. Melody Braun, Research Staff Associate of Columbia University and Dr. Saleemul Huq, Director of International Centre for Climate Change and Development (ICCCAD), founding members of the Bangladesh Academy for Climate Services (BACS) initiative, led the interactive workshop. Dr. Saleemul Huq said, "*We are hopeful to build such an institution that can help set up a long term capacity building movement for climate services in Bangladesh*".

The workshop encouraged the active networking of the participants from across sectors spanning health, agriculture, economic development and the financial sector, and disaster management. Participants discussed and identified constraints to long-term national capacity development in climate services, as well as ways to develop curricula and solutions to improve educational access to climate science and communication courses. The importance of developing both professional short course and advanced degree curricula was highlighted and discussed at length. This was the first of a series of events aimed at developing a self-sustaining cross-institutional academy for climate services in Bangladesh.

"*We are happy to partner with a broad range of organizations, committed individuals, educators, and universities to build a national platform to support education on climate services in Bangladesh,*" commented Timothy J. Krupnik, "*While both my own and my organization's expertise lies in agriculture, we envision that the BACS will be cross-sectoral. It will therefore appeal to young students and professionals to apply and communicate climate science to the public to improve decision making, not only in agriculture, but in a diversity of sectors relevant to Bangladesh's national Development*".

Participants identifying constraints to long-term national capacity development in climate services, and also ways to develop curricula and solutions to improve educational access to climate science and communication courses.
Photo: Uttam Barma (CIMMYT)

Climate Services for Resilient Development (CSRD) is a global partnership whose core mission is to translate actionable climate information into easy to understand formats to spread awareness and use of climate services. The CSRD consortium in South Asia is led by the International Maize and Wheat Improvement Center (CIMMYT) in partnership with the Bangladesh Meteorological Department (BMD), Bangladesh Department of Agricultural Extension (DAE), Bangladesh Agricultural Research Council (BARC), Bangladesh Agricultural Research Institute (BARI), International Center for Integrated Mountain Development (ICIMOD), International Institute for Climate and Society (IRI), University de Passo Fundo (UPF), and the University of Rhode Island (URI).

Strategic alignment

Published by: International Maize and Wheat Improvement Center (CIMMYT): House 10/B, road 53, Gulshan 2, Dhaka 1212, Banglade
For more information pls. contact: t.krupnik@cgiar.org

Bangladesh's agriculture community drives creation of new climate services

A series of three workshops focused on improving climate information tailored for the agriculture sector took place starting in November 2017. These workshops were sponsored by the USAID funded *Climate Services for Resilient Development (CSRD) in South Asia and Bangladesh* project and have brought about improved forecasting capabilities of the Bangladesh Meteorological Department (BMD). The workshops also helped to strengthen the relationship between BMD and Bangladesh's Department of Agriculture Extension (DAE). The activities pave the way for new climate information products developed especially for DAE's needs, and ultimately to help the farmers it serves.

An interactive workshop held in 2018 at IRI in New York, USA where BMD scientists learned to use a new, automated version of the Climate Predictability Tool. Officers from DAE also participated in this training. Photo: Timothy Krupnik (CIMMYT)

The International Maize and Wheat Improvement Center (CIMMYT) is the lead partner of the USAID-funded project. Columbia University's International Research Institute for Climate and Society (IRI), BMD and DAE are the other major partners. The trainings included foundational climate science concepts, such as how to verify and calibrate forecasts, and improve the efficiency and quality of forecasting. In an extended two-week training held in March 2018 at IRI's headquarters in New York, the BMD scientists learned to use a new, automated version of the Climate Predictability Tool.

BMD scientists expressed the usefulness of learning of how climate services could be applied in different sectors. *"It is a very new dimension," said Bazlur Rashid, a BMD scientist. "In our country, people think that a weather forecast means it is disaster-related event. But we can apply climate information not only to the disaster sector but to other sectors as well, such as health and agriculture."* At the March training, DAE participants clarified the time and phases for activities in the production of several major crops, to BMD and other workshop participants so that the crop calendar developed showed where and when climate information could best be used.

"In the vegetative growth phase, we need rainfall and temperature information. In the reproductive phase of rice, we need humidity," Shehab Uddin, an agronomist from DAE said. "When it is hot and humid, more insects will come. But then if we know in advance we can advise farmers to take preparations to protect their crop from attack." Moving forward, close collaboration between BMD and DAE is essential to continue to develop effective climate services for agriculture in Bangladesh. "*This is easier said than done*", said Timothy Krupnik, an agronomist and CSRD Project Leader at the International Maize and Wheat Improvement Center (CIMMYT) and CSRD Project Leader. "*There aren't incentives for cross-ministry, cross-department collaboration in Bangladesh, but collaboration can add a significant value through our work with IRI, BMD and DAE to strategically leverage for impact, ultimately benefitting farmers by merging agronomy with climate and extension science.*"

Climate Services for Resilient Development (CSRD) is a global partnership whose core mission is to translate actionable climate information into easy to understand formats to spread awareness and use of climate services. The CSRD consortium in South Asia is led by the International Maize and Wheat Improvement Center (CIMMYT) in partnership with the Bangladesh Meteorological Department (BMD), Bangladesh Department of Agricultural Extension (DAE), Bangladesh Agricultural Research Council (BARC), Bangladesh Agricultural Research Institute (BARI), International Center for Integrated Mountain Development (ICIMOD), International Institute for Climate and Society (IRI), University de Passo Fundo (UPF), and the University of Rhode Island (URI).

Strategic alignment

Published by: International Maize and Wheat Improvement Center (CIMMYT); House 10/B, road 53, Gulshan 2, Dhaka 1212, Bangladesh
For more information pls. contact: t.krupnik@cgiar.org

On-the job training boosts national remote sensing skills for drought monitoring in Bangladesh

A two-week on-the-job training took place in March on the application of remote sensing in drought monitoring and crop mapping in Kathmandu, Nepal o build the capacity of young and mid-career professionals from the Bangladesh Agricultural Research Council (BARC), Bangladesh's apex agricultural research body, and the Bangladesh Agricultural Research Institute (BARI). The training was organized with the support of the USAID funded Climate Services for Resilient Development (CSRD) project under the lead of International Maize and Wheat Improvement Center (CIMMYT) led initiative in South Asia, in collaboration with the International Centre for Integrated Mountain Development (ICIMOD).

Dr. Suraya Parvin (left), Senior Scientific Officer of BARC, discussing with the facilitator in the training. Photo: Faisal Mueen Qamer

This learning exchange coached the BARC and BARI professionals to learn new tools in drought monitoring and forecasts. With these tools, farmers can be advised on how to address the risks for agricultural drought in north-western Bangladesh where farmers have limited access to irrigation, resulting in bottlenecks in crop productivity and adverse impact on the livelihoods of smallholder farmers who are reliant on variable and unpredictable precipitation. Access to quality drought monitoring and forecasts would assist farmers in adapting to these climactic risks and meteorological and agricultural research institutions play a crucial role in providing improved information flow and drought risks advisories to farmers. The training strengthened the remote sensing capabilities of professionals from BARC and BARI in using satellite-based remote sensing tools and crop mapping to monitor drought risks. Dr. Mir Matin, Theme Leader of Geospatial Solutions, organized the training on behalf of CSRD and ICIMOD, along with Dr. Rajesh Bahadur Thapa, Capacity Building Specialist and Bhoj Raj from ICIMOD's Bhoj Raj.

Dr. Suraya Parvin, Senior Scientific Officer of BARC commented that "*Bangladesh, especially the northern region, is most susceptible to drought and it is difficult to grow year-round crops here. To increase the cropping intensity in this region, drought monitoring is very essential. I think this training was extremely useful to prepare us for this challenge.*"

The CSRD partnership and ICIMOD are working together to establish user-oriented platforms for the provision of easily accessible, timely and decision relevant scientific information, in the form of climate services. "*This training, and the applied science products that will come from it, will be a crucial part of efforts to increase the resilience of Bangladesh's smallholder farmers to climatic risks,*" commented Dr. Timothy J. Krupnik, Systems Agronomist and CSRD Project Leader. "*Working with the graduates of the training on a day-to-day basis, we expect to deepen BARC and BARI's contributions to applied climate services in Bangladesh.*"

Climate Services for Resilient Development (CSRD) is a global partnership whose core mission is to translate actionable climate information into easy to understand formats to spread awareness and use of climate services. The CSRD consortium in South Asia is led by the International Maize and Wheat Improvement Center (CIMMYT) in partnership with the Bangladesh Meteorological Department (BMD), Bangladesh Department of Agricultural Extension (DAE), Bangladesh Agricultural Research Council (BARC), Bangladesh Agricultural Research Institute (BARI), International Center for Integrated Mountain Development (ICIMOD), International Institute for Climate and Society (IRI), University de Passo Fundo (UPF), and the University of Rhode Island (URI).

Strategic alignment

Published by: International Maize and Wheat Improvement Center (CIMMYT): House 10/B, road 53, Gulshan 2, Dhaka 1212, Bangladesh
For more information pls. contact: t.krupnik@cgiar.org

No more doubts about droughts

A regional drought forum delves into the current state of climate information availability and calls for sharing information regarding natural hazards.

Droughts have affected agriculture, food security, and the livelihoods of millions of people in South and Southeast Asia with increasing frequency and severity. As the climate continues to change, agricultural productivity across nations will likely suffer as changes in rainfall patterns and intensity affect agricultural production. This scenario demands a dramatic increase in the availability of timely and accurate information on climate and crop conditions.

Agricultural and hydrological drought monitoring and early warning systems; drought impacts and climate risk financing; land use practices and policies; and crop mapping and yield estimation are key areas related to agriculture and climate services. These issues and the emerging potential of Earth observation information and climate modelling for reducing climate-related vulnerabilities in the agriculture sector in South and Southeast Asia were discussed at a forum held in Kathmandu. The Regional Knowledge Forum on Drought was held at the International Centre for Integrated Mountain Development (ICIMOD) from 8–10 October, 2018.

Delegates at the Regional Knowledge Forum on Drought, ICIMOD, Kathmandu.
Picture: Jitendra Bajracharya/ ICIMOD

Climate Services for Resilient Development (CSRD) is a global partnership whose core mission is to translate actionable climate information into easy to understand formats to spread awareness and use of climate services. The CSRD consortium in South Asia is led by the International Maize and Wheat Improvement Center (CIMMYT) in partnership with the Bangladesh Meteorological Department (BMD), Bangladesh Department of Agricultural Extension (DAE), Bangladesh Agricultural Research Council (BARC), Bangladesh Agricultural Research Institute (BARI), International Center for Integrated Mountain Development (ICIMOD), International Institute for Climate and Society (IRI), University de Passo Fundo (UPF), University of Rhode Island (URI) and the University of Reading (UoR).

The knowledge forum established an expert working group comprised of representatives from different institutions working on drought early warning systems and agriculture advisory services to foster regional cooperation on agriculture and drought monitoring and management. Discussing examples from South and Southeast Asia, panellists at the forum showcased the contributions Earth observation technologies and climate services make to establishing national and regional drought monitoring and early warning systems and agro-advisory services. Their contribution is especially important in cases where ground level data are minimal or non-existent. The forum also reiterated the need for regional collaboration in developing and sharing information on climate-induced hazards.

The event was organized by ICIMOD and ADPC under the framework of the SERVIR initiative, a joint initiative between the United States Agency for International Development (USAID) and the National Aeronautics and Space Administration (NASA). The Climate Services for Resilient Development (CSRD), the International Maize and Wheat Improvement Center (CIMMYT), and the World Food Program (WFP) partnered in organizing the knowledge forum.

Strategic alignment

Published by: International Maize and Wheat Improvement Center (CIMMYT); House 10/B, road 53, Gulshan 2, Dhaka 1212, Bangladesh
For more information, pls. contact t.krupnik@cgiar.org

End of despair over disparity

The Bangladesh Academy for Climate Services helps bridge information gaps and provides a platform for stakeholders to communicate their findings and needs.

In Bangladesh and many other countries, there is a disconnect between climate science and its use. Hence, decision makers ranging from policy makers to farmers could benefit from increased access to relevant climate information. This creates the need for a platform to connect the users and producers of climate information. Therefore, to ensure that actionable climate service information is delivered to decision makers, the Bangladesh Academy for Climate Services (BACS) was launched on 5 August, 2018 in the Bangladesh Meteorological Department (BMD). The academy was jointly founded by the International Center for Climate Change and Development (ICCCAD), the International Research Institute for Climate and Society (IRI) at Columbia University and the International Maize and Wheat Improvement Center (CIMMYT).

Dr. Saleemul Haque, Director of International Centre for Climate Change and Development (ICCCAD) explained why it was necessary to introduce an academy like BACS. Photo: M. Shahidul Haque Khan

BACS was created to open trans-sectorial and multi-stakeholder dialogue on climate services to identify existing initiatives, challenges and opportunities. The academy also aims to design tailored certification courses for students and early- to mid-level professionals to help address identified needs, and plans to create graduate-level curricula to train a new generation of weather, climate and sector experts with the skills needed to face the uncertainty of the coming decades.

Speaking at the event, Dr. Timothy J. Krupnik, senior scientist and systems agronomist at CIMMYT, said, "This academy is vital for bringing climate information to the public and is open for partners who are working in this area. Our job is to help the improvement of the use of climate services in Bangladesh."

The courses offered by BACS are intended for early- to mid-level professionals and students who are working in fields related to agriculture and food systems, disaster preparedness and response, and public health, among others, and who want to actively engage in developing climate services for their sectors in Bangladesh.

Climate Services for Resilient Development (CSRD) is a global partnership whose core mission is to translate actionable climate information into easy to understand formats to spread awareness and use of climate services. The CSRD consortium in South Asia is led by the International Maize and Wheat Improvement Center (CIMMYT) in partnership with the Bangladesh Meteorological Department (BMD), Bangladesh Department of Agricultural Extension (DAE), Bangladesh Agricultural Research Council (BARC), Bangladesh Agricultural Research Institute (BARI), International Center for Integrated Mountain Development (ICIMOD), International Institute for Climate and Society (IRI), University de Passo Fundo (UPF), University of Rhode Island (URI) and the University of Reading (UoR).

Strategic alignment

Published by: International Maize and Wheat Improvement Center (CIMMYT); House 10/B, road 53, Gulshan 2, Dhaka 1212, Bangladesh
For more information pls. contact: t.krupnik@cgiar.org

Filling the gaps in climate forecasting

The first graduates of the BACS training program learned to make better decisions regarding climate services.

The first training course of the Bangladesh Academy for Climate Services (BACS) concluded on 25 October in the conference room of the Bangladesh Meteorological Department (BMD). BACS was jointly founded by the International Center for Climate Change and Development (ICCCAD), the International Research Institute for Climate and Society (IRI) at Columbia University and the International Maize and Wheat Improvement Center (CIMMYT), under the Climate Services for Resilient Development (CSRD) partnership in South Asia. The academy has taken the first steps to ensure important climate information and other services are delivered to the relevant parties by conducting a training program that began on 21 October 2018.

The BACS training program focused mainly on a deeper understanding of climate services and also on the challenges and expectations involved. Photo: Shahidul/CIMMYT

Participants from the private sector, educational institutes, government departments, and international NGOs attended the training program. The 5-day program included educational discussion sessions, informative presentations, question-and-answer sessions, and a field visit to Manikganj, a district adjacent to the capital of Bangladesh. The visit was organized to teach participants about the decision-making flowchart (DMF) in detail, which will help them make better decisions regarding climate services.

"It is crucial to decipher forecasts correctly to anticipate future disasters and for taking necessary precautions. Also, learning about the feasibility and limitations of climatology will help us design our forecasting needs," said participant Lamiya Mahpara Ahmed, an analyst at Start Fund Bangladesh. At end of the training program, participants identified climate-sensitive decisions within their respective fields and developed an understanding of existing decision-making processes. The program also aimed to provide participants with a basic understanding of climate data, climate services, and available products, as well as teach them about strategies that will enhance their use of climate services.

Climate Services for Resilient Development (CSRD) is a global partnership whose core mission is to translate actionable climate information into easy to understand formats to spread awareness and use of climate services. The CSRD consortium in South Asia is led by the International Maize and Wheat Improvement Center (CIMMYT) in partnership with the Bangladesh Meteorological Department (BMD), Bangladesh Department of Agricultural Extension (DAE), Bangladesh Agricultural Research Council (BARC), Bangladesh Agricultural Research Institute (BARI), International Center for Integrated Mountain Development (ICIMOD), International Institute for Climate and Society (IRI), University de Passo Fundo (UPF), University of Rhode Island (URI) and the University of Reading (UoR).

"As someone with limited technical knowledge, issues like weather forecasting, using climate data, and acknowledging limitations and challenges have become easier for me to understand and work with, thanks to this course," said Hossain Ishrath Adib, Head of Programme Implementation in Practical Action

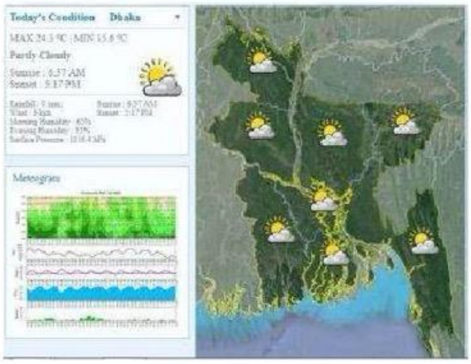
Strategic alignment

Published by: International Maize and Wheat Improvement Center (CIMMYT); House 10/B, road 53, Gulshan 2, Dhaka 1212, Bangladesh
For more information pls. contact: t.krupnik@cgiar.org

Forecasts made feasible for farmers

In partnership with CSRD, BMD to start working on a newer, updated version of weekly agrometeorological bulletin for the benefit of farmers and decision-makers.

The generation of relevant and high-quality agrometeorological information must be communicated effectively to end users. One of the ways in which the Bangladesh Meteorological Department (BMD) communicates such information to farmers and decision makers is through a weekly agrometeorological bulletin. The bulletin includes information on the weekly relevant weather variables, weather forecasts for coming two weeks and a general interpretation regarding the implications for local crops. BMD is keen on updating the information provided through its bulletin towards a better-developed and relevant product by including a better design, high-quality graphics, text and more relevant variables regarding weather forecasts and monitoring. For this, CSRD is working with BMD and the International Research Institute of Climate and Society (IRI) of Columbia University in the identification of relevant information to be provided in the context of local crops and different seasons in Bangladesh in terms of general variables and extreme weather events.



CSRD is working closely with BMD to launch a newer, updated version of agrometeorological bulletin for the farmers and decision-makers.

New climatic and geographic databases have been generated in order to work in a new up-to-date product that can be useful for extension agents and agricultural planners regarding agro climate conditions experienced during previous days and their implications for crops and management decisions, and also in the context of long-term observations to contrast against previous seasons. This information is complemented by the weather forecasting of the following 5 days, which provides information about basic variables as well as computed ones, which will be accompanied by a series of advisories to provide management options and possibilities for different crops and seasons.

Climate Services for Resilient Development (CSRD) is a global partnership whose core mission is to translate actionable climate information into easy to understand formats to spread awareness and use of climate services. The CSRD consortium in South Asia is led by the International Maize and Wheat Improvement Center (CIMMYT) in partnership with the Bangladesh Meteorological Department (BMD), Bangladesh Department of Agricultural Extension (DAE), Bangladesh Agricultural Research Council (BARC), Bangladesh Agricultural Research Institute (BARI), International Center for Integrated Mountain Development (ICIMOD), International Institute for Climate and Society (IRI), Universidad de Passo Fundo (UPF), University of Rhode Island (URI) and the University of Reading (UoR).

A simple and practical way to provide this information will be through a web application in which users can quickly access updated and tailored information, useful for decision making based on customized and updated information, as well as through a weekly generated document which will include more detailed analysis. Speaking of the bulletin, Mr. Shamsuddin Ahmed, Director, BMD says, "The proposed newer version of the agrometeorological bulletin will make farming easier by providing the farmers convenient and quickly accessible weather information."

Strategic alignment

Published by: International Maize and Wheat Improvement Center (CIMMYT); House 10/B, road 53, Gulshan 2, Dhaka 1212, Bangladesh
For more information pls. contact: t.krupnik@cgiar.org

The fight against blight

CSRD scientists help farmers use the right amount of fungicide with the help of the weather-based *Stempedia* model.

Lentils are an integral part of many nutrition-sensitive farming systems in Bangladesh, India, and Nepal. However, lentil fields in South Asia are being plagued by diseases, the most prominent being Stemphylium blight (SB). The prevalence and intensity of this disease fluctuate under varying weather conditions and can be controlled by the application of foliar fungicides. However, farmers often find it difficult to determine the frequency and amount of fungicide they should use. This requires special consideration because fungicides affect yield as well as the environment. To address this issue, the 'Stempedia' model was developed by scientists working with Climate Services for Resilient Development (CSRD) to assess the regional and seasonal risks of SB within South Asia and ultimately help farmers decide how much fungicide to use.

Identified early symptom of lentil Stemphylium blight (leaf, shown on arrow heads) in farmer's field in Bardiya site of Nepal on 20 November 2018, and laboratory testing of the sample for pathogenic confirmation (right).
Photo: Moin Salam

Data on SB were collected during the 2017-2018 growing season from 480 farmers' fields in Bangladesh with support from India's Department of Agricultural Extension (DAE), and the help of the Cereal Systems Initiative for South Asia (CSISA) funded by USAID, the Bill & Melinda Gates Foundation, and Bihar Agricultural University (BAU). In Nepal SB data were collected with the assistance of the CSRD project in partnership with the Nepal Agricultural Research Council's National Grain Legume Research Program (NGLRP).

The CSRD team assessed the status of SB before harvest and found that it was more prevalent in Bangladeshi and Nepalese sites than in Indian sites. After 800 yield datasets were compiled from all the sampled fields in each country, it was found that Indian sites produced better yields, while Nepalese sites generated poorer yields. Relevant weather data were used to run the Stempedia model and results showed that in each of the tested sites, there was either a slight underestimation or overestimation between the observed data and the model's prediction. The model is currently being calibrated to achieve better prediction accuracy, and more data from a similar number of fields in the three countries are being collected for comprehensive model testing.

Climate Services for Resilient Development (CSRD) is a global partnership whose core mission is to translate actionable climate information into easy to understand formats to spread awareness and use of climate services. The CSRD consortium in South Asia is led by the International Maize and Wheat Improvement Center (CIMMYT) in partnership with the Bangladesh Meteorological Department (BMD), Bangladesh Department of Agricultural Extension (DAE), Bangladesh Agricultural Research Council (BARC), Bangladesh Agricultural Research Institute (BARI), International Center for Integrated Mountain Development (ICIMOD), International Institute for Climate and Society (IRI), Universidad de Passo Fundo (UPF), University of Rhode Island (URI) and the University of Reading (UoR).

Speaking about the Stempedia model, Dr. Anurag Kumar of CSISA, Bihar, India, said, "Farmers in Bihar had no clue how to control the disease and had been blindly using chemicals for controlling SB. This model will guide farmers on when to use fungicides or whether to use them at all."

Strategic alignment

Published by: International Maize and Wheat Improvement Center (CIMMYT); House 10/B, road 53, Gulshan 2, Dhaka 1212, Bangladesh
For more information pls. contact: t.krupnik@cgiar.org

App decreases delays in weather data supply

To enhance the speed of daily weather data collection and supply, CSRD has trained BMD and institutionalized use of synoptic weather observation collection using smartphones and tablets

The USAID supported Climate Services for Resilient Development (CSRD) in South Asia project organized a two-day training workshop on Open Data Kit (ODK) for digital meteorological data collection and instantaneous data supply on May 19 and 20, 2019. The workshop was held at the Bangladesh Meteorological Department (BMD). This capacity building program was attended by 21 officials from BMD's weather observational offices throughout the country.

The goal of the workshop was to familiarize the participants with the concept and the use of ODK, a free and publicly accessible software for collecting, and managing field data using smartphones and/or handled tablets. Timely and efficient weather data collection is crucial in the supply of climate services to stakeholders in Bangladesh. In addition, CSRD is currently engaged in the development of early warning systems (EWS) for wheat blast and lentil *Stemphylium* blight diseases. These diseases are affected by weather conditions, and as such can be predicted using mathematical models. Model outputs will be used to advise the farmers on the likely occurrence of the crop viruses and the prevention measures. Where near-real time data can be supplied, the models can be rapidly validated and then used to help control damage and crop loss.

Now that ODK is being used to record data, the supply of observed weather information to a centralized cloud server is nearly instantaneous. This replaces dated methods of recording data by hand, sending data on paper to Dhaka, and manually entering data into computers. "The training workshop gave me opportunity to learn a new technology. I understand that using this system will facilitate sharing data from the district level weather office to the server in the fastest time. In addition, I learnt applying the weather data and information in an easy and farmer friendly way." said Shah Md. Shajib Hossain, a participant at the training.

Electronic tablets were distributed among the participants in order to facilitate data collection via ODK. The device can be easily carried into the field for use, and there are also options for data collection even when there is no internet network available. Thus, data procurement and availability has been made considerably faster by the CRD project. Using such data, wheat and lentil farmers can be advised and warned in time to act and prepare for the ensuing threat with the help of these models.

Participants having hands on experience collecting synoptic weather station data and uploading in ODK.
Photo: Uttam Barman ICIMMYT

Climate Services for Resilient Development (CSRD) is a global partnership with the core mission to translate actionable climate information into easy to understand presentations to spread the awareness and to promote use of climate services. The CSRD consortium in South Asia is led by the International Maize and Wheat Improvement Center (CIMMYT) in partnership with the Bangladesh Meteorological Department (BMD), Bangladesh Department of Agricultural Extension (DAE), Bangladesh Agricultural Research Council (BARC), Bangladesh Agricultural Research Institute (BARI), International Center for Integrated Mountain Development (ICIMOD), International Institute for Climate and Society (IRI), University de Passo Fundo (UPF), and the University of Reading (UoR).

Strategic alignment

Published by: International Maize and Wheat Improvement Center (CIMMYT); House 10/B, road 53, Gulshan 2, Dhaka 1212, Bangladesh
For more information pls. contact: t.krupnik@cgiar.org

Bridging the Gap Between Theory and Reality

An intensive workshop provided participants with an in depth understanding of GIS and similar technologies and how they can be applied in climate services and similar aspects of their work.

A four-day training workshop was held on 'The principles and application of GIS in agricultural planning and decision making' at Bangladesh Agricultural Research Council (BARC) from March 11 to March 14, 2019. The workshop was organized by the International Maize and Wheat Improvement Center (CIMMYT) and International Center for Integrated Mountain Development (ICIMOD), as part of the USAID supported Climate Services for Resilient Development (CSRD) project.

A GIS training workshop helped improve the overall decision making and planning processes related to climate services with application of geospatial tools and techniques. Photo: M. Wasil BARC.

Climate Services for Resilient Development (CSRD) is a global partnership with the core mission to translate actionable climate information into easy to understand presentations to spread the awareness and to promote use of climate services. The CSRD consortium in South Asia is led by the International Maize and Wheat Improvement Center (CIMMYT) in partnership with the Bangladesh Meteorological Department (BMD), Bangladesh Department of Agricultural Extension (DAE), Bangladesh Agricultural Research Council (BARC), Bangladesh Agricultural Research Institute (BARI), International Center for Integrated Mountain Development (ICIMOD), International Institute for Climate and Society (IRI), University de Passo Fundo (UPF), and the University of Reading (UR).

Nineteen participants, mainly scientists and senior government officials from a number of organizations; i.e. Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU), BARC, Soil Resource Development Institute (SRDI), Bangladesh jute research institute (BJRI), Department of Agricultural Extension (DAE), Bangladesh Agricultural Research Institute (BARI), Bangladesh Rice Research Institute (BRRI), Bangladesh Meteorological Department (BMD) and Sher-e-Bangla Agricultural University attended the workshop. Mr. Birendra Bajracharya (Chief of Party – SERVIR-HKH, ICIMOD) and nine other professionals from ICIMOD, BARC and CIMMYT facilitated the training program.

GIS technology helps better planning and effective decision making in many fields including agricultural climate services. Bangladeshi professionals in the agriculture sector often possess basic knowledge on geospatial tools, however, their regular application and use for climate services is often lacking. In particular, there is a lack of adequate capacity among the relevant officials in applying and incorporating GIS research outputs in regular planning and the decision making process.

"A previous CSRD supported workshop dealt with hands-on training on the basics of GIS using agricultural datasets. The current training provided the next level conceptual teaching in addition to hands-on-exercises with real-life data for better understanding and learning on the application of geo information for agricultural climate services," said Mustafa Kamal, CIMMYT GIS Specialist and one of the facilitators of the training workshop.

Strategic alignment

Published by: International Maize and Wheat Improvement Center (CIMMYT); House 10/B, road 53, Gulshan 2, Dhaka 1212, Bangladesh
For more information pls. contact: t.krupnik@cgiar.org

Building Resilience Against Wheat Blast Disease through Collaborative Climate Services Research and Action

In 2016, more than 15,000 hectares in Bangladesh were infected by a devastating fungal disease named wheat blast. The disease causes wheat grains to shrivel and wrinkle within a week from the first symptoms visible to the naked eye. Wheat blast is risky – South Asia's wheat farmers could lose 1.77 million tons of wheat per year as a consequence of the light blast infections affecting only 10% of the crop. In order to combat the blast and to strengthen the resilience of the farmers to control the disease outbreak through advisory and early warning systems, the International Maize and Wheat Improvement Center (CIMMYT) led and USAID supported Climate Services for Resilient Development (CSRD) in South Asia Partnership project works closely with the Bangladesh Meteorological Department (BMD) and the Department of Agricultural Extension (DAE).

Md. Harun-Or-Rashid is collecting wheat blast samples from a spore trap installed in a wheat field in Jashore. Spores are collected to validate predictions and improve the blast disease early warning system model. Photo: Munim/CIMMYT

A well-known prevention measure for blast is the use of fungicides. However, the Bangladeshi smallholder farmers are hesitant to adopt this step due to their limited knowledge on fungicides and because fungicides can be prohibitively expensive when applied on a preventative basis. Preventative application of fungicides can also entail environmental risks. Therefore, CSRD, in association with the University of Passo Fundo (UPF) and the Brazilian Agricultural Research Corporation (EMBRAPA), has developed a prototype blast early warning system (EWS) driven by weather forecasts generated by BMD. The DAE and Bangladesh Wheat and Maize Research Institute (BWMRI) are also collaborating with CSRD to validate the EWS. The EWS is an open-source and interactive website that will predict a blast outbreak and inform the users before the incident happens. "If we have access to an EWS for potential blast outbreaks, we can then inform the farmers about when to spray the antifungal agents and take other necessary precautions associated with safer chemical use. This climate service is crucial for rational and sound use of fungicides to protect the wheat crop" commented Dr. Mazharul Aziz, Project Director of the Agrometeorological Information Systems Development Project of DAE.

Through this blast EWS, extension agents and farmers will be able to be prepared for the disease in advance. This ultimately will increase the resilience in the wheat production systems in the face of crop risk from the blast disease.

Climate Services for Resilient Development (CSRD) is a global partnership with the core mission to translate actionable climate information into easy to understand presentations to spread the awareness and to promote use of climate services. The CSRD consortium in South Asia is led by the International Maize and Wheat Improvement Center (CIMMYT) in partnership with the Bangladesh Meteorological Department (BMD), Bangladesh Department of Agricultural Extension (DAE), Bangladesh Agricultural Research Council (BARC), Bangladesh Agricultural Research Institute (BARI), International Center for Integrated Mountain Development (ICIMOD), International Institute for Climate and Society (IRI), University de Passo Fundo (UPF), and the University of Reading (UR).

Strategic alignment

Published by: International Maize and Wheat Improvement Center (CIMMYT); House 10/B, road 53, Gulshan 2, Dhaka 1212, Bangladesh
For more information, pls. contact t.krupnik@cgiar.org

Bangladesh Met. Department joins climate services partnership

With approval from the Office of the Prime Minister, the Bangladesh Meteorological Department (BMD) formally joined the Climate Services for Resilient Development (CSRD) partnership in South Asia in September of 2017.

The Bangladesh Meteorological Department (BMD) formally joined the CSRD partnership during a signing ceremony on 28th September, 2017, held in the conference room of the Ministry of Defense in Dhaka. Representatives from BMD and International maize and Wheat Improvement Center (CIMMYT), which leads CSRD activities in South Asia, signed as the collaborative parties of the project. CSRD is a global partnership whose core mission is delivering climate services — including the production, translation, transfer, and use of climate information — purposefully designed to enable decision-makers to address climate problems and create solutions. CSRD's efforts in South Asia focus on assisting smallholder farmers and stakeholders in agriculture to make better use of climate information to increase farm resilience.

Mr. Akhter Hussain Bhuyia, Secretary, Ministry of Defense, Mr. David Westerling, the Acting Economic Growth Office Director and the Feed the Future Team Leader, USAID, Mr. Shamsuddin Ahmed, Director, BMD, Dr. Timothy J. Krupnik, CIMMYT and CSRD in South Asia Project Leader, Dr. Ghulam Hussain, CSRD Senior Coordinator, and Dr. Thakur Prasad Tiwari, CIMMYT-Bangladesh Country Representative, were present in the ceremony.

"By working CIMMYT and the and other national and international CSRD partners, BMD will greatly benefit from this unique partnership that aims to integrate agriculturally relevant meteorological information into easy-to-use and demand-driven decision support platforms to improve climate advisory services for crop management" said Mr. Shamsuddin Ahmed, Director, BMD.

Part of the Government of Bangladesh, BMD issues meteorological forecasts and warnings in Bangladesh and is responsible for providing climate information to public and private sector agencies in Bangladesh.

"We are excited by this new opportunity to develop new tools, services, and approaches and to increase forecasting capacity in BMD through CSRD." Mr. Shamsuddin Ahmed added that "This work will strengthen our ability to generate agriculturally relevant information and increase climate resilience in Bangladesh."

Dr. Thakur Prasad Tiwari, Country Representative, CIMMYT-Bangladesh and Mr. Shamsuddin Ahmed, Director, BMD signed the partnership agreement in Dhaka, Bangladesh on 28th September 2017. *Photo: MSH Khan (CIMMYT)*

Climate Services for Resilient Development (CSRD) is a global partnership whose core mission is to translate actionable climate information into easy to understand formats to spread awareness and use of climate services. In South Asia, CSRD supported by USAID and led by the International Maize and Wheat Improvement Center (CIMMYT) in partnership with the Bangladesh Meteorological Department (BMD), Bangladesh Department of Agricultural Extension (DAE), Bangladesh Agricultural Research Council (BARC), Bangladesh Agricultural Research Institute (BARI), International Center for Integrated Mountain Development (ICIMOD), International Institute for Climate and Society (IRI), University de Passo Fundo (UPF), and the University of Rhode Island (URI).

Strategic alignment

Published by: International Maize and Wheat Improvement Center (CIMMYT); House 10/B, road 53, Gulshan 2, Dhaka 1212, Bangladesh
For more information pls. contact: t.krupnik@cgiar.org

Scientists set new regional climate services agenda

Scientists from across South and Southeast Asia launched a new agenda to boost farmer involvement in developing climate information and services

Over 45 climate researchers gathered in Dhaka, Bangladesh for a three-day workshop from September 17-19, 2017. They evaluated how climate and agricultural extension advisories are currently produced and conveyed, and identified opportunities on how to improve these services for farming communities in Bangladesh, India, Indonesia, Myanmar, Nepal, Philippines, Sri Lanka and Vietnam.

"Key to climate services is emphasis on the *service*," said Dr. Timothy J. Krupnik, Systems Agronomist at the International Maize and Wheat Improvement Center (CIMMYT) and Project Leader for Climate Services for Resilient Development (CSRD) activities in South Asia. "We must be able to rapidly extend information to farmers and others who require climate data and tools to inform their decision making, and to assure that research outputs are translated in an easy to understand way that communicates to farmers, extension workers and policy makers," said Krupnik. "Equally important is feedback from farmers on the quality of climate services, so they can be adapted and improved over time."

During the workshop, which was supported by USAID and implemented with the assistance of the USAID funded SERVIR and Climate Services Support Activity, delegates assessed different ways to incorporate seasonal climate forecasts into farmer decision making, using several African countries as examples. Participants learned how to simply but effectively depict probabilistic forecasts in graphs understandable by farmers. Participants also identified strengths, weaknesses, opportunities and threats for climate services in each country. Subsequent discussions examined how participants can collaborate in south-south exchanges to support ongoing work in agricultural climate services. Weather index based agricultural insurance was also discussed, after which participants proposed new institutional arrangements to improve climate information generation and flow to farmers in each of their countries.

"CSRD's activities are relevant to the U.S. government's commitment to building resilience of smallholder farmers and to ensure increased production, as well bolster country resilience," said David Westering, the Acting Economic Growth Office Director and Feed the Future Team Leader for the United States Agency for International Development's mission in Bangladesh. "That is why we are behind this effort."

(Top) Participants' gathering in front of the workshop venue. (Below) Dr. Carlo Montes, CIMMYT Ag. Climatologist, discusses the interpretation of historical climate data Photos: CIMMYT

Climate Services for Resilient Development (CSRD) is a global partnership whose core mission is to translate actionable climate information into easy to understand formats to spread awareness and use of climate services. In South Asia, CSRD supported by USAID and led by the International Maize and Wheat Improvement Center (CIMMYT) in partnership with the Bangladesh Meteorological Department (BMD), Bangladesh Department of Agricultural Extension (DAE), Bangladesh Agricultural Research Council (BARC), Bangladesh Agricultural Research Institute (BARI), International Center for Integrated Mountain Development (ICIMOD), International Institute for Climate and Society (IRI), University de Passo Fundo (UPF), and the University of Rhode Island (URI).

Strategic alignment

Published by: International Maize and Wheat Improvement Center (CIMMYT); House 10/B, road 53, Gulshan 2, Dhaka 1212, Bangladesh
For more information pls. contact: t.krupnik@cgiar.org

Boosting forecasting skills in service of agriculture

By partnering with United States based advanced research institutes, the CSRD partnership supports agricultural climate services for resilient development in South Asia

Half of Bangladesh's population in some way works in agriculture. A new effort from the International Research Institute for Climate and Society (IRI) and International Maize and Wheat Improvement Center (CIMMYT) under the Climate Services for Resilient Development (CSRD) partnership in South Asia aims to give the Bangladesh's agricultural sector better access to climate information to farm production risks including drought and extreme temperatures that can lower farm productivity.

Providing technical support to the Bangladesh Meteorological Department (BMD) in developing new climate information products tailored to agricultural needs is the core to CSRD. Recently, IRI's Senior Research Scientist, Dr. Simon Mason, visited BMD to help increase forecasting skills and capacity to develop new climate information products.

International Research Institute for Climate and Society's Senior Research Scientist for International Outreach, Simon Mason, spent several weeks in 2017 assisting BMD through the CSRD project Photo: E. Gawthrop (IRI)

"The BMD has a core of very competent and highly qualified meteorologists, but these scientists have not had sufficient opportunity to engage in sustained interaction with BMD's clients," said Mason. BMD could therefore benefit from collaborations aimed at making climate information more relevant and understandable. "This can be done without compromising on the technical standards," commented Mason.

Mason and the CSRD team therefore worked with BMD throughout 2017 to identify actions required to improve climate data collection, processing and analysis, all of which underpin the development of quality climate services products. The team also identified specific crop management decisions and activities implemented by farmers that could be improved with climate information and services. Weather events that affect farm productivity, such as heat waves, cold and dry spells were also prioritized for improved forecasting, in addition to efforts to the supply of extended-range forecasts to farmers and extension agents.

"CSRD's engagement with IRI is highly strategic. As a US-based and global leader in climate services, linking IRI with BMD will strengthen forecasting skills and capacities to deliver relevant climate information. We are mobilizing the best minds in climate science in service of smallholder farmers through CSRD", commented Timothy J. Krupnik, CSRD Project Leader and CIMMYT scientist.

Climate Services for Resilient Development (CSRD) is a global partnership whose core mission is to translate actionable climate information into easy to understand formats to spread awareness and use of climate services. In South Asia, CSRD supported by USAID and led by the International Maize and Wheat Improvement Center (CIMMYT) in partnership with the Bangladesh Meteorological Department (BMD), Bangladesh Department of Agricultural Extension (DAE), Bangladesh Agricultural Research Council (BARC), Bangladesh Agricultural Research Institute (BARI), International Center for Integrated Mountain Development (ICIMOD), International Institute for Climate and Society (IRI), University de Passo Fundo (UPF), and the University of Rhode Island (URI).

Strategic alignment

Published by: International Maize and Wheat Improvement Center (CIMMYT); House 10/B, road 53, Gulshan 2, Dhaka 1212, Bangladesh
For more information, pls. contact t.krupnik@cgiar.org

From weather forecasts to the field:

New partnerships reduce drought risks in South Asia

Partnerships for agricultural climate services in South Asia will reduce drought risks for resource-poor smallholder farmers

Millions of farmers across Afghanistan, Bangladesh, Nepal and Pakistan lack access to irrigation and rely on increasingly unpredictable rainfall to grow the crops that sustain their families. Science generated by researchers in South Asia is being applied to tackle one of the region's greatest threats to resource-poor smallholder farmers: drought. Increasing farmers' access to drought forecasts – especially before the crop seasons begins – is powerful way to help farmers reduce farm production risks by using drought resistant crop and varieties.

The USAID supported Climate Services for Resilient Development (CSRD) is a new partnership that connects climate, agricultural and data science, to generate new information to be transferred as decision support tools and training to agricultural decision-makers and farmers. CSRD is led by the International Maize and Wheat Improvement Center (CIMMYT) in South Asia, and has embarked on a new partnership with USAID, and with the International Center for Integrated Mountain Development (ICIMOD) through the National Aeronautics and Space Administration (NASA) supported SERVIR-Hindu Kush Himalaya (HKH). The SERVIR-HKH leverages NASA's satellite products and Earth Observation Platforms to monitor water balance and agricultural drought risks across the region. With the support of CSRD, drought risk forecasts are being translated into easy to understand messages in the form of crop choice and management advisories for farmers.

Fisal Mueen Qumar, Remote Sensing Specialist with ICIMOD commented that *"The products generated through this service will be utilized by both national meteorological agencies and institutions involved in designing locally relevant climate services. CSRD support will enable filed validation and capacity building activities and operationalize these products in decision making process."*

CSRD collaboration with SERVIR-HKH was kicked off in May of 2017. Scientists are first building the computing facilities needed to make pre-season drought predictions in Bangladesh, in partnership with the Bangladesh Agricultural Research Council. Subsequent work will test different types of drought forecasting for their accuracy before translating them into formats that farmers can apply to mitigate drought impacts on food production and security.

CSRD partners are forecasting drought risk and also translating into easy to understand messages in the form of crop choice and management advisories for farmers. Photo: Faisal Mueen Qamer

Climate Services for Resilient Development (CSRD) is a global partnership whose core mission is to translate actionable climate information into easy to understand formats to spread awareness and use of climate services. The CSRD consortium in South Asia is led by the International Maize and Wheat Improvement Center (CIMMYT) in partnership with the Bangladesh Meteorological Department (BMD) Department of Agricultural Extension (DAE), Bangladesh Agricultural Research Council (BARC), Bangladesh Agricultural Research Institute (BARI), International Center for Integrated Mountain Development (ICIMOD), International Institute for Climate and Society (IRI), University de Passo Fundo UPF), and the University of Rhode Island (URI).

Strategic alignment

Published by: International Maize and Wheat Improvement Center (CIMMYT); House 10/B, road 53, Gulshan 2, Dhaka 1212, Bangladesh
For more information, pls. contact t.krupnik@cgiar.org

Bangladesh to boost farmer-friendly climate advisories

Bangladesh sets its sights on expanding climate services to benefit millions of farmers

Bangladesh is South Asia's most densely populated, poor, and environmentally vulnerable country. Home to over 160 million people, farmers in Bangladesh grapple with unreliable precipitation and temperature leading to floods, droughts and heat waves, all of which can reduce farm productivity. Bangladesh's Meteorological Department (BMD) has worked since 1978 to provide timely weather forecasts, and is now setting their sights on custom-designed advisories for farming communities across the country. Communicating these forecasts through simple to understand messages and advisories can better prepare smallholder farm families for adverse weather, ultimately reducing production risks.

The USAID supported Climate Services for Resilient Development (CSRD) is a new partnership that connects climate, agricultural and data science, to generate new information to be transferred as decision support tools and training to agricultural decision-makers and farmers. CSRD is led by the International Maize and Wheat Improvement Center (CIMMYT) in the South Asian region, and is working to increase the agricultural relevance of BMD's forecasts and to develop new communications tools and systems with Bangladesh's Department of Agricultural Extension (DAE) to spread climate advisories to farmers.

DAE has over 14,000 field extension agents poised to boost farmers' access to climate advisories. One of the methods used by DAE to spread awareness on weather forecast among in rural areas is the use of musical jingles using loudspeakers that are moved about on bicycle carts or trucks. Partnering with CSRD, this and other media communication technologies will be tested so farmers can receive BMD's weather forecasts for farm management.

"It is essential to communicate weather related crop production threats efficiently to farmers in a timely manner to reduce risks," commented Dr. Aziz Mazharul, Deputy Director of Planning and Implementation & Information and Communication Technologies at DAE. *"CSRD activities which will integrate agriculturally relevant meteorological information into easy-to-use and demand-driven decision support platforms to improve climate advisory services and farmer crop management".*

Department of Agricultural Extension (DAE) uses mobile loudspeakers to spread awareness and weather forecasts among the farmers in rural areas. *Photo:DAE*

Climate Services for Resilient Development (CSRD) is a global partnership whose core mission is to translate actionable climate information into easy to understand formats to spread awareness and use of climate services. The CSRD consortium in South Asia is led by the International Maize and Wheat Improvement Center (CIMMYT) in partnership with the Bangladesh Meteorological Department (BMD) Department of Agricultural Extension (DAE), Bangladesh Agricultural Research Council (BARC), Bangladesh Agricultural Research Institute (BARI), International Center for Integrated Mountain Development (ICIMOD), International Institute for Climate and Society (IRI), University de Passo Fundo (UPF), and the University of Rhode Island (URI).

Strategic alignment

Published by: International Maize and Wheat Improvement Center (CIMMYT); House 10/B, road 53, Gulshan 2, Dhaka 1212, Bangladesh
For more information pls. contact: t.krupnik@cgiar.org

Annex 6: Links to other communications and news and pieces about CSRD

Project news stories and blogs

- CSRD Technical Exchange on Participatory Approaches to Agricultural Climate Services Development and Extension in South and South East Asia – CCAFS
  https://ccafs.cgiar.org/csrd-technical-exchange-participatory-approaches-agriculturalclimate-services-development-and#.WeQdsROCxE8
- New initiative strengthens agricultural drought monitoring in Bangladesh
  http://www.cimmyt.org/new-initiative-strengthens-agricultural-drought-monitoring-inbangladesh/
- Bangladesh Agricultural Research Council and Partners to Collaborate on Strengthening Climate Services for Drought Monitoring
  https://reliefweb.int/report/bangladesh/bangladesh-agricultural-research-council-andpartners-collaborate-strengthening
- High-level meeting to set climate services agenda for South and Southeast Asia
  http://www.cimmyt.org/high-level-meeting-to-set-climate-services-agenda-for-south-andsouth-east-asia/
- Scientists, policymakers meet in Bangladesh to produce climate services agenda for Asia
  http://www.cimmyt.org/press_release/scientists-policymakers-meet-in-bangladesh-toproduce-climate-services-agenda-for-asia/
- Researchers set new climate services strategy in Bangladesh
  http://www.cimmyt.org/climate-services-asia/
- "We need climate information." – Bangladesh's agriculture community drives creation of new climate services
  https://iri.columbia.edu/news/we-need-climate-informationbangladeshs-agriculture-community-drives-creation-of-new-climate-services/
- On-the job training boosts drought monitoring skills in Bangladesh
  https://www.cimmyt.org/on-the-job-training-boosts-drought-monitoring-skills-inbangladesh/
- Building the Resilience of South Asia's Smallholder Farmers Through Effective Climate Services
  https://www.agrilinks.org/post/building-resilience-south-asias-smallholderfarmers-through-effective-climate-services
- Accelerating Smallholder Farmers' Access to Climate Services in Bangladesh
  https://www.agrilinks.org/post/accelerating-smallholder-farmers-access-climate-servicesbangladesh

Note: These project news stories and blogs will soon be posted on the CCAFS landing page for CSRD in South Asia. The other materials and project information are already online at: https://ccafs.cgiar.org/flagships/climate-services-and-safety-nets/projects.

Press Releases

- Scientists, policymakers meet in Bangladesh to produce climate services agenda for Asia http://www.cimmyt.org/press_release/scientists-policymakers-meet-in-bangladesh-to-produceclimate-services-agenda-for-asia/

Agrilinks website

- Building the Resilience of South Asia's Smallholder Farmers Through Effective Climate Services – https://www.agrilinks.org/post/building-resilience-south-asias-smallholder-farmers-through-effective-climate-services
- Accelerating Smallholder Farmers' Access to Climate Services in Bangladesh: CIMMYT, which leads CSRD in South Asia, is partnering with the Bangladesh Meteorological Department (BMD), the Department of Agricultural Extension (DAE) and the University of Reading in the United Kingdom, to adapt and pilot the 'Participatory Integrated Climate Services for Agriculture' (PICSA) approach across 20+ villages in Bangladesh in 2018 https://www.agrilinks.org/post/accelerating-smallholder-farmers-access-climate-services-bangladesh

CCAFS website

- Expanding horizons: The Bangladesh Academy for Climate Services – M. Shahidul Haque Khan.
  A first of its kind in Bangladesh, an academy was launched with the aim to embed climate thinking in decision-making processes and close the gap between climate information providers and end users.
  https://ccafs.cgiar.org/news/expanding-horizons-bangladesh-academy-climate-services#.XCCENVwzaUn
- Newly founded Bangladesh Academy for Climate Services held its first training course Sector leaders in Bangladesh gathered at the Bangladesh Academy for Climate Services training to learn about climate services and using climate information in decision-making.
  https://ccafs.cgiar.org/news/newly-founded-bangladesh-academy-climate-services-held-its-first-training-course#.XCCT8VwzaUl

CIMMYT website

- **In pictures: Six agricultural innovations combating climate change** – The photo story from the International Maize and Wheat Improvement Center (CIMMYT) shows the advantages of joint action by farmers, researchers, governments, not-for-profits and businesses.

  https://www.cimmyt.org/multimedia/in-pictures-six-agricultural-innovations-combating-climate-change/
- **On-the job training boosts drought monitoring skills in Bangladesh** – A two-week on the job training was organized with the support of the International Maize and Wheat Improvement Center (CIMMYT)-led Climate Services for Resilient Development (CSRD) initiative in South Asia, alongside the International Centre for Integrated Mountain Development (ICIMOD).
  https://www.cimmyt.org/on-the-job-training-boosts-drought-monitoring-skills-in-

bangladesh/

- **Photo story: Six Agricultural Innovations Combating Climate Chan**ge
  Highlights some encouraging innovations for improving resilience and productivity for agriculture under climate change. These examples from the International Maize and Wheat Improvement Center (CIMMYT) show the advantages of joint action by farmers, researchers, governments, not-for-profits and businesses.
  https://spark.adobe.com/page/Al071WqwodPXJ/

Dhaka Tribune website

- Bangladesh Academy for Climate Services launched – SM Abrar Aowsaf
  Bangladesh Academy for Climate Services (BACS) was launched at the Bangladesh Meteorological Department (BMD) in Dhaka, Bangladesh. BACS has been created to open trans-sectoral and multi-stakeholder dialogue on climate services to identify existing initiatives, challenges and opportunities.
  https://www.dhakatribune.com/bangladesh/dhaka/2018/08/06/bangladesh-academy-for-climate-services-launched

- Climate data matters – Tasfia Tasnim
  To bridge the gap between climate scientists and decision makers, Bangladesh Meteorological Department (BMD) together with the International Center for Climate Change and Development (ICCCAD), the International Wheat and Maize Improvement Center (CIMMYT), and the International Research Institute for Climate and Society (IRI) at Columbia University have jointly founded a climate services academy and started offering short courses.
  https://www.dhakatribune.com/climate-change/2019/02/18/climate-data-matters

ICIMOD website

- Bangladesh Agricultural Research Council and Partners to Collaborate on Strengthening Climate Services for Drought Monitoring – *ICIMOD*
  The International Centre for Integrated Mountain Development (ICIMOD), the Bangladesh Agricultural Research Council (BARC), and the International Maize and Wheat Improvement Centre (CIMMYT) organized a day-long consultation and user engagement workshop on collaborative development of agricultural drought monitoring services in Bangladesh.
  https://reliefweb.int/report/bangladesh/bangladesh-agricultural-research-council-and-partners-collaborate-strengthening

IRI website

- "We need climate information." – Bangladesh's agriculture community drives creation of new climate services – Elisabeth Gawthrop
  A series of training workshops were conducted to improve the forecasting capabilities of the Bangladesh Meteorological Department (BMD), while also strengthening the relationship between BMD and Bangladesh's Department of Agriculture Extension (DAE). The activities focused on new climate information products developed especially for DAE's needs, which would ultimately to help the farmers it serves.
  https://iri.columbia.edu/news/we-need-climate-information-bangladeshs-agriculture-

community-drives-creation-of-new-climate-services/

- Creating Climate Services in Bangladesh – Elisabeth Gawthrop
  4th annual Gobeshona Conference for Research on Climate Change was held in Bangladesh. The conference focused on research-based solutions to local vulnerabilities in Bangladesh and brought together researchers, policymakers, government and non-government representatives, donor agencies and international organizations.
  https://iri.columbia.edu/news/creating-climate-services-in-bangladesh/

- Climate mapping tools support resilient development in East Africa – Tesfamariam Tekeste
  IRI helped to organize the Climate Services for Resilient Development (CSRD) Technical Exchange workshop in Zanzibar on August 2017, which was held immediately after the 47th Greater Horn of Africa Climate Outlook Forum (GHACOF47) in order to capitalize on the presence of many climate and sector experts from across the region.
  https://iri.columbia.edu/news/mapping-tools-to-support-climate-services-in-east-africa/

CSISA website

- Stempedia Model: Fighting Blight in Lentil – M. Shahidul Haque Khan and Sultana Jahan
  CSRD, in collaboration with CSISA project, mobilized national partners and collected data on the incidence and severity of Stemphylium blight to enable national scientists and extension officers in Bangladesh, India and Nepal to test the Stempedia model and assess the regional and seasonal risks of Stemphylium blight occurring.
  https://csisa.org/stempedia-model-fighting-blight-in-lentil-2/

Videos on CSRD

- Overcoming Barriers to Partnership for Climate Services and Agriculture in Bangladesh: Video produced by Elizabeth Gawthrop at IRI on collaboration between CIMMYT, IRI, BMD and DAE to build capacity for climate services in Bangladesh.
  https://vimeo.com/344367748

- IRI Training to support Climate Services for Resilient Development (CSRD) in South Asia: Video produced by Elizabeth Gawthrop at IRI on intensive climate services training through CSRD at IRI for national partners Bangladesh.
  https://vimeo.com/344367779

News on regional drought monitoring facilitated by CSRD

- Regional drought outlook system launched at SAARC regional training in Islamabad – Pakistan Agricultural Research Council
- Regional drought outlook system launched at SAARC regional training in Islamabad – Parliament Times (Pakistan)
- New Drought Monitoring System Will Reduce Climate Risks for South Asian Farmers – ReliefWeb

Annex 7: Agvisely: Methodology and approach used to generate automated and location-specific agricultural climate information services for farmers in Bangladesh

SK Ghulam Hussain, Mutasim Billah, Faisal Washik, Aziz Mazharul, Md. Abdul. Mannan, Carlo Montes, Timothy J. Krupnik

1. Background

Bangladeshi farmers experience considerable variability in two important climatic parameters – temperature and precipitation – upon which the productivity of several crops are partially dependent. To improve resilience to climate variability and extremes, smallholder farmers in Bangladesh can benefit from timely access to weather forecasts and complementary crop management advisories. The ways in which the data generated to develop advisories, however, is of key importance. Advisories both scientifically valid and also easy for farmers to understand and implement.

For each phase in the growth of plants, there is a temperature range within which growth and development is optimum. When the temperature drops below a certain minimum or exceeds a certain maximum value plant growth stops. These three temperature points are the cardinal or threshold temperatures for a given plant. The lowest temperature at which crop growth can occur is referred to as the base temperature; which is also known as the minimum cardinal temperature. The maximum cardinal temperature is the highest temperature above which plant growth can stops (Alvarado and Bradford, 2002; TNAU, 2018). Crop species including rice, wheat, maize, potato and pulses, all tend have an optimum range of temperatures for normal growth and development. This thermal range depends not only on the species but also on the phenology or growth and developmental stages of a given crop, in addition to the varietal characteristics of a particular cultivar. When temperature crosses above or below this optimal range, the crop can experience stress that may adversely affect growth and yield. Therefore, knowing the upper threshold (i.e., the temperature above which interference in growth and developmental processes can be expected) and the lower threshold (i.e., the temperature below which plant growth and development may be hampered), can be useful for advising farmers methods to increase resilience to climate extremes.

Scientists have developed complex crop growth models that relate precipitation and atmospheric, soil, and water temperatures to the growth rates of many crop species and cultivars. This detailed mechanistic understanding is useful from a research perspective, but maybe less actionable when used to develop practical and daily recommendations to tens of thousands or even millions of farmers growing diversity of varieties in different locations or that may be in different crop growth stages. In order to simplify and generalize advisories for very large groups of farmers – such as those in population dense Bangladesh – the methods described below consider atmospheric thermal stress thresholds in reference to crop species but not particular varieties. When integrated with temperature forecasts on a down-scaled and localized basis, we have aimed to provide 'rule of thumb' recommendations to farmers on methods to overcome thermal stresses and to more wisely economize on precipitation by optimizing irrigation, while also avoiding within-field waterlogging risks.

The text below describes how work conducted in the Climate Services for Resilient Development (CSRD) in South Asia project and the Cereal Systems Initiative for South Asia (see Agvisely Methods Appendix I) that led to the development of the Agvisely climate services decision support tool. Researchers involved with these projects developed ranges for the phenological growth stages of major crops within Bangladesh. The methods used to do this are detailed with a description of a systematic literature review to define species- and phenological stage-specific thermal stress thresholds. We then explain how weather forecast model outputs are retrieved from the Bangladesh Meteorological Department and applied to these thresholds, after which the ways in which we generated automatic climate-smart recommendations for farmers at the sub-district scale for a variety of crops are discussed.

2. Determining Phenology and Growth Stages of Major Field Crops of Bangladesh

In Bangladesh, rice *(Oryza sativa)* is grown in three seasons: '*boro*', '*aus*', and '*aman*' corresponding to the winter, spring and summer cropping season. Since *boro* and *aus* can overlap, their growing seasons can also be classified as relatively dry in comparison to the wetter monsoon *aman* season. *Boro* season rice is mostly transplanted in January-February and harvested in May-June. *Aus* is mostly broadcast direct-seeded. Seeds are sown during March-April and harvested in July-August. In the *aman* season, rice seeding is done at the beginning of the rainy season (July-August) and harvested in November-December. In most cases, 25-35-day-old seedlings are recommended for transplanting. Other common field crops – wheat *(Triticum aestivum)*, maize *(Zea mays)*, potato *(Solanum tuberosum)*, and lentil (*Lens culinaris)* considered are *'rabi'* winter season crops grown generally from October through May. During late Rabi or pre-kharif (January-May) mung bean [*Vigna radiata* (L.) R. Wilczek] is grown in the country.

It is important to note that these dates are presented in broad ranges. This is because the actual dates on which farmers may establish crops can vary considerably, both on a localized scale, but also nationally. For example, there are typically large north-south gradients in the timing of crop establishment in Bangladesh because of cropping systems, flooding, on set of monsoon, etc. Many crops, both tropical and temperate origin, are cultivated in the country. Agricultural land use at a local level is determined by the spatial and temporal distribution of crops or cropping patterns. While, cropping pattern depends on the physiography, agricultural land availability, environment, and socioeconomic conditions of a particular area. (Nasim et al., 2017, Hasan et al., 2013, Shahidullah, et al., 2006). In addition to sowing and transplanting dates, the phenology of field crops also varies with the duration of the crop in question, which is strongly affected by the cultivar grown by farmers (BRRI, 2019; BARI, 2019; BINA,2017).

The purpose of Agvisely is to provide a national climate information service for farmers. The complexity of seasons, sowing and transplanting dates, and diversity of cultivars grown in Bangladesh however makes the generation of extremely localized and variety- or farmer-specific information challenging. For example, two farmers growing the same variety of rice could establish their crops several weeks apart from one another, despite having neighbouring fields or using the same variety. Similarly, farmers tens or even hundreds of kilometres apart could establish their crops on the same day, but the use of intermediate vs. a short duration variety will have strong effects on the speed of crop growth. To make things more complex, there are more than 90 varieties of rice that have been released by the Bangladesh Rice Research Institute (BRRI, 2019), and potentially hundreds more local varieties grown by farmers (Kamruzzaman, et al., 2017).

This complexity makes detailed climate information service recommendations challenging, and calls for a simpler and actionable approach. We therefore aimed to estimate a generalizable 'window' of sowing and transplanting dates for the whole of Bangladesh by considering the potential earliest and latest date within the cropping season when farmers can seed or transplant their crops. We then calculated the generalized number of days required to complete sequential phenological states based on information on phenological durations of crops in Bangladesh based on the sowing, transplanting and harvesting dates provided by the Agricultural Research Institutes (ARIs) of Bangladesh National Agricultural Research System (NARS) [BRRI, 2019; BARI, 2019].

For example, *boro* rice sowing typically occurs over a very long period in Bangladesh, which we estimated in a range from the earliest possible establishment on October 31 to the latest reasonable seeding date of December 15. After sowing, *boro* rice requires about 5 days to emerge, and another 45 days before seedlings are uprooted and transplanted. As such, the decision tree algorithm used in Agvisely assumes that transplanting is likely to take place all over Bangladesh within the window of December 15 and January 30, respectively. About ten more days will be required for the crop to recover from transplanting shock. Following this, maximum tillering of *boro* will be reached in the next 45 days. Booting and flowering will require roughly ten more days each, with and ripening and maturity in the following 25 to 30 days i.e., between March 30 to April 30. Table A7.1 summarizes the phenological stage 'windows' growth for major field crops of Bangladesh used in Agvisely. The phonological stages and approximate stage to stage duration (days) for rice (Yoshida, 1981; IRRI, 2018), wheat (Large, 1954; Acevedo et al., 2002), maize (Pringle, 2017), potato (Obidiegwu et al., 2015), mung bean (Chauhan et al., 2010) and lentil (Sen et al., 2016) were estimated based on the literature cited.

3. Crop Species Specific Thermal Stress Thresholds

Given their importance globally and also in Bangladesh, a systematic literature review was undertaken to identify appropriate thermal stress thresholds for different phenological stages of rice, wheat, and maize. The literature review was carried out using four databases including Scopus, Web of Science, CAB Direct and AGRICOLA. Comprehensive strings of database-specific search queries/criteria were developed to identify thresholds from literature. An example of a search query for the Scopus database, the following search string was applied in the stated and the same key search terms was used to search for grey literature.

(TITLE-ABS-KEY (heat OR "high temp*" OR "high-temp*" OR "heat stress" OR "heat-stress" OR "thermal stress" OR "thermal-stress" OR cold OR "cold temp*" OR "cold-temp*" OR "cold stress" OR "cold-stress" OR "terminal heat stress" OR "terminal heat-stress" OR "terminal heat") AND ABS ("zea mays" OR maize OR corn OR "triticum aestivum" OR wheat OR "oryza sativa" OR rice) AND ABS (yield))

Where TITLE-ABS-KEY means a search in the title, abstract, and keywords fields, * replaces zero or more characters or truncates the search item, and ABS means a search in the abstract, while OR and AND are operators. Resulting citations were stored in EndNote (Ver 8, Clarivate Analytics). The combination of all searches on thermal stresses resulted in 24,506 articles (Figure A7.1).

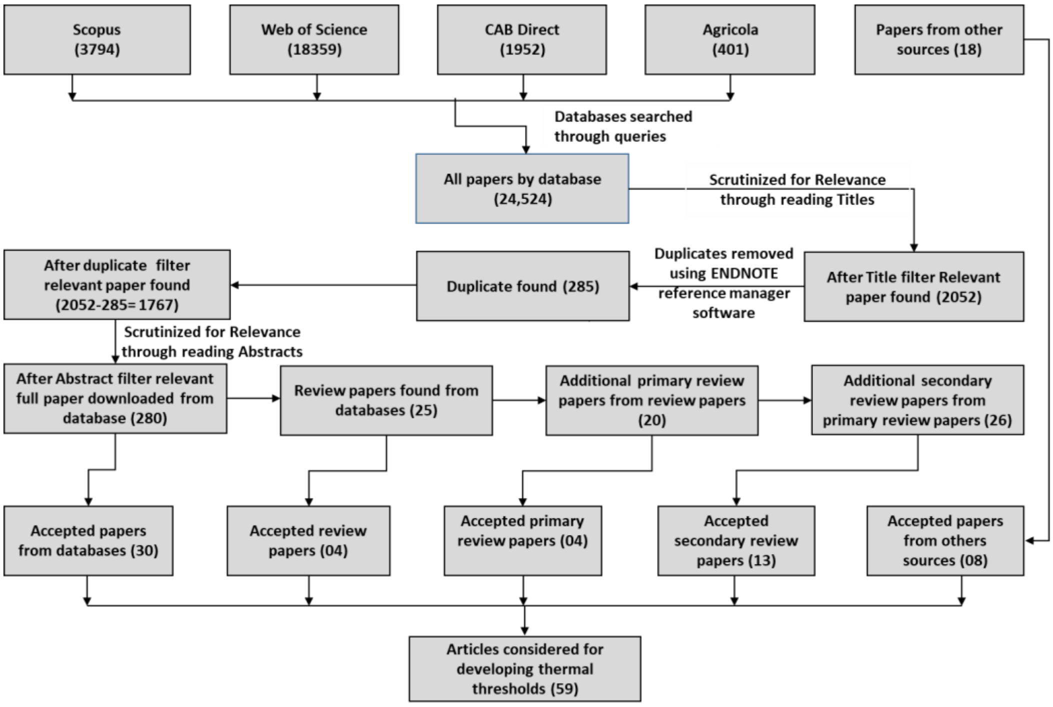


Figure A7.1: Methodological process used during systematic literature review to identify peer-reviewed papers from which data were extracted to determining rice, wheat and maize stress thresholds. Numbers in parentheses indicate the number of papers identified or retained.

After scrutinizing paper titles, 22,454 articles were excluded as being irrelevant to this research. Duplicates recorder were subsequently removed from our database, leaving 1,767 papers. Abstracts were next read to identify papers that quantitatively demonstrated thermal stress thresholds with at least one measured high- and/or low- atmospheric temperature threshold for each crop. Due to the potential for experimental artifacts in growth chambers, only field studies that involved experimental manipulation of micro-climate or field-specific observations of temperature immediately above the canopy were included. Similarly, studies that did not make use of standard 'best practices' (e.g., adequate fertilization, irrigation, pest management etc.) recommended for their particular locations were excluded.

This resulted in 280 remaining papers that were downloaded and scrutinized for thermal stress-related thresholds at different phonological stages. In addition to these 280 articles, 25 additional papers were by carefully reviewing the citation lists included in these papers. In addition, another 20 review papers that summarized acceptable measurements of high or low-temperature stresses from methodologically sound field studies were included. Another 26 secondary review papers were found in the citation lists of the primary review studies described above. After further scrutiny for experimental rigor, 59 peer-reviewed papers were admitted and were used to develop the thresholds embedded in Agvisely.

Following this literature search, data were entered into a spreadsheet and plotted as scatter plots that depicting crop species yield performance as a function of temperature. Maximum or minimum temperatures after which yield decline was observed for particular phenological stages were taken and used to develop thresholds. Where papers reported single temperature values as thresholds above or below which yield decline was observed, we admitted this value as indicative of the maximum or minimum stress threshold, respectively (Table A7.1). References for papers used to complete this work are found in Agvisely Methods Appendix III.

In addition to rice, wheat, and maize, thresholds for potato, mung bean and lentil were obtained through a literature review of textbooks, journal articles, and MSc. and Ph.D. dissertations specific to Bangladesh that utilized similarly acceptable experimental approaches and measurements were included (see Agvisely Methods Appendix IV). These were subject to the same threshold summary approach described above.

Table A7.1: Phenological windows of field crops in Bangladesh with estimates of the number of days required for each stage[1] and temperature thresholds. *n*[2] indicates the number of study observations included to calculate thresholds.

Crop	Phenological stage	*n*	Start Date	End Date	Approximate stage to stage duration (days)	Minimum temperature threshold (°C)	Maximum Temperature Threshold (°C)
Boro rice	Sowing	*1, 1*	31-Oct	15-Dec	0	10.0	45.0
	Germination and emergence	*3, 3*	3-Nov	18-Dec	3	12.0	40.0
	Seedling	**1, 24**	10-Dec	25-Jan	40	10. 0	35.0
	Transplanting and recovery	1,2	15-Dec	30-Jan	7	12.0	35.0
	Maximum tillering	1,1	29-Jan	11-Mar	40-45	14.00	35.0
	Booting	1,1	13-Feb	23-Mar	12-15	15.0	35.0
	Heading and flowering	**16, 45**	28-Feb	5-Apr	13-15	17.0	35.0
	Ripening	**5, 9**	20-Mar	20-Apr	15-20	13.00	33.0
	Maturity		30-Mar	30-Apr	10	-	-
			Approximate total duration		140-155		
Aus rice	Sowing	*1, 1*	20-Mar	25-Apr	0	10.0	45.0
	Germination and emergence	*3, 3*	22-Mar	27-Apr	2	12.0	40.0
	Seedling	**1, 24**	11-Apr	17-May	20	10. 0	35.0
	Transplanting and recovery	1,2	18-Apr	24-May	7	12.0	35.0
	Maximum tillering	1,1	23-May	23-Jun	30-35	14.00	35.0
	Booting	1,1	5-Jun	5-Jul	12-13	15.0	35.0
	Heading and flowering	**16, 45**	17-Jun	17-Jul	12	17.0	35.0
	Ripening	**5, 9**	3-Jul	30-Jul	13-16	13.00	33.0
	Maturity		13-Jul	9-Aug	10	-	-
			Approximate total duration		106-115		
Aman rice	Sowing	*1, 1*	20-Jun	31-Jul	0	10.0	45.0
	Germination and emergence	*3, 3*	22-Jun	2-Aug	2	12.0	40.0
	Seedling	**1, 24**	17-Jul	3-Sep	25-32	10. 0	35.0
	Transplanting and recovery	1,2	23-Jul	11-Sep	6-8	12.0	35.0
	Maximum Tillering	1,1	11-Sep	21-Oct	40-50	14.00	35.0
	Booting	1,1	24-Sep	3-Nov	13	15.0	35.0
	Heading and flowering	**16, 45**	6-Oct	15-Nov	12	17.0	35.0
	Ripening	**5, 9**	22-Oct	1-Dec	16	13.00	33.0
	Maturity		1-Nov	11-Dec	10	-	-
			Approximate total duration		134		

Crop	Phenological stage	*n*	Start Date	End Date	Approximate stage to stage duration (days)	Minimum temperature threshold (°C)	Maximum Temperature Threshold (°C)
Wheat	Sowing	2, 1	10-Nov	15-Dec	0	5.0	33.0
	Germination	**2, 1**	15-Nov	20-Dec	5	5.0	33.0
	Vegetative	0, **1**	20-Dec	24-Jan	35	6.4	30.0
	Heading	**4, 41**	25-Dec	29-Jan	5	6.4	32.0
	Flowering	**4, 41**	30-Dec	3-Feb	5	6.5	32.0
	Grain filling	**2, 18**	19-Jan	23-Feb	20	8.5	32.0
	Ripening	**2, 18**	8-Feb	15-Mar	20	8.5	32.0
	Maturity		23-Feb	30-Mar	15	-	-
			Approximate total duration		105		
Maize	Sowing	1,1	15-Oct	7-Jan	0	8.00	40. 0
	Germination	1,1	20-Oct	12-Jan	5	8.00	>36.0
	Vegetative	**2, 3**	14-Dec	7-Mar	55	7.50	35.00
	Silking and tasseling	**1, 15**	29-Dec	22-Mar	15	7.50	35.00
	Cob formation and grain filling	**2, 2**	2-Feb	26-Apr	35	8.00	33.00
	Ripening and physiological maturity	2,2	17-Feb	11-May	15	15.00	33.00
	Ready for Harvest		9-Mar	31-May	20	-	-
			Approximate total duration		145		
Potato	Sowing	1,2	1-Nov	5-Dec	0	<10.0	>30.0
	Sprouting and emergence	1,2	16-Nov	20-Dec	15	<10.0	27.0
	Stolon initiation	1,1	6-Dec	9-Jan	20	<15.0	>23.0
	Tuber initiation	1,1	26-Dec	29-Jan	20	<15.0	>20.0
	Tuber bulking	1,1	25-Jan	28-Feb	30	<15.0	>20.0
	Maturity	1,1	4-Feb	10-Mar	10	<15.0	27.0
			Approximate total duration		95		
Lentil	Sowing	1,2	15-Oct	25-Nov	0	<4.0	>25.0
	Emergence		25-Oct	5-Dec	10	<10.0	>25.0
	Vegetative	1,2	4-Dec	14-Jan	40	<10.0	>30.0
	Flowering and grain filling		24-Dec	3-Feb	20	<10.0	>30.0
	Physiological maturity		28-Jan	9-Mar	35	<10.0	>30.0
			Approximate total duration		105		
Mung bean	Sowing	2,2	22-Jan	15-Mar	0	<11	>40
	Emergence	2,2	28-Jan	25-Mar	6	<11	>40
	Flower initiation		3-Feb	4-Apr	30	-	>35
	Pod initiation	0,3	9-Feb	14-Apr	5	-	>35
	Flowering	1,3	15-Feb	24-Apr	10	<25	>35
	Maturity		21-Feb	4-May	27	-	-
			Approximate total duration		78		

1 All values are approximations, as the values may vary over years, production environments, and locations.

2 Numbers in this column 'n' indicate the number of study observations included to calculate thresholds where the first and number is for minimum and the second one is for maximum temperature thresholds. Bold numbers indicate the number of observations included from the systematic literature review. The references for temperature thresholds are included in Agvisely Methods Appendix III and Agvisely Methods Appendix IV.

4. Precipitation Thresholds Applied to Major Field Crops of Bangladesh

Because there are considerable variation in precipitation patterns and soil water holding capacity throughout the world and in Bangladesh, defining a single threshold definition what constitutes 'heavy precipitation' is not easily feasible. To provide consistent general guidance in defining extreme precipitation, some basic parameters, including magnitude (intensity), duration, severity and spatial extent affected, should be included. These parameters should be enabled on multiple time scales of precipitation extremes, such as hourly, daily, and multi-day scales (TT-DEWCE, 2016). As a simple and actionable solution to these complex problems, Agvisely makes use of the Government approved Bangladesh Meteorological Department (BMD)'s criteria for rainfall events, including the following:

Table A7.2: Criteria for rainfall intensity used approved by the Bangladesh Meteorological Department

Light rain	<10 mm day^{-1}
Moderate rain	11 -22 mm day^{-1}
Moderately heavy rain	23-43 mm day^{-1}
Heavy rain	44-88 mm day^{-1}
Very heavy rain	>89 mm day^{-1}

Source: URL: http://live3.bmd.gov.bd/p/Glossary/

The above categories of rainfall for different crops at a different phonological stage have varied impacts. Therefore, depending on the category of rainfall crop-wise and at phonological stage, specific advisories were formulated for inclusion in Agvisely that are location-specific and easy to understand.

Based on the forecasted rainfall amount the crop-wise and phonological stage-wise advisories are formulated, if the amount is inadequate to meet the moisture deficit then advice for irrigation is triggered. If there is a chance moderate to moderately heavy rain then farmers are advised to refrain from irrigation and application of fertilizers and other agrochemicals. One the other hand, if there is a chance of heavy to very heavy rain then advise is given to protect the crop from inundating or waterlogging.

If there is no rain in the next five days or there are rainfall events of less than 1 mm day-1 and the cumulative amount of rain is less than 5 mm in five days then it is considered as a dry spell. Accordingly, advisories are formulated for meeting the moisture deficit by irrigating the crop.

Most of the agronomic management advisories were developed based on the literature published by the affiliated institutes of the National Agricultural Research System of Bangladesh and the Department of Agricultural Extension.

5. Agriculturally Relevant Weather Forecasts Produced at the Sub-District Level

The BMD generates three hourly weather forecast outputs using the Weather Research and Forecasting (WRF) model. Model outputs are supplied at a 3-hour interval, starting from 6 am (local time of Bangladesh) of the day of the generation of each of the forecast files. This results in everyday which makes 81 forecast outputs over every ten days. The 18 km gridded WRF forecasts are generated with each grid having a single centroid point value. With such a resolution to cover the whole of Bangladesh requires more than 450 grid points. Bangladesh has eight administrative Divisions, 64 districts and 491 sub-districts locally known as Upazilas. With 18 km, the gridded data points always fall evenly within the 491 Upazilas as their size and shape vary considerably. Responding to this problem, we modified the resolution forecast outputs to 4.5 km data through re-gridding, placing three more points on every consecutive two grid points. New point values were estimated through bilinear interpolation. With this higher resolution gridded forecast, every Upazila of Bangladesh has at least one grid that falls within each Upazila boundary. The climate forecast for any variable of a particular Upazila is then calculated by considering all the forecast grid points falling within the Upazila boundary, and taking the linear average of that variable of the particular instance of the forecast.

Using these model outputs for temperature and precipitation forecasts at an Upazila level, the above described thresholds for the likely phonological stage of each crop are compared to the forecast values. If the model forecast output is above or below the thermal threshold the anticipated impact on the crop is detrimental or damaging, then advisory for mitigating the impact is automatically triggered. Similarly, based on the forecasted rainfall amount as categorized by BMD, the potential impact on crop productivity is assessed and an advisory automatically generated for the location and crop of interest. Such automatic triggering happens in an algorithm that is built as a series of decision trees depending on the next 5-day forecast period (for which acceptable skill is possible), location, and the probable crop phenological stage at the time of the forecasts. The advisories were collected from various sources such as reference books, websites, or designed based on scientific/expert judgment and experiences, and were designed in a consultation workshop with experts from the Bangladesh Meteorological Organization, Bangladesh Agricultural Research Institute, Bangladesh Agricultural Research Council, Bangladesh Wheat and Maize Research Institute, Bangladesh Rice Research Institute, and the Department of Agricultural Extension.

6. Climate Information Service Advisories for Major Field Crops of Bangladesh

For these notifications to deploy, the web application 'Agvisely' was collaboratively developed by the International Maize and Wheat Improvement Centre, the Department of Agricultural Extension (DAE), and BMD in Bangladesh. Data on the climate thresholds for each phenological stage of the crops considered in the tool are stored in a server using MongoDB database software (Figure A7.2). Agvisely is built on Java and React, and hosted on the Google Cloud Platform (GCP). It ingests the WRF model outputs, which Agvisely receives from BMD on a daily basis on the GCP's storage, that are used to can generate Upazila specific temperature and rainfall forecasts for the next five days. Agvisely's decision tree architecture is built on a series of 'if-then' statements: If a threshold is passed for a particular Upazila at a particular time given the crop phenological windows summarized in Table A7.1, then a crop management advisory is automatically generated

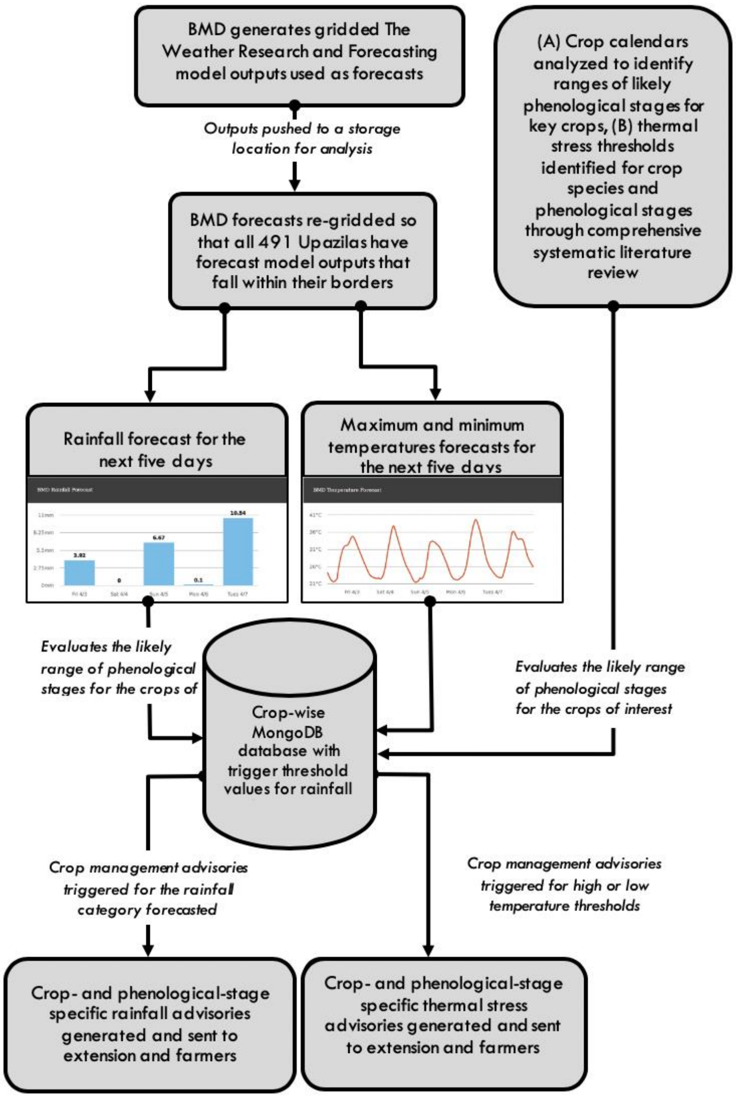


Figure A7.2: The architecture of Agvisely showing how forecast model outputs are integrated with climate stress thresholds for different crops depending on likely phenological stages during forecast periods to generate climate-smart crop management advisories.

Agvisely Methods Appendix I
Projects supporting the research that led to Agvisely

Climate Services for Resilient Development (CSRD) in South Asia

This agricultural climate information services tool was developed as part of the Climate Services for Resilient Development (CSRD) in South Asia project. CSRD is a global partnership supported by USAID that connects climate and environmental science with data streams to generate decision support tools and training for decision-makers in developing countries. Translating complex climate information into easy to understand actionable formats to spread awareness in the form of climate services is core to CSRD's mission. In South Asia, CSRD focusses the development, supply and adaptation of agricultural climate services to reduce vulnerability by increasing resiliency in smallholder farming systems. These goals are strategically aligned with the Global Framework for Climate Services.

The CSRD consortium in South Asia is led by the International Maize and Wheat Improvement Center (CIMMYT) in partnership with the Bangladesh Meteorological Department (BMD), Bangladesh Department of Agricultural Extension (DAE), Bangladesh Agricultural Research Council (BARC), Bangladesh Agricultural Research Institute (BARI), International Center for Integrated Mountain Development (ICIMOD), International Institute for Climate and Society (IRI), and the University de Passo Fundo (UPF). This consortium provides strength and technical expertise to develop relevant climate products that can assist farmers and other stakeholders with relevant information to improve decision making, with the ultimate goal of increasing resilience to climate-related risks. The CSRD consortium also works to assure that climate information can be conveyed in ways that are decision-relevant to farmers and other agricultural stakeholders. As a public-private partnership, CSRD is supported by the United States Agency for International Development (USAID), UK AID, the UK Met Office, the Asian Development Bank (ADB), the Inter-American Development Bank (IDB), ESRI, Google, the American Red Cross.

Cereal Systems Initiative for South Asia

With the support of USAID and the Bill and Melinda Gates Foundation, the Cereal Systems Initiative for South Asia (CSISA) was established in 2009 with the goal of increasing the productivity and resilience of millions of farmers by the end of 2020. CSISA is led by the International Maize and Wheat Improvement Center (CIMMYT) and is implemented jointly with the International Food Policy Research Institute (IFPRI) and the International Rice Research Institute (IRRI) in addition to numerous public and private sector partners.

- Operating in rural Bangladesh, India and Nepal, CSISA works to increase the adoption of resource-conserving and climate-resilient agricultural technologies, and improve farmers' access to market information and enterprise development.
- CSISA supports women farmers by improving their access and exposure to modern and improved technological innovations, knowledge and entreprenUSDial skills.
- In synergy with regional and national efforts, CSISA collaborates with numerous strategic public, civil society and private-sector partners.

The project has over time developed into a more comprehensive research for development program with many additional and synergistic investments by USAID/Washington and USAID's Missions in Nepal and Bangladesh to deepen the scope and impact of CSISA's work.

Agvisely Methods Appendix II
Search strings used to locate literature on thermal stress thresholds for rice, wheat, and maize by database.

Scopus basic search codes:

(TITLE-ABS-KEY (heat OR "high temp*" OR "high-temp*" OR "heat stress" OR "heat-stress" OR "thermal stress" OR "thermal-stress" OR cold OR "cold temp*" OR "cold-temp*" OR "cold stress" OR "cold-stress" OR "terminal heat stress" OR "terminal heat-stress" OR "terminal heat") AND ABS ("zea mays" OR maize OR corn OR "triticum aestivum" OR wheat OR "oryza sativa" OR rice) AND ABS (yield))

CAB basic Search codes:

title:("heat" OR "high temp*" OR "high-temp*" OR "heat stress" OR "heat-stress" OR "thermal stress" OR "thermal-stress" OR "Cold" OR "cold temp*" OR "cold-temp*" OR "cold stress" OR "cold-stress" OR "terminal heat stress" OR "terminal heat-stress" OR "terminal heat" OR "terminal-heat" OR "Threshold" OR "temp* threshold" OR "temp*-threshold" OR "cold injury" OR "cold-injury" OR "day* temp*" OR "day*-temp*" OR "night* temp*" OR "night*-temp*" OR "cardinal temp*" OR "cardinal-temp*") AND ab:("zea mays" OR "maize" OR "corn" OR "triticum aestivum" OR "wheat" OR "oryza sativa" OR "rice") AND ab:("yield")

WOS advance search codes:

TS=(heat OR high temp* OR high-temp* OR heat stress OR heat-stress OR thermal stress OR thermal-stress OR Cold OR cold temp* OR cold-temp* OR cold stress OR cold-stress OR terminal heat stress OR terminal heat-stress OR terminal heat OR terminal-heat OR Threshold OR temp* threshold OR temp*-threshold OR cold injury OR cold-injury OR day* temp* OR day*-temp* OR night* temp* OR night*-temp* OR cardinal temp* OR cardinal-temp*) AND TS=(Zea mays OR maize OR corn OR Triticum aestivum OR wheat OR Oryza sativa OR rice) AND TS=(yield)

AGRICOLA search codes:

tkey"heat"OR"high temp*"OR"high-temp*"OR"heat stress"OR"thermal stress"OR"cold stress"OR"cold-stress"OR "cold"OR"cold temp*"OR"cold-temp*"OR "terminal heat stress"OR"terminal heat-stress"OR"terminal heat"OR"terminal-heat"OR"threshold"OR"temp* threshold"OR"cold injury"OR"day* temp*"OR"night* temp*"OR"cardinal temp*"AND tkey"maize"OR "corn"or"wheat"or"rice"AND tkey"yield"

Agvisely Methods Appendix III.
Papers used in systematic literature review to determine temperature stress thresholds for rice, wheat and maize.

1. Aghamolki, M. T. K., Yusop, M. K., Oad, F. C., Jaafar, H. Z. Khalatbari, A. M. Kharidah, S. and Musa, M. H. 2016. Impact of heat stress on growth and yield of rice (Oryza sativa L.) cultivars. Journal of Food, Agriculture and Environment,14: 111-116
2. Aghamolki, M. T. K., Yusop, M. K., Oad, F. C., Zakikhani, H., Jaafar, H. Z., Kharidah, S. and Musa, M. H. 2014. Heat stress effects on yield parameters of selected rice cultivars at reproductive growth stages. Journal of Food, Agriculture and Environment, 12:741-746
3. Ali, Z. I., Mahalakshmi, V., Singh, M., Ortiz-Ferrara, G. and Peacock, J. M. 1994. Variation in cardinal temperatures for germination among wheat (Triticum aestivum) genotypes. Annals of Applied Biology, 125: 367-375. doi:10.1111/j.1744-7348.1994.tb04977.x
4. Alvarado-Sanabria, O. H., Garces-Varon, G. A. and Restrepo-Diaz, H. 2017. The effects of night - time temperature on physiological and biochemical traits in rice. Notulae Botanicae Horti Agrobotanici Cluj-Napoca. 45:157-163. DOI:10.15835/nbha45110627
5. Angus, J. F., Mackenzie, D. H., Morton, R. and Schafer, C. A. 1981.Phasic development in field crops II. Thermal and photoperiodic responses of spring wheat, Field Crops Research, 4:269-283. https://doi.org/10.1016/0378-4290(81)90078-2.
6. Arshad. M., Amjath-Babu, T. S., Krupnik, T.J., Aravindakshan. S., Abbas. A., Kächele. H. Miller, K. 2017. Climate variability and yield risk in South Asia's rice–wheat systems: emerging evidence from Pakistan. Paddy and Water Environment. 2;15(2):249-261. https://doi.org/10.1007/s10333-016-0544-0
7. Asseng, S., Foster, I. and Turner, N. C. 2011. The impact of temperature variability on wheat yields. Global Change Biology, 17: 997-1012. doi:10.1111/j.1365-2486.2010.02262.x
8. Bheemanahalli, R., Sathishraj, R., Tack, J., Nalley, L. L., Muthurajan, R., and Jagadish K.S.V. 2016. Temperature thresholds for spikelet sterility and associated warming impacts for sub-tropical rice. Agricultural and Forest Meteorology, 221:122-130, https://doi.org/10.1016/ j.agrformet. 2016.02.003.
9. Blum, A. and Sinmena, B. 1994. Wheat seed endosperm utilization under heat stress and its relation to thermotolerance in the autotrophic plant, Field Crops Research, 37(3):185-191. https://doi.org/ 10.1016/0378-4290(94)90097-3.
10. Bonhomme, R., Derieux, M. and Edmeades G.O. 1994. Flowering of Diverse Maize Cultivars in Relation to Temperature and Photoperiod in Multilocation Field Trials. Crop Science Abstract. 34:156-164.
11. Boote, K. J., Allen, L. H., Prasad, P. V. V., Baker, J. T., Gesch, Russ. W., Snyder, A. M., Pan, D. And Thomas, J. M. G. 2005. Elevated Temperature and CO2 impacts on pollination, reproductive growth and yield of several globally important crops. Journal of Agricultural Meteorology, 60:469-474
12. Cao, Y.-Y., Duan, H., Yang, L.-N., Wang, Z.-Q., Liu, L.-J., Yang, J.-C. 2009. Effect of High Temperature during Heading and Early Filling on Grain Yield and Physiological Characteristics in Indica Rice. Acta Agronomica Sinica. 35: Issue 3512-521. doi.org/10.1016/S1875-2780 (08)60071-1.
13. Chakrabarti, B., Aggarwal, P. K., Singh, S. D., Nagarajan, S., and Pathak, H. 2010. Impact of high temperature on pollen germination and spikelet sterility in rice: comparison between basmati and non-basmati varieties. Crop and Pasture Science. 61:363-368

14. Das, S., Krishnan, P., Nayak, M. and Ramakrishnan, B. 2014. High temperature stress effects on pollens of rice. Environmental and Experimental Botany. 101:36-46. dx.doi.org/10.1016/j.envexpbot.2014.01.004
15. Di, H., Jing, W., Tong, D., Liping, F., Jianping, Z., Xuebiao, P. and Zhihua, P. 2014. Impact of climate change on maize potential productivity and the potential productivity gap in southwest china. Journal of Meteorological Research. 28:1155-1167. DOI:10.1007/s13351-014-4047-x
16. Fu, G., Feng, B., Zhang, C., Yang, Y., Chen, T., Zhao, X., Zhang, X., Jin, Q. and Tao, L. 2016. Heat stress is more damaging to superior spikelets than inferior of rice (oryzea sativa L.) due to their different organ temperatures. Frontires in plant science. 7: Article1637. DOI:10.3389/fpls.2016.01637
17. Ghadirnezhad, R. and Fallah, A. 2014. Temperature effect on yield and yield components of different rice in flowering stage. International Journal of Agronomy, vol. 2014, Article ID 846707, 4 pages, 2014. https://doi.org/10.1155/2014/846707
18. Greaves, J. A. 1996. Improving suboptimal temperature tolerance in maize the search for variation. Journal of Experimental Botany. 47:307-323
19. Herrero, M. P., and Johnson, R. R. 1980. High temperature stress and pollen viability of maize. Crop Science Abstract, 20:796-800. doi:10.2135/cropsci1980.0011183X002000060030x
20. Hlavacova, M., Klem, K., Smutna, P. Skarpa, P., Hlavinka, P., Novotna, K., and Rapantova, B. 2017. Effect of heat stress at anthesis on yield formation in winter wheat. Plant Soil Environment, 63:139-144. DOI:10.17221/73/2017-PSE
21. Holzkamper, A., Calance, P., and Fuhrer, J. 2013. Identifying climatic limitations to grain maize yield potentials using a suitability evaluation approach. Agricultural and Forest Meterology. 168: 149-159. doi.org/10.1016/j.agrformet.2012.09.004
22. Hossain, A., Sarker, M.A.Z., Saifuzzaman, M., Texeira da Silva, J.A., Lozovskaya, M.V. and Akhter, M.M. 2013. Evaluation of growth, yield, relative performance and heat susceptibility of eight wheat *(Triticum aestivum* L.) genotypes grown under stress. International journal of plant production. 7(3): 615-636. DOI: 10.22069/IJPP.2013.1121
23. Ishimaru, T., Hirabayashi, H., Ida, M., Takai, T., San-Oh, Y. A., Yoshinaga, S., Ando, I., Ogawa, T. and Konodo, M. 2010. A genetic resource for early-morning flowering trait of wild rice Oryza officinalis to mitigate high temperature -induced spikelet sterility at anthesis. Annals of Botany. 106:515-520. DOI:10.1093/aob/mcq124
24. Jagadish, S.V.K., Craufurd, P.Q. and Wheeler, T.R. 2007. High temperature stress and spikelet fertility in rice (Oryza sativa L.). Journal of Experimental Botany. 58:1627-1635. DOI:10.1093/jxb/erm003
25. Jenner, C. F. 1991. Effects of exposure of wheat ears to high temperature on dry matter accumulation and carbohydrate metabolism in the grain of two cultivars. I. Immediate responses. Australian Journal of Plant Physiology, 18:165-177. https://doi.org/10.1071/PP9910165
26. Kabir, M. S., Howlader, M., Biswas, J. K., Mahbub, M. A. A. and Nur-E-Elahi M. 2015. Probability of low temperature stress at different growth stage of boro rice. Bangladesh rice journal, 19:19-25
27. Karim, M. R., M Ishikawa, Ikeda, M. and Islam, M. T. 2012. Climate change model predicts 33% rice yield decrease in 2010 in Bangladesh. Agronomy for Sustainable Development, 32:821-830. DOI:10.1007/s13593-012-0096-7

28. Kumar, N., Kumar, N., Shukla, A., Shankhdhar, S.C. and Shankhdhar, D. 2015. Impact of terminal heat stress on pollen viability and yield attributes of Rice (*Oryza sativa* L.). Cereal Research Communications 43:616-626. DOI:10.1556/0806.43.2015.023
29. Liu, B., Liu, L., Asseng, S., Zou, X., Li, J. and Cao, W. 2016. Modelling the effects of heat stress on post-heading durations in wheat: A comparison of temperature response routines. Agricultural and Forest Meterology, 222:45-58. DOI:dx.doi.org/10.1016/ j.agrformet. 2016.03.006
30. Lizaso, J. I., Ruiz-Ramos, M., Rodriguez, L., Gabaldon-Leal, C., Oliveira, J. A., Lorite, I. J., Sanchez, D., Garcia, E. and Rodriguez, A. 2018. Impact of high temperatures in maize: phenology and yield components. Field Crop Research. 216:129-140. doi.org/10.1016/j.fcr.2017.11.013
31. Lu, D., Sun, X., Yan, F., Wang, X., Xu, R. and Lu, W. 2014. Effects of heat stress at different grain-filling phases on the grain yield and quality of waxy maize. Cereal Chemistery. 91:189-194 dx.doi.org/10.1094/CCHEM-05-13-0083-R
32. Matsui, T., Namuco, O. S., Ziska, L. H., and Horie, T. 1997. Effect of high temperature and CO_2 concentration on spikelet sterility in indica rice. Field Crop Research, 51:213-219
33. Matsui, T., Omasa, K. and Horie, T. 2000. High temperature at flowering inhibits swelling of pollen grains a driving force for thecae dehiscence in rice (oryzae sativa L.). Plant Production Science. 3:430-434. doi.org/10.1626/pps.3.430
34. Morita, S., Yonemaru, J-I. and Takanashi J-I. 2005. Grain growth and endosperm cell size under high night temperature in rice (Oryza sativa L.). Annals of Botany. 95:695-701. DOI:10.1093/aob/mci071
35. Nawaz, A., Farooq, M., Cheema, S. A. and Wahid, A. 2013. Differential response of wheat cultivers to terminal heat stress. International journal of Agriculture and Biology,15(6):1353-1358
36. Pararajasingham S. and Hunt, L. A. 1990. Wheat spike temperature in relation to base temperature for grain filling duration. Canadian Journal of Plant Science, 71:63-69
37. Pradhan, G.P. and Prasad, P. V. V. 2015. Evaluation of Wheat Chromosome Translocation Lines for High Temperature Stress Tolerance at Grain Filling Stage. PLOS ONE 10(2): e0116620. https://doi.org/10.1371/journal.pone.0116620
38. Prasad P.V. V. and Djanaguiraman, M. 2014. Response of floret fertility and individual grain weight of wheat to high temperature stress: Sensitive stages and thresholds for temperature and duration. Functional Plant Biology, 41:1261-1269. dx.doi.org/10.1071/fpi1461
39. Ritchie, J.T., and NeSmith, D.S. 1991. Temperature and crop development. In: Hanks J, Ritchie JT (eds) Modelling plant and soil systems. American Society of Agronomy, Madison, Wisconsin, pp5–29
40. Saini, H.S., Sedgley, M. and Aspinall, D. 1983. Effect of heat stress during floral development on pollen tube growth and ovary anatomy in wheat (triticum aestivum L.).Australian Journal of Plant Physiology. 10: 137-144. doi.org/10.1071/PP9830137
41. Sanchez, B., Rasmussen, A. and Porter, J. R. 2014. Temperature and the growth and development of maize and rice. Global Change Biology, 20:408-418
42. Satake, T. and Yoshida, S. 1978. High temperature - induced sterility in Indica rices at flowering. Japanese Journal of Crop Science. 47: 6-17
43. Segata, V. 1964. Physiology of the cold - resistance of maize during germination. The reaction of maize (Zea mays L.) to low temperature during germination and its cold-resistance. Biologia Plantarum. 6:189-197

44. Steven J. Crafts-Brandner, Michael E. Salvucci. 2002. Sensitivity of Photosynthesis in a C4 Plant, Maize, to Heat Stress. American Society of Plant Physiology, 129 (4) 1773-1780; DOI:10.1104/pp.002170
45. Subedi, K. D., Floyd, C. N., and Budhathoki, C. B. 1998. Cool temperature-induced sterility in spring *wheat (Triticum aestivum* L.) at high altitude in Nepal: variation among cultivars in response to sowing date. Field Crop Research 55:141-151
46. Subedi, K. D., Gregory, P. JM Summerfield, R. J., and Gooding, M. J. 2000. Pattern of grain set in boron-deficient and cold-stressed wheat (Triticum aestivum L.). J- Agric. Sci. 134:25-31.
47. Sun, T., Hasegawa, T., Tang, L., Wang, W., Zhou, J., Liu, L., Liu, B., Cao, W. and Zhu, Y. 2018. Stage-dependent temperature sensitivity function predicts seed-setting rates under short-term extreme heat stress in rice. Agricultural and Forest Meteorology, 256-257:196-206. doi.org/10.1016/j.agrformet.2018.03.006
48. Sun, W. and Huang, Y. 2011. Global warming over the period 1961-2008 did not increase high-temperature stress but did not reduce low-temperature stress in irrigated rice across china. Agricultural and Forest Meteorology, 15:1193-1201. DOI:10.1016/j.agrformet.2011.04.009
49. Suwa, R., Hakata, H., Hara, H., El-Shemy, H. A., Adu-Gyamfi, J. J., Nguyen, N. T., Kanai, S., Lightfoot, D. A., Mohapatra, P. K., and Fujita, K. 2010. High Temperature effects on photosynthate partioning and sugar metabolism during ear expansion in maize (Zea mays L.) genotypes. Plan Physiology and Biochemistry, 48: 124-130, DOI:10.1016/j.plaphy.2009.12.010
50. Talukder, A.S.M.H.M., McDonald, G. K. and Gill, G. S. 2014. Effect of short-term heat stress prior to flowering and grain set on the grain yield of wheat. Field Crops Research. 160:54-63. DOI: org/j.fcr.2014.01.013
51. Tashiro, T., and Wardlaw, I. F. 1990. The response to high temperature shock and humidity changes prior to and during the early stages of grain development in wheat. Functional Plant Biology, 17:551-561
52. Teixeira, E. I., Fischer, Guenther., Velthuizen, H. van., Walter, C. and Ewert, F. 2013. Global hot-spots of heat stress on agricultural crops due to climate change. Agricultural and Forest Meteorology, 170:206-215DOI:10.1016/j.agrformet.2011.09.002
53. Veisz, O., Balla, K., Bencze, S., Bencze, S. and Bedő, Z. 2008. Effect of heat stress on the quantitative and qualitative components of wheat grain. Eds. Prohens, J. and Badenes, M. L. Modern Variety Breeding for Present and Future Needs (2008) Editorial Universidad Politécnica de Valencia, Valencia, Spain. pp654-660
54. Wardlaw, I. F. and Moncur, L. 1995. The Response of Wheat to High Temperature Following Anthesis. I. The Rate and Duration of Kernel Filling. Functional Plant Biol., 22(3):391-397. https://doi.org/10.1071/PP9950391
55. Wheeler, T. R., Craufurd, P. Q., Ellias, R. H., Porter, J. R. and Prasad, P.V.V. 2000. Temperature variability and the yield of annual crops. Agriculture, Ecosystems and Environment, 82:159-167. doi.org/10.1016/S0167-8809(00)00224-3
56. White, J. W., Kimball, B. A., Wall, G. W. and Ottman, M. J. 2012. Cardinal temperature for wheat leaf appearance as assessed from varied sowing dates and infrared warming. Field Crop Research. 137:213-220. dx.doi.org/10.1016/j.fcr.2012.08.013
57. Wollenweber, B., Porter, J.R. and Schellberg, J. 2003. Lack of interaction between extreme high-temperature events at vegetative and reproductive growth stages in wheat. Agronomy and Crop Science, 189:142-150. doi.org/10.1046/j.1439-037X.2003.00025.x

58. Zhang, L., Yang, B., Li, Sen., Hou, Y. and Huang, D. 2018. Potential rice exposure to heat stress along the Yangtze River in China under RCP8.5 scenario. Agricultural and Forest Meteorology, 248:185-196. dx.doi.org/10.1016/j.agrformet.2017.09.020
59. Ziska, L. H., Manalo, P. A. and Ordonez, R. A. 1996. Intraspecific variation in the response of rice (Oryzae sativa L.) to increased CO_2 and temperature: growth and yield response of 17 cultivars. Journal of Experimental Botany. 47: No. 302, pp1353-1359 doi.org/10.1093/jxb/47.9.1353

Agvisely Methods Appendix IV. Literature used to determine phenologies of all crops, temperature stress thresholds for potato, lentil, and mung bean. And for cereal crops for phonological stage not covered considered in the systematic review.

1. Acevedo, E. Silva, P. and Silva, H. 2002. Wheat growth and physiology. In Bread Wheat: Improvement and Production. Curtis B.C., Rajaram, S. and Gómez, M. H. (Eds.). FAO Plant Production and Protection Series No. 30, Food and Agriculture Organization of the United Nations. Rome.
2. Ahlawat, I. P. S. (nd) Agronomy – Rabi Crops Lentil. https://www.academia.edu/8115138/Agronomy_Rabi_Crops_Lentil
3. Al-Qasem, H., Kafawin, O. and Duwayri, M. 1999. Effects of seed size and temperature on germination of two wheat cultivars. Dirasat Agric. Sci. 26(1): 1-7.
4. Alvarado, V. and Bradford, K. J. 2002. A hydrothermal time model explains the cardinal temperatures for seed germination. Plant Cell Environ., 25(8)1061-1069.
5. Anonymous, 2019. Virginia Potato Disease Advisory – 2010. Sponsored by the Virginia Irish Potato Board. URL: http://blogs.ext.vt.edu/ag-pest-advisory/files/2014/07/VPDAMay192010.doc. Accessed on January 08, 2019.
6. BARI (Bangladesh Agricultural Research Institute). 2019. Krishi Projukti Hatboi (Handbook on Agro-Technology), 8th Edition. Azad et al., (Eds). Bangladesh Agricultural Research Institute, Gazipur-1701, Bangladesh
7. BINA (Bangladesh Institute of Nuclear Agriculture). 2017. BINA Varieties: At a glance. Bangladesh Institute of Nuclear Agriculture BAU Campus, Mymensingh. http://www.bina.gov.bd/site/ page/429b2747-9105-49fc-a141-6cebead52833/-
8. BRRI (Bangladesh Rice Research Institute). 2019. Adhunik Dhaner Chash (Cultivation of Modern Rice) Bangladesh Rice Research Institute, Gazipur-1701.
9. Chauhan, Y.S., Douglas, C., Rachaputi, R.C.N., Agius, P., Martin, W., King, K. and Skerman, A. 2010. Physiology of Mubg bean and Development of the Mubg bean Crop Model. Proceedings of the 1st Australian Summer Grains Conference, Gold Coast, Australia, 21–24 June 2010.
10. DAFF (Department: Agriculture, Forestry and Fisheries). 2010. Mung bean Production Guidelines. Department: Agriculture, Forestry and Fisheries, Republic of South Africa. https://www.daff.gov.za/docs/Brochures/ MbeanpGUDELINS.pdf
11. Delahunty, A., Nuttall, J., Nicolas, M., and Brand, J. (2015). "Genotypic heat tolerance in lentil," in Proceedings of the 17th ASA Conference (Hobart), 20-24.
12. Elsheikh, A., Ranya, Shariff, Rashid, Amiri, Fazel, Ahmad, Noordin, Balasundram, Siva, and Amin, M. 2013. Agriculture Land Suitability Evaluator (ALSE): A decision and planning support tool for tropical and subtropical crops. Computers and Electronics in Agriculture, vol 93: 98-110. DOI 10.1016/j.compag.2013.02.003
13. Gowda, C. L. L. and Kaul, A.K. 1983. Pluses in Bangladesh. Bangladesh Agricultural Research Institute and the Food and Agriculture Organization (FAO).
14. GRiSP (Global Rice Science Partnership). 2013. Rice almanac, 4th edition. Los Baños (Philippines): International Rice Research Institute. pp 283
15. Hasan, M. N., Hossain, M. S., Bari, M. A. and Islam, M. R. 2013. Agricultural land availability in Bangladesh. SRDI, Dhaka, Bangladesh.

16. Institute of Agriculture and Natural Resources (IANR). 2019. Forecasting Late Blight: Severity Values. https://cropwatch.unl.edu/potato/late_blights_forecasting. Accessed on January 10, 2019.
17. IRRI (International Rice Research Institute). 2018. IRRI Crop calendar - IRRI Rice Knowledge Bank. http://www.knowledgebank.irri.org/
18. Islam, M.T. 2015. Effects of High Temperature on Photosynthesis and Yield in Mubg bean. Bangladesh J. Bot. 44(3): 451-454
19. Kamruzzaman, M., Marjuk, O. A. and Alam, M. 2017. Local Rice Varieties in Climate Vulnerable Areas of Bangladesh: Prospects and Barriers. Proceedings of 7th International Symposium, 7th & 8th December 2017 at South Eastern University of Sri Lanka. pp423-433.
20. Kang, J.S., Harmeet Singh, Gurbir Singh, Harrajdeep Kang, Vajinder Pal Kalra and Jagroop KaurInt. 2017. Abiotic Stress and Its Amelioration in Cereals and Pulses: A Review J.Curr.Microbiol.App.Sci (2017) 6(3): 1019-104
21. Kumar, K., Solanki, S., Singh, S.N. and Khan, M.A. 2016. Abiotic constraints of pulse production in India. (In) Disease of Pulse Crops and their Sustainable Management, pp. 23–39, Biswas, S.K., Kumar, S. and Chand, G. (Eds). Biotech Books, New Delhi, India.
22. Large, E.C. 1954. Growth stages in cereals. Illustration of the "Feekes" Scale. Plant Pathol., 3: 128-129.
23. Miedema, P., Post, J. and Groot, P.J. 1987. The effects of low temperature on seedling growth of maize genotypes. Wageningen: Pudoc. - Fig., tab. - (Agricultural research reports; 926) With ref. pp124.
24. Moldenhauer, K., Counce, P. and Hardke, J.T. 2018. Chapter 2: Rice Growth and Development. Rice Production Handbook. Hardke, J. T. (Ed) University of Arkansas Division of Agriculture Cooperative Extension Service. pp9-20. https://www.uaex.edu/publications/pdf/mp192/chapter-2.pdf
25. Nasim, M., Shahidullah, S. M., Saha, A., Muttaleb, M. A., Aditya, T. L., Ali, M. A. and Kabir, M. S. 2017. Distribution of Crops and Cropping Patterns in Bangladesh. Bangladesh Rice J. 21 (2): 1-55
26. Obidiegwu Jude, Bryan Glenn, Jones Hamlyn, Prashar Ankush 2015. Coping with drought: stress and adaptive responses in potato and perspectives for improvement. Frontiers in Plant Science, 6:542. URL=https://www.frontiersin.org/article/10.3389/fpls.2015.00542
27. Pavlista, A.D. and Stevenson, W.R. 1995. Forecasting Late Blight. Univ. Nebraska Coop. Extension Circ. 95-1250.
28. Prange, R.K., McRae, K.B., Midmore, D.J. and Deng, R. 1990. 'Reduction in potato growth at high temperature. Role of photosynthesis and dark respiration. American Potato Journal, 67:357-369
29. Pringle, G. 2017. Maize production: Managing critical plant growth stages. Farmer's Weekly Magazine. URL:https://www.farmersweekly.co.za/crops/field-crops/maize-production-managing-critical-plant-growth-stages/
30. Rahman, M. M., Bakr, M. A., Mia, M. F., Idris, K. M., Gowda, C. L. L., Kumar, J., Deb, U. K., Malek, M. A., and Sobhan, A. 2000. *Legumes in Bangladesh*. In: Legumes in rice and wheat cropping systems of the Indo-Gangetic Plain - constraints and opportunities. International Crops Research Institute for the Semi-Arid Tropics, Patancheru, Andhra Pradesh, India, pp. 5-34.

31. Rehman, A., Khalil, S. K., Nigar, S., Rehman, S., Haq, I., Akhtar, S., Khan, A. Z. and Shah, S. R. 2009. Phenology, plant height and yield of mung bean varieties in response to planting date. Sarhad J. Agric. Vol.25, No.2, 2009.

32. Sale, P. J. M. (1979). Growth of potatoes (Solanum tuberosum L.) to the small tuber stage as related to soil temperature. Australian Journal of Agricultural Research. 30, 667-675.

33. Sen, S., Ghosh, M., Mazumdar, D., Saha, B., and Dolui, S. 2016. Effect of sowing date and variety on phenology and yield of lentil during rabi season. Journal of Crop and Weed, 12:135-138.

34. Shahidullah, S. M., Talukder, M. S. A., Kabir, M. S., Khan, A.H. and Elahi. N. E. 2006. Cropping patterns in the South East Coastal Region of Bangladesh. J. Agric. Rural Dev. 4(1&2): 53-60.

35. Simon, E. W., Minchin, A., McMenamin, M. M. and Smith, J. M. 1976. The Low Temperature Limit for Seed Germination. The New Phytologist. Vol. 77, No. 2 (Sep., 1976), pp. 301-311.

36. Struik, P. C. 2007. Response of the potato plant to temperature. In D. Vreugenhil (Ed.), Potato biology and biotechnology: advances and perspectives (pp. 367-393). Amsterdam: Elsevier.

37. Sys, C., Van Ranst, E., Debaveye, J., and Beernaert, F. 1993. Land Evaluation Part III: Crop Requirements. Agricultural Publications - N° 7. General Administration for Development Cooperation, Place du Champ de Mars 5 bte 57 - 1050 Brussels – Belgium.

38. TNAU (Tamil Nandu Agricultural Universitiy). 2018. Agrometeorology: Temperature and Plant Growth. URL: http://agritech.tnau.ac.in/agriculture/agri_agrometeorology_temp.html. Accessed on 20 January, 2020.

39. TT-DEWCE (Task Team on Definitions of Extreme Weather and Climate Events) 2016. Guidelines on the Definition and Monitoring of Extreme Weather and Climate Events. Draft Version – First Review by TT-DEWCE, December 2015. WMO

40. Vikaspedia portal.ND. Government of India initiative. URL:http://vikaspedia.in/agriculture/crop-production/package- of-practices/vegetables-1/potato#section-3. Accessed on January 10, 2019.

41. Yoshida, S. 1981. Fundamentals of Rice Crop Science. International Rice Research Institute, Los Banos, Laguna, Philippines. 269 pages.

Annex 8: Draft Paper on Regional Climatological Analysis of Wheat Blast Disease Risks

Climate suitability for wheat blast in Asia: A model based analysis considering interannual variability

Carlo Montes[1,14] and Timothy J. Krupnik

1. Introduction

Wheat blast disease was first reported in Bangladesh in 2016, which is indicative of the adaptability of the pathogen and the suitable conditions of the region for the development the development of *Magnaporthe oryzae* Triticum (MoT) (Islam et al., 2019). As for any other fungal crop disease, wheat blast occurrence represents a major potential abiotic stress causing significant loses to farmers (Mottaleb et al., 2018), and although the advances in new resistant varieties and efficient and environmentally safe chemical control are numerous, losses associated with fungal diseases incidence are still very important and, in some cases, devastating (Fisher et al., 2012). This is particularly important in the current context of less effective natural barriers due to greater commercial exchange and products transportation, which increases the exposure of crops to new diseases non-existing locally. This is the case of the appearance of wheat blast in Bangladesh (Malaker et al., 2016), after having been reported for years only in South America (Brazil, Bolivia, Argentina, Paraguay), generating significant yield losses in wheat producing regions of those countries (Cruz et al., 2016; Duveiller et al., 2016).

The incidence and impact of fungal diseases and their spread in different regions depends, among other factors, on the cultural practices associated with agronomic management, the susceptibility of the varieties, or the prevailing environmental conditions (Anderson et al., 2004). Multiple tools have been developed for the monitoring and forecasting of fungal diseases outbreaks based on field observations or empirical and deterministic numerical models that combine different weather variables to generate an early warning of potential risk of disease outbreaks (e.g. Launay et al., 2014). Given the increase in the availability of environmental data and computing capacities, the use of simulation models for the diagnosis and forecasting of favorable conditions for the development of crop diseases has taken on great importance during the last years (e.g. Donatelli et al., 2017). Applications vary from regional assessment of climate suitability (Bebber et al., 2017), sensitivity analysis to environmental drivers and parameterizations (Bregaglio et al., 2012) or future projections in risks of crop diseases associated with climate change (Bregaglio et al., 2013). Given that the adequate conditions for the establishment of fungal diseases are well described and there is agreement that factors such as atmospheric humidity and temperature are to the main drivers that can trigger their development, it is possible to use mathematical models to assess the potential incidence of specific diseases in poorly studied regions and their spatial and temporal patterns and associated factors. The later becomes relevant in the case of wheat blast in Bangladesh and the potential expansion to new wheat producing areas in South and Southeast Asia and the associated impact on food security in a highly populated area.

In this context, the aim of this work is to provide a general overview of the spatial and time variability in climate suitability for the development of wheat blast in wheat-growing countries

[14]c.montesv@cgiar.org. [1]International Maize and Wheat Improvement Center (CIMMYT), Dhaka, Bangladesh

of South and Southeast Asia, based on the analysis of the results obtained from a climate-driven potential infection model. Considering as hypothesis the potential expansion of wheat blast over other countries of the continent after its appearance in Bangladesh, the information generated by this work represents an estimate of the potential pressure of wheat blast disease associated with climate variables, and that can be useful for regional planning regarding early warning systems and local extension activities.

2. Materials and methods

2.1 Potential wheat blast infection modeling

Considering the application in previous studies to the regional scale using grilled data (Bregaglio et al., 2013) and its biological meaningful parameterizations, the generic potential infection model developed by Magarey et al. (2005) was selected to be applied with the above-described data. As mentioned by Bregaglio et al. 2012, this model has been proved to effectively respond to input data variability. The model considers both hourly air temperature and leaf wetness (or relative humidity) duration to simulate the response of a generic fungal pathogen by means of two functions describing its sensitivity to both variables.

The model uses the air temperature response function proposed by Yann and Hunt (1999), which combines a set of pathogen's cardinal temperatures to estimate the shape of the response as:

$$f(T) = \left(\frac{T_{max}-T}{T_{max}-T_{opt}}\right)\left(\frac{T-T_{min}}{T_{opt}-T_{min}}\right)^{(T_{opt}-T_{min})/(T_{max}-T_{opt})} \quad (1)$$

where *f*(*T*) (dimensionless, values from 0 to 1) is the temperature response function; *T* (°C) is the hourly air temperature; T_{min}, T_{max} and T_{opt} are the minimum, maximum and optimum temperatures for infection, respectively. These cardinal temperatures were taken from Cruz et al. (2016), who suggested the following values for wheat blast: T_{min} = 10°C, T_{max} = 32°C, and T_{opt} = 27.5°C. As an example, Figure A8.1 shows the resulting shape of *f*(*T*), where an exponential increasing response to temperature is observed between T_{min} and around 20°C, which turns from almost lineal to a decreasing increment until T_{opt}, to then drop drastically until *f*(*t*) = 0 at T_{max}.

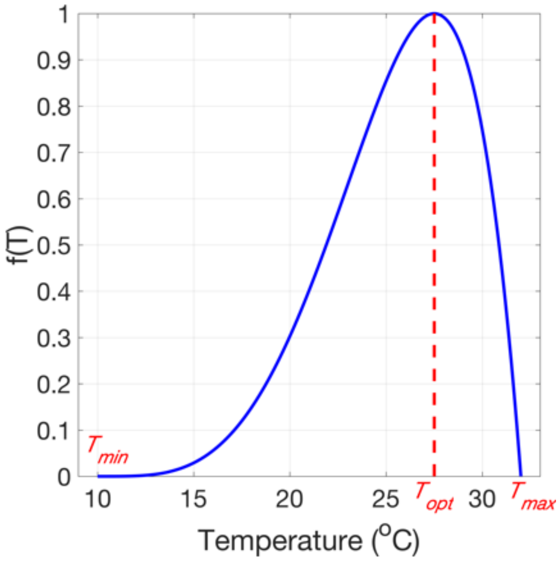


Figure A8.1: The shape of temperature response curve obtained by Equation (1) using parameters for wheat blast (explained the text).

The air temperature response *f*(*T*) is subsequently scaled to the wetness duration requirement according to the following relationship:

$$W(T) = \begin{cases} \frac{WD_{min}}{f(T)}, if\ \frac{WD_{min}}{f(T)} \leq WD_{max} \\ 0 \quad elsewhere \end{cases} \quad (2)$$

where *W*(*t*) (dimensionless, values from 0 to 1) corresponds to the wetness response function, and WD_{min} and WD_{max} (hours) are the minimum and maximum leaf wetness duration requirement for infection, respectively.

As explained by Magarey et al. (2005), when infection models use hourly forcing data, it is necessary to know the number of hours that may interrupt a wet period without terminating the infection process. For this, the model considers the impact of critical dry periods through the parameter *D*50 that is calculated as:

$$W(T) = \begin{cases} W_1 + W_2, if\ D \leq D50 \\ W_1,\ W_2,\ elsewhere \end{cases} \quad (3)$$

where W_{sum} is the sum of the surface wetting periods and W_1 and W_2 indicate two wet periods separated by a dry period (*D*, in hours). As in Magarey et al. (2005), *D*50 is defined as the duration of a dry period at relative humidity < 95% that will result in a 50% reduction in disease compared with a continuous wetness period. Like this, if *D* > *D*50, the model considers the two wet periods as separated wetting events. When the leaf is wet and *f*(*T*) > 0, the model adds a cohort of spores and considers that an infection event occurs if the value of W_{sum} ranges between WD_{min} and WD_{max} (Bregaglio et al., 2012).

2.2 Infection model forcing

A significant number of global climate products are currently available and that can be potentially used in modeling and diagnostic of crop diseases. However, this information must be provided at appropriate time and space scales given the behavior of crop pathogens. For example, a short (sub-daily) event of precipitation can trigger the development of a disease when the amount of rainfall is adequate and is accompanied by ideal temperatures during a phenological state of high susceptibility. Among the meteorological variables most used for crop diseases we can mention the air temperature, precipitation, relative humidity and leaf wetness (Donatelli et al., 2017). Complex transport-based lagrangian models can require wind speed and direction as well.

Most global gridded products are provided at daily time-steps as the higher temporal resolution, which may be limiting for the study of crop diseases. Although there are methods to statistically disaggregate daily time series to hourly values via empirical models or weather generators (e.g. Bregaglio et al., 2010), their accuracy can be limited by the available historical data and their implementation can be difficult when it comes to large datasets.

In this study, the global 3-hourly Princeton University Global Meteorological Forcing (GMF) dataset (Sheffield et al., 2006) version 3.0 was used as meteorological observations. This product corresponds to a 0.25° × 0.25° resolution dataset generated by merging global observation-based products with the National Centers for Environmental Prediction-National Center for Atmospheric Research (NCEP-NCAR) reanalysis (Kalnay et al., 1996). The observational products include the Global Precipitation Climatology Project (GPCP; Adler et al., 2003), ground truth precipitation data from stations, the Climatic Research Unit (CRU) precipitation and temperature (Harris et al., 2013), the NASA Langley surface radiation budget (Stackhouse et al., 2004) and the Tropical Rainfall Measuring Mission (TRMM) Multi-satellite Precipitation Analysis (TMPA; Huffman et al., 2007). The later allowing the disaggregation from daily to 3-hourly values. Other meteorological variables such as incoming radiation, specific humidity, surface pressure and wind speed are corrected and downscaled using elevation data as a covariate. The preliminary output datasets are further corrected for systematic biases and random errors are removed by using in situ measurements (Chaney et al., 2014).

Finally, hourly time series of air temperature, air specific humidity and surface atmospheric pressure were generated from the original 3-hourly values by applying a spline interpolation method to obtain a 67-years hourly time-series dataset for the period 1950-2016. As explained below, the infection model used requires relative humidity as an input, which was calculated by widely used thermodynamic relationships combining specific humidity, atmospheric pressure and temperature (Wallace and Hobbs, 2006).

2.3 Representing wheat distribution and phenology

The climate suitability for wheat blast infection was estimated for the phenological period comprising from heading to the end of the reproductive phase (maturity). The starting and ending dates of this susceptible period was calculated using wheat phenology modeling and global products. Thus, the spatially-explicit critical dates necessary for bounding the modeling time window are: sowing date, emergence, beginning of heading stage and beginning of physiological maturity.

The spatial distribution of wheat in Asia was represented by the Spatial Production Allocation Model SPAM 2010 v1.0 global crop production data product developed by the International

Food Policy Research Institute IFPRI (Wood-Sichra et al., 2016; IFPRI, 2019). This product provides statistics on crop productivity by merging sub-national statistics, satellite-derived land cover data, environmental crop suitability, population, cropping systems and markets, among other variables. The operational product is generated after the crop production data derived from the above-mentioned information is aggregated into a regular grid of spatial resolution of around 10 km × 10 km using a cross-entropy method (You and Wood, 2006). In this work, the original data grid was bilinearly interpolated to the 0.25° × 0.25° climate forcing resolution and then converted into a binary mask.

After representing the spatial distribution of wheat, the key phenological dates were stated. First, winter wheat sowing dates were obtained from the interpolated Crop Calendar Dataset of Sacks et al. (2010) product, which provides 5' × 5' spatial resolution global dates of crop sowing and harvest dates representative of the year 2000. Here, the original resolution dataset was bilinearly aggregated to match the 0.25° × 0.25° resolution of the GMF meteorological data. It is important to mention that, as discussed by Sacks et al. (2010), spring wheat might be misclassified as winter wheat over temperate tropical and subtropical regions such as India since over these regions spring wheat is usually grown in winter given the relatively high temperatures not allowing the vernalization requirements of winter varieties to be fulfilled. In addition, sowing dates are variable annually and they can be settled as a function of the onset of the rainy season (e.g. Mathison et al., 2018) or other climate variables defining suitable conditions for sowing. However, including a sowing calculation date scheme would certainly add complexity that is beyond the climate-suitability scope of this work given its continental scale application.

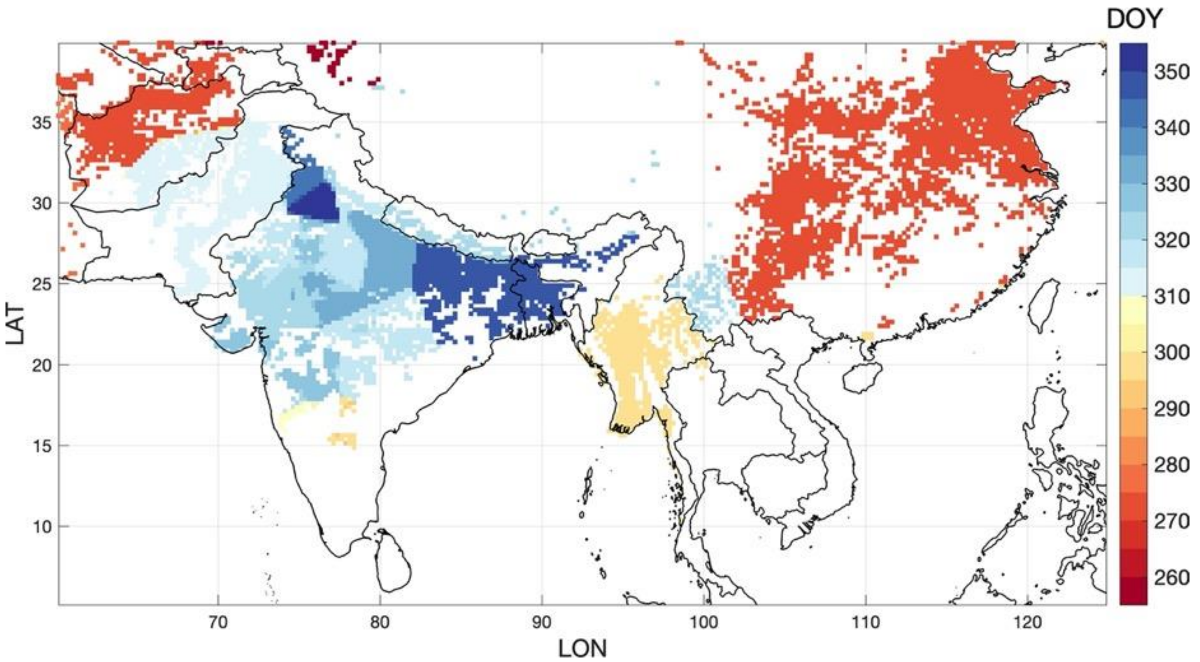


Figure A8.2: Map of what sowing dates (day of the year DOY) for winter wheat in Asia MapSPAM wheat mask.

Once wheat sowing dates were defined, subsequent weather-dependent developmental stages were estimated using crop phenology modeling. First, the day of the year (DOY) of plants emergence was estimated as a function of accumulated growing degree days (GDD) by taking a constant thermal time of 125 GDD after sowing date (Groot, 1987; Wang and Engel, 1998). Secondly, subsequent phenological stages were calculated using the model proposed by Wang and Engel (1998). This model allows estimating the main wheat phenological dates by combining the effect of temperature, vernalization and photoperiod, using only air temperature as forcing variable. The model defines a development stage parameter (DS) ranging from 0 at emergence to 1 at anthesis (vegetative phase), until a maximum value of 2 at maturity (reproductive phase). Like this, for the time period t between emergence (e) and maturity (m), the seasonal evolution of developmental stages is calculated as $DS = \sum_{t=e}^{t=m} R$, where R is the daily developmental rate calculated separately for the vegetative and reproductive phase according to the actual accumulated value of DS:

$$R = \begin{cases} R_v, if\ 0 \leq DS \ \leq \ 1 \\ R_r, if\ 1 < DS \ \leq \ 2 \end{cases} \tag{4}$$

with R_v and R_r the actual development rate (day^{-1}) for vegetative and reproductive phase, respectively. For the vegetative phase, the original model of Wang and Engel (1998) considers the multiplicative effect of three functions representing the effect of temperature, vernalization and photoperiod, restricting a constant maximum development rate. In this way, the development rate during the vegetative phase R_v (emergence to anthesis) is expressed by:

$$R_v = R_{max,v} f(T) f(P) f(v) \tag{5}$$

where $R_{max,v}$ is the reciprocal of the minimum number of days necessary to complete the vegetative phase under optimal environmental conditions (a list of model parameters is provided in Table A8.1), and *f*(*T*), *f*(*P*) and *f*(*v*) the corresponding response functions for temperature, photoperiod and vernalization, respectively, which range from 0 to 1. In the case of the reproductive phase, only the effect of temperature is considered, therefore the development rate R_r is expressed by:

$$R_r = R_{max,r} f(T) \tag{6}$$

with the parameter $R_{max,r}$ being the maximum development rate during the vegetative phase. The temperature response function for both vegetative and reproductive phases is calculated by (Wang and Engel, 1998):

$$f(T) = \begin{cases} \frac{2(T-T_{min})^{\alpha}(T_{opt}-T_{min})^{\alpha}-(T-T_{min})^{2\alpha}}{(T_{opt}-T_{min})^{2\alpha}}, \text{if } T_{min} \leq T \leq T_{max} \\ 0, \text{if } T < T_{min} \text{ or } T > T_{max} \end{cases} \tag{7}$$

where T is the daily mean air temperature, and T_{min}, T_{max} and T_{opt} are cardinal temperatures defining the minimum, maximum and optimum values for plant development, respectively (Table A8.1). The parameter α acts as a shape (skewness) factor and is calculated as:

$$\alpha = \frac{\ln 2}{\ln[(T_{max} - T_{min})/(T_{opt} - T_{min})]}$$
(8)

The photoperiod response function for the vegetative phase is calculated as (Wang and Engel, 1998):

$$f(P) = 1 - \exp[-\omega(P - P_c)]$$
(9)

where P is the actual photoperiod, calculated as a function of the latitude and DOY using widely used trigonometric relationships, P_c is the critical photoperiod below which no development occurs, and ω is a parameter defining photoperiod sensitivity (Table A8.1).

The effect of vernalization is simulated similar to temperature using the same set of equations of $f(T)$ but using specific parameters for T_{max}, T_{opt} and T_{min} of 15.7°C, 4.9°C and -1.3°C, respectively (Streck et al., 2003a).

The phenological model was used to estimate a climate-dependent dates of occurrence of heading and physiological maturity, stages in which the wheat blast infection model was applied, for which *DS* values of 0.88 (heading) and 2 were used (Streck et al., 2003a). This modeling approach has been used for multiple models such as CERES-Wheat (Ritchie, 1991) and applications to predict winter wheat phenology (Streck et al., 2003a), specific developmental stages (Xue et al., 2004; Streck et al., 2003b), or yields (Mahbod et al., 2015) over different regions.

As mentioned above, since spring wheat varieties are grown during winter over a vast region of South Asia (e.g. India), the effect of vernalization on phenological development should not be considered in the model ($f(v) = 1$) over those regions, so the separation between spring and winter wheat growing areas is necessary. For this, the global model-based product on daily probabilities of winter and spring wheat sowing and harvesting dates around 2000 developed by Iizumi et al. (2019) was used for the division between the two areas. Since these data corresponds to probabilities, the areas where the probability of having winter spring is 0 were taken as exclusive areas of winter wheat.

Table A8.1: List of parameters in the wheat phenology model.

Parameter	Description	Value	Units	Reference	Comment
$R_{max,v}$	Maximum daily development rate in the emergence-anthesis phase, cultivar dependent	0.022	Days^{-1}	Streck et al., (2003)	Averaged from different cultivars
$R_{max,r}$	Maximum daily development rate in the anthesis-physiological maturity phase (which is cultivar dependent)	0.04545	Days^{-1}	Streck et al., (2003)	Averaged from different cultivars
T_{opt}	Optimum temperature for development	24 for vegetative phase 29 for reproductive phase	°C	Streck et al., (2003), Xue (2000)	-
T_{min}	Minimum temperature for development	0 for vegetative phase 8 for reproductive phase	°C	Streck et al., (2003), Xue (2000)	-
T_{max}	Maximum temperature for development	35 (for vegetative phase) 40 (for reproductive phase)	°C	Streck et al., (2003) Xue (2000)	-
P_c	Critical photoperiod below which no development occurs	8.25	h	Streck et al., (2003), Xue (2000)	Averaged from different cultivars
ω	Photoperiod sensitivity coefficient	0.25	h^{-1}	Streck et al., (2003), Xue (2000)	Averaged from different cultivars

3. Results

In this section, model results are presented as maps of average conditions and variability between 1951-2010, also as the relationship between the number of potential infections and global climate indices, and summarized for the main wheat producing countries in Asia.

Figure A8.3 shows the interannual average number of potential infections for Asia. The spatial pattern of wheat blast risk shows wheat-producing areas whose range of air temperature and humidity during the cold season would not represent conditions conducive to the development and outbreaks of the disease. This is the case of most areas in Afghanistan, Pakistan and Northern China. On the other hand, Bangladesh, Myanmar and the small area where wheat is cultivated in North East India show the higher number of potential infections driven by weather conditions, where, in average, a number of ~20 outbreaks are estimated. Then mean seasonal number of potential infections id 2.4 and the maximum 80, interquartile range from 0.1 to 1.7. Figure A8.2 shows the interannual standard deviation of potential infections in Asia, where it is possible to observe a strong interannual variability in the areas of higher incidence (Bangladesh, Myanmar), but also southward increase in India, which suggests that the occurrence of years of higher risk than others may be important.

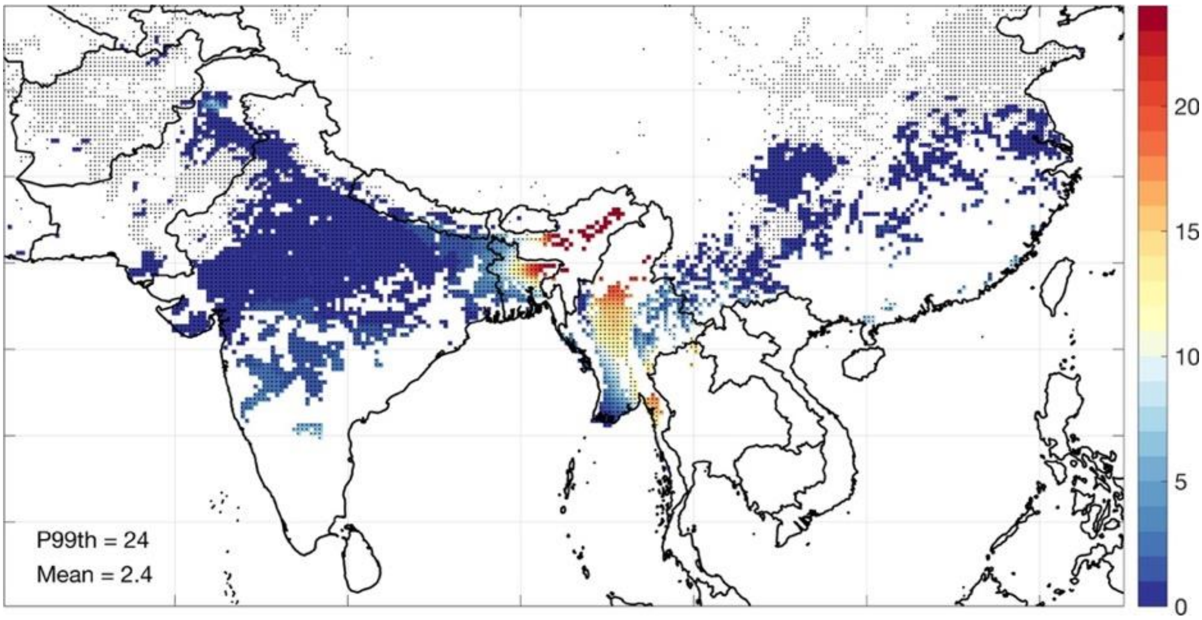


Figure A8.3: Spatial pattern of the inter-annual average number of potential infections in Asia. Black *dot* symbols represent grid cells with presence of wheat. P99th is the 99% percentile.

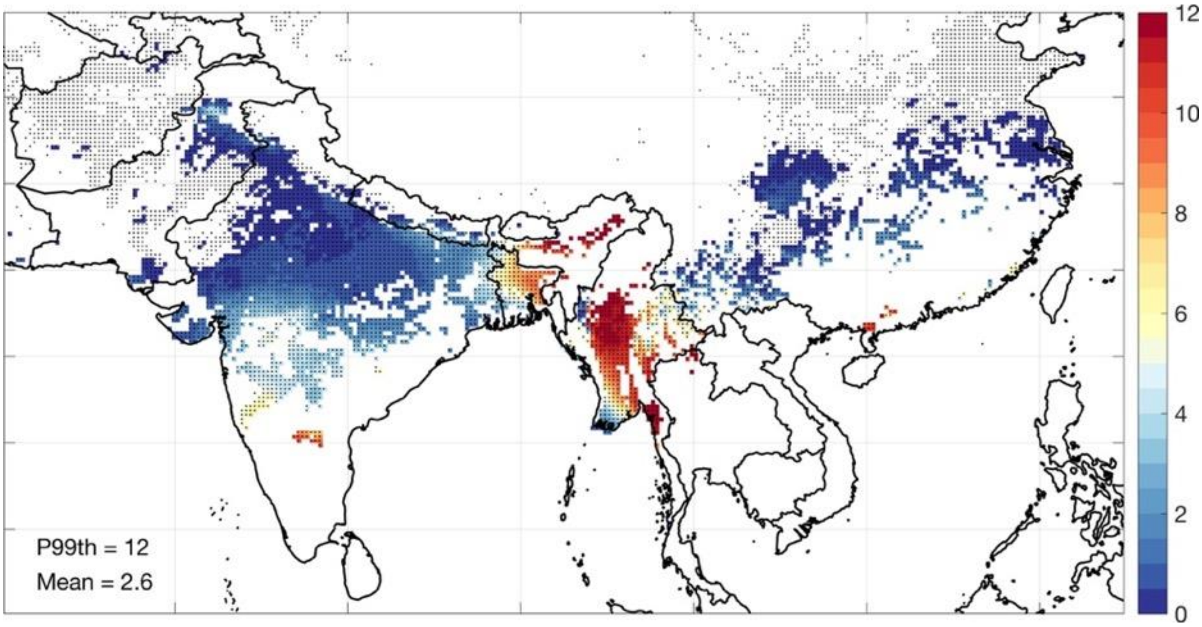


Figure A8.4: As in Figure A8.3 but for inter-annual standard deviation

In order to summarize the above results by country, inter-annual and spatial statistics were aggregated. Figure A8.5a shows the distribution of the spatial differences of potential infections in the five main wheat producing countries in Asia. It is clear from this figure that Myanmar and Bangladesh are the countries with the highest potential incidence of wheat blast, followed by India, China and Pakistan. Countries with lower incidence show a higher number of points considered outliers, which indicates that the risk of infection concentrates in a smaller area. Figure 5b shows a similar information but now for the distribution in the inter-annual country-averaged number of potential infections. In this case it is possible to see that in spite of the low average incidence in India, China and Pakistan, the observed inter-annual variability observed can be important.

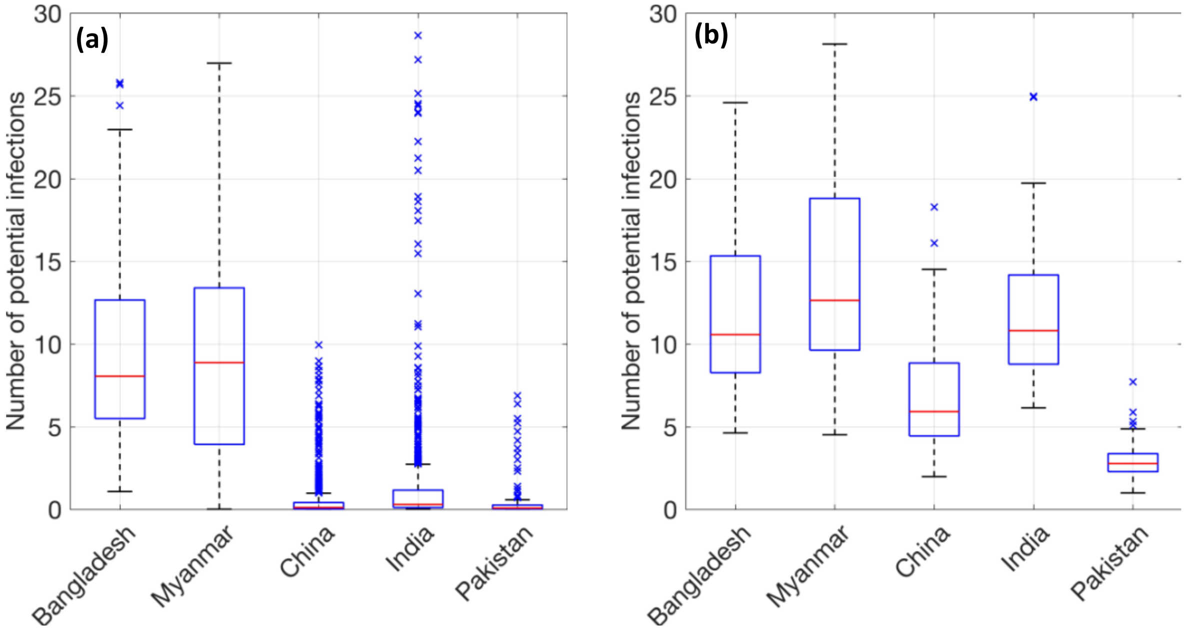


Figure A8.5: (a) Boxplots of spatial distribution of the inter-annual average number of potential wheat blast infections. (b) Boxplots of temporal distribution of country averaged number of potential infections. For each boxplot, the central mark shows the median and the edges are the 25th and 75th percentiles; dashed lines extend to the most extreme values not considered outliers, and outliers are plotted individually (x sign)

In order to further understand the above-presented results, maps of inter-annual averages of air temperature and relative humidity are displayed in Figure A8.6. Although being global averages values, it can be observed that the regions whose winter climate does not represent a risk for the development of wheat blast, as in the case of Afghanistan or the northeast of China, they have average temperatures that are too low, out of the range for development of the disease according to the model (Magarey et al., 2005; Cruz et al., 2016). In the case of central India, where the number of potential infections is lower for the same latitude of Bangladesh or Myanmar, it is observed that despite presenting favorable temperature conditions, atmospheric humidity is too low in relation to the ideal range by over 95%.

The availability of long-term climate time series makes it possible to analyze the relationship between the potential weather-based incidence of wheat blast and large-scale drivers that control the inter-annual climate variability in Asia, such as El Niño Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD), considered two of the main factors controlling inter-annual climate variability over the region. For this, the local correlation between the number of potential infections and the Oceanic Niño Index[15] (ONI) and the Dipole Mode Index[16] (DMI) were calculated. Both for ONI and DMI, the average values between October and December were considered for the analysis.

15 https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php
16 https://www.esrl.noaa.gov/psd/gcos_wgsp/Timeseries/DMI/

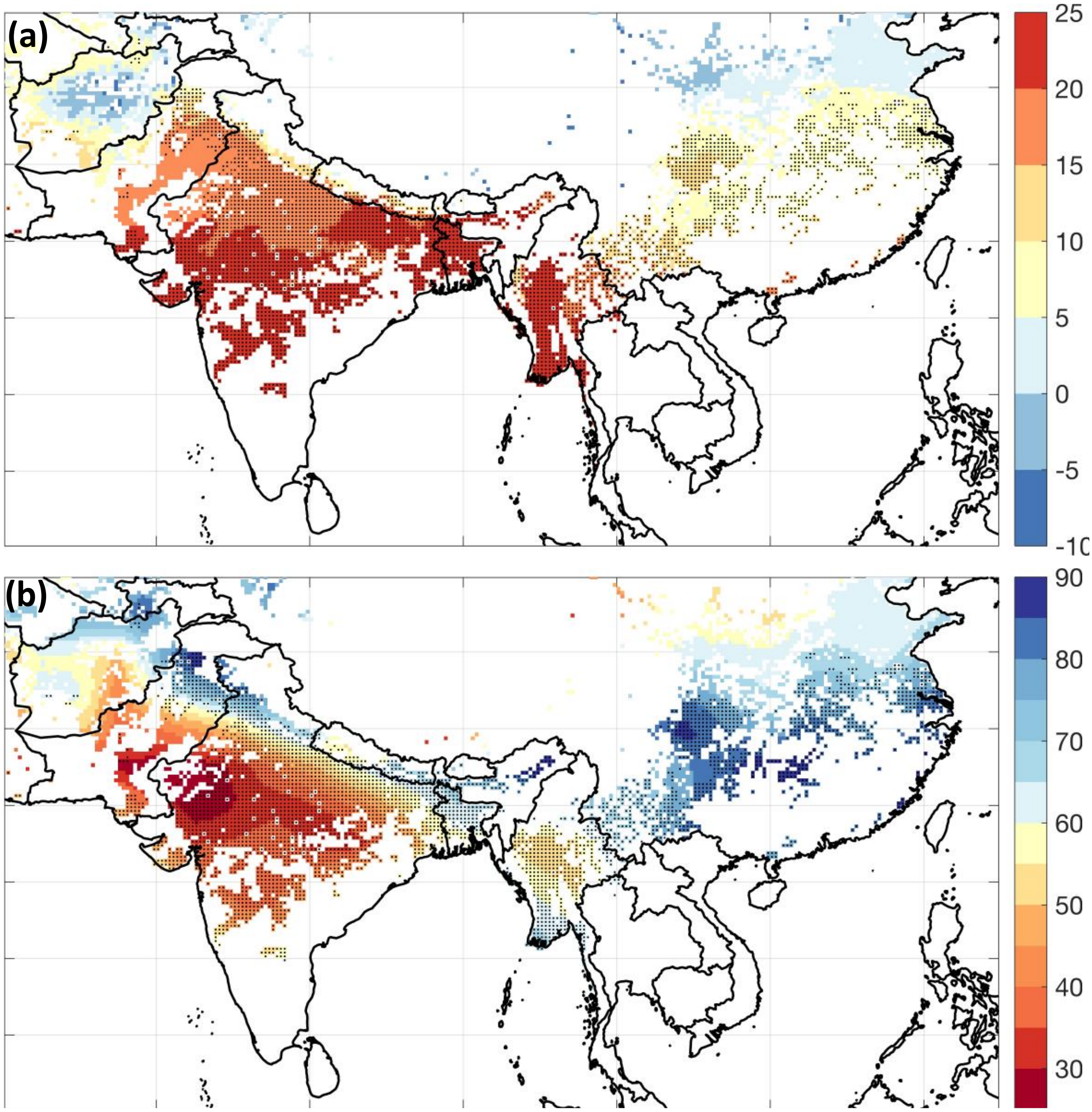


Figure A8.6. Maps of inter-annual average (a) air temperature (ºC) and (b) relative humidity (%) during the cold season. Black *dot* symbols represent the points of Figure A8.3 where wheat blast is present.

Figure A8.6 shows the correlation between the number of potential infections and ONI/DMI. A very similar spatial pattern of positive and negative correlations is clearly observed, which varies in the magnitude of the correlations. However, this behavior is reversed in areas of eastern China, where correlations with ONI (DMI) are positive (negative). The highest magnitudes of positive correlations for both ONI and DMI are presented in India, with values that can be close to 0.5. The highest magnitudes in negative correlations are observed in Bangladesh and Myanmar for both ONI and DMI, in the Indian area west of Bangladesh, in addition to western India in the case of ONI.

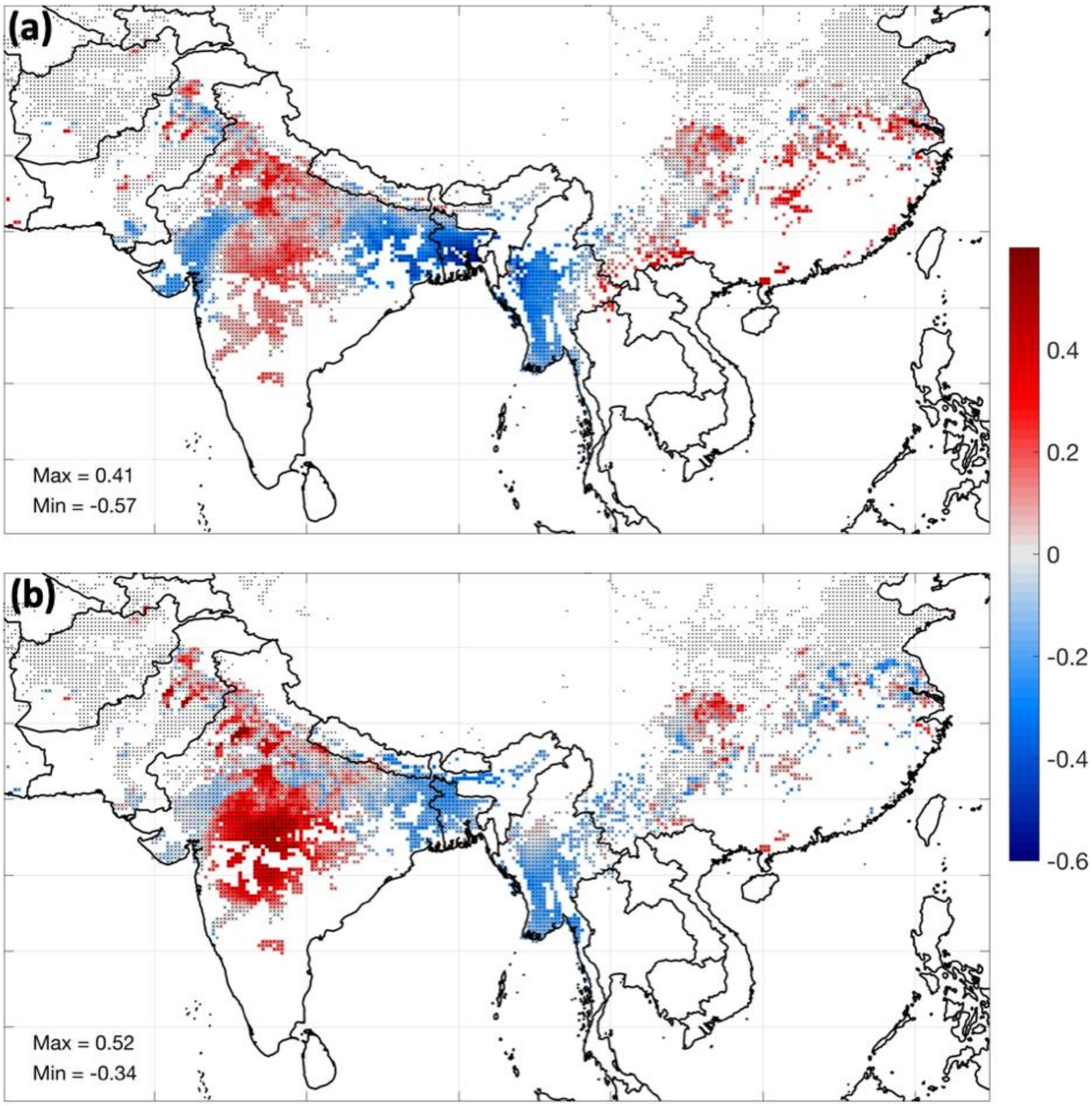


Figure A8.7. (a) Local correlation between the number of potential infections and ONI. (b) As in (a) but for number of potential infections and DMI.

In order to see how the potential incidence of wheat blast in Asia behaves with respect to the different phases of ENSO and IOD, the average incidence index provided by the model was calculated for the El Niño phases (ONI > 0.5) and La Niña (ONI < -0.5). Similarly, the average incidence of the disease was calculated for the positive and negative phase of DMI. Results are presented as the difference between both phases (positive *minus* negative) in Figure A8.8. In general, it is observed that unlike the inter-annual correlation (Figure A8.7), the spatial pattern is less clear for the different phases of ENSO and IOD. However, in areas with highest incidence in Bangladesh and Myanmar, in addition to the southern part of India, the correlation seems to be clearer correlation. For the case of ENSO, the positive phase (El Niño) is observed to induce negative anomalies in the number of potential infections in relation to the negative phase (La Niña) in Bangladesh and Myanmar, relationship that is reversed in India. On the other hand, the anomalies induced by the positive phase of DMI in relation to the negative are associated with lower incidence of wheat blast in the north of Bangladesh, and some parts of India and Myanmar, but these anomalies are positive in the south of Bangladesh.

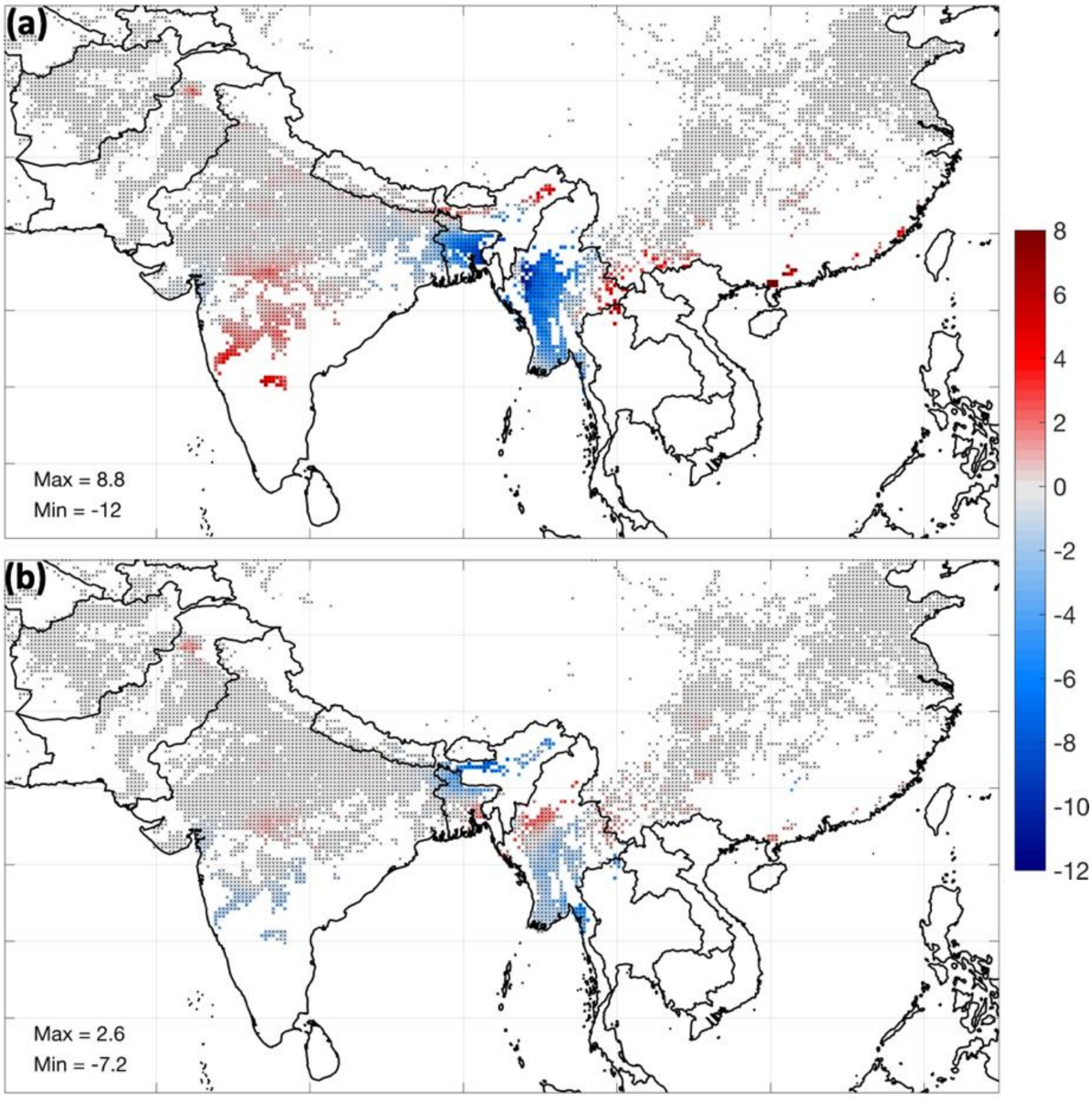


Figure A8.8. (a) Composites of the difference between number potential infections for the positive and negative face of ONI (a) and DMI (b).

4. Concluding remarks and future research

The results obtained in the present work allow us to conclude the following. First, the results from the infection model show that there is an important spatial variability in the climatic suitability for the establishment of wheat blast in Asia. For wheat producing regions, the higher potential dissemination is observed in Bangladesh, Myanmar and some regions in India. These regions show at the same time the higher inter-annual variability, so wheat blast incidence could be very important during some years of higher favorable conditions. On the other hand, wheat producing regions with too low temperature and humidity in China or India do not present an important potential for wheat blast establishment, since the infection model applied in this work considers temperature and humidity thresholds to estimate the potential risk. However, the high inter-annual variability presented by these areas imply that in some years the conditions could be suitable for wheat blast. The latter results may be relevant when planning disease prevention actions through new varieties or early warning systems.

According to the observed relationship between inter-annual variability in the number of potential infections and the associated large-scale climatic drivers (ENSO, IOD), there is a clear relationship with ONI and DMI indices, associated with their impact on air temperature and humidity. In turn, the different phases of ENSO and IOD show a greater contrast in Bangladesh and Myanmar in terms of the incidence of wheat blast, especially in the case of ONI. This should be explored further using different indices and lead-time periods in order to establish some statistical relationship that can be used in a forecasting system.

Currently, CIMMYT scientists are working on developing a strategy and methodology that allows the results generated so far to be translated into an estimate of the potential economic benefit to farmers of having a surveillance and forecasting system of potential wheat blast infections. In this way, it would be possible to have a better perspective on the areas over Asia where the wheat blast pressure infections can have a higher impact, in addition to its association with factors of temporal variability in climate, and therefore where the development of adaptation tools are a priority.

References

Adler, R.F., G.J. Huffman, A. Chang, R. Ferraro, P.-P. Xie, J. Janowiak, B. Rudolf, U. Schneider, S. Curtis, D. Bolvin, A. Gruber, J. Susskind, P. Arkin and E. Nelkin. 2003. The Version-2 Global Precipitation Climatology Project (GPCP) monthly precipitation analysis (1979-present), *J. Hydrometeorol.* 4, 1147-1167.

Anderson, P.K., A.A Cunningham, N.G. Patel, F.J. Morales, P.R. Epstein and P. Daszak. 2004 Emerging infectious diseases of plants: pathogen pollution, climate change and agrotechnology drivers. *Trends Ecol. Evol.* 19, 535-544.

Bebber, D.P., A.D. Castillo and S.J. Gurr. 2017. Modelling coffee leaf rust risk in Colombia with climate reanalysis data. *Phil. Trans. R. Soc. B.* 371: 20150458.

Bregaglio, S., M. Donatelli, R. Confalonieri and S. Orlandini. 2010. An integrated evaluation of thirteen modelling solutions for the generation of hourly values of air relative humidity. *Theor. Appl. Climatol.* 102, 329-438.

Bregaglio, S, G. Cappelli and M. Donatelli. 2012. Evaluating the suitability of a generic fungal infection model for pest risk assessment studies. *Ecol. Modell.* 247, 58-63.

Bregaglio, S., M. Donatelli and R. Confalonieri. 2013. Fungal infections of rice, wheat, and grape in USDope in 2030-2050. *Agron. Sustain. Dev.* 33, 767-776.

Chaney, N.W., J. Sheffield, G. Villarini E.F. and Wood. 2014. Development of a high-resolution gridded daily meteorological dataset over Sub-Saharan Africa: spatial analysis of trends in climate extremes. *J. Climate.* 27, 5815-5835.

Cruz, C.D., R.D. Magarey, D.N. Christie, G.A. Fowler, J.M. Fernandes, W.W. Bockus, V. Valent and J. Stack. 2016. Climate suitability for *Magnaporthe oryzae Triticum* pathotype in the United States. *Plant Dis.* 100, 1979-1987.

Duveiller E., X. He and P.K. Singh. 2016. Wheat blast: an emerging disease in South America potentially threatening wheat production. World Wheat Book, Volume 3. A History of Wheat. Bonjean A. and van Ginkel M. (Eds.) Pages 1107-1122. Lavoisier, Paris, France.

Donatelli, M., R.D. Magarey, S. Bregaglio, L. Willocquet, J.P.M. Whish and S. Savary. 2017. Modelling the impacts of pests and diseases on agricultural systems. *Agric. Syst.* 155, 213-224.

Fisher, M.C., D.A. Henk, C.J. Briggs, J.S. Brownstein, L.C. Madoff, S.L McCraw and S.J. Gurr. 2012. Emerging fungal threats to animal, plant and ecosystem health. *Nature*. 484, 186-194.

Groot, J. J. R. 1987. Simulation of nitrogen balance in a system of winter wheat and soil. Simulation report CARBO-TT no. 13. Centre for Agrobioloigical Research (CABO) and Department of Theoretical Production Ecology, Agricultural University Wageningen.

Harris, I., P.D. Jones, T.J. Osborn and D.H. Lister. 2013. Updated high-resolution grids of monthly climatic observations - the CRU TS3.10 Dataset. *Int. J. Climatol*. 34, 623-642.

Huffman, G.J., R.F. Adler, D.T. Bolvin, G. Gu, E.J. Nelkin, K.P. Bowman, Y. Hong, E.F. Stocker and D.B. Wolff. 2007. The TRMM Multisatellite Precipitation Analysis (TMPA): quasi-global, multiyear, combined-sensor precipitation estimates at fine scales. *J. Hydrometeorol*. 8, 38-55.

Iizumi, T., W. Kim and M. Nishimori. 2019. Modeling the global sowing and harvesting windows of major crops around the year 2000. *J. Adv. Model. Earth Sy*. 11, 99-112.

International Food Policy Research Institute (IFPRI), 2019, "Global Spatially-Disaggregated Crop Production Statistics Data for 2010 Version 1.0", https://doi.org/10.7910/DVN/PRFF8V, Harvard Dataverse, V2.

Islam MT, Kim KH, Choi J. 2019. Wheat blast in Bangladesh: the current situation and future impacts. *Plant Pathol. J*. 35:1-10.

Kalnay, E. and Coauthors. 1996. The NCEP/NCAR 40-Year Reanalysis Project. *Bull. Amer. Meteor. Soc.* 77, 437-471.

Launay, M., J. Caubel, G. Bourgeois, F. Huard, I. Garcia de Cortazar-Atauri, M.-O. Bancal and N. Brisson. 2014. Climatic indicators for crop infection risk: application to climate change impacts on five major foliar fungal diseases in Northern France. *Agric. Ecosys. Environ*. 197, 147-158.

Magarey, R.D., T.B. Sutton and C.L. Thayer. 2005. A simple generic infection model for foliar fungal plant pathogens. *Phytopathol*. 95, 92-100.

Mahbod, M., S. Zand-Parsa and A. R. Sepaskhah. 2015. Modification of maize simulation model for predicting growth and yield of winter wheat under different applied water and nitrogen. *Agr. Water Manage*. 150, 18-34.

Malaker P.K., N.C.D. Barma, T.P. Tiwari, W.J. Collis, E. Duveiller, P.K Singh and H.-J. Braun. 2016. First report of wheat blast caused by *Magnaporthe oryzae* pathotype *Triticum* in Bangladesh. *Plant Dis*. 100, 2330.

Mathison, C. Deva, C., Falloon, P., & Challinor, A.J. Estimating sowing and harvest dates based on the Asian summer monsoon. Earth Sys. Dynam., 9, 563-592 (2018).

Mottaleb KA, Singh PK, Sonder K, Kruseman G, Tiwari TP, Barma NCD, et al. 2018. Threat of wheat blast to South Asia's food security: an ex-ante analysis. PLoS ONE 13(5): e0197555.

Ritchie, J.T., 1991. Wheat phasic development. In: R.J. Hanks, Ritchie J.T. (Eds.), Modeling Plant and Soil Systems. ASA, CSSA, SSSA, Madison, WI, pp. 31-54.

Sacks, W. J., D. Deryng, J. A. Foley, and N. Ramankutty, 2010: Crop planting dates: An analysis of global patterns. *Global Ecol. Biogeogr*. 19, 607-620.

Sheffield, J., G. Goteti and E.F. Wood. 2006. Development of a 50-year high-resolution global dataset of meteorological forcings for land surface modeling. *J. Climate.* 19, 3088-3111.

Stackhouse, P.W., S.K. Gupta, S.J. Cox, J.C. Mikowitz, T. Zhang and M. Chiacchio. 2004. 12-year surface radiation budget data set. GEWEX News, Vol. 14, No. 4. International GEWEX Project Office, Silver Spring, MD, 10–12.

Streck, N. A., A. Weiss, Q. Xue, P. S. Baenziger. 2003. Improving predictions of developmental stages in winter wheat: a modified Wang and Engel model. *Agric. Forest Meteorol.* 115, 139-150.

Streck, N. A., A. Weiss, Q. Xue, P. S. Baenziger. 2003. Incorporating a chronology response into the prediction of leaf appearance rate in winter wheat. *Ann. Bot*. 92, 181-190.

Wallace, J. and P. Hobbs. 2006. Atmospheric Science: an introductory survey. Amsterdam, Elsevier Academic Press.

Wang, E. and Engel, T. 1998. Simulation of phenological development of wheat crops. *Agric. Syst*. 58 (1), 1-24.

Wood-Sichra U, Joglekar AB, You L. Spatial production allocation model (SPAM) 2005: Technical documentation. Washington, D.C.: International Food Policy Research Institute (IFPRI) and St. Paul: International Science and Technology Practice and Policy (InSTePP) Center, University of Minnesota; 2016. HarvestChoice Working Paper

Xue, Q., A. Weiss and P. S. Baenziger. 2004. Predicting leaf appearance in field-grown winter wheat: evaluating linear and non-linear models. *Ecol. Model.* 175, 261-270.

Yan, W. and L.A. Hun. 1999. An equation modeling the temperature response of plant growth and development using only the cardinal temperatures. *Ann. Bot*. 84, 607-614.

You, L. and S. Wood. 2006. An entropy approach to spatial disaggregation of agricultural production. Agricultural Systems, Vol. 90(1-3), pp. 329-347.