Final Technical Report

CAF2016-RR07-CMY-Shaheen

"Climate smart agriculture through sustainable water use management: Exploring new approaches and devising strategies for climate change adaptation in South Asia

The following collaborators worked on this project:

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PROJECT OVERVIEW

Project Duration	:	2 years
Funding Awarded	:	US$ 45,000; for Year 1; US$ 44,000 for Year 2; US$89,000 for whole duration
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PROJECT SUMMARY

South Asia is home to well over one-fifth of the world's population, making it the most densely populated region of the world with the highest regional Global Hunger Index leading to food insecurity. IPCC fifth assessment report shows regional effects of climate change likely to create major impacts on water, energy and food security. Due to the impacts of climate change, many regions are expected to see a decline in food productivity, with the largest numbers of food-insecure people in South Asia.

The main objective of the project is to scale up climate-smart agriculture for building resilience in food security at national and regional scales; as well as mainstreaming adaptation and mitigations related to agriculture and crop water management in developing countries of Asia Pacific region. This project will provide a conceptual framework to address food security under conditions of water scarcity in agriculture.

The main theme of the project is to model how the projected climate change scenarios will spatially and temporally impact cereal production, a dietary staple for billions of people in South Asia. Climate change scenarios of temperature and precipitation will be constructed using state of the art statistical downscaling approaches. Impact assessment with climate-smart approaches using simulation models and devising climate change adaptation strategies for integration in policymaking will help build resilience in water-efficient agriculture and food security.

Keywords: *South Asia, Climate Change, food security, statistical downscaling, Crop water models*

PROJECT OUTPUTS AND OUTCOMES

Project outputs:

- Identification of food insecure and climate change vulnerable districts in three South Asian countries namely, Bangladesh, Pakistan and Sri Lanka
- Climate change impact assessment on future food security, pilot studies conducted in selected districts of partner countries of South Asia.
- Crop water models, AquaCrop and APSIM, have been parameterized for South-Asia
- Provision of point scale future climate change scenarios data product for the region. Future projection of climate change for medium control and business as usual scenarios were downscaled for selected districts of Pakistan, Bangladesh and Sri Lanka and shared with regional project partners.

Project outcomes:

- Enhanced scientific knowledge and capacities of scientists on the use of top-down and bottom-up approaches in modelling; Capacity building of young scientists from research organizations, academia and government ministries of partner countries in the use of modelling techniques.
- Research results leading to the formulation of well informed and effective policies, decisions and action plans for national and regional level water and food security management through the dissemination of major findings to policymakers
- Publication of key findings of the project in peer-reviewed journals.

KEY FACTS/FIGURES

- Number of sites that were selected and tested for vulnerability against the impact of climate change on food security in each collaborating country

Country	Number of sites
Pakistan	13
Sri Lanka	3
Bangladesh	11

- **Models used**: The daily climatic data (maximum temperature, minimum temperature, average temperature and rainfall) was downloaded for 21 regional climate models (RCMs), climate scenarios of 4.5 and 8.5 over three-time slices i.e. near-century, mid-century and far century.

Capacity building of young scientists:

Capacity building of young scientists and students from research organizations, academia and government ministries of partner countries has been done in the use of modelling techniques. This was achieved by holding two back to back regional training workshops on statistical downscaling and crop water models. This capacity building training workshop resulted in an increased knowledge base and research capabilities of scientists in the region and enhanced capacity in conducting climate modelling and impact assessment research. A total of 21 young scientists, 12 from Sri Lanka, 2 from Cambodia, 2 from Bangladesh and 5 from Pakistan, participated in the training conducted by the GCISC under this project.

POTENTIAL FOR FURTHER WORK

This project has successfully achieved the goal of testing 13 sites in Pakistan, 3 sites in Sri Lanka, 11 sites in Bangladesh and 3 sites in Cambodia for the impact of climate change on vulnerability of cereal crops. Further expansion of the project can be done in order to implement the same practice to increase the number of sites in each partner country. The horizon of the research project can also be broadened by using more novel and precise software technology on finer resolutions in order to obtain more accurate and realistic results. Inter-comparison of simulation models can also be inducted in the research to widen the perimeter of the said project.

PUBLICATIONS

- Nuzba Shaheen (2017), "Climate Change Adaptation and Mitigation in South Asia under Paris Agreement", Asia-Pacific Network for Global Change Research. Proceedings of the APN, LoCARNet, and AIT/RRC.AP Capacity Building Workshop and Science-Policy Dialogue on Climate Change: Low Carbon and Adaptation Initiatives in Asia. Kobe: APN, http://www.apn-gcr.org/resources/items/show/2082
- Nuzba Shaheen," User-Oriented Applications of Climate data: Performance Evaluation and Statistical Downscaling of CORDEX-RCMs for Impacts Studies in South Asia", Poster paper, International Conference on Downscaling Studies" Oct 03, 2017, Tsukuba, Japan.
- Nuzba Shaheen (2017), "Climate Smart Agriculture: Using Best Practices for Adaptation and Mitigation in Asia", paper presented in Science-Policy Conference on Climate Change (SP3C), December 18-20, 2017, Islamabad, Pakistan
- Nuzba Shaheen (2017), Poster paper, "Climate Model Predictions and Fate of Future Food Security in Pakistan", in Science-Policy Conference on Climate Change (SP3C), December 18-20, 2017, Islamabad, Pakistan
- Nuzba Shaheen (2018), "Impact of future Sub seasonal variations in growing degree days over major wheat growing areas of Pakistan" (manuscript ready for publication)

AWARDS AND HONOURS

- The project leader was nominated for and contributed in CORDEX-Asia Empirical Statistical Downscaling group activities from Pakistan, established in November 2016.
- Project leader contributed as an external reviewer to review the APN-project proposals.

PULL QUOTE

In a challenging world where agriculture simultaneously impacts and is impacted by climate change and the drastic increase in food demand is required, transformative solutions are direly needed. Climate-smart agriculture provides an opportunity to cope with climate change and food security challenges. (Mr Muhammad Arif Goheer, Head-Agriculture and Coordination, GCISC)

ACKNOWLEDGEMENTS

I would like to thank APN for the financial support to the project which made this useful work on an important issue of food and water security assessment in South Asia, possible. APN, since its establishment, is known to support research and development activities in the region in a real spirit. APN funded projects are an excellent platform to provide support for capacity building of young researchers in the region by conducting training workshops and seminars. Credit also goes to the APN for promoting research networking and collaborations, crucial to achieve shared learning, new research opportunities, establishing new research projects, and joint applications for funds, data provision and technology transfer.

Global Change Impact Studies Centre (GCISC) has a history of completing a number of APN awarded projects, successfully and this project is not an exception. This project has achieved its objectives positively, and also accomplished some additional research goals which were a way forward in the planned project proposal. This has all been possible with the help of dedicated research efforts of the whole project team.

The project has significantly contributed to the Capacity-building agenda of APN by conducting two back-to-back regional training workshops and trained 21 participants on the 'use of Statistical Downscaling techniques and AquaCrop model' from South and East Asian region. For which we are indebted to Food and Agriculture Organization of United Nations (FAO) - Pakistan office for partially supporting the training on the use of AquaCrop model and Dr Dirk Raes, the University of Belgium for imparting training on the use of Aquacrop in Sri Lanka. Thanks are also due to Prof. Dr Hayley Fowler and Dr Nathan Forsythe from School of Civil Engineering and Geosciences, Newcastle University, UK for contributing to the project as a developed country partner and providing resource person support for Statistical downscaling training and data acquisition.

The efforts of participating Country Counterparts; Dr Punyawardena from Sri Lanka and Dr Hassan from Bangladesh and Dr Kum Veesna and their team members particularly Dr Nisanka from Sri Lanka are gratefully acknowledged for carrying out the project activities and providing various reports and other necessary inputs. It is a pity that Cambodia could not contribute to the project completely due to one or other reasons.

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My acknowledgement would not be complete without mentioning the four researchers who assisted very dedicatedly during the whole course of this project. Ms Khadija Haider, Mr Saadoon

Hammad, Mr Muhammad Bilal and Ms Ambreen Jahandad provided effective assistance in the accomplishment of all project activities.

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1. INTRODUCTION

1.1 Background

Asia is the largest of all seven continents in the world, playing as host to about 24% of the world population which makes about 1.9 billion people on the continent. It has a wide range of physical landscapes, political units, and ethnic groups. Asian regions include South Asia, East Asia, and Southeast Asia. South Asia extends south from the central part of the continent to the Indian Ocean**.** The Indian Ocean, the Himalayas and Afghanistan are the physical demarcations of South Asia. In the west, Pakistan and India are bordered by the Arabian Sea while the Bay of Bengal borders India and Bangladesh in the east. The western boundary of South Asia is the desert region where Iran and Pakistan share a common border between Sistan province of Iran and Balochistan in Pakistan.

Three key rivers cross South Asia, all originating from the Himalayas. The Indus River starts in Tibet and flows through the centre of Pakistan to fall into the Arabian Sea near the Karachi city port. The Ganges River flows through northern India, creating a core region of the country. The Brahmaputra River enters India, flowing through Tibet from the east, where it meets with the Ganges in Bangladesh forming world's largest delta which flows into the Bay of Bengal.

In the limited sense of the term, South Asia consists of the Indo-Gangetic Plain, peninsular India, and Sri Lanka. The Indo-Gangetic Plain consists of combined alluvial plains of the Indus, Ganges (Ganga), and Brahmaputra rivers. The alluvium sediments provide fertile soil in the Ganges and Brahmaputra basins as well as in irrigated parts of the Indus basin, while the margins of the Indus basin have turned sandy deserts. Platform plateaus and tablelands are the key physiographic features of Peninsular India and Sri Lanka, including the vast Deccan plateau.

The countries of South Asia include Sri Lanka, India, Bangladesh, Bhutan, Nepal, Pakistan, and the Maldives. South Asia is still predominantly rural where over 70% of its population is living in rural areas; the majority make their living by depending on the natural resources available in the surroundings, most common are land, freshwater and coastal fisheries. According to the World Bank report, about 56.68% of the South Asian land is under agricultural usage, depicting that more than half of the total land area is under crop cultivation in South Asia. Small landholdings prevail in the region, with a significant dependence on fisheries for protein, livestock for draft power, manure, milk, and food security. Statistically, the average size of holdings in Bangladesh is only 0.5 hectares, and small farms account for 96% of operational holdings while in India 81% of landholders have farms that are less than 2 hectares in size with an average farm holding size of 1.4 hectares. In Sri Lanka, the average size of the farm is 0.8 hectare while Pakistan is the country having the largest farm holdings in the region with an average farm of 3 hectares.

Despite the substantial increase in per capita GDP across South Asia during the last decades, yet the actual poverty and marginalization have not declined much, rather income inequality is increasing. Despite endless efforts including many policies, plans and initiatives by respective governments, NGOs and international organizations, a considerable proportion of the world's impoverished people are yet reported in South Asia. Besides poverty, inequality of resources and income the region is also prone to disasters and calamities that may include floods, cyclones, storms, landslides, earthquakes, arsenic poisoning and erosion of soil are some of the frequent disasters regularly occurring in South Asia. Global warming and climate change are also pose dire threats that may not only harm the interests of millions of people in the region but also put them under serious risks. As these economies rely upon, to a great extent, on agriculture, natural resources, forestry and fisheries sectors, increased risk levels of floods and drought spells have severe effect on the production in these sectors leading to the exacerbation of the condition of poor (Fischer et al., 2005).

Generally, the trend for past and present climatic conditions in South Asia is linearly increasing. However, over the last century, an increase in the frequency, as well as the intensity of the extreme events, has been recorded. Twenty-first-century temperature projections suggest an increasing trend with the highest in the last quarter of the century. The indications drawn by the recent modelling experiments suggest that there would be significant warming in Tibetan plateau, Himalayan highlands and arid regions of Asia. The projections show an increase in the frequency of extreme weather events that may include heatwave, intense precipitation and interannual variability of Asian monsoon rains. Mostly the tropical areas will be affected in terms of agricultural production as increased temperatures will negatively affect the crop growth, whereas the crops in tropical regions are already growing near the threshold tolerance level. The direct effects of temperature increase that are enhanced by the indirect effect of water availability and depleting soil moisture conditions will be severely felt, in particular, by the small landholder farmers, who constitute a significant portion of the population in the region and have low technical and financial capacity to combat the effects of climate change.

1.2 Country Context

1.2.1 Pakistan

Pakistan being an agricultural economy, is one of the countries in South Asia that are most susceptible to climate change. Agriculture sector contributes 18.5% (Economic Survey of Pakistan, 2019) to the GDP and employs 47% of the total population. Punjab is the largest province of Pakistan in terms of population and its contribution to agricultural services. The total geographical area of Punjab is about 20.63 million hectares as reported in the annual report of Punjab Bureau of Statistics in 2016, out of which 88% is irrigated either by canals or by tube-wells and other sources, and 12% is the area that depends on rainfall.

The irrigation system of Pakistan is the largest and most extensive canal irrigation system, known as The Indus Basin Irrigation System (IBIS) irrigating all of the Punjab and Sindh, with a command area of 20 million hectares and an annual irrigation capacity of over 12 million hectares. Pakistan possesses the largest river systems of South Asia called The Indus, with its 5 tributaries, namely Chenab, Jhelum, Ravi, Kabul and Sutlej making it one of the mightiest river systems in the world. The River-System comprises three storage reservoirs (Chashma, Tarbela and Mangla dams), 19 large rivers Headworks, 45 Canal Systems measuring 58,000 kilometres and about 1.6 million kilometres of water-courses and field Irrigation Channels.

The Indus Basin is located under an unconfined aquifer of 16 million hectares. Six million hectares of these sixteen million hectares are the freshwater resource, while the rest of the 10 million are saline water (Haider et al., 1999). The average difference between the available safe groundwater supply and the estimated industrial and domestic water demand is about 11 billion cubic meters (PWP, 2001). Despite the supply being in excess, the evidence of increasing salt concentration in the groundwater and the continuously decreasing levels of groundwater table indicate that the potential for future groundwater manipulation is very limited. Another challenge for water management in Indus Basin is the low storage capacity and poor irrigation infrastructure. Relative to other countries having similar environmental conditions Pakistan has an alarmingly low storage capacity of 15% of annual river flow. That is why Pakistan's agricultural production will be severely affected by the effects of climatic changes particularly on water availability in the future scenarios.

The extreme events induced by climate change can harm crop production, aggravating the issue of food insecurity that directly affected 58% of the country's population (UNICEF, 2011). Significantly adverse effects of climate change on agriculture have already directly affected the food production. If the situation does not improve, there would be a colossal impact and there can be severe food shortages. The extent of these impacts will depend not only on the intensity and timing of the changes but also on their combination, which is more uncertain, and on local conditions.

1.2.2 Sri Lanka

Sri Lanka is a small island in the Indian Ocean, situated to the south-east of India. It hosts a population of 21 million people in a relatively small area of 65,610 km^2. Sri Lanka has traditionally been an agricultural country and its economic situation depends heavily on the trends and the growth in the agriculture sector. Of the total cultivable land (2.9 m ha), 65% (1.9 m ha) is cultivated. The staple crop of rice occupies 40%, coconut 20%, tea 12%, rubber 7% and the remainder 21% accounts for all other crops (such as horticultural crops and export crops). Agriculture continues to be an essential sector of the Sri Lankan economy in terms of contribution to GDP, employment and income. Presently agriculture contributes 12 % to the country's GDP. About one-third of the workforce is employed in the agriculture sector. In the Sri Lankan rural sector, 60% of its population depends on agriculture for their livelihood. The production of food crops like paddy the staple diet and other field crops have been vital in terms of both employment and income of the rural population. Relatively high rainfall (1830 mm annually) and an equable temperature regime along with fertile soils have enabled the adequate provision of food and water to its people. While advances in agricultural research have been noteworthy, the challenge of securing food supply has been exacerbated by the conversion of agricultural lands, limited technological inputs, and periodic shortages of water that constrain yield. Among the crops that account for 78% of the agricultural GDP are rice, tea, and coconut which contribute 13.4%, 10.1%, and 10.9% to the agricultural GDP, respectively. The cultivation of rice covers 34% of the total cultivated area of the country (www.agridept.gov.lk). Rice is grown around 0.7 million ha in the major cropping season of Maha (October to March) and about half of that extent in the minor season of Yala (April to September), depending largely on the availability of water. Around 879,000 farmer families are engaged in rice cultivation (20% of the population), providing livelihoods for up to 32% of the population. The country has become nearly self- sufficient in rice production. Being a county which is vulnerable to climate change, rice being the main food crop, it is important to understand the impact of climate change on the rice production to identify adaptation measures using different approaches such as crop models

1.2.3 Bangladesh

Bangladesh is also an agrarian country. Agriculture is the single largest producing sector of the economy since it contributes 20% to the country's GDP (MoF, 2012) and employs around 44% of the total labour force (BBS, 2009). In Bangladesh, around 8.4 million hectares (around 58% of total land) area is cultivated (GOB, 2010) which is one of the highest percentages in Asia. The vast majority of the population depends on agriculture for a large part of their food and income. Rice is the predominant crop in Bangladesh accounting for about 79% of agricultural land use. Other major crops include wheat (5.0%), jute (3.2%), pulses (3.4%), oilseed (3.0%), and sugarcane (1.2%). High-value crops include vegetables, fruits, spices and potatoes, which account for only about 5 % of the total cropped area (GoB, 2010). Rice sector contributes half of the agricultural GDP and one-sixth of the national income in Bangladesh. In 1971-72, total rice production in Bangladesh was around 9.7 million metric ton which increased to 31.9 million metric ton in 2009-10 (BBS, 2010). This increased rice production has been possible largely due to the adoption of modern rice varieties on 66% of the rice land, which contributes to 73% of the country's total rice production. Also, other factors have contributed to increased yields such as the development of flood control projects, application of fertilizer, and irrigation. Government of Bangladesh has identified ‘food security’ as one of the cornerstones for achieving sustainable development (Vision 2021: General Economics Division, GoB, 2012). It also emphasised achieving the adequate capacity to mitigate the adverse impact of climate change. In this respect, GoB has also put ‘food security’ as the first thematic pillar in the Bangladesh Climate Change Strategy and Action Plan (Ministry of Environment and Forests (MoEF), 2009). Food security stands listed as a priority area in these action plans.

1.3 Projecting Crop Yields under Future Climate Scenarios

Crop forecasting is the art of predicting crop yields and production before the harvest takes place. It relies on computer programmes that describe plant-environment interactions in quantitative terms. Such programmes are called "models", and they attempt to simulate plant-weather-soil interactions. They need, therefore, information and data on the most important factors that affect crop yields - the model inputs. After being processed by the model, the inputs are converted to several outputs, such as maps of crop conditions and yields in tons/ha etc.

Forecasting the effects of climate change, in future, on the production of agriculture sector requires a specific set of data, tools and models at the spatial scale of real production area sites. One of the major tools is the Global Circulation Models (GCMs) that use different emission scenarios for the projection of climate change. However, the coarse resolution of GCM projections limits their direct use in impact assessment as impact models require climate observations at point scale. Statistical downscaling techniques have been very useful for successful downscaling of coarse resolution GCM scenarios up to point scale resolutions that are required by Crop simulation models.

Data on future climate change scenarios have been downscaled using quantile mapping approach. In this method, biases are calculated for each percentile in the cumulative distribution function from the present simulation. Then the calculated biases are added to the future simulation to correct the biases of each percentile. This information will then be applied to crop water models to simulate yield response to water for climate change impact assessment. Assessment of water use productivity and water-limited attainable yields of cereal crops, wheat and rice have been done for different agro-ecological zones under present and future climate change scenarios. Outcomes of this project are useful for devising climate change adaptation strategies for policymaking and building resilience in water-efficient agriculture by sustainable use of limited resources in South Asia.

1.4 Objective of the Study

Bangladesh, Pakistan and Sri Lanka are among the developing countries in Asia where the implication of climate change on food security is anticipated to be more visible than the other countries in the region. This project has been executed to model the spatial and temporal impact of projected climate change scenarios on cereal production with sustainable crop water management in South Asia.

The main objectives of the project were:

1. To strengthen regional networking and communication gaps through scientific workshops and meetings.
2. To assess food and water security in South Asian Countries for sustainable development under changing climate using crop simulation and water management models
3. To identify appropriate adaptation strategies to meet the future demand and provide guidance to national planners/policymakers for introducing necessary adaptive measures.

2. METHODOLOGY

During the project kick-off meeting, country collaborators discussed and devised a common framework including methodologies, tools, sources and nature of data to be used. The timeline, data formats and policies were also discussed and a Standard Common Research Framework (SCPF) was mutually agreed and finalized by all collaborators. Salient points of this SCPF, which have been used for the execution of the project, are given below:

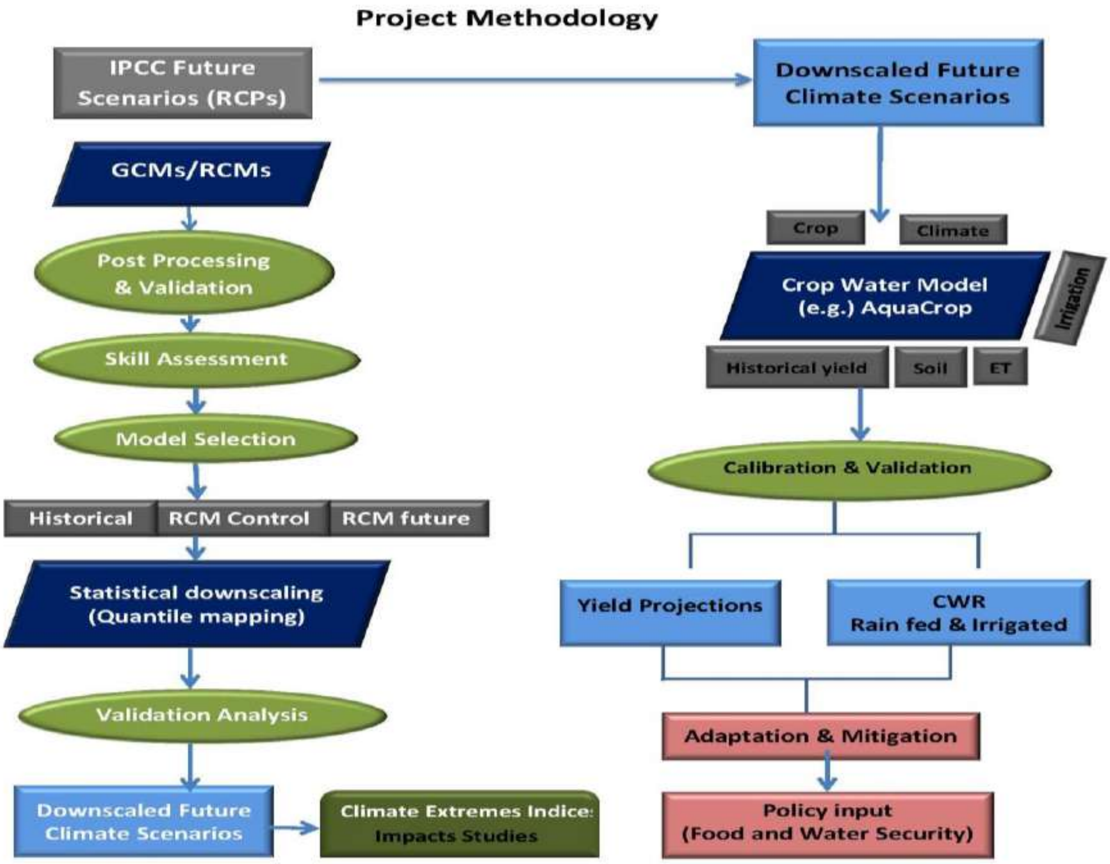


Fig. 1 Framework for the project methodology

2.1 Crops Selection

Since project participating countries have agrarian economies; where rice and wheat are the major staple foods, the impact assessment of climate change will be made on these two primary crops. Maize is also one of the important cereal crops in this region which is evident by its rapidly increasing demand not only for food but also as livestock feed. Hence, maize will also be included as the third crop in this study based on the availability of crop data.

Bangladesh:	Rice
Cambodia:	Rice
Pakistan:	Wheat /Maize
Sri Lanka:	Rice

2.2 Selection of Case Study Sites

Selection of case study sites was made in line with the criteria mentioned in the standard common project framework (SCPF) agreed upon by all partner countries during the project inception workshop. According to this, all collaborating partner countries are desired to select sites (districts), minimum but not limited to three, belonging to different agro-ecological zones with potential food-insecure districts. Other criteria include; most productive areas which are being vulnerable due to climate change, aridity classes (humid, sub-humid, semi-arid, arid and hyper-arid), Cropping patterns (major crops grown, production area, cropping intensities), Data availability (Detailed sets of data must be available over selected sites for weather variables, crop management, phenology, growth and yield, soil characteristics, soil water and irrigation).

Initially, every country had selected a number of case study sites categorized as Phase-I and phase-II. By looking at the quantum of work it was decided that Phase-I study sites will be accomplished during the course of this project while work on phase-II study sites will be continued later. Details of the selection of case study sites for each country are as under.

2.2.1 Site selection for Pakistan

Pakistan is predominantly an arid country. The country area is divided into 10 agro-ecological zones (AEZ) based on physiography, climate, land use and water availability. The main limitation for the development of agriculture in Pakistan is water shortage because of arid climate, heat stress and insufficient rainfall. The conditions for food security are inadequate in 61% districts (80 out of 131districts) of Pakistan. Almost half of the population of Pakistan (48.6%) does not have access to sufficient food for an active and healthy life at all times.

There are two principal growing seasons: The **Kharif** season starts between April and June and ends between October and December, with main crops being cotton, rice, sugarcane, tobacco, maize and millet, while the **Rabi** season starts between October and December and ends during April or May, main crops of this season are wheat, Barley, oilseeds and grams. Four major cropping patterns are in practice, which includes: a) rice-wheat; b) cotton-wheat; c) sugarcane-wheat, and d) maize-wheat.

In the case of Pakistan, for a multi-locational analysis site from 10 agro-ecological zones and a wide range of climatic conditions have been selected. These sites have been divided into two phases for ease of handling and completing the task efficiently. Meteorological observatories are not located in every district; thus, as an alternative strategy, nearby station data will be used in those cases. Selected case study sites and their characteristics are mentioned in the following map (Figure 2) and Tabl

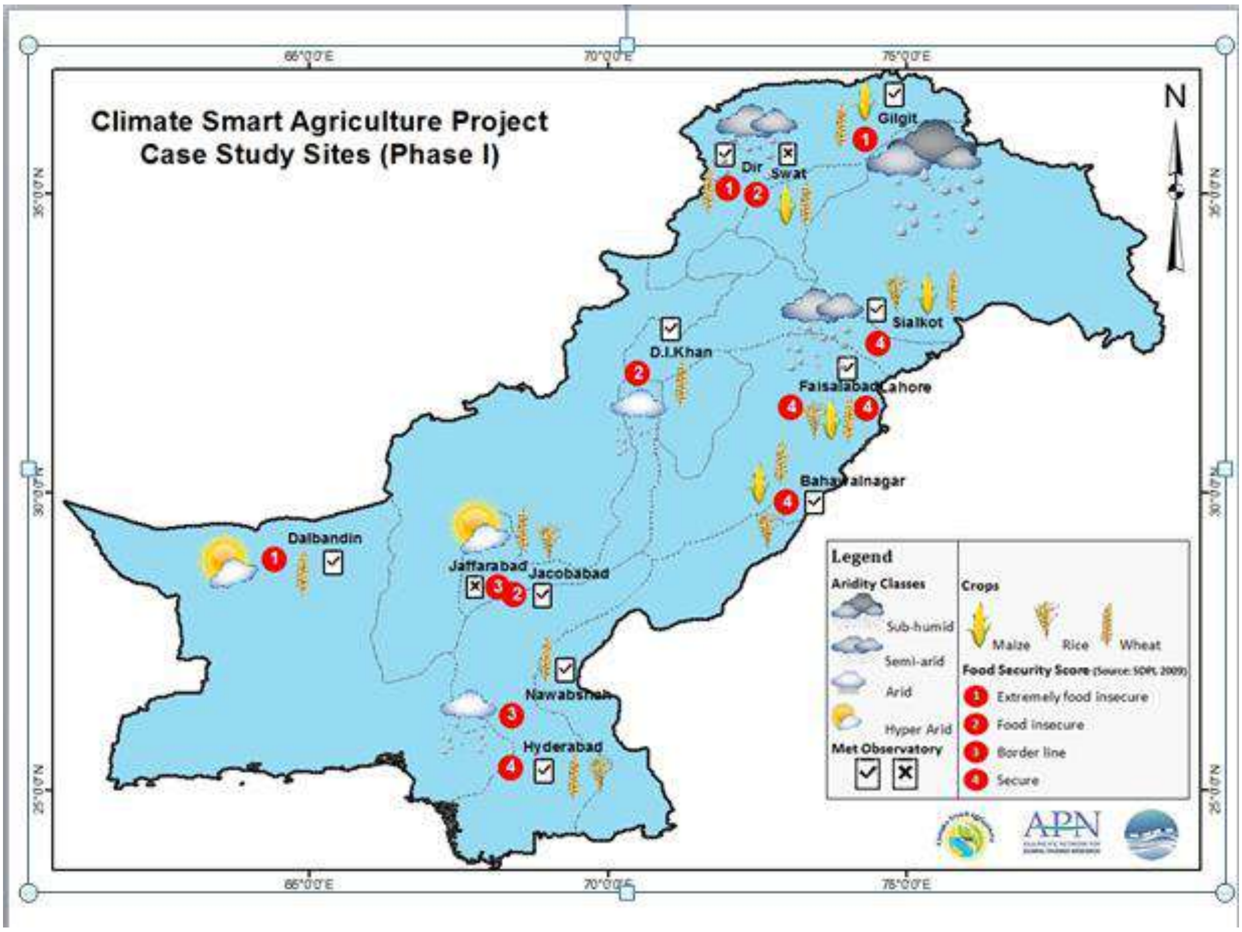


Fig. 2 Selected Study Sites in Pakistan

Table 1 Characteristics of Selected Study Sites in Pakistan

Sr. No.	Areas	Crops*	Vulnerability*	Met. Station	Production (000 tons)	Aridity Class	Agroecological zone	Food Security Score*
				Phase-I				
1	Sheikhupura	W, R	T+F	x	496, 310	Semi-Arid	Zone-IV-a (Northern irigarted plains)	0.86(4)
2	Sargodha	W, R, M	T	✓	595, 83, 79	Dry Semi-Arid		0.79(3)
3	Faisalabad	W, R, M	T	✓	846, 61, 125	Dry Semi-Arid		0.89(4)
4	Sahiwal	W, R,M	T	✓	460, 52, 307	Dry Semi-Arid		0.87(4)
5	Multan	W	T	✓	590	Arid		0.72(3)
6	Bahwalnagar	W, R,M	T + R	✓	990, 125, 34	Arid		0.87(4)
7	Bahawalpur	W	T	✓	885	Arid	Zone-III (Sandy Desert)	0.74(3)
8	Chakwal	W	R	✓	169	Wet Semi-Arid	Zone-V (Barani Lands)	0.76(3)
9	Sialkot	W, R,M	T + R	✓	543, 341, 22	Dry Sub humid		0.93(4)
10	Hyderabad	W, R	T+F	✓	55.4, 33950	Extremely Arid	Zone-I (Indus delta)	0.80(4)
11	Mirpur khas	W,	T	✓	218	Arid		0.53(1)
12	Badin	W, R	S+F	✓	93, 270	Arid		0.61(2)
13	Thatta	W , R	S+F	✓	42, 203	Arid		0.66(2)
				Phase-II				
16	Dadu	W,R	T+F	✓	160, 206	Extremely Arid	Zone-II (Southern Irrigated Plains)	0.53(1)
17	Larkana	W,R	T+F	✓	113, 370	Extremely Arid		0.84(4)
18	Sukkhur	W	T+F	✓	158	Extremely Arid		0.81(4)
19	Jaccobabad	W,R	T+F	✓	278, 294	Extremely Arid		0.65(2)
20	Nawabshah	W	T	✓	38	Extremely Arid		0.79(3)
21	D.I. Khan	W	T+F	✓	84	Dry Semi-Arid	Zone-X (Sulaiman Piedmont)	0.58(2)
22	D.G. Khan	W,R	T + R+F	✓	388, 80	Dry Semi-Arid		0.59(2)
23	Mardan	W,M	T+R+F	x	99, 110	Wet Semi-Arid	Zone-IV-b (Northern irrigated plains)	0.64(2)
24	Swabi	W,M	T+R+F	x	93, 71	Semi-Arid Humid		0.61(2)
25	Swat	W,M	T+R+F	x	71, 101	Semi-Arid Humid	Zone-VII (Northern Dry Mountains)	0.60(2)
26	Dir	W	T+R	✓	17	Humid		0.46(1)
27	Gilgit	W,M	T,R	✓		Arid		0.51(1)
28	Chitral	W,M	T,R	✓	16, 13	Dry Semi-Arid		0.55(2)
29	Lucki Marwat	W	T+R	x	16	Dry Semi-Arid	Zone-VIII (Western dry mountains)	0.44(1)
30	Bajour	W	T	x	24	Wet Sub Humid		0.42(1)
31	Jaffarabad	W,R	T+F	x	113, 432	Extremely Arid		0.76(3)
32	Naseerabad	W,R	T+F	x	222, 208	Extremely Arid		0.77(3)
33	Khuzdar	W	T	✓	80.7	Arid		0.47(1)

*Crops W=Wheat R=Rice M=Maize

*Vulnerability T= Extreme temperature R=Extreme Rainfall F=Floods S=Salinity

*Food Security Score has been adopted from a joint study report "Food Insecurity in Pakistan" (2009) by Sustainable Development Policy Institute (SDPI) and World Food Program (WFP) and is based on following indicator(s):

i) Average daily per capita calorie supply
ii) Food production index per capita
iii) Self-sufficiency ratio
iv) Real price of food

2.2.2 Site Selection for Sri Lanka

Sri Lanka exhibits a very typical tropical monsoonal climate, which is hot and humid all year round with distinct wet and dry seasons. Based on rainfall Sri Lanka has been generalised into three major climatic zones in terms of “Wet Zone” in the southwestern region including the central hill country, and “Dry Zone” covering predominantly, northern and eastern part of the country, and being separated by an “Intermediate zone,” skirting the central hills.

Sri Lanka primary form of agriculture is rice production. Rice is cultivated during Maha and Yala seasons. Rice is the most critical crop occupying 34% (0.77 /million ha) of the total cultivated area in Sri Lanka. Sri Lanka currently produces over three million tonnes of rough rice annually and satisfies around 99% of the domestic requirement. Rice provides 45% total calorie and 40% total protein requirement of an average Sri Lankan.

Irrigation is widespread in the drier areas of Sri Lanka, where the rainfall pattern requires water storage for successful irrigated cropping. The area under irrigation is presently estimated at 600,000 ha, with over 80% of the irrigated area falling within the dry zone.

Dry and Intermediate climatological zones are the most vulnerable regions of the country for climate change in the context of food security. Recurrent and intense droughts, frequent floods in flood plains where the rice cultivation is mainly practised and slow and yet continuous rising temperature pose serious biotic and abiotic stresses on rice production in Sri Lanka.

Sri Lanka is divided into three major AEZ based on ecological parameters and these are further subdivided into 24 AEZs based on rainfall, elevation and soils. For the selection of case study sites, 6 sites have been selected from the North Western, North Central, Southern and Eastern parts of the country which represents a wide range of geographical conditions and aridity classes. Detail of selected case study sites is mentioned in Table 2.

Table 2 Characteristics of Selected Case Study Sites for Sri Lanka

PHASE-I								
Sr. No.	**Areas**	**Crops**	**Vulnerability**	**Met. Station**	**Production (000 tonnes)****	**Aridity Class$**	**Agroecological zone**	**Food security Score ***
1	District 1 (Kurunegala) *Maho* *7.817; (7° 49' N)* *80.267; (80° 16' E)*	Rice	T+P	✓	278 (Total of irrigated and rain-fed paddy)	>1100	Low country (L) (<300 m amsl) Intermediate-Zone (I) (1750-2250 mm mean annual RF), IL_3	37.8%
2	District 1 (Kurunegala) *Bathalagoda* *7.533; (7° 32' N)* *80.450; (80° 27' E)*	Rice	T+P	✓	278 (Total of irrigated and rain-fed paddy)	>1400	Low country (L) (<300 m amsl) Intermediate-Zone (I) (1750-2250 mm mean annual RF), IL_{1a}	37.8%
3	District 2 (Anuradhapura) *Mahailluppallama* *8.100; (8° 06' N)* *80.450; (80° 27' E)*	Rice	T+P	✓	354 (Total of irrigated and rain-fed paddy)	>900	Low country (L) (<300 m amsl) Dry-Zone (D) (< 17500 mm mean annual RF), DL_{1b}	35.2%

PHASE-II								
4	District 3 Pollonnaruwa	Rice	T+P	✓	350 (Total of irrigated and rain-fed paddy)	>900	Low country (L) (<300 m amsl) Dry-Zone (D) (< 17500 mm mean annual RF) DL_{1c}	32.9%
5	District 4 Ampara	Rice	T+P	✓	306 (Total of irrigated and rain-fed paddy)	>1100	Low country (L) (<300 m amsl) Dry-Zone (D) (< 17500 mm mean annual RF) DL_{2b}	32.9%
6	District 5 Hambanthota	Rice	T+P	✓	145 (Total of irrigated and rain-fed paddy)	>650	Low country (L) (<300 m amsl) Dry-Zone (D) (< 17500 mm mean annual RF), DL_5	30.6%

* 75% expectancy-value of annual rainfall in mm

* Total production by district 2014/2015 Maha and 2015 Yala seasons (annual average of 2015), Department of Census and Statistics Ministry of National Policies and Economic Affairs (Season wise production statistics is available for the previous decade)

**Food insecure population proportions (%) at District level (Minimum dietary energy requirement (MDER) 2030 Kcal) based on the publication of "Geetha Mayadunne and K.Romeshun. 2013. Estimation of Prevalence of Food Insecurity in Sri Lanka Centre for Poverty Analysis. Sri Lankan Journal of Applied Statistics, Vol (14-1) ©IASSL ISBN-1391-4987 27."

2.2.3 Site Selection for Bangladesh

Bangladesh's climate is tropical with a mild winter from October to March, and a hot, humid summer from March to June. The country has never recorded an air temperature below 0 °C. A warm and humid monsoon season lasts from June to October and supplies most of the country's rainfall.

Bangladesh is widely recognized to be one of the country's most vulnerable to climate change and is among the countries most prone to natural floods, tornados and cyclones. Natural hazards that come from increased rainfall, rising sea levels, and tropical cyclones are expected to increase as climate changes, each seriously affecting agriculture water and food security. Bangladeshi water is contaminated with arsenic frequently because of the high arsenic contents in the soil. Up to 77 million people are exposed to toxic arsenic from drinking water. Hence, water and food security conditions seriously demand immediate action on research and policy level.

Although rice and jute are the primary crops, wheat is assuming greater importance. Rice dominates the cropping pattern throughout Bangladesh. It has been broadly divided into three classes viz, *aman* (transplanted and broadcast varieties), *boro*, and *aush* according to the season in which they are harvested, namely, in December-January, March-May and July-August respectively. Because of Bangladesh's fertile soil and usually ample water supply, rice can be grown and harvested three times a year in many areas. Most of the crops cultivated in Bangladesh are rain-fed except Boro Rice, Wheat and Millets. About 90 % of the area under *aus* and *aman* rice cultivation is rain-fed. The dependence of groundwater as a source of irrigation was increased from 40% in 1980 to 79% in 2010. However, globally, groundwater provides 20% of the water used for irrigation.

Bangladesh has been divided into 30 AEZs as per its land-soil, crops and agro-climate. For the selection of case study sites, 25 sites have been selected from various agro-ecological zones in Bangladesh. Details of selected sites and their characteristics are mentioned in Table 3.

Table 3 Characteristics of Selected Case Study Sites for Bangladesh

Sr. No.	Areas	Division	Crops	Vulner-ability	Met. Station	Production (000tonnes)	LatN; LonE	Agro ecological zone
Phase-I								
1	Rangpur	Rangpur	R, W	T+F+D	✓	848.4; 8.16	25.73; 89.27	AEZ 3 Tista Meander Floodplain
2	Gaibandha		R, W	T+F+D	x	708.7; 4.95	-	
3	Nilphamari		R, W	T+F+D	x	579.6; 9.59	-	
4	Kurigram		R, W	T+F+D	x	620.8; 20.03	-	
5	Panchagar		R, W	T+F+D	x	382.9; 45.41	-	
6	Dinazpur		R, W	T+F+D	✓	1314.0; 53.49	25.65; 88.68	
7	Bogra		R, W	T+F+D	✓	1136.6; 2.56	24.85; 89.37	
8	Rajshahi	Rajshahi	R, W	T+D	✓	573.7; 72.4	24.37; 88.70	AEZ 26 High Barind Tract
9	Chapainawabganj		R, W	T+D	x	404.7; 44.71	-	
10	Naogaon		R, W	T+D	x	1444.6; 27.69	-	
11	Chuadanga	Khulna	R, W	T+D	✓	275.7; 12.84	23.65; 88.82	AEZ11 High Ganges River Floodplain
12	Jessore		R, W	T+D	✓	1086.0; 9.11	23.20; 89.33	
13	Iswardi	Rajshahi	R, W	T+D	✓	496.1; 86.37	24.15; 89.03	
Phase-II								

14	Barishal	Barishal	R, W	S+I	✓	549.1; 1.32	22.72; 90.37	AEZ 13 Ganges Tidal Flood Plain
15	Pathuakhali		R, W	S+I	✓	476.3; 0.008	22.33; 90.33	
16	Khulna	Khulna	R, W	S+I	✓	352.6; 0.32	22.78; 89.57	
17	Satkhira		R, W	S+I	✓	565.9; 2.48	22.72; 89.08	
18	Bhola	Barishal	R, W	S+I	✓	631.2; 6.29	22.68; 90.65	AEZ 18 Young Meghna Estuarine Flood Plain
19	Feni	Chittagong	R, W	S+I	✓	322.7; 0.15	23.03; 91.42	
20	Noakhali		R, W	S+I	✓	531.4; 0.06	22.87; 91.10	
21	Chittagong (city)		R, W	S+I+R	✓	814.9; 0.008	22.35; 91.82	
22	Sylhet	Sylhet	R, W	R+T+D	✓	588.6; 0.39	24.90; 91.88	AEZ 20 Eastern Surma-Kushiara Flood Plain
23	Moulvibazar		R, W	R+T+D+Ff	✓	443.2; 0.096	24.30; 91.73	
24	Sunamganj		R, W	R+T+D+Ff	x	778.6; 0.329	-	
25	Habiganj		R, W	R+T+D+Ff	x	613.2; 1.29	-	

T=High temperature; F=Flood; D=Drought; S=Salinity; I= Inundation; R=Rain;
Ff= Flash flood

2.2.4 Site Selection for Cambodia

Cambodia consists of four principal AEZ. The country's four agro-ecological zones, namely the Tonle Sap Plain, Mekong Plain, Plateau/Mountain Region, and the Coastal Area reflect heterogeneous agricultural activities, populations and livelihood systems.

Cambodia has a monsoon climate, with a six-month wet season and a six-month dry season. The southwest monsoon brings the rainy season from mid-May to mid-September/early October. The northeast monsoon flows of dry cooler air from early November to March are followed by hotter air from April until early May. Wet season rice farming generally starts early in the wet season and the crop is harvested six months later. Changes in rainfall pattern delay wet season rice farming. This would also impact on other crops or rice cultivation in the next season. In addition, a short drought occasionally occurs during the wet season between late July and early August. If this drought is prolonged, it is likely to have a significant impact on crops. Farmers recognise that the damage caused to their farming in recent years is associated with climate-related issues (irregular rainfall, drought and flood).

Site selection for Cambodia was done by selecting three provinces consisting of districts and communes having diversified geography and climate. Characteristics of the study sites are as follows:

Kandal

The province is subdivided into 11 districts (*srok*). The districts are further subdivided into 146 communes (*khum*) and 1087 villages. The province consists of the typical plain wet area, covering rice fields and other agricultural plantations. The average altitude of the province is no more than 10 meters above sea level. The province also features two of the biggest rivers in the country, the Bassac and Mekong Rivers. The province has a warm and humid tropical climate. The monsoon season typically begins in May and runs through October, while the rest of the year is the dry season. The warmest period of the year occurs between March and May, while the coldest period is from November through March.

Takeo

It consists of 10 districts, 100 communes and 1,116 villages. It is located in the southwest of Cambodia. There seems to be water everywhere in the surrounding countryside during the rainy season. Therefore, the province consists of the typical plain wet area for Cambodia, covering rice fields and other agricultural plantations. Takeo province is one of the province representatives of the Mekong floodplain zone and has a high population and potential for crop cultivation. During the raining season, water from the Mekong floods large areas of the province, thus providing the fertilizer, soil and water for crop cultivation, especially rice production. In the dry season, crop cultivation is depending on rainfall.

Kampong Speu

The total land area of the Kampong Speu **(**KPS) province is approximately 653,396 hectares divided into eight districts and 87 communes and 1,308 villages. Climate change has significantly reduced agricultural production affecting food security and livelihood sustainability of

Cambodians. Kampong Speu province is one of the provinces most affected by natural disasters in the country. The drought was the most severe hazard from 1999 to 2011 in Kampong Speu because it occurred in both the lowland and upland areas. The agricultural sector was found to be the most sensitive sector because of the frequency of drought in the province.

2.3 Data Sets

Acquisition and compilation details of data sets used under this project along with other technical specifications are provided as the below.

2.3.1 Baseline period and future scenarios

Bassline period: **1980-2005**

RCPs = Medium controlled scenario **RCP4.5** & Business as usual scenario **RCP8.5**

Future Periods = **F1** (2011-2040), **F2** (2041-2070) and **F3** (2071-2099)

2.3.2 Model data

Arrangements and efforts were made for downloading of CORDEX-RCM data for use in the APN CSA project.

- This task was accomplished by downloading daily data of twenty-one RCMs for two RCP Scenarios (RCPs 4.5 & 8.5) over three future time scales including near-century, mid-century and far-century for three climatic variables namely; precipitation, minimum and maximum temperature.
- This data was downloaded using various internet resources including NCP, GCISC, developed country partners and personal.

2.3.3 Observed data

Observed station data acquired from Pakistan Meteorological Department (PMD) over selected study sites were used in the validation of climate model data sets, statistical downscaling of future climate change scenarios and crop model simulations.

2.3.4 Reanalysis data Sets

Reanalysis-gridded, updated data products over available baseline periods for precipitation and temperature at GCISC, was downloaded for the following:

(i) CRU (Climate Research Unit, 1901-2012)

(ii) ERA-Interim (1979-2010)

(iii) NASA-MERRA-II (1980-2005)

(iv) NCEP - Reanalysis – II (1979-2016)

(v) WATCH Forcing Data (WFD) - GPCC (Rainfall GPCC) 1901-2001

These datasets were extracted over point locations for three study sites representing, wet, dry and monsoon dominated climate. A boxplot analysis was carried out to show the statistical agreement of these data sets with observed station data. Data sets which were in good agreement with station data were used for validation of climate model data sets and for impact assessment studies.

2.3.5 Input Data Required by AquaCrop and APSIM Model

Different options and sources were identified and explored for acquiring input data for AquaCrop model. Required data sets were then compiled and digitized for calibration and evaluation of AquaCrop model for selected sited over Pakistan. Different sources and efforts include:

- Email correspondence and meetings with CAEWRI, NARC (APN-CSA project partner from Pakistan) for the acquisition of required data for AquaCrop
- Some published literature and PhD dissertations were also consulted for relevant data.
- For calibration and validation of AquaCrop model Crop phenology and management and soil, data were used from the operational field experiments of the wheat crop having an area performed in National Agriculture Research Centre (NARC) Islamabad and University Research Farm Koont (URFK) Chakwal, Pakistan. The experimental sites are classified as a sub-humid and semi-arid climate with cool winters and warm summers.

2.4 Tools and Software

2.4.1 AquCrop V5.0

AquaCrop is the crop growth model developed by FAO to address food security and assess the effect of the environment and management on crop production. AquaCrop simulates the yield response of herbaceous crops to water and is particularly well suited to conditions in which water is a key limiting factor in crop production

2.4.2 APSIM

The **A**gricultural **P**roduction **S**ystems s**IM**ulator (APSIM) is a comprehensive model developed to simulate biophysical processes in agricultural systems, particularly as it relates to the economic and ecological outcomes of management practices in the face of climate risk. It is also being used to explore options and solutions for the food security, climate change adaptation and mitigation and carbon trading problem domains

2.4.3 Regional Climate Modelling Evaluation System (RCMES)

The Regional Climate Model Evaluation System (RCMES) is a comprehensive suite of software resources to standardize and streamline the process of interacting with observational data and climate model output to conduct regional climate model evaluations. The Regional Climate Model Evaluation System (RCMES) has been developed at NASA JPL jointly with researchers at UCLA. This system is used to evaluate the performance of regional climate models by comparing model data against observations.

2.4.4 Statistical Language R

R is a programming language and environment commonly used in statistical computing, data analytics and scientific research. It is one of the most popular languages used by statisticians, data analysts, researchers and marketers to retrieve, clean, analyse, visualize and present data.

2.4.5 CDO and NCO under Linux Environment

CDO and NCO are Linux based, widely used third-party software packages for netCDF data handling. CDO is a collection of command-line operators to manipulate and analyze climate and numerical weather prediction data; includes support for netCDF-3, netCDF-4 and GRIB1, GRIB2, and other formats. On the other hand, the NCO is a package of command-line operators that manipulates generic netCDF data and supports some CF conventions.

2.4.6 Panoply Version 4.0

Panoply is a Java-based cross-platform application which plots geo-gridded arrays from netCDF, HDF and GRIB datasets. It supports operations like; slice and plot specific latitude-longitude, combine two arrays, plot lon-lat data on a global or regional map, overlay continent outlines, overlay continent outlines etc.

2.4.7 MeteoInfo V 2.0

Meteoinfo is an open Source Software Suite for Multi-Dimensional Meteorological Data Computation and Visualization. MeteoInfo Java software tools were developed for meteorological data analysis and visualization by integrating a Geographic Information System (GIS) and Scientific Computation Environment (SCE).

2.5 Techniques

2.5.1 Regional Climate Model Selection and Use of Ensemble Approach

The Coordinated Regional Downscaling Experiment (CORDEX) data sets of 23 Global Climate Models (GCMs) from Coupled Model Inter-comparison Project Five (CMIP5) downscaled by Four Regional Climate Models (RCM) on daily time scale was downloaded at 50km x 50km resolution. These models were divided into four groups mainly on the bases of developing institute of RCMs:

- **6** GCMs downscaled by CCAM (RCM) developed by CSIRO (Commonwealth Scientific and Industrial Research Organization, Australia)
- **5** GCMs downscaled by RegCM4 (RCM) developed by IITM (Indian Institute of Tropical Meteorology, India)
- **11** GCMs downscaled by RCA4 (RCM) developed by SMHI (Swedish Meteorological and Hydrological Institute, Sweden)
- **1** GCM downscaled by REMO2009 (RCM) developed by MPI (Max Planck Institute for meteorology, Germany)

Above given 23 models are RCMs, which downscaled various CMIP5 GCMs.

Each of the above-mentioned group was evaluated relative to CRU (Gridded observed data sets), models among each group showed almost similar behaviour but considerable differences among different groups. Then as a subsequent strategy, ensemble approach was used and models within each group were ensemble using grid point averages of all dimensions for selected variables. Ensemble approach was helpful to average out positive negative biases and to minimize chances of errors.

2.5.2 Climate Change Scenario Generation

Climate change scenarios at local scale resolutions were developed using Statistical downscaling methods for collaborating countries. This was achieved by prepared codes in statistical language R which were used for extraction of climate change scenario data for three variables Maximum temperature, minimum temperature and Precipitation on daily timescale using CORDEX Regional climate model ensembles.

These codes were run to extract data on partner country sites. Prepared codes in Statistical Language R, for downscaling climate change scenario data, using Quantile mapping approach at point location on three above mentioned climatic variables for partner countries over their selected study sites with CORDEX data sets.

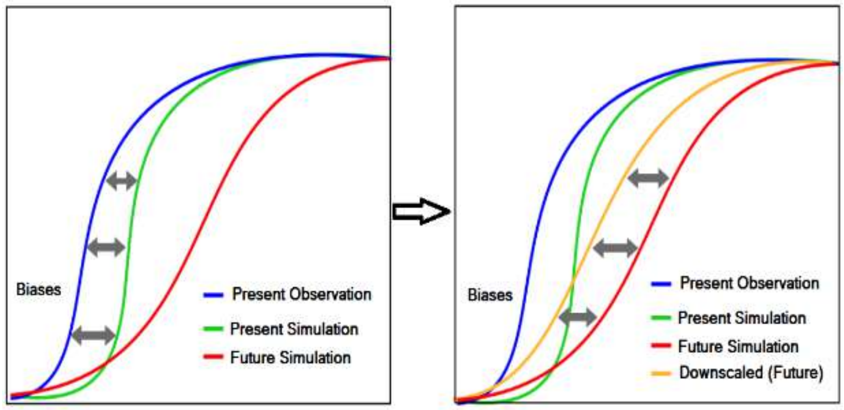


Fig. 3 Quantile mapping approach

Data on future climate change scenarios have been downscaled using quantile mapping approach. In this method, biases are calculated for each percentile in the cumulative distribution function from the present simulation (blue) (Figure 3). Then the calculated biases are added to the future simulation to correct the biases of each percentile.

2.5.3 Climate change Impact assessment on cereal production

Assessment of water-limited available crops was done for different agro-ecological zones under present and future climate change scenarios. Future scenarios of climate change for different time slices were used for studying the impact of projected future climate on yield and water use efficiency of wheat, maize and rice under rainfed and irrigated conditions using Food and Agriculture Organization's Crop water model Aqua Crop v4.0, which focuses on simulating the attainable crop biomass and harvestable yield in response to water, and Australian crop simulation model APSIM v7.10. Based on the results obtained, adaptation strategies for sustainable crop and water management were devised that will help in achieving food security in the region.

2.6 Data Analysis

In order to analyses data and interpret results in various kinds of statistical, validation and graphical analysis test was performed using different software applications. Details of these analyses are as follows.

2.6.1 Comparison of Reanalysis and Gridded Data Products for Use in Validation

5 different gridded and Reanalysis data products including CRU, ERA-Interim, NCEP-R-II, JERRA-50 and NASA-MERRA-II were downloaded for Tmin, Tmax and precip, extracted at point scale for three representative climates; wet, dry and monsoon dominated. Box plot statistics were evaluated for representative sites. The comparison revealed that NASA-MERRA-II is in good agreement with observed climate and can be used for validation purposes

2.6.2 Post-processing of CORDEX, RCM Data Sets

Strenuous efforts were made in exploration and familiarization of tools and techniques used for post-processing of CORDEX RCM-data which was released with updated/new NetCDF data format V4. Climate data post-processing tasks were accomplished, independently; using different programming and GUI-based NetCDF data handling tools (e.g. GrADS, CDO, NCO, statistical language R, ArcGIS, and Panoply). These tasks involved:

- Clipping and extraction of climate model data over regional, country and station domains
- Display of NetCDF data using different mapping tools
- Conversion of NetCDF format data into readable formats i.e. ASCII and .csv Formats for analysis
- Re-gridding and interpolation
- Changing map projections of climate data from rotated polar grids to regular lat-lon grid projections
- Concatenation of 5-year model data files into single 30-year files for analysis

2.6.3 Climate Data Analysis and Validation

2.6.3.1 Box plot analysis of CORDEX RCMs for APN Project Study Sites

Box plot analysis of 13 case study sites from Pakistan was carried out for monthly total precip, monthly Tmin and Tmax to assess the degree of reproducibility of model data with observed at point scale.

2.6.3.2 Performance assessment of CORDEX Regional Climate Model (RCM) datasets over South and East Asian region

A dedicated attempt was made, spending substantial time and efforts in reaching a robust and efficient Regional Climate Model Evaluation System developed by NASA for impact assessment studies. This system was successfully installed and prepared for running. Since the system is built in Python, some programming difficulties were encountered initially, but these were sorted out successfully and a state of the art analysis of 21 Regional Climate Models of CORDEX data sets was carried out.

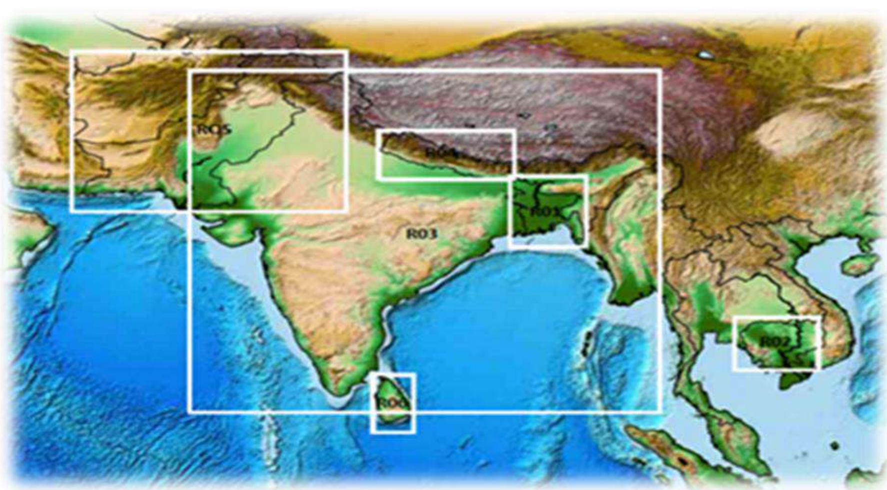


Fig. 4 Sub regions mentioned in table 3.2

The following are performance metrics that were calculated using RCMES for 6 different sub-regions of Asia, namely Bangladesh, Cambodia, India, Nepal, Pakistan and Sri Lanka:

- Bias (i.e. spatial grid of differences)
- Temporal Standard Deviation for Sub-regions
- Standard Deviation Ratio
- Pattern Correlation
- Temporal Correlation for Sub-regions
- Temporal Mean Bias for Sub-regions
- RMS Error (with mean computed over time and space)
- Monthly model comparison for sub-regions.

All these metrics were evaluated for monthly mean precip, tmin, tmax, Av.temp and diurnal temperature range at annual and seasonal scale, seasonal analysis included three distinct seasons i.e. DJF, MAM, JJAS

2.6.4 Analysis of future extremes with CORDEX data at regional and country scale

Analyses and Visualization of climatic extremes were carried out using CORDEX RCMs. This analysis includes;

- Spatial distribution of daily extreme precipitation events and inter-annual variations
- Spatial distribution of daily extreme temperature events above 40 degrees over Pakistan
- Spatial patterns of the diurnal temperature range for winter and summer seasons and annual cycle of diurnal range from model outputs

2.6.5 Region-specific extraction and downscaling of climate change scenario data

- Codes were prepared in statistical language R which were used for extraction of climate change scenario data for three variables Maximum temperature, minimum temperature and Precipitation on daily timescale using CORDEX Regional climate model ensembles. These codes were run to extract data on partner country sites

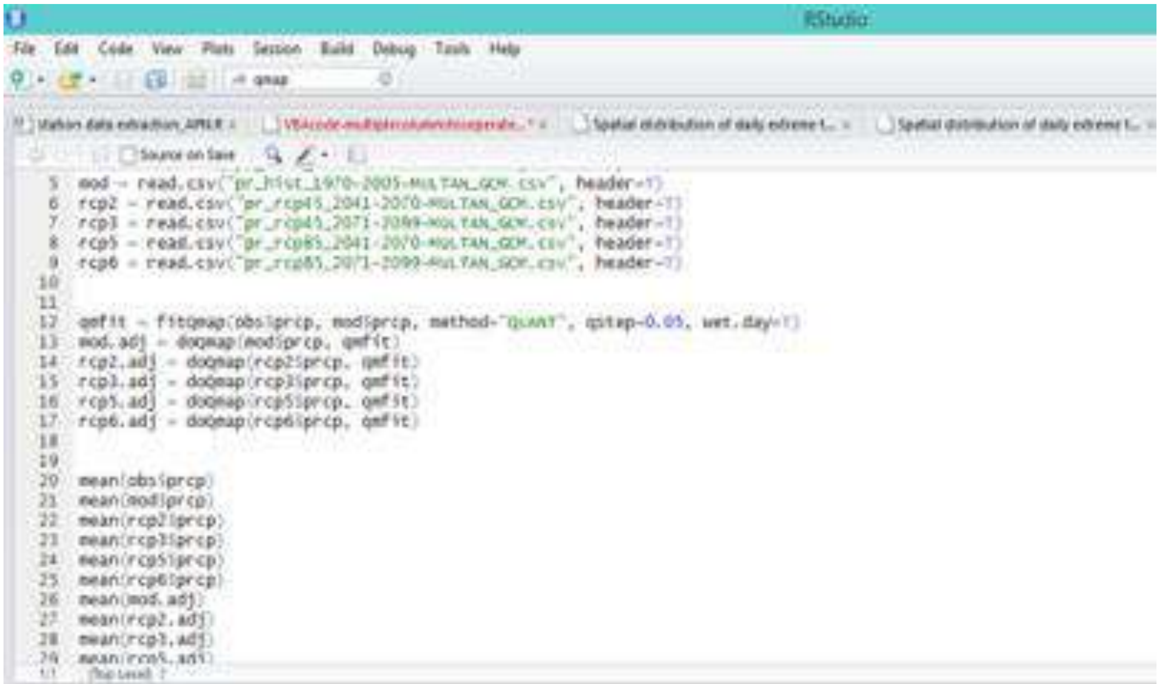


Fig. 5 R code for data extraction

- Codes were prepared in Statistical Language R, for downscaling climate change scenario data, using Quantile mapping approach at point location on three above mentioned climatic variables for partner countries over their selected study sites with CORDEX data sets. Data has successfully been downscaled and the same will be shared with partner countries for impact assessment.

Data on future climate change scenarios have been downscaled using quantile mapping approach. In this method, biases are calculated for each percentile in the cumulative distribution function from present simulation (blue). Then the calculated biases are added to the future simulation to correct the biases of each percentile.

For Pakistan, future climate change scenarios of daily maximum, minimum temperature and precipitation on twelve study sites including Bahawalnagar, Dir, Dalbandin, DI Khan, Faisalabad, Gilgit, Hyderabad, Jaccobabad, Jaffarabad, Nawab Shah, Swat and Sialkot have been downscaled.

Sri Lanka has selected 3 study sites, which have been downscaled i.e. Mahailluppallama, Maho and Bathalagoda, they have been provided with the climate change scenarios, worked out by the lead country, for the selected sites

Daily downscaled data on climate change scenarios have also been prepared by lead country on 11 study sites selected by Bangladesh for using with Crop model. These downscaled study sites include; Barisal, Bhola, Bogra, Dhaka, Dinajpur, Jessorie, Mymensingh, Patuakhali, Rajpur, Rangpur and Srimongal.

Validation analysis of downscaled study site “Sialkot-Pakistan is shown as under

2.6.6 Downscaled Future Climate Change Scenario data validation

Validation analysis of downscaled (future bias corrected) study site "Sialkot-Pakistan using quantile mapping approach is shown for tmin tmax and precip variables for RCP 8.5 and RCP 4.5 during near century, mid-century and far century.

2.6.7 Analysis of cropping season-specific station scale projections of temperature changes over Pakistan, Bangladesh and Sri Lanka

This analysis includes downscaled future temperature projections for minimum and maximum temperatures during major cropping seasons (Average) in Bangladesh, Pakistan and Sri Lanka. In Pakistan, these are carried out for two cropping seasons, R*abi* (Nov-Apr) and *Kharif* (Apr-Sep). For Sri Lanka two main cropping seasons *Maha* (Sep-Mar) and *Yala* (May-Aug), while for Bangladesh projections were evaluated for three cropping seasons, *Rabi* (Nov-Mar), *Kharif-I* (Mar-Jul) and *Kharif –II* (July-Nov).

2.6.8 Mapping warming-induced projected changes in growing degree days of the wheat crop in different wheat growing zones of Pakistan

The main objective of this study was the assessment of the impacts of increasing mean daily temperatures on wheat-growing areas during past and future Rabi season on wheat crop in Pakistan. GSL was determined both in terms of calendar days and accumulated heat units (GDD) for the full duration of the cropping period starting from sowing to harvest maturity, using a base temperature of 5 ^{0}C. The base temperatures are the minimum temperatures, below which there is insufficient heat for biological activity. Increase in growing degree days' decreases growing season length of crops by enhancing metabolic processes in plants with warming leading to forced maturity, plants are thus unable to express their genetic potential and yields are reduced. The global climate change will affect the growing season length of crops due to higher temperature, reduced soil moisture, affecting the partitioning and quality of biomass, crop pests and diseases and entail spatial shifts in potential areas of agricultural crops

2.6.9 Analysis of Future warming extremes, impacting critical crop growth stages of the Wheat crop in Pakistan

Consecutive summer day index (CSU) is consecutive 5 or more days of daily maximum temperature occurrences above a specific threshold. Beyond theses temperatures thresholds/upper limits, which are different for different critical crop growth stages, yield losses may occur. Heat stresses directly affects crop physiology and metabolism of the plants. Such conditions are characterized by leaf senescence resulting in a reduction in plant leaf area due to fewer tillers & smaller leaves, and photosynthetic rates eventually leading towards reduced seed set, decreased grain filling duration and reduced grain size.

A comprehensive analysis of Consecutive Summer day index per time period with a thresh hold of 32 and 36 degrees Celsius for Flowering and ripening stages (respectively) of the wheat crop was done to assess likely future impacts of warming in major wheat-growing areas of Pakistan

3. RESULTS & DISCUSSION

For historical and future projections (period 1980–2100) we used daily data sets of total precipitation amounts (mm) maximum temperature (^{0}C), minimum temperature (^{0}C), daily mean temperature (^{0}C), and diurnal temperature range (^{0}C), from 23 regional climate model (RCM) simulations of the Coordinated Regional Downscaling Experiment (CORDEX) over Asian domain, with a resolution of 0.44°. CORDEX was initiated by the World Climate Research Program (WCRP) in 2009 in response to the need for a coordinated framework for evaluating and improving regional climate downscaling (RCD) techniques and producing a new generation of RCD-based fine-scale climate projections for identified regions worldwide.

In the set of simulations, 4 RCMs are driven by 23 different general circulation models forced with two scenarios, RCP4.5 and RCP8.5 adopted by the Intergovernmental Panel on Climate Change (IPCC) for its fifth Assessment Report (AR5, Christensen et al., 2013). Climate simulations with RCPs (RCP2.6 and RCP6.0) were not available. For the comparison with the reference data, we used historical simulations of gridded data set CRU available at monthly time scale and a daily reanalysis data product, NASA-MERRA2 for the period 1980 – 2005. Ensemble model outputs used in this study were comprised of 23 simulations listed in Table 3.1, detailing; 11 RCA4 (Swedish Meteorological and Hydrological Institute (SMHI)) model simulations (Swedish Meteorological and Hydrological Institute) forced with 11 global climate models, 6 CCAM (Commonwealth Scientific and Industrial Research Organization (CSIRO)) simulations driven by lateral boundary conditions of 6 global climate models, 05 simulation with RegCM4 (Indian Institute of Tropical Meteorology (IITM)) and one driven by REMO2009 (Max Planck Institute for Meteorology (MPI)).

Table 4 Details of CORDEX Regional Climate Model (RCMs) Simulations used in the study

Driving GCM	**RCM**	**Model Institute**
CCCma-CanESM2	**RCA4**	Swedish Meteorological and Hydrological Institute (SMHI)
CNRM-CERFACS-CNRM-CM5		
CSIRO-QCCCE-CSIRO-Mk3		
ICHEC-EC-EARTH		
IPSL-IPSL-CM5A-LR		
IPSL-IPSL-CM5A-MR		
MIROC_MIROC5		
MOHC-HadGEM2-ES		
MPI-M-MPI-ESM-LR		
NCC-NorESM1-M		
NOAA-GFDL-GFDL-ESM2M		
ACCESS1-0	**CCAM**	Commonwealth Scientific and Industrial Research Organization (CSIRO)
CCAM-CCSM4		
CNRM-CM5		
GFDL-CM3		
MPI-ESM-LR		
NorESM1-M		
CCma-CanESM2	**RegCM4**	
CNRM-CERFACS-CNRM-CM5		
ECMWF-ERAINT_evaluation		
MPI-M-MPI-ESM-MR		
NOAA-GFDL-GFDL-ESM2M		
MPI-M-MPI-ESM-LR	**REMO2009**	Max Planck *Institute* for Meteorology (MPI)

Table 5 The sub-regions mentioned in Fig 4

Region-I	**(R-I)**	**Bangladesh**
Region-II	(R-II)	Cambodia
Region-III	(R-III)	India
Region-IV	(R-IV	Nepal
Region-V	(R-V)	Pakistan
Region-VI	(R-VI)	Sri Lanka

3.1 Climate data analysis and validation

3.1.1 Comparison of Reanalysis and Gridded data products used for validation

Reanalysis and other gridded data products may represent a good alternative dataset of precipitation and temperature data for regions where weather stations are sparsely distributed or absent or the quality of data in terms of available records are inadequate, with long-missing records. Since climate model data products are in gridded data format, their validation and comparison analysis using point data (non-gridded formats) is not straightforward hence reanalysis and gridded data products act as good reference data.

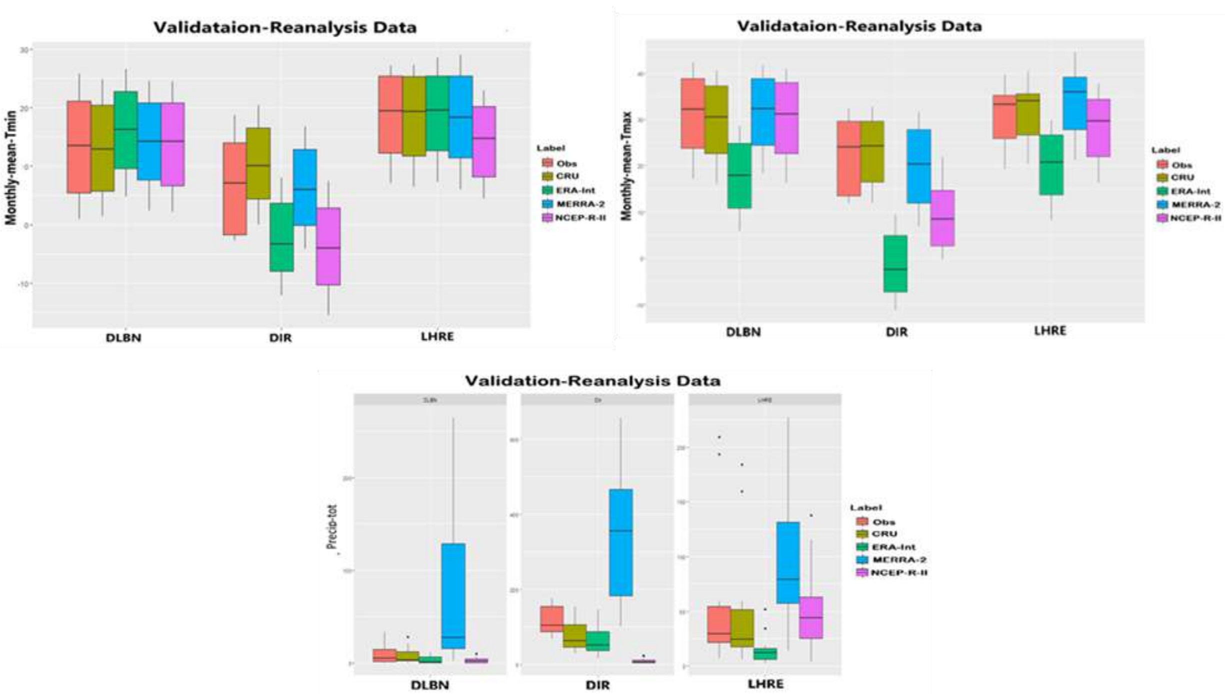


Fig. 6 Boxplot analysis of Observed v/s Reanalysis data sets

Figure 6 shows the mean monthly box plot analysis of four different reanalysis and gridded data sets against observed station data over the historical period 1980-2005. Three stations were chosen as they are representative of the geographical variation of weather conditions over dry (dalbandin) wet (Dir) and monsoon dominated (Lahore) climates. Climate Research unit data(CRU) is in good agreement with observed station data sets overall selected stations for maximum and minimum temperatures, which is a monthly gridded data product.

In high-altitude areas of Indus basins, gridded datasets use only a few station data having commonly available old observatories which do not exhibit the topographic and contiguous variance of precipitation in those areas (Reggiani and Rientjes, 2015).

Among daily scale reanalysis data sets, results reveal a clear superiority of NASA-MERRA 2 with the gauge based station data overall selected sites in Pakistan for temperature. ERA-Interim underestimates observed climatology of maximum temperature over selected stations. The monthly total precipitation amounts are represented better through the CRU over selected sites. MERRA2 is showing higher precipitation than that of observed. In monsoon dominated precipitation region, the EAR-Interim underestimates while NCEP overcast monsoon precipitation. A recent study also confirms this finding, a comparative investigation of gridded data products over summer monsoon in China (Zhao, 2006)

3.1.2 Box plot analysis of CORDEX RCMs for selected case study sites over Pakistan

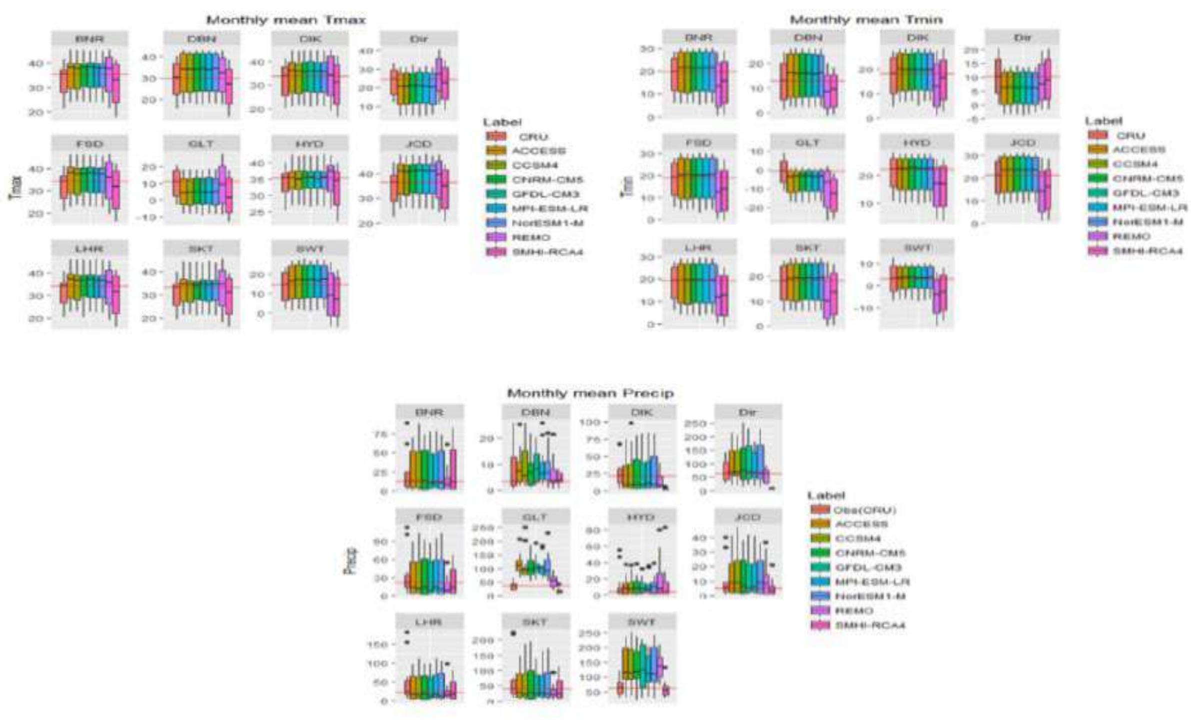


Fig. 7 Box plot analysis of CORDEX RMs for selected case study sites over Pakistan

3.2 Performance assessment of CORDEX Regional Climate Model (RCM) data sets for suitability of use in impact studies over South and East Asia Region

3.2.1 Observed Climatology and model biases (Annual Scale)

Precipitation

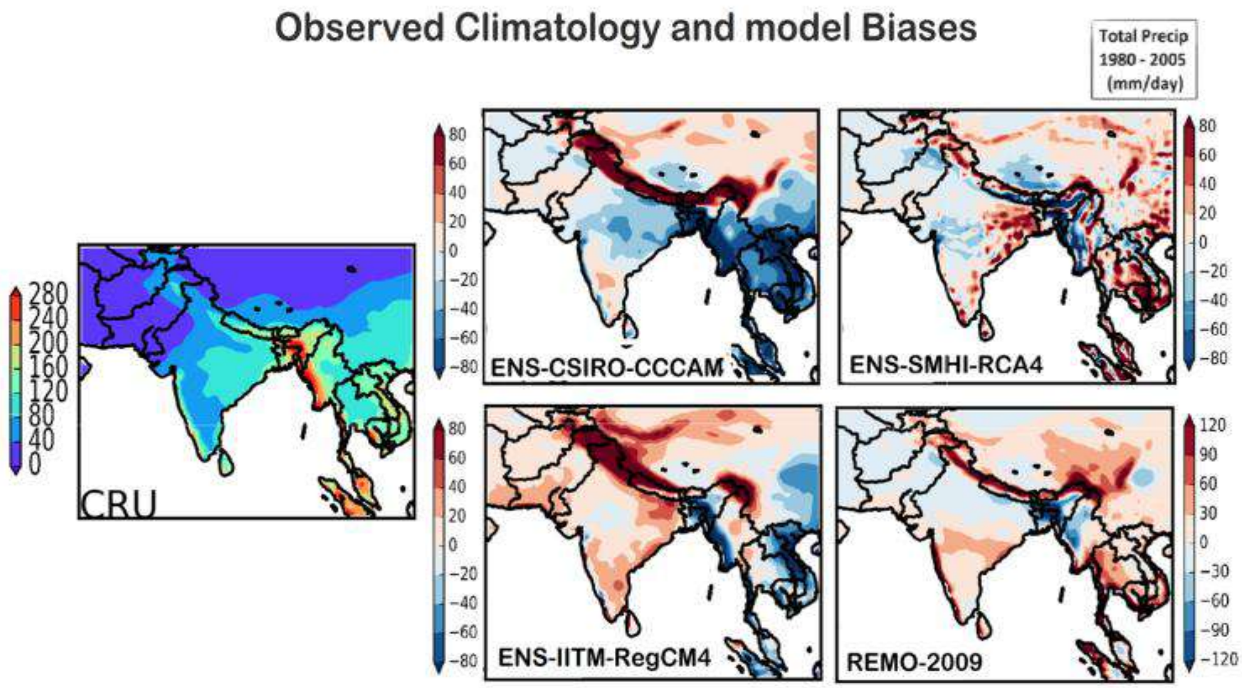


Fig. 8 Observed Climatology and Model Biases of ensembles over South and East Asia region

Figure 8 shows observed climatology and model biases of total precipitation amounts of the CRU data for the historical period (1980-2005). Among four RCMs model simulations, CSIRO-CCAM model ensemble shows a strong degree of wet bias up to 80mm per day over whole northern Hindu Kush and Himalaya (HKH) region and an extreme degree of equivalent dry bias over south-eastern part. IITM-RegCM4 model simulations indicate extreme wet bias over HKH and Tibetan plateau and medium degree of positive bias extended over southern parts of Pakistan and India. SMHI-RCAR is the best available group of models for Asian domain with less to moderate degree of wet and dry biases, Remo is also appeared to perform comparably good with RCA4 in simulating precipitation over South and South-eastern Asia**.**

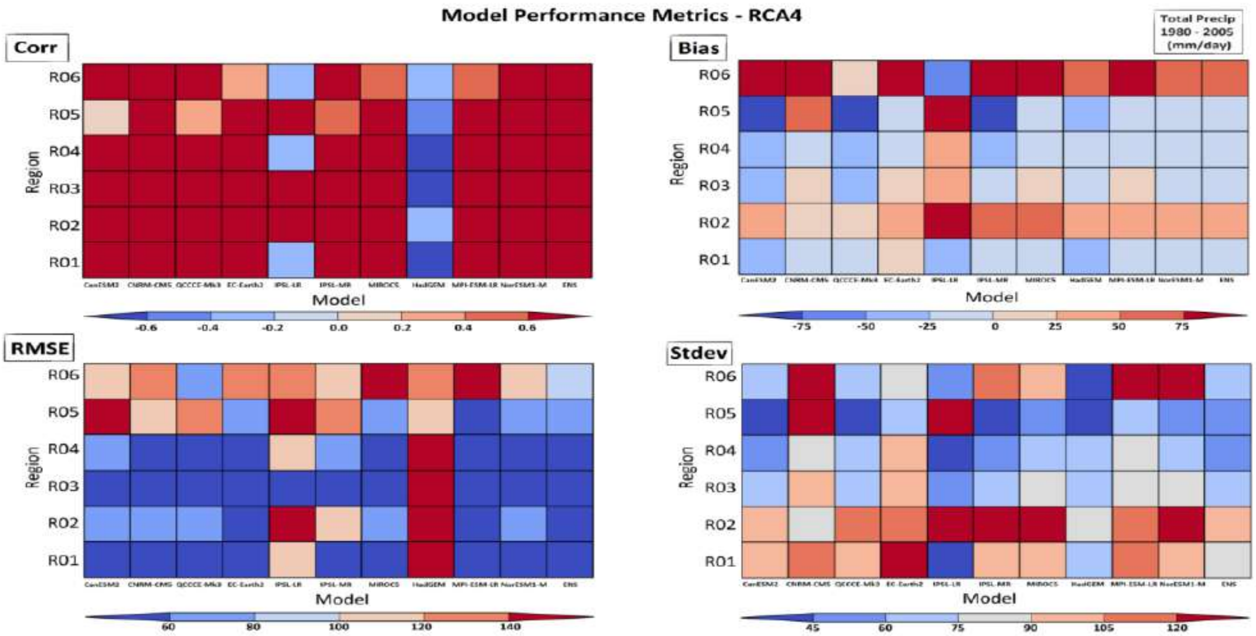


Fig. 9 Portrait diagrams showing correlation coefficient, RMSE, bias and standard deviation between simulated (RCA4) precipitation and CRU data

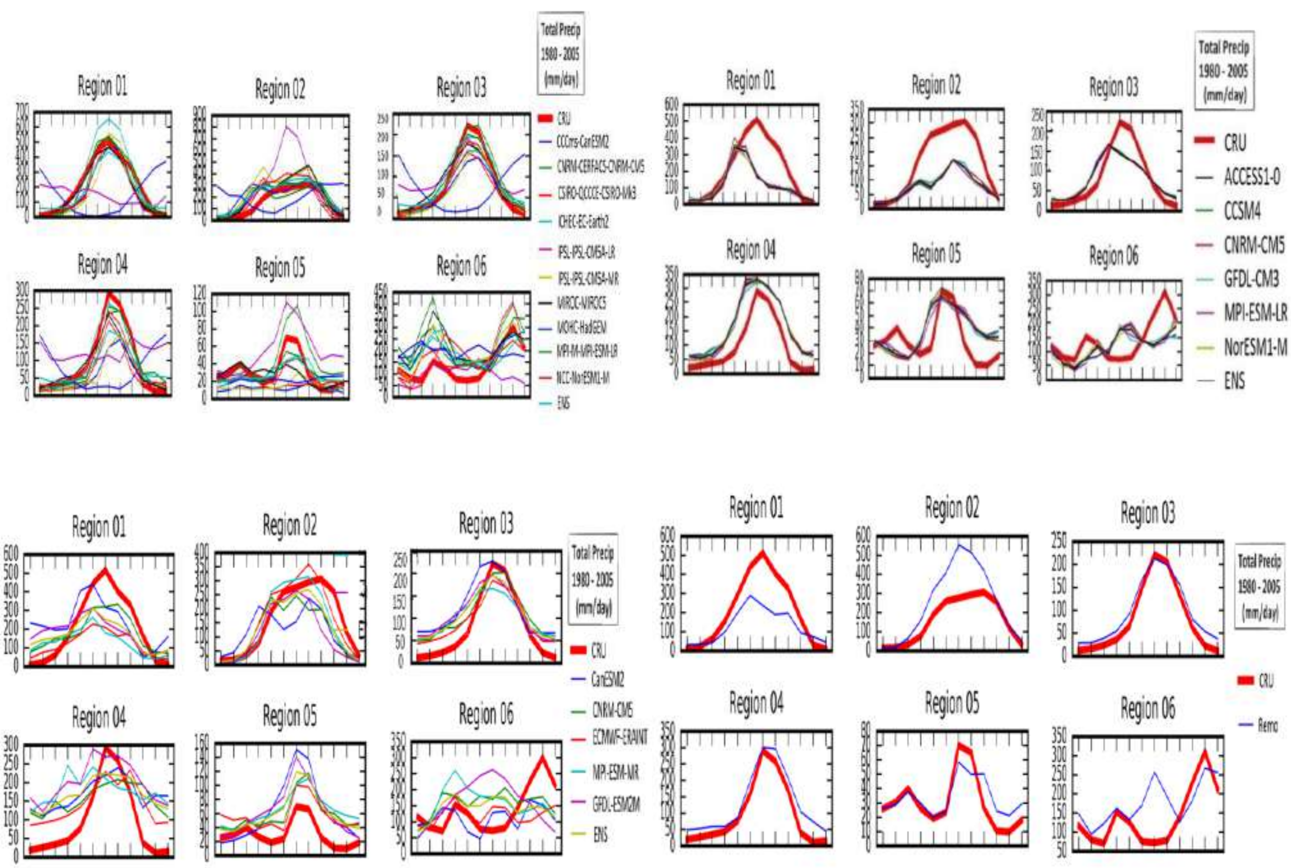


Fig. 10 Annual cycle climatology of four selected RCMs and their downscaling GCMs over selected sub regions (sub-regions mentioned in Table 3.2)

Figure 9 presents the annual cycle analysis of total precipitation for sub-regions (mentioned in Table 3.2) over the sub-seasonal scale. All the four modelling groups of RCM ensembles reproduced annual cycle climatology of Region-III (India) and Region-IV (Nepal) reasonably well both in terms of rainfall patterns and amounts. RCA4 ensemble members show skills in capturing uncertainties using large spread while CSIRO-CCAM model exhibits good skills in reproducing total monthly precipitation patterns.

Figure 10 shows portrait diagrams of temporal correlations coefficient, RMSE, bias and temporal standard deviations between simulated precipitation and CRU data. Portrait diagrams were used for evaluating the skill of various RCMs in simulating precipitation for all the sub-regions. Figure 6 also shows that for most of the regions, the value of correlation coefficient lies above 60% of CRUs precipitation for almost all RCMs in all the sub-regions, except for IPSL-IPSL-CM5A-LR and MIROC5, where weaker correlation for all the sub-regions are shown. SMHI-RCA4 model shows a mix of bias in the range of +/- 75 mm for all the sub-regions with the strong positive bias of over 75 mm in Region 06 (Sri Lanka). RMSE was also evaluated for all selected sub-regions for SMHI-RCA4 simulations. NorESM1 simulations resulted in highest error ranging between 100-140mm for all sub-regions. Region-I, III and IV (Bangladesh, India and Nepal) show least RMSE i.e. less than 60 mm least temporal standard deviations were observed reference to CRU for Pakistan (less than 45 mm)

Average temperature

Figure 11 presents the annual cycle analysis of average temperature (^{0}C) for sub-regions (mentioned in Table 3.2) over the sub-seasonal scale. All the six ensemble members of CCAM RCM reproduced annual cycle climatology of Region-III (India), Region-IV (Nepal) and Region-V (Pakistan) reasonably well both in terms of magnitude as well as trend. It is illustrated in the figure that the results for average annual temperatures in the above-mentioned regions are highly in agreement with the reference line (CRU data).

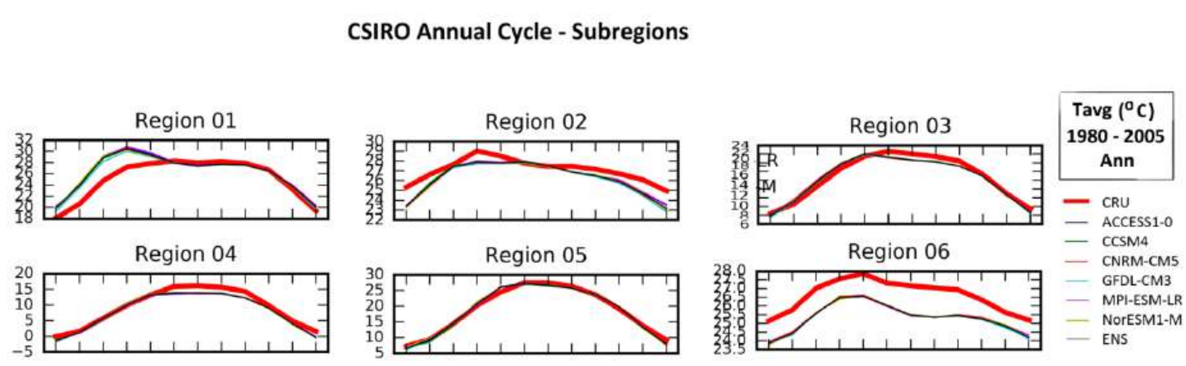


Fig. 11 Annual cycle climatology of CSIRO-CCAM RCM and down-scaling GCMs over selected sub regions (sub regions mentioned in Table 3.2)

The results for annual average temperature in Region-I and Region-II also show a significant correspondence with reference values but, in Region-I, initially, the temperature values considerably deviate until it reaches half of the simulation period. Region-II has shown an agreement with the standard to a lesser degree and kept on deviating on and off throughout the simulation period. Region-VI appeared to be the outcast, reproducing the pattern but a lag of almost 3^0C from compared to the reference data.

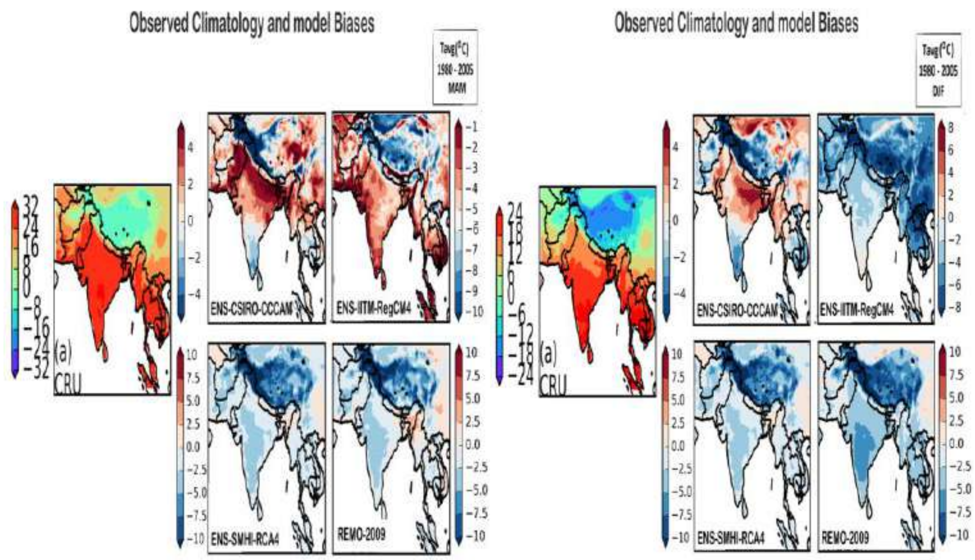


Fig. 12 Seasonal analysis of observed climatology and model biases for average temperatures during (Dec-Jan-Feb) and (Mar-Apr-May) seasons over South and South Eastern Asia for period 1980-2005

Seasonal temperature analysis of four RCM ensembles, i.e. CSIRO-CCAM, IITM-RegCM4, SMHI-RCA4 and Remo-2009 have been conducted for two seasons i.e. (Dec-Jan-Feb) and (March-April-May). These are two climatological seasons which together corresponds to *Rabi* (winter) season in which one of the major cereal, winter wheat is grown. Average temperature fluctuations can result in severe implications for crop physiology and production. As seen in Figure 12, CSIRO-CCAM produced the best results with minimum bias having a range of ± 4 with reference to observe reference data CRU. A warm bias of over 4^0C is observed over most of Pakistan (except for south-western parts of Khyber Pakhtunkhuwa and the major portion of Baluchistan and western parts of Sindh), northern parts of India and most of Bangladesh, whereas extremely cold bias of over -4^0C is shown in HKH region. A medium cold bias is shown in southern parts of India and Cambodia. Nepal shows a mixed range of bias with warmer bias in the southern and south-western parts and moderately cold bias in the northern areas. Tibetan plateau dominates with warm bias.

Ensemble IITM-RegCM4 does not appear to be a better model for temperature simulations as the wide-ranged bias scale only simulates cold bias with values ranging from -1 to -10. It shows an extremely cold bias of over -8^0C in Tibetan plateau while northern parts of Hindu Kush-Himalayan region also exhibit extremely cold bias of the same magnitude. The indo-Pak region is under cold bias ranging from -2^0C to -4^0C, likewise Cambodia and Nepal are also under the cold bias of lesser degree. The results for SMHI-RCA4 and Remo 2009 are similar showing cold bias all over the region with very few parts falling under the warm bias of extremely lesser degree having a temperature range of 0^0C to 2.5^0C.

Ensemble IITM-RegCM4 does not appear to be a better model for temperature simulations as the wide-ranged bias scale only simulates cold bias with values ranging from -1 to -10. It shows the extremely cold bias of over -8^{0}C in Tibetan plateau while northern parts of Hindu Kush-Himalayan region also exhibit extremely cold bias of the same magnitude. The indo-Pak region is under cold bias ranging from -2^{0}C to -4^{0}C, likewise, Cambodia and Nepal are also under the cold bias of lesser degree. The results for SMHI-RCA4 and Remo 2009 are similar showing cold bias all over the region with very few parts falling under warm bias of extremely lesser degree having a temperature range of 0^{0}C to 2.5^{0}C.

For DJF season CSIRO-CCAM has shown a cold bias prevailing along with the northern parts of the HKH region, south India, southern parts of Tibetan plateau and western half of Cambodia. Whereas, Pakistan, southern parts of India, Nepal, Bangladesh and northern parts of Tibetan plateau show warm bias of over 3^{0}C. Other three RCM ensembles have simulated cold bias for all over the region with extreme conditions of bias having values of over -10^{0}C are prevailing in the Tibetan plateau as well as Hindu-Kush-Himalayan region for all three ensembles. Being the start of the hot season MAM average temperature biases are of warm nature agreed by the RCMs.

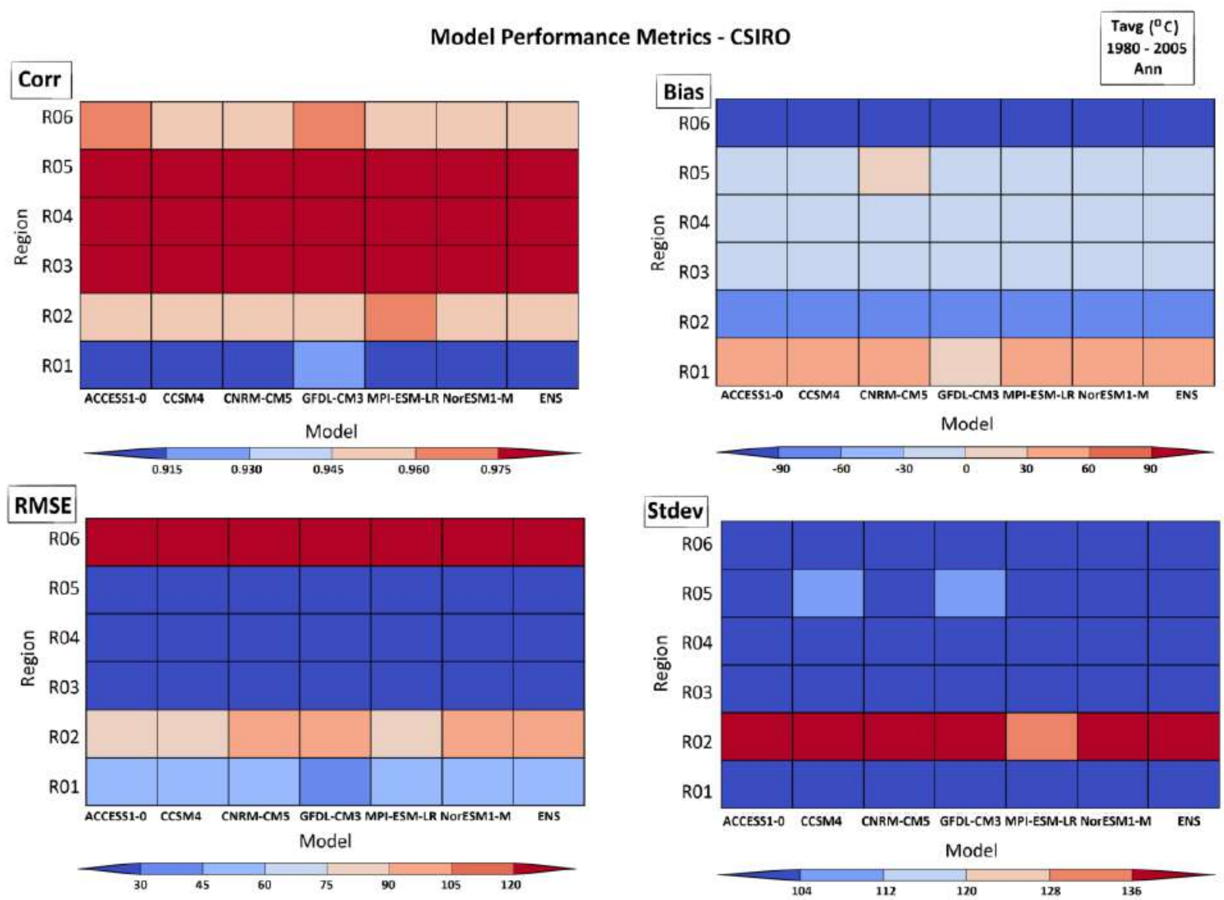


Fig. 13 Portrait diagrams showing correlation coefficient, RMSE, bias and standard deviation between simulated (CCAM) Average Temperature and CRU data

Figure 13 shows the portrait diagrams showing temporal correlations coefficient, RMSE, bias and temporal standard deviations between simulated average annual temperature and CRU data. Portrait diagrams were used for evaluating the skill of various RCMs in simulating average temperature for all the sub-regions. Figure 13 shows that the simulations are highly correlated with correlation percentage ranging from 91.5% to 97.5% with best results for Region-III (India), Region-IV (Nepal) and Region-V (Pakistan) while least correlated regions include Region-I (Bangladesh). It is also shown that for all of the regions, the value of correlation coefficient lies above 90% of CRUs average annual temperature for all RCMs in all the sub-regions.

The figure shows negative bias for most of the models in the majority of regions with least bias recorded for Region-VI (Sri Lanka) over 90 and comparatively higher bias has been simulated for Region-I (Bangladesh). All the models have shown a negative bias for all regions except for Region-I.

RMSE was also evaluated for all selected sub-regions for CSIRO-CCAM simulations and all ensemble members showed values of over -30 for three regions i.e. III, IV and V, whereas highest RMSE has been simulated for Region-VI (Sri Lanka). Region-III, IV and V (India, Nepal and Pakistan) show least RMSE i.e. less than 30. Least temporal standard deviations were observed with reference to CRU for all regions except for Region-II (Cambodia).

Temperature (Minimum & Maximum)

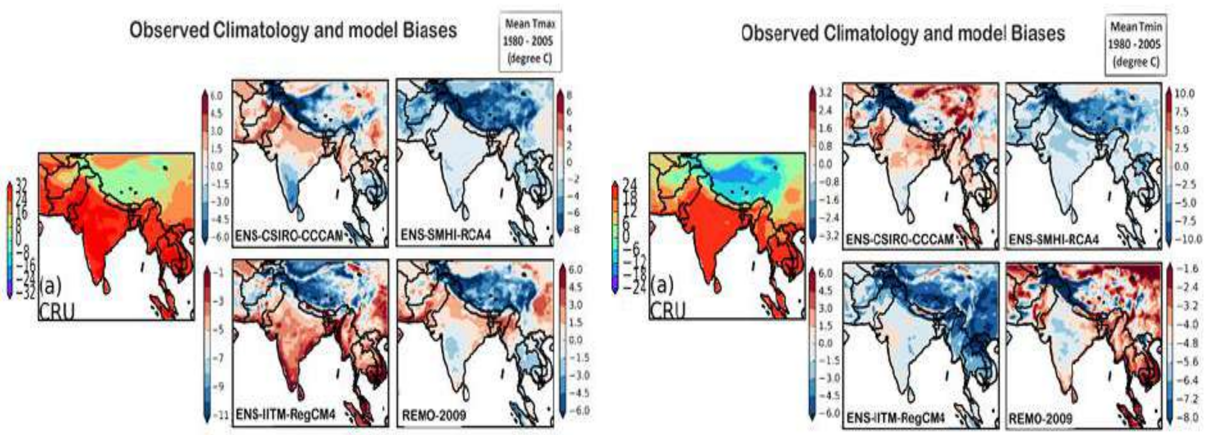


Fig. 14 Seasonal analysis of observed climatology and model biases for Minimum and Maximum temperatures during (Dec-Jan-Feb) and (Mar-Apr-May) seasons over South and South Eastern Asia for period 1980-2005

Figure 14 shows the spatial biases of the minimum and maximum daily temperature of observed data for the period 1980-2005. In case of daily maximum temperature two RCM ensembles, CCAM and REMO2009 show a mix of cold and warm bias of +/- 6^0C, with cold bias dominating over Tibetan plateau for REMO2009 simulation. RegCM4 appears to be an extremely cold biased model reaching up to 11^0C of cold bias prevailing in Tibetan plateau. RCA4 is also a cold bias dominated model.

For daily minimum temperature simulations all the three RCMs including RCA4, RegCM4 and REMO2009 show enormously cold biases while CCAM model showed the best performance with least bias range pf ±3 degree.

Diurnal Temperature Range (DTR)

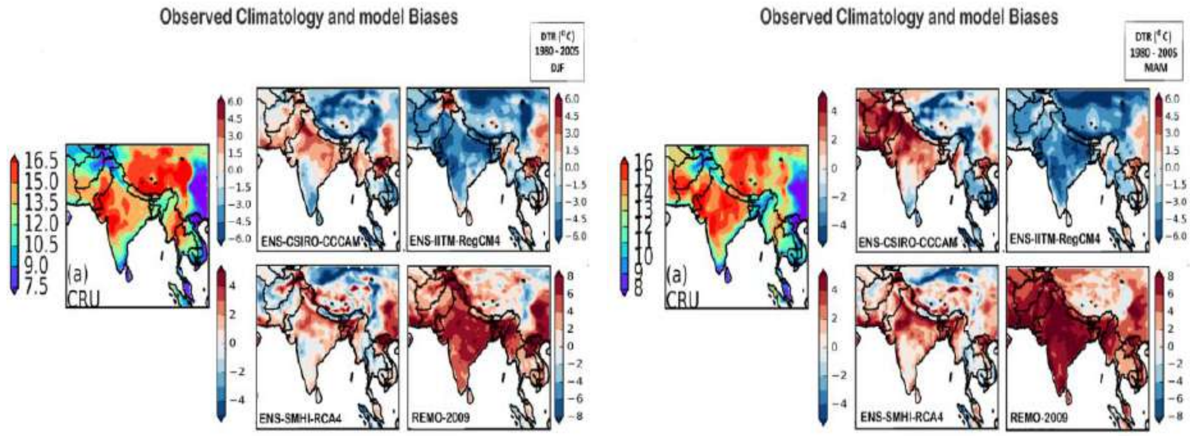


Fig. 15 Seasonal analysis of observed climatology and model biases for Diurnal Temperature Range (DTR) temperatures during (Dec-Jan-Feb) and (Mar-Apr-May) seasons over South and South Eastern Asia for period 1980-2005

Figure 15 shows the seasonal Diurnal Temperature Range (DTR) analysis for MAM and DJF seasons of four RCM ensembles for the historical period. DTR, which is the difference between the daily minimum and maximum temperature and may reflect the competing effect of DTR on water stress and crop development rates. Lobell (2007) noted a clearly negative impact of DTR on yield for several countries that produces rice and maize. During DJF and MAM season REMO2009 shows the highest degree of positive DTR of 8^0C, contrasting to this trend RegCM4 is showing the highest degree of negative bias of 6^0C. RCA4 model performs better in capturing observed DTR climatology with medium biases $\pm$ 4^0C over both the seasons.

3.3 Statistical Downscaling technique validation

Figure 16 illustrates validation results variable Tmin, Tmax and Precipitation of future downscaled projections for RCP4.5 and RCP 8.5 scenarios over a selected site in Pakistan, which has been done using quantile mapping approach. This approach has been used by many studies for effectively downscaling daily variables of climate data. Our results showed that Q-map method applied bias correction technique and fitted control simulation results with efficiency for all the selected variables.

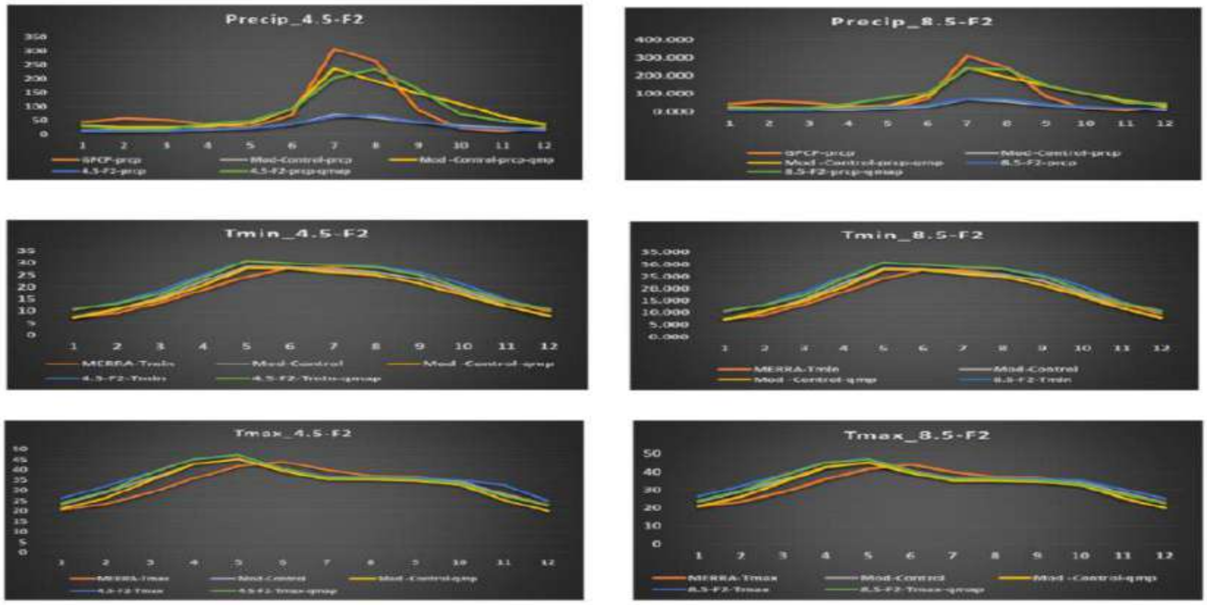


Fig. 16 Statistical Downscaling of Future Climate Change Scenarios using Quantile mapping approach over Sialkot-Pakistan

3.4 Analysis of cropping season-specific station scale projections of temperature Changes over project participating countries

3.4.1 Future Temperature and Precipitation projections over Pakistan

Fig. 17-a shows the downscaled future temperature projections for minimum and maximum temperatures during two major cropping seasons in Pakistan i.e. *Rabi* (Nov-April) and *Kharif* (May-Sep) under two scenarios, RCP 4.5 and RCP 8.5 for three-time slots i.e. near-century, mid-century and far-century.

The results for projected changes in average minimum temperature during *Rabi* season in Pakistan (Figure 17-a (i)) show a linear increase during near-century in both representative concentration pathways (RCPs) while a significantly contrasting trend has been observed in the projections of both scenarios for mid-century as well as far century. RCP 4.5 shows a steeper curve up till mid-century and then a sharp decrease is noticed for far century projections. A change of 2.1^{0}C is projected for RCP 4.5 till 2100 with respect to the control period. The projections of RCP 8.5 are opposite to those of RCP 4.5 showing a decrease for mid-century and a steep curve shows a rapid increase in average minimum temperature in the far century. An increase of 5.4^{0}C is expected for RCP 8.5 till 2100 following the historical period

Projected changes in average minimum temperature for *Kharif* season (Figure 17a (ii)) for both RCPs show harmony till mid-century depicting an increasing trend which is assumed by RCP 8.5 till the end while, after mid-century, the projections of a far-century for RCP 4.5 abruptly change the course and presents a sharply decreasing trend. An overall decrease of 2.1^{0}C has been projected for RCP 4.5 and that of RCP 8.5 goes down to -5.8^{0}C.

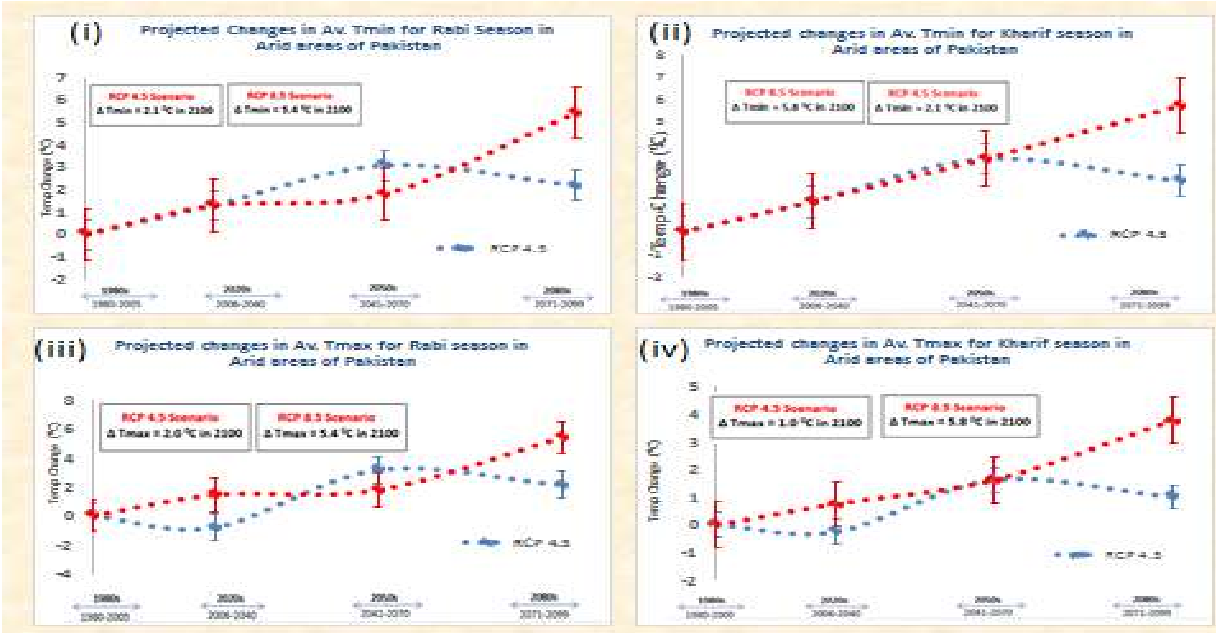


Fig. 17-a-i. Downscaled future temperature projections for minimum and maximum temperatures during major cropping seasons in Pakistan

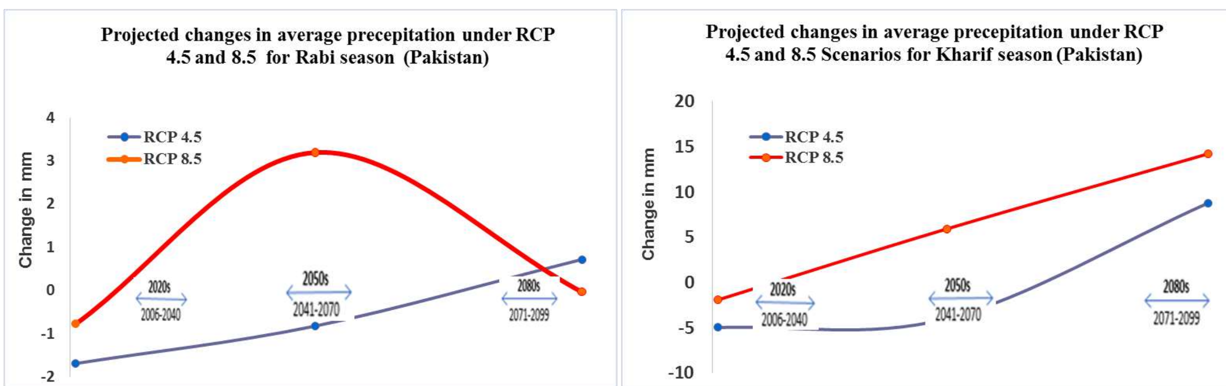


Fig. 17-a--ii. Downscaled future precipitation projections during major cropping seasons in Pakistan

The graph lines in Figure 17-a (iii) depict trends for average maximum temperatures for *Rabi* season in Pakistan. The wavy nature of the graph line suggests frequent fluctuations in average maximum temperature projections. Projections for both RCPs are antagonistically plotted with the depression of RCP 4.5 plotted at the crest of RCP 8.5 and the trend follows throughout the projection period. In RCP 4.5 initially rapid decrease average maximum temperature in *Rabi* season is observed in the near-century followed by a steep curve showing abrupt increasing trend during mid-century.

The projections for end-century present a smooth declining curve showing a gradual decrease in average maximum temperatures for *Rabi* season in the arid regions of Pakistan. Overall, an increasing trend in the average maximum temperature has been observed for the future projections for both RCPs, with 2.0^{0}C for RCP 4.5 and 5.4^{0}C for RCP 8.5 during *Rabi* season.

Kharif season projections show different trends for both RCPs (Figure 17-a (iv)). RCP 4.5 show fluctuations during the whole projection period showing slightly declining pattern during near-century followed by comparatively increasing temperature situations for mid-century. Far century projections suggest a distinctively decreasing situation for the average maximum temperature during Kharif season. An overall increase of 1^0C is predicted for RCP 4.5 while RCP 8.5 suggest an increase of 5.8^0C for the whole projection period.

Fig-17-a-ii reveals Rabi season has shown minimum changes in precipitation under both RCPs with negligible changes in precipitation throughout the century during Rabi season. Kharif season is the crop season which receives monsoon rainfall and is considered as the wet part of the year.

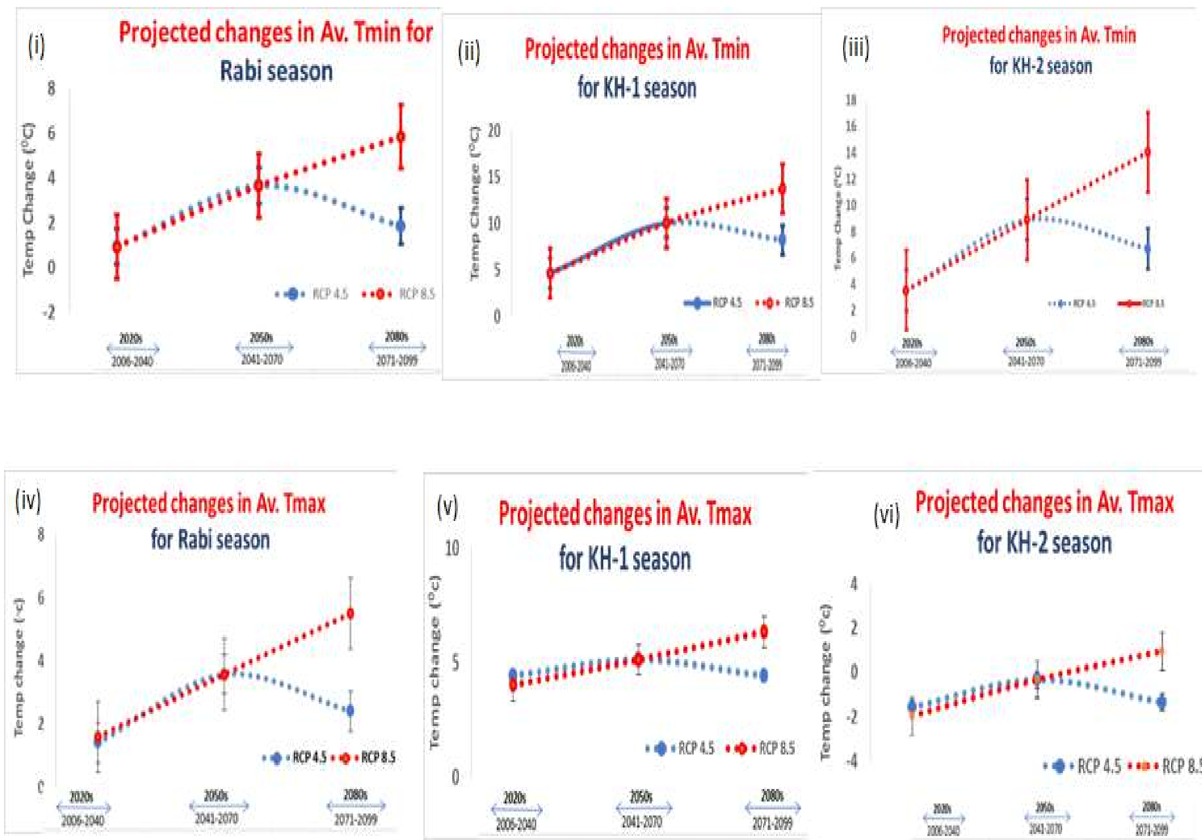


Fig. 17-b-i. Downscaled future temperature projections for minimum and maximum temperatures during major cropping seasons in Bangladesh

The projections for RCP 8.5 depict precipitation increase of 15 mm expected in the 2080s.

3.4.2 Future Temperature and Precipitation projections over Bangladesh

Figure 17-b (i) illustrates that, in Bangladesh, projections for average minimum temperature in Rabi season under RCP 4.5 and 8.5 are in strong agreement with more or less the same magnitude as far as mid-century. Under RCP 4.5 a sharp decline is observed in the average minimum temperature for Rabi season which keeps on decreasing uniformly till the year 2100. Temperature projections for RCP 8.5 continue to increase with the same magnitude until the end of the century for *Rabi* season in Bangladesh. For Bangladesh, the projection trend of average maximum and minimum temperature for all three seasons i.e. *Rabi*, *Kharif-I* and *Kharif-II* is similar; showing a

sound agreement between two scenarios for half of the projection period (up to mid-century) and as for the end-century projections, the results for RCP 4.5shows a definite decrease in temperature while RCP 8.5 continues with the same pace as for the initial projection period. During *Rabi* season in Bangladesh, the precipitation simulations under RCP 8.5 has shown a marked increase of 14 mm in 2050, and further increases until 18 mm in the 2080s. In *Kharif-I*, being the wettest part of the year, the projections for RCP 4.5 show a distinctive increase of 40 mm for the end-century while under RCP 8.5 predictions say that precipitation may rise up to 110 mm. The precipitation projections for *Kharif-II* predict a marked decrease of 35 mm in the precipitation intensity under RCP 4.5 while RCP 8.5 has maximum precipitation increase of 30 mm during the 2050s.

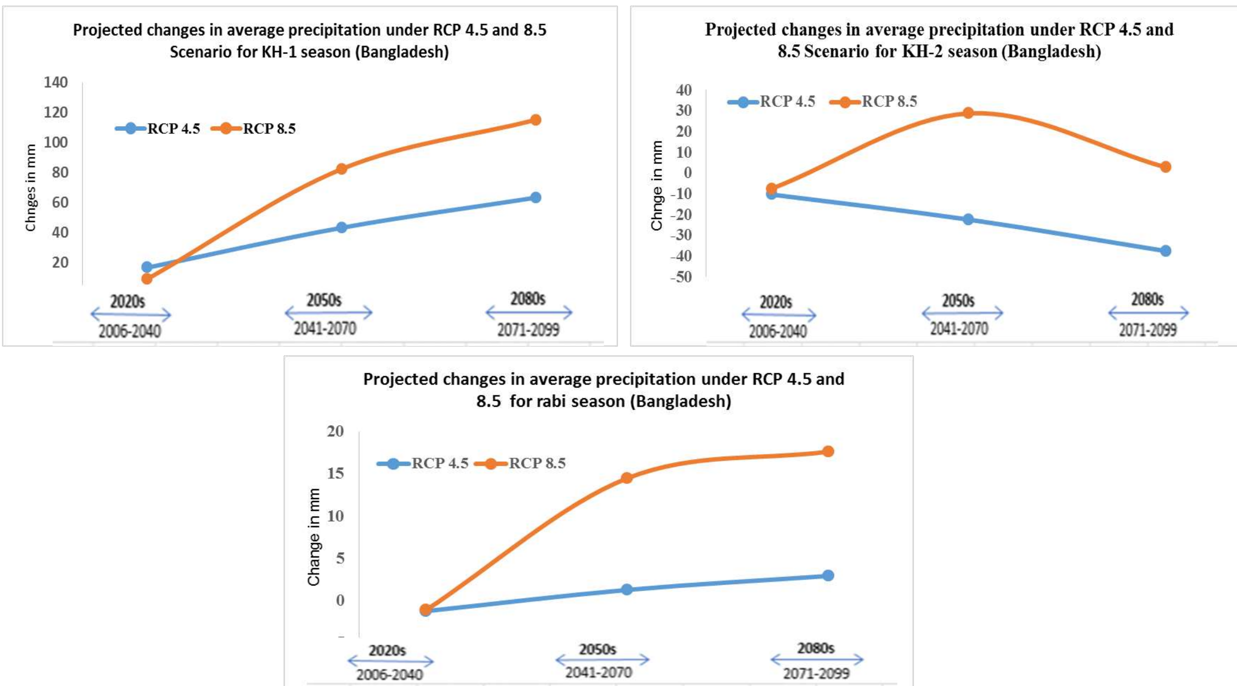


Fig. 17-b-ii. Downscaled future precipitation projections for minimum and maximum temperatures during major cropping seasons in Bangladesh

3.4.3 Future Temperature and Precipitation projections over Sri Lanka

Sri Lanka has two crop growth seasons, *Maha*, the longer winter growing season of six months, and *Yala*, the shorter summer growing season of only three months. The future projections for average maximum temperature illustrated in Figure 17-c (i) are showing similar trends for both growing seasons. RCP 4.5 projections show a linearly accelerated trend till mid-century simulation while for the far century the projections render distinctive, uniform deceleration till the end of the century, whereas, under RCP 8.5 the trend for mean maximum temperature goes on increasing till the end of the projection period. The more significant difference between the end century projections for both seasons is inevitable. The changes in the average minimum temperature for the *Yala* season under both scenarios are illustrated in Figure 17-c (iii). The near-century projections temperature increases more sharply for RCP 8.5 and continues to increase with a slightly bent curvature at the point of mid-century projections, whereas, the minimum temperature under RCP 4.5 increases smoothly till mid-century and then continuous, gradual retardation in the change in minimum temperature is expected.

The graph shows that projections under both scenarios remain highly correlated till mid-century and then RCP 4.5 part ways towards a continuous, gradually decreasing trend for end century projections whereas, RCP 8.5 resumes initially increasing trend with the same magnitude. Figure 17-c (iv) delineates changes in average minimum changes during *Maha* season under RCP 4.5 and 8.5. Figure 17-c-ii shows *Maha* season in Sri Lanka is the most extended season receiving most of the rainfall during the year. The projections indicate an increase of 270 mm in the rain and RCP 4.5 projections give a figure of 150 mm increase in precipitation during *Maha* season. On the other hand, projections for precipitation during *Yala* season indicate a decrease of 9 mm during the 2050s under both RCPs.

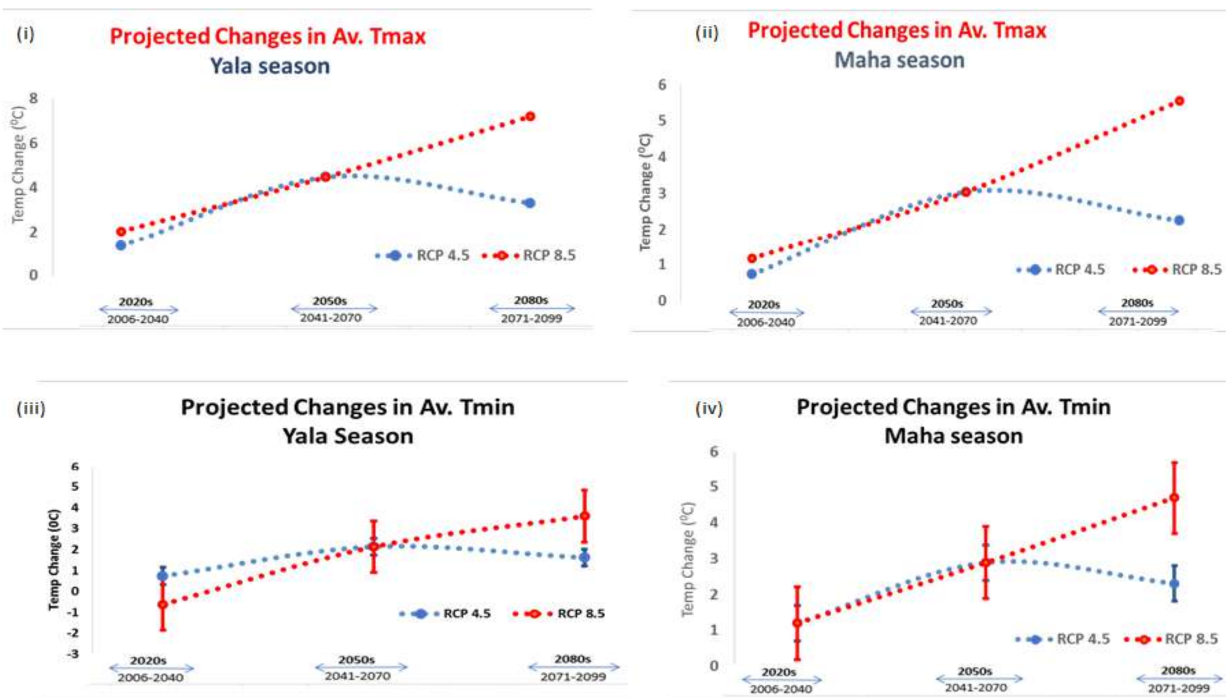


Fig. 17-c-i Down scaled future temperature projections for minimum and maximum temperatures during major cropping seasons in Sri Lanka

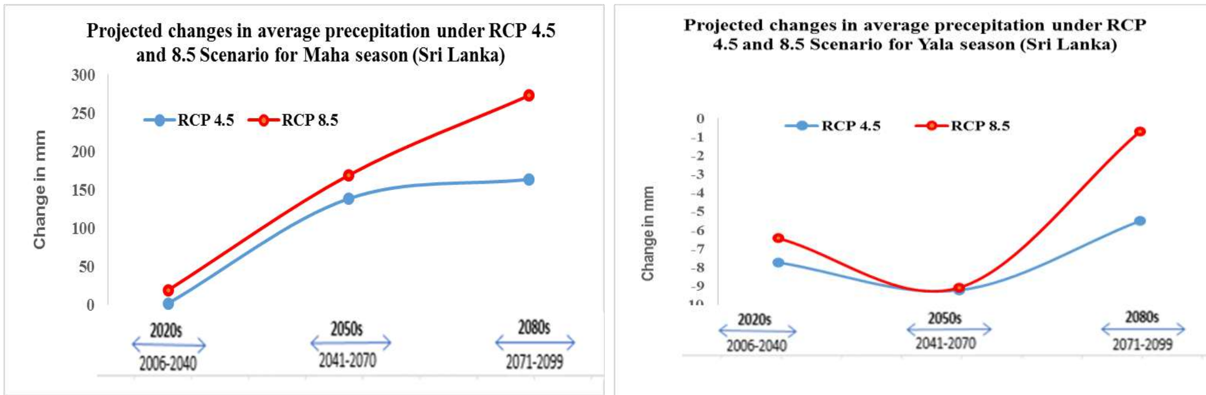


Fig. 17-c-ii Down scaled future precipitation projections during major cropping seasons in Sri Lanka

3.5 Mapping of warming-induced projected changes in growing degree days of the wheat crop in different wheat growing zones of Pakistan

Figure 18 illustrates the spatial mapping of seasonal GDD's of the wheat crop over Pakistan for control, near-century and mid-century periods for two future climate change scenarios including RCP 4.5 (medium control scenario and RCP 8.5 (business as usual scenario). Maps tend to identify hotspots with the highest GDD's change in future over major wheat-producing areas of Pakistan. GDs are calculated each day as maximum temperature plus the minimum temperature divided by 2, minus the base temperature. GDDs are accumulated by adding each day's GDs progresses. The base temperatures are the minimum temperatures, below which there is insufficient heat for biological activity. This is crop-specific and may be different for a different region. A base temperature of 5^0C was used for this study (Gill et al., 2014). An increase in daily mean temperature will accumulate more degree days as heat and hasten crop maturity with accelerated growth early in the season. An increase in seasonal atmospheric temperature of 2–4°C (e.g., Wheeler et al., 2000) can shorten the crop life cycle, which likely to reduces yield (Batts et al., 1997; Ahmed and Hassan, 2015). Higher temperatures together with reduced soil moisture decrease growing season length of crops which can alter the stages of plant growth ultimately affecting the partitioning and quality of biomass, resulting in yield reduction (Hakim et al., 2012). Figure 18 shows an increase in accumulated growing degree days in all major wheat producing zones of Pakistan including Sindh central and southern Punjab and Potohar region which is dominated by rain-fed wheat production under both RCP scenarios RCP 4.5 and RCP 8.5. However, this increase is more intense in RCP 8.5 during mid-century. An overall increase of 1000 GDD b/w historical and late Century extreme scenario in South-Eastern parts (lower Sindh province) of Pakistan has been observed. Hence these results are evident that South Eastern side of Pakistan including wheat-producing districts of Sindh province (Thatta, Badin, Umerkot, Hyderabad and Sanghar) are likely to become unsuitable for wheat production due to temperature extremes during mid-century.

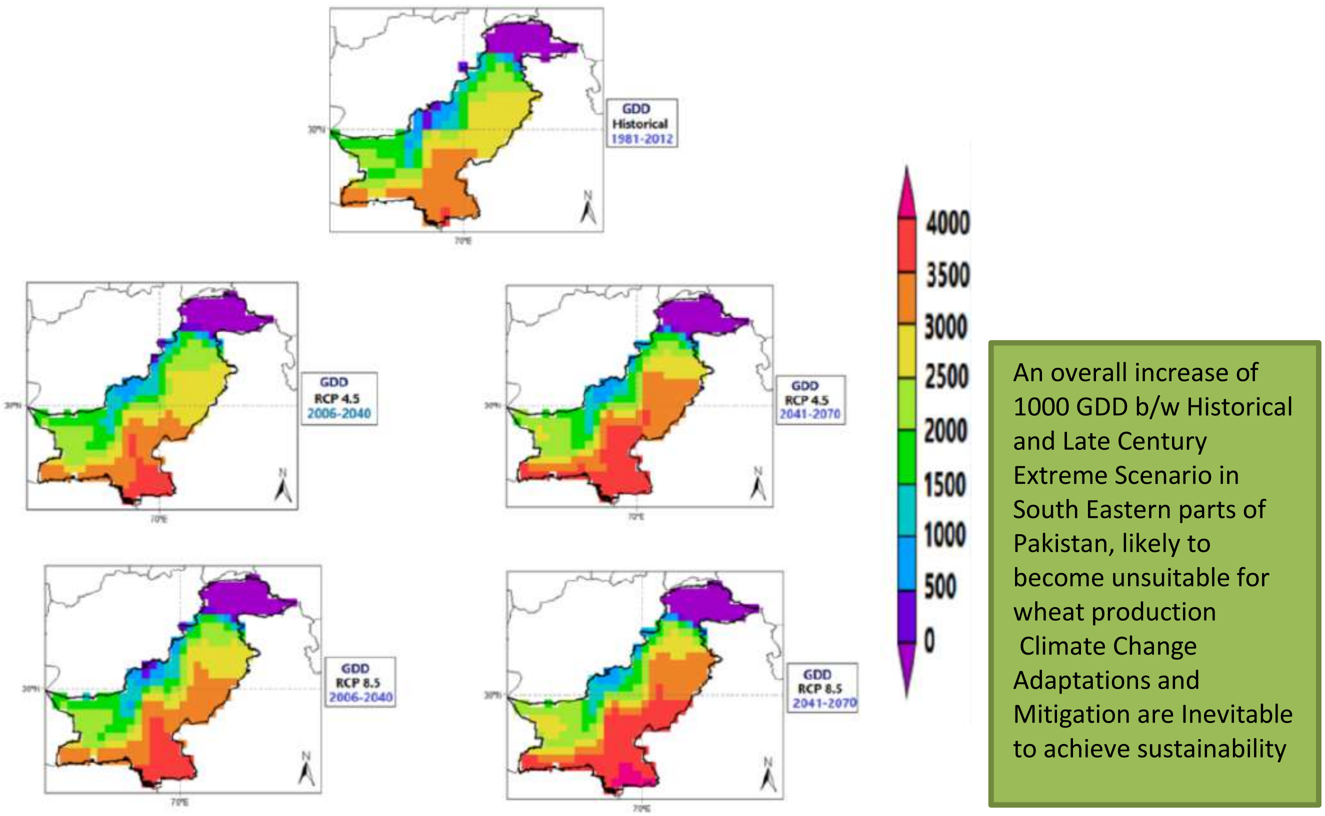


Fig. 18 Spatial Mapping of seasonal GDD's over Pakistan for control, F1 (Near century), F2 (mid-century) and F3 (end-century) for RCP 4.5 and RCP 8.5 contribution as the season

3.6 Analysis of future warming extremes (Consecutive Summer Day Index (CSU), impacting critical crop growth stages of wheat crop in Pakistan

Figure 20 shows the consecutive summer day index CSU. CSU 32 is consecutive 5 or more days of daily maximum temperature occurrences. 32^0C is the threshold/upper limit in wheat during flowering, while the threshold of 36^0C was taken for ripening, beyond theses temperatures yield losses occur. It is evident from Observed data that the South Eastern side of Pakistan is most vulnerable for the flowering stage of Wheat Crop due to consecutive heat days.

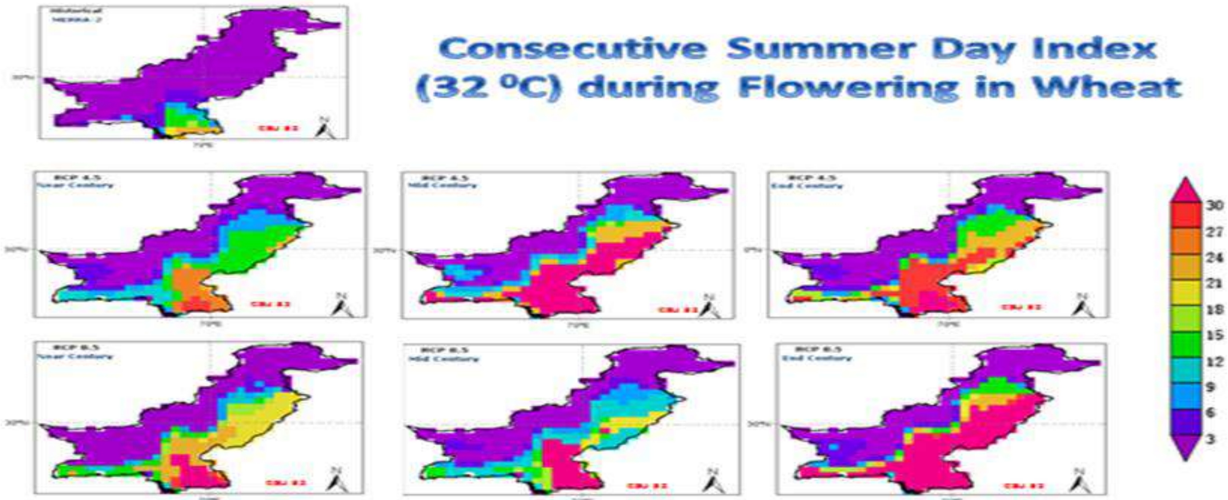


Fig. 19 Extremes analysis: Consecutive summer day index during flowering of Wheat crop in Pakistan in Future

In Future this vulnerability is increasing both spatially and temporally till the end of 21st Century under both RCPs. The extent of vulnerability is proliferating to all the major wheat-producing zones from Lower Sindh to Potohar. Heat stress seems to affect flowering stage more as compared to ripening and the westward expansion of heat days is more pronounced in the ripening stage. Generally, winter wheat grown during Rabi season favours cool and moist weather conditions during vegetative growth period followed by relatively warmer and dry weather needed for grain filling to ripening stage. The significant responses of wheat to heat stress include the enhancement of leaf senescence, reduction of photosynthesis, deactivation of photosynthetic enzymes, and generation of oxidative damages to the chloroplasts; heat stress also reduces grain number and size by affecting grain setting, assimilate translocation and duration and growth rate of grains. One-degree rise in average temperature during reproductive phase can cause severe yield loss in wheat (Bennett et al., 2012; Yu et al., 2014). Increase in temperature of 1–2°C reduces seed mass by accelerating seed growth rate and by shortening the grain-filling periods in wheat (Nahar et al., 2010). 4-5 million tons yield loss for every 1°C rise of temperature during wheat growing season India was noted by (Aggarwal, 2008) and (Samara and Singh, 2004). Studies conducted in India and China revealed that Increase in temperature is directly proportional to the sterility percentage of pollen grains (Chaudhary et al., 2015; Cao et al., 2015). The effect of high-temperature stress on six wheat cultivars exposed to 35-40°C in Pakistan revealed that anthesis growth stage was found to be more sensitive to heat stress than seed development at the milky stage. Overall, heat stress reduced yield 75 % at anthesis and 40 % at the milky stage (Khan et al., 2015).

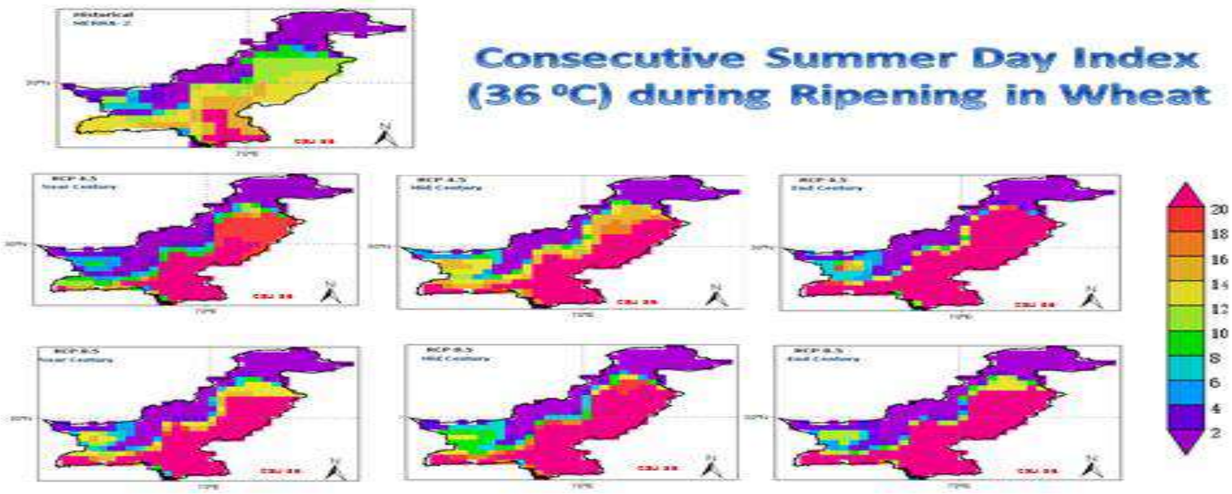


Fig. 20 Extremes analysis: Consecutive summer day index during ripening of Wheat crop in Pakistan in Future

3.7 Model Calibration and Validation

3.7.1 Pakistan

3.7.1.1 The AquaCrop Model

Aqua crop model was calibrated using field data by minimizing the differences between observed and simulated results of canopy cover (CC in %), above-ground biomass (AGB kg/ha), soil water content (SWC) and grain yield (Y kg/ha) during the wheat growing season. The same procedure was followed by (Paredes et al., 2015) who calibrated Aqua Crop for accurate simulations. Model parameters are interdependent so CC, B and SWC were given more focus for effective calibration results.

Figure 21 explains the results of biomass and CC of wheat cultivated at NARC, Islamabad, during 2016. The model showed good agreement with that of observed data for CC with an accuracy of r =0.99, d= 0.99, EF= 0.93, RMSE= 6.3%, CVRMSE= 11.4% over different developmental stages. AGB simulation results also showed a reasonable agreement with observed data over entire growth period, with statistical indices values for Aqua Crop evaluation as: r =0.99, d= 0.99, EF= 0.96, RMSE= 0.7 tons/ha, CVRMSE= 12.2%. Figure 23 shows the statistical indices for calibration of CC and AGB in Wheat, generated by Aqua Crop.

The soil water content was simulated accurately showing the same trend as observed values, which progressively decreased overgrowth stages due to an increase in evapotranspiration. Statistical indices for SWC were r =0.86, d= 0.90, EF= 0.88, RMSE= 21.5 mm, CVRMSE= 8.9%. Simulated SWC drops as compared to observed particularly at maturity because of the inclusion of dried leaves by the model which worsened the ET estimation at maturity. However, the overall model precisely simulated CC, AGB and SWC at varying growth stages of wheat. The model was evaluated for validation with field data of wheat crop in next wheat growing season.

In Figure 23, simulated and observed results showed strong agreement which confirms the model calibration. The statistical parameters for CC, biomass and SWC were r =0.98, 1.0, 0.90, d= 0.99, 0.99, 0.85, EF= 0.0.97, 0.98, 0.51, RMSE= 4.9%, 0.607 tons/ha, 25.3 mm and CVRMSE= 9.8 %, 12.0 %, 11.6% respectively. Aqua crop was further evaluated at Chakwal during wheat growing seasons 2016-17and 2017-18 (Figure 22) to remove the biasness and to prepare the model for large scale simulations throughout the country.

At Chakwal the calibrated parameters (Table 3.3) of the aqua crop were used and the results were shown in Figure 23. In all simulations, the EF above than 0.51 showing a good relationship between observed and simulated results proved the model capability and robustness.

In this study, the AquaCrop model was examined to simulate crop development and yield. Based upon our results during two growing seasons at two locations evidenced the aqua crop simulations and the model capability as well.

Table 6 Aqua crop calibrated parameters for wheat crop

S. No	Description	Parameter	Unit	Wheat
1	Initial canopy cover	CC_o	(%)	8.15
2	Increase in canopy cover	CGC	(% per day)	5.13
3	Decrease in canopy cover	CDC	(% per day)	6.3
4	Maximum canopy cover	CC_x	(%)	97
5	Curve number	C_n		47
6	Minimum effective rooting depth	Z_n	(m)	0.3
7	Maximum effective rooting depth	Z_x	(m)	1.5
8	Base temperature	Tb	(°C)	5.0
9	Upper temperature	Tu	(°C)	35
10	Crop coefficient of maximum transpiration	Kc_{trx}		1.1
11	Decline of crop coefficient	f sen	(% per day)	0.7
12	Water Productivity normalized for ET_o and CO_2	WP*	(gram/m2)	17

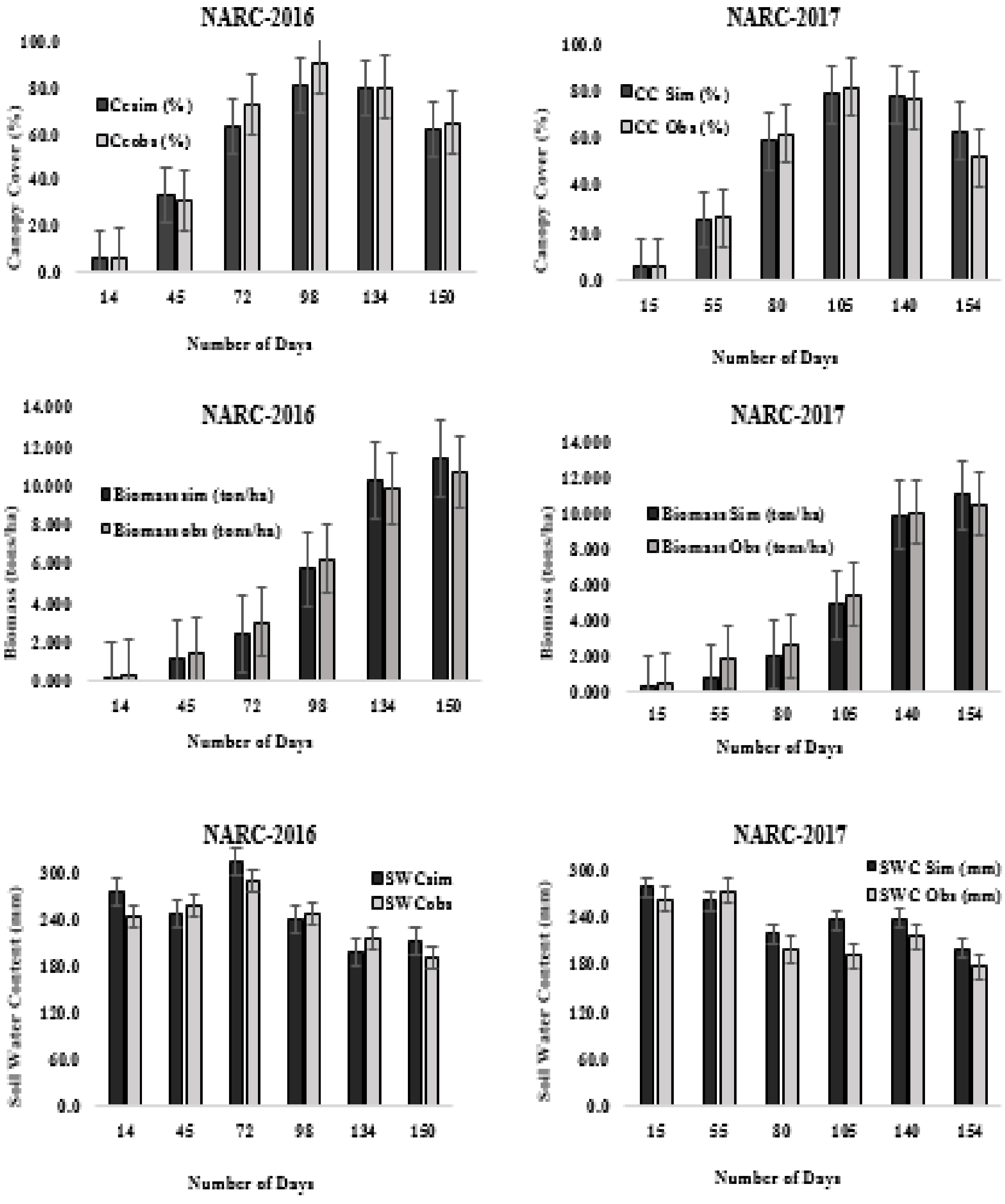


Fig. 21 . Comparison of observed and Aqua crop simulated canopy cover (% CC), biomass (ton/ha) and soil water content (SWC) at NARC Islamabad

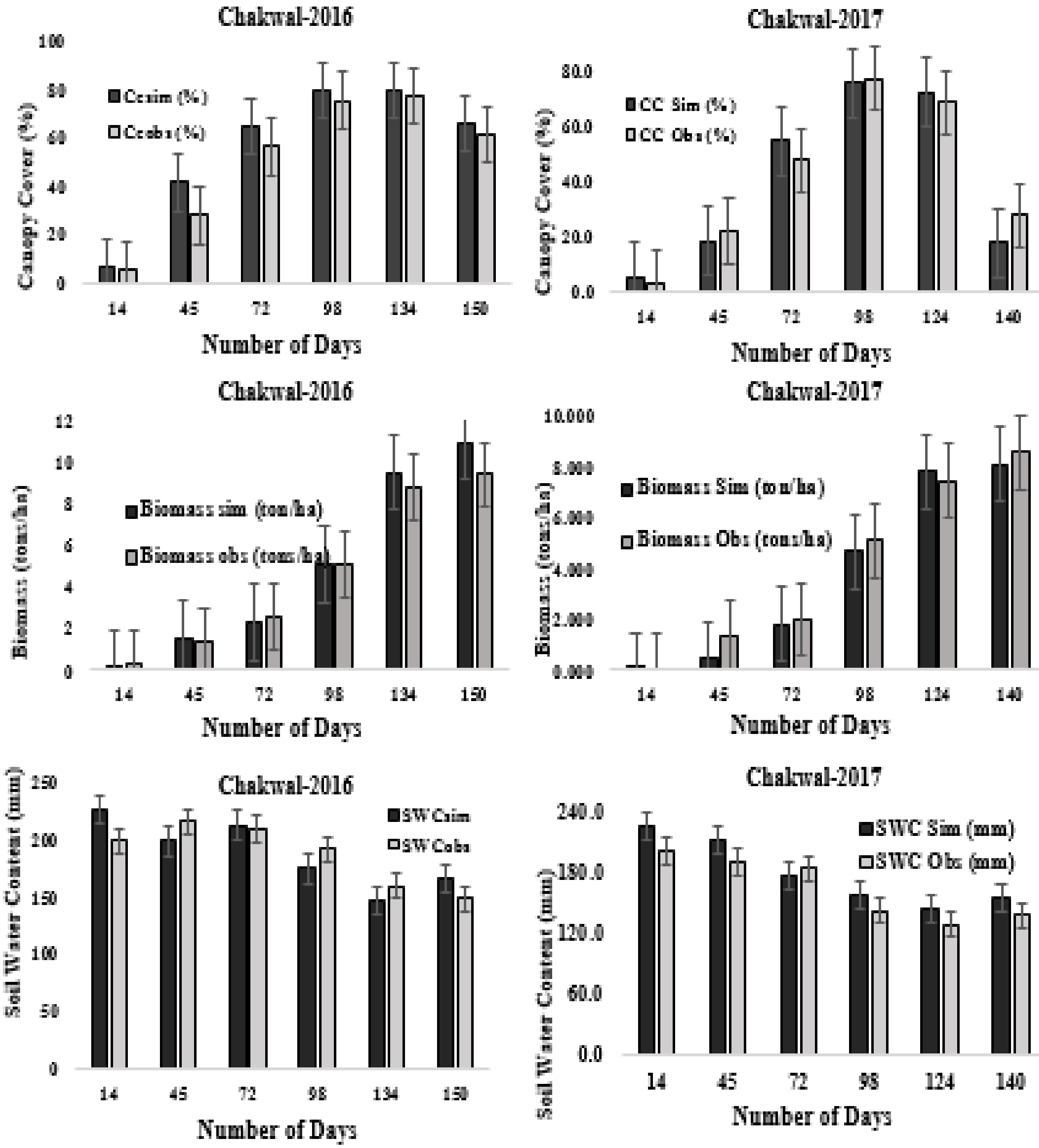


Fig. 22 Comparison of observed and Aqua crop simulated CC, biomass (ton/ha) and SWC at Chakwal

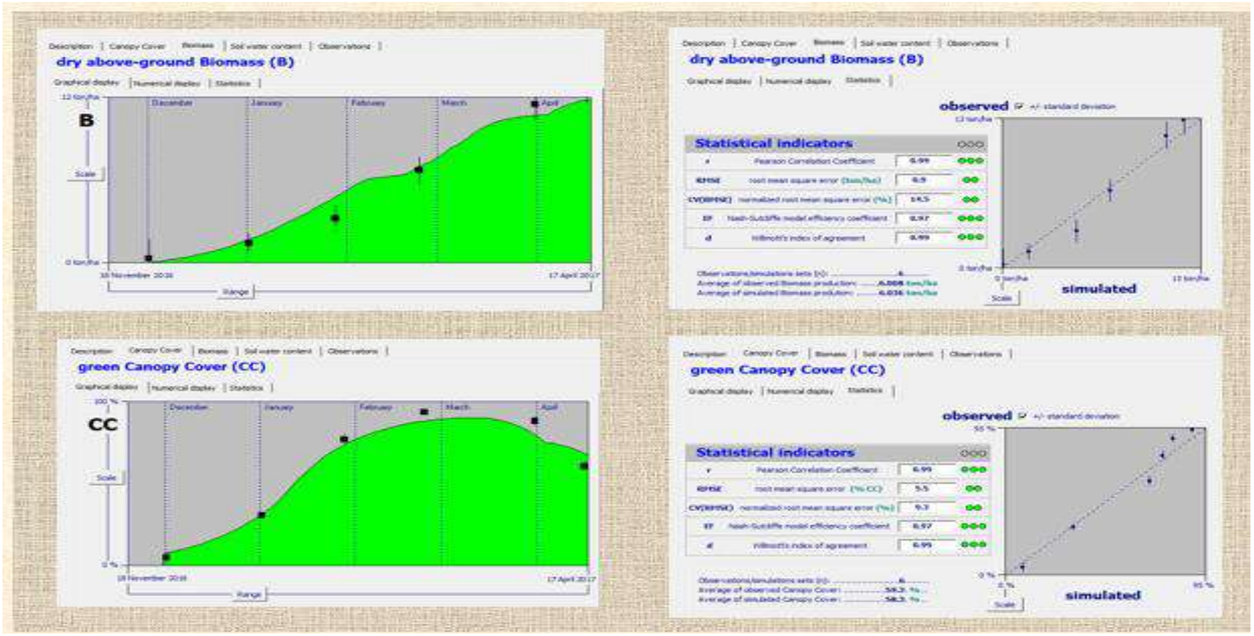


Fig. 23 AquaCrop calibration results for canopy cover (CC) and dry above-ground Biomass (B) in wheat in semi-arid regions of Pakistan

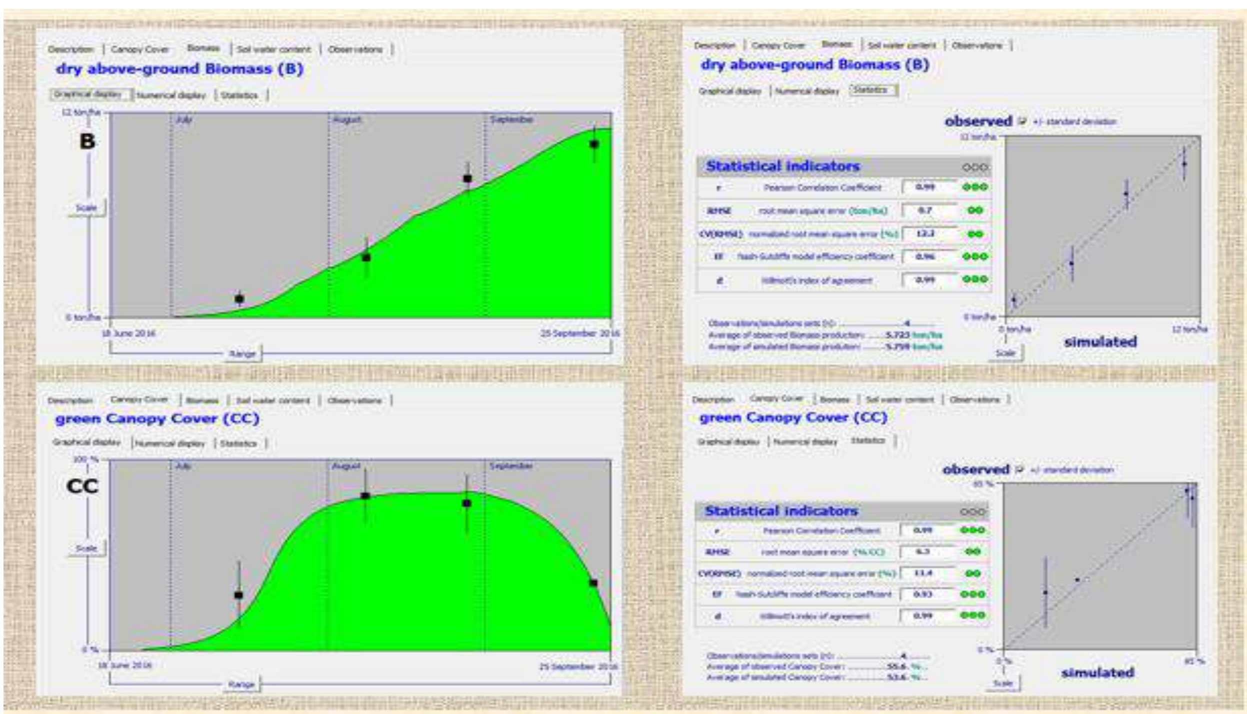


Fig. 24 AquaCrop calibration results for canopy cover (CC) and dry above-ground Biomass (B) for maize in semi-arid regions of Pakistan

3.7.1.2 The APSIM Model

Agricultural Production Systems Simulator (APSIM) was created in response to the need to improve planning and forecasting for crop production under different climatic, soil and management conditions on rural properties in Australia (Keating et al., 2003). The 10 components contained in the model are described in detail by Keating et al. (2003), as follows: annual crop, water balance and movement of solutes in the soil; soil organic matter and N; residue; phosphorus; soil pH; erosion; management; Intercropping /weeds/ consortium systems; and multipoint simulation (Probert et al., 1998; Thorburn et al., 2001; Keating et al., 2003).

3.7.1.2.1 Characterizing the System: Input Data Requirements

APSIM needs quantitative information on each part of the system and the interaction among all of its components. According to the scientific approaches used in the model, a model like APSIM generally would require (i) weather information, inclusive of air temperature, solar radiation, wind speed, relative humidity and rainfall; (ii) site description, including elevation, latitude, and longitude; (iii) soil information, including soil bulk density, soil lower drain limit, soil upper drain limit, soil texture, thermal properties, and chemical properties; (iv) plant information, including plant cultivar characteristics, sensitivity to photoperiod, phenology, especially thermal units to anthesis and physiological maturity; and (v) management information, including tillage, plant management, irrigation, fertilization, and pesticide applications. Table 3.4 lists the minimum necessary information needed to define a system in APSIM.

Table 7 Minimum data required to run APSIM

Data type	Minimum dataset required
Rainfall	Amount
Daily weather	Daily meteorology data (minimum and maximum air temperature, wind speed, solar radiation, and relative humidity)
Site description	Latitude, elevation, longitude
Soil properties	Soil horizon delineation, soil texture, and bulk density. Optional soil hydraulic properties: 330- or 100 cm-suction water content and saturated hydraulic conductivity
Plant properties	Specifying a crop cultivar from supplied database
Management information	Estimate of dry mass and age of residue on the surface, tillage, irrigation, planting/harvest, fertilization, irrigation, pesticide application
Initial soil conditions	Initial soil moisture contents/water table, temperatures, pH, cation exchange capacity values; initial nutrient status, including soil residue, humus, microbial populations, mineral NO3–N and NH4–N

One important, but less discussed, the issue in model calibration is how to quantify the goodness of a calibration. In most cases, a model is considered well-calibrated if it responds to management practices with reasonable accuracy in terms of root mean squared error (RMSE), relative biases, model efficiency, coefficient of determination (r^2), and the D index (Ahuja and Ma, 2002). In this experiment, the following statistical indices were used to mark the efficiency of the model. For a data set with N measured points, RMSE is defined as

$$\mathrm{RMSE} = \left[\sum_{i=1}^{n} Wi \frac{(P_i - O_i)^2}{n} \right]^{0.5}$$

Where, Wi is the weight factor often set equal to 1.0, and Pi and Oi are the models predicted and experimental measured or observed points, respectively. The N observed data points might be from one treatment or multiple treatments (Ma and Selim, 1997). The RMSE reflects the magnitude of the mean difference between experimental and simulation results. Another commonly used approach is to conduct a regression analysis between measured and predicted outputs. A coefficient of determination (r^2) is then calculated as:

$$r^2 = \frac{\left[\sum_{i=1}^{N} \left(O_i - O_{\mathrm{avg}} \right) \left(P_i - P_{\mathrm{avg}} \right) \right]^2}{\sum_{i=1}^{N} \left(O_i - O_{\mathrm{avg}} \right)^2 \sum_{i=1}^{N} \left(P_i - P_{\mathrm{avg}} \right)^2}$$

The r^2 value ranges from 0 to 1. $r^2 = 1$ indicates a perfect correlation between experimental and simulation results, and $r^2 = 0$ means no correlation between the two results. The D index (Willmott, 1981), is more sensitive to systematic model bias. It also has values ranging from 0 to 1, where D = 1 means perfect simulation. It is defined as:

$$D = 1.0 - \frac{\sum_{i=1}^{N} \left(P_i - O_i \right)^2}{\sum_{i=1}^{N} \left(\left| P_i - O_{\mathrm{avg}} \right| + \left| O_i - O_{\mathrm{avg}} \right| \right)^2}$$

3.7.2 Sri Lanka

AquaCrop computes crop yield using a step-wise approach. Initially, it requires identifying generic growth stages of time to emergence, maximum canopy cover, the start of senescence, and maturity. Next, evapotranspiration is partitioned into transpiration and soil evaporation. The transpiration is later converted into biomass and subsequently to yield according to the harvest index. Thus, the yield is a product of biomass and harvest index. Some of the key cultivar-specific and other environment and/or management dependent parameters required by AquaCrop are shown in Table 3.5. For all the conservative parameters, values given in the default crop file were used while cultivar specific and management parameters were used from experimental data.

A manual calibration method was used in this study. It involved systematically changing model parameters, within an acceptable range, to improve the match between the observed and simulated response (Figure 25). A statistical evaluation method involving the minimization of the sum of square error (SSE) between the observed and simulated result was employed.

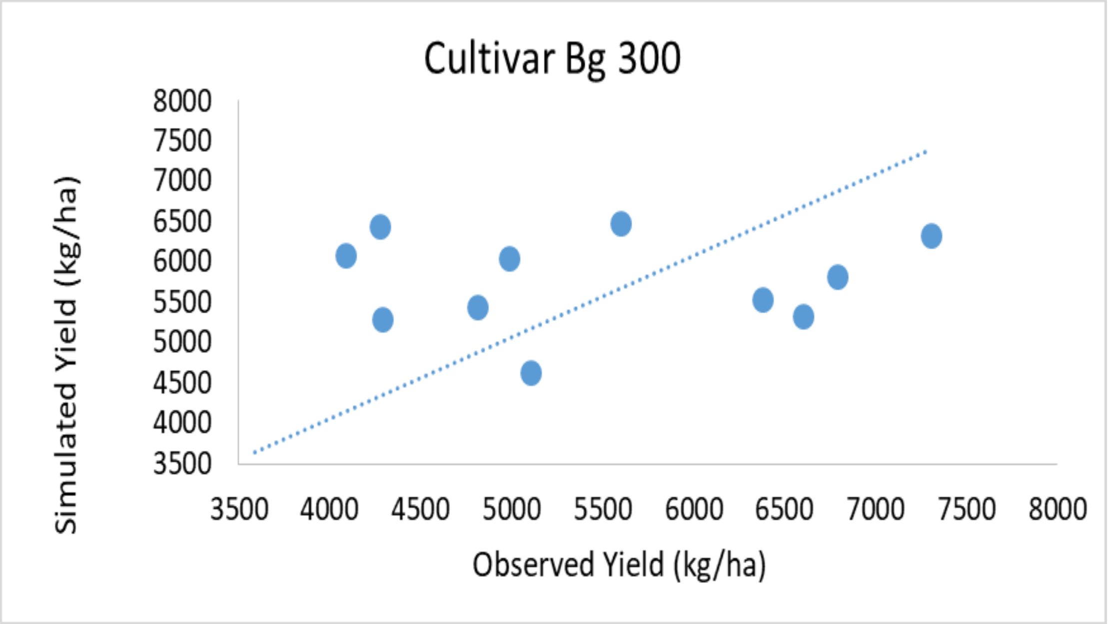


Fig. 25 Model Calibration results for Cultivar Bg 300 for two seasons in Sri Lanka

Table 8 Key cultivar specific parameters used in AquaCrop

Parameter	**Unit**	**Measured or Calibrated**
Soil surface covered by an individual seedling at 90% recover	(cm^2/plant)	Measured
Number of plants per hectare	-	Measured
Time from broadcasting to germinate	Days	Measured
Maximum canopy cover, CC_x	%	Calibrated
Time from transplanting to start senescence	Days	Calibrated
Time from transplanting to maturity, i.e. length of crop cycle	Days	Measured
Time from transplanting to flowering	Days	Measured
Length of the flowering stage	Days	Calibrated
Maximum effective rooting depth	(m)	Measured
Time from sowing to maximum rooting depth	Days	Calibrated
Reference Harvest Index (HI_0)	%	Measured

Water Productivity (WP*)	g/m^2	Calibrated
Soil texture	-	Measured (Silty clay loam)
Height of bunds	(m)	Measured

Table 9 Calibrated values for different parameters

Parameter	**Unit**	**Value**
Time from Broadcasting to germinate	Days	3
Maximum canopy cover, CC_x	%	96
Time from emergence to maximum canopy cover	Days	43
Time from emergence to start of senescence	Days	59
Length of the flowering stage	Days	9
Time from sowing to maximum rooting depth	Days	30
Water Productivity (WP*)	g/m^2	19
Reference Harvest Index (HI_0)	%	50

3.7.3 Bangladesh

Besides the experimental data of the year 2013-2014, data from expert judgement were used to calibrate the AquaCrop model. The calibration was performed against above-ground biomass yield and canopy cover for well-watered conditions. Climatic data files were prepared with measured data except for the CO_2 concentration, which was taken as the default value of AquaCrop (Mauna Loa Observatory records in Hawaii, USA). The average value of the harvest index (HI) was used (and kept constant) in the calibration process. The Model was run keeping the measured/observed data about constant for getting target yield. Crop, Soil and growth parameters were initially gauged from literature value adjusting with crop cultivar and climatic condition. The parameter values were changed systematically realizing their practical range, literature value suggested conservative parameters and local conditions (crop characteristics, crop duration, soil and climatic condition) for getting the target yield. Figure 26 presents the visual goodness of fit of the model calibration.

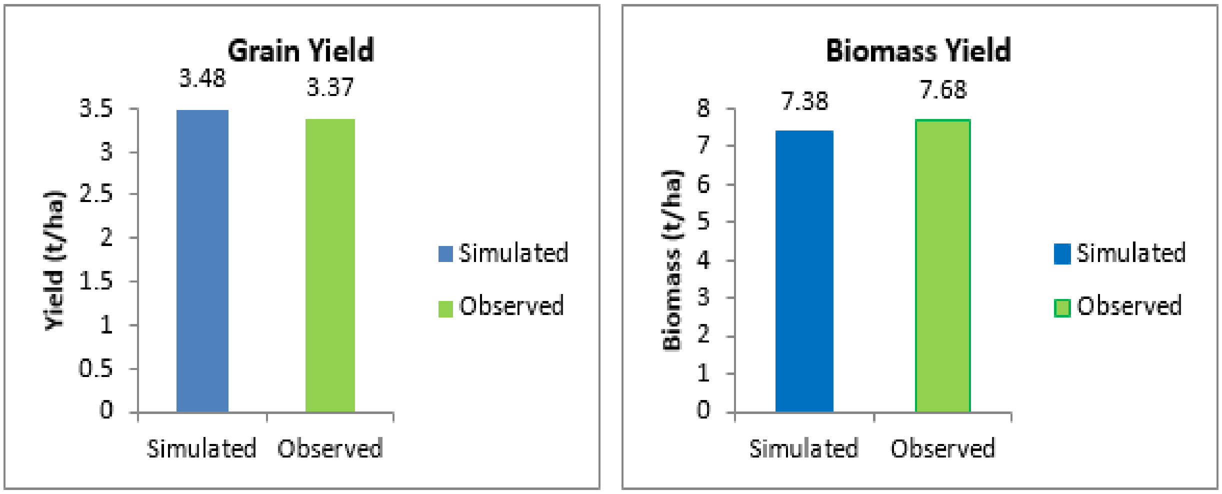


Fig. 26 Observed and simulated grain yield and aboveground biomass results for rice crop obtained for the calibration of AquaCrop in Bangladesh

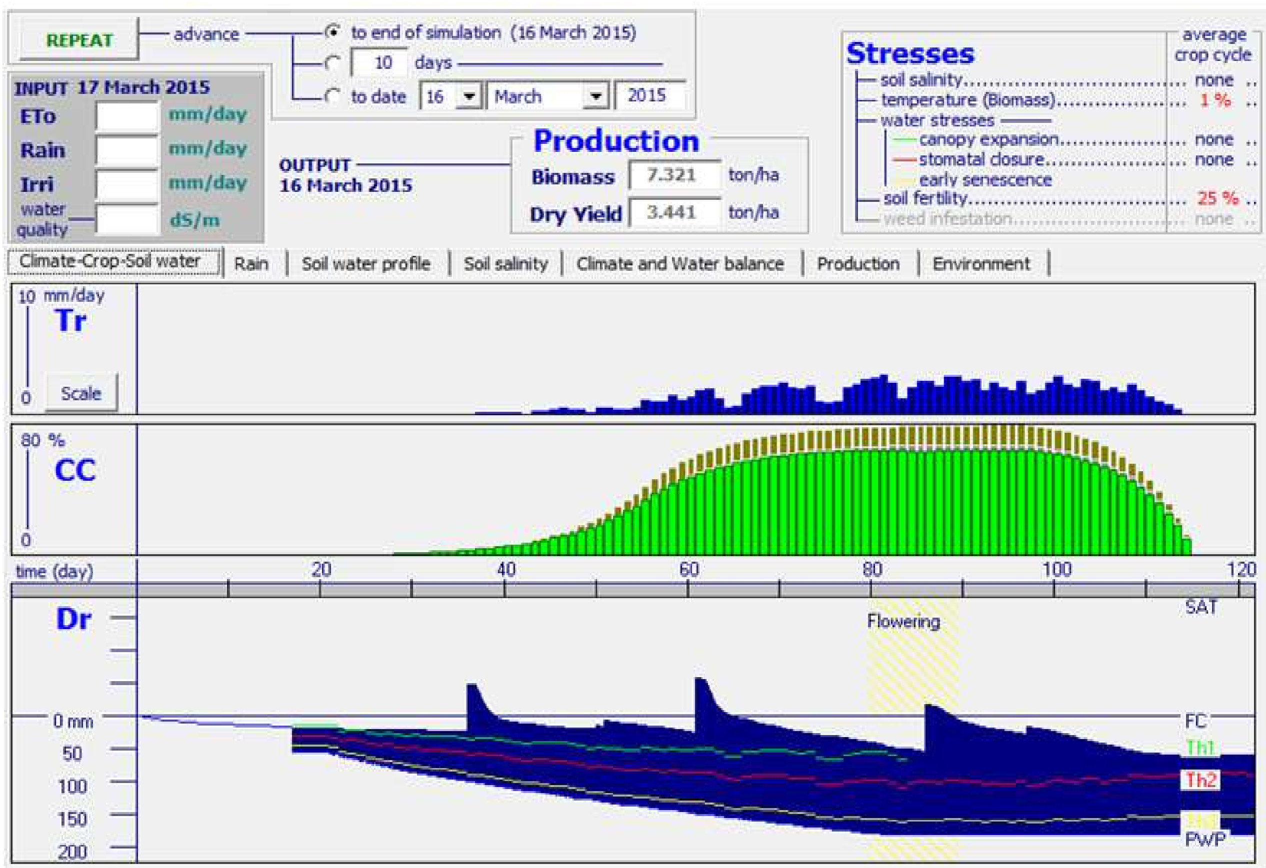


Fig. 27 Calibrated parameters of the AquaCrop model for the selected site in Bangladesh

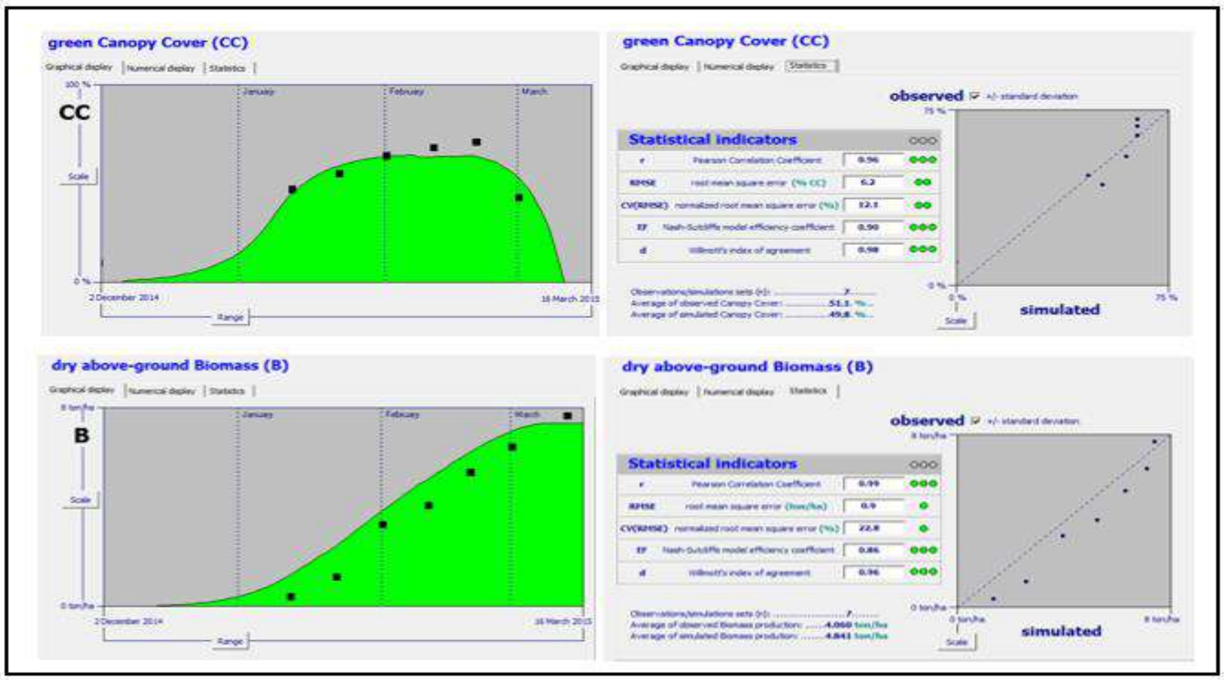


Fig. 28 Validation results for Observed and simulated Canopy Cover (CC) and aboveground biomass (AGB) in Bangladesh

The simulated canopy cover and biomass (for the year 2014-15) are depicted in Figure 28. The data points are close to the 1:1 line, which indicates the reasonable prediction of canopy cover and biomass yield. The statistical indicators of the simulation outputs such as mean error, mean absolute error, root mean square error and relative error are reasonable, which indicate that the model can simulate yield with acceptable accuracy. The Pearson correlation coefficient, root mean squared error, model efficiency coefficient and index of agreement, were 0.96, 6.2%, 0.90 and 0.98, respectively, which indicates that the model fitted the observed data set very well. Similarly, validated biomass production shows similar results.

3.8 Model simulation results

AquaCrop has efficiently simulated the results for wheat and maize crop in the arid regions of Pakistan. For both the crops under two different scenarios, the AquaCrop model simulation generated two contrasting trends. For instance, the calibrated conditions show a marked increase (71%) for wheat yield under RCP4.5, whereas under RCP8.5 the increase is (71%) but for maize crop the results were opposite to those of wheat, showing a linear decrease up to 41% in yield under RCP 8.5 while under RCP 4.5 the crop has shown a yield increase up to 26% during the 2020s and then there is a continuous decrease of 34% till the end of the century.

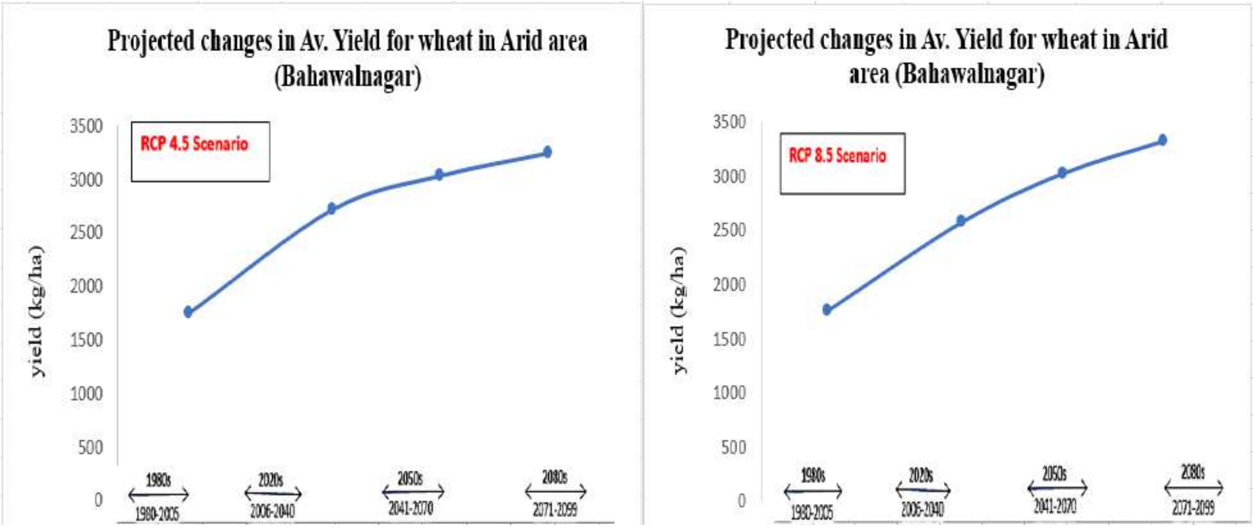


Figure 29 Projected changes in average wheat yield under RCP 4.5 and RCP 8.5

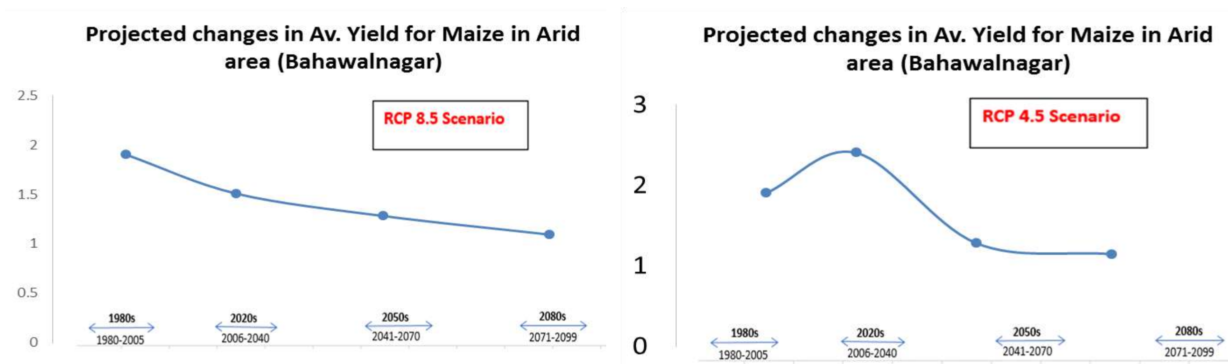
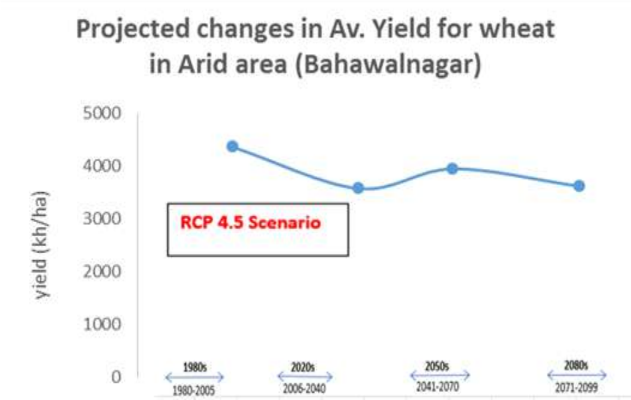


Figure 30 AquaCrop simulated projected changes in Av. Yield for Maize in arid region of Pakistan

3.8.2 APSIM model simulations

APSIM (version 7.10) has produced realistic future yield projections for wheat crop in the arid regions of Pakistan. There has been a decrease of 18% in the projected yield during the 2020s (Figure 31). On the other hand, a decrease of 17% for the end- century has been simulated by APSIM for the time slot of the 2080s under RCP 4.5 scenario. The yield projections for RCP 8.5 scenario have shown a decrease of 21% in the 2020s while the far century projections for 2080s suggest a yield decrease of 40% for wheat crop in arid regions of Pakistan.



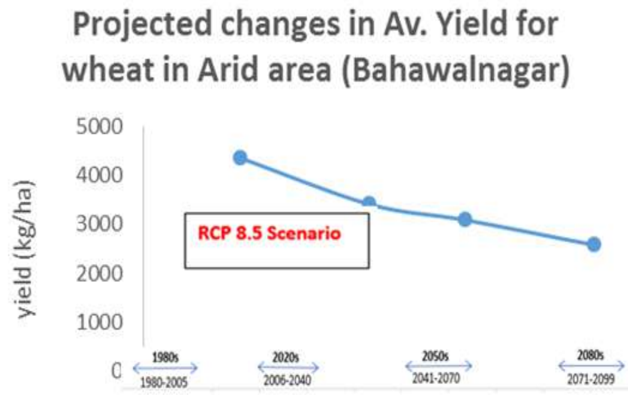


Fig. 31 APSIM simulation for projected changes in wheat yield under RCP 4.5 and RCP 8.5

4. CONCLUSION

The main theme of the project is to model how the projected climate change scenarios will spatially and temporally impact cereal production, a dietary staple for billions of people in South Asia. Climate change scenarios of temperature and precipitation were constructed using state of the art statistical downscaling approaches. Impact assessment with climate-smart approaches using simulation models and devising climate change adaptation strategies for integration in policymaking will help build resilience in water-efficient agriculture and food security.

A comprehensive regional analysis of recently available climate model data sets with the help of state of the art statistical techniques helped identify best regional climate models, which were able to reproduce historical climatology well. These models can be used steadfastly by the modelling community and researchers for impact assessment studies in various fields. Our studies revealed that RCA4 developed by SMHI showed extraordinary skills for Asian domain in simulating precipitation fields with less to moderate degree of wet and dry biases. Whereas, CCAM and REMO show less degree of cold and warm bias in reproducing temperature regimes, hence suitable for agricultural impact studies.

The studies carried out in Pakistan, Bangladesh and Sri Lanka disclose that climate change, manifested by an increase in temperature in the main cereal crop growing areas of these countries, will negatively affect the yield of staple crops of wheat, maize and rice thereby posing a threat to food security of this highly populated region. While, precipitation projections showed highly erratic and uncertain patterns, evaluated for different crop growth seasons, for all the selected countries of South Asia. Bangladesh is a subtropical country with high total annual rainfalls shows predominantly increasing trends during Kharif-I cropping season prevailing during March-July in the pre-monsoon and during monsoon season too. Sri Lanka is also predicted to experience exceptionally high rainfalls in Maha season during mid and end century periods.
Country specific findings follow below:

Bangladesh

The temperature changes for Tmin for future scenarios in Bangladesh show an increase of 3^0C for *Rabi* season under both RCPs i.e. 4.5 and 8.5 for the 2050s whereas, RCP 8.5 shows an increase of almost 6^0C for 2080s and RCP 4.5 shows an increase of 1.5^0C for 2080s. An increase of 6^0C in minimum temperature is projected under both RCPs in the 2050s for both *Kharif-I and Kharif-II* seasons while RCP 8.5 show 4^0C and 6^0C for *Kharif-I* and *Kharif-II* respectively. The maximum temperature projections for *Rabi* season suggest a rise of 2^0C and 1^0C for *Rabi* and *Kharif-I* respectively under both RCPs in the 2050s and for 2080s RCP 8.5 indicates an increase of 2^0C.

AquCrop model showed reasonable skills in simulating, growth and yield components with reasonable indicators of the simulation outputs such as mean error, mean absolute error, root mean square error, and relative error are reasonable, which indicate that the model can simulate yield with acceptable accuracy. The model fitted the observed data set very well. Similarly, validated biomass production shows similar results. The effects of climate change on yield of a popular winter rice cultivar in Bangladesh were assessed using the biophysical simulation model ORYZA2000. This model was first validated for 2000–2008 using experimental field data from Bangladesh, with a thorough test of climate data daily for station-wise and reanalysis datasets. The model performance was satisfactory enough to represent crop productions in nine major rice-growing districts. Then, simulation experiments were carried out for 2046–2065 and 2081–2100. Results show a 33% reduction of average rice yields for 2046–2065 and 2081–2100 for three locations. Projected rainfall pattern and distribution will also have a negative impact on the yields by increasing water demands by 14 % in the future. The model also showed that later transplanting will have less damage under the projected climate.

Pakistan

In Pakistan, the results of projected changes in average minimum temperature during *Rabi* season show a linear increase during near-century in both the representative concentration pathways (RCPs) whereas a significantly contrasting trend has been observed in the projections of both the scenarios for midterm as well as for long term. A change of 2.1^0C in minimum temperature is projected for RCP 4.5 whereas 5.04C is projected for RCP 8.5 by the end of the century. As far as maximum temperatures in the *Rabi* season are concerned, initially, a rapid decrease in average maximum temperature is observed in the near-century in case of RCP4.5 followed by a steep curve showing abrupt increasing trend during midcentury. Overall, an increasing trend in the average maximum temperature has been observed for the future projections for both RCPs, with 2^0C for RCP 4.5 and 5.4^0C for RCP 8.5 during the *Rabi* season.

Projected changes in average minimum temperature for *Kharif* season (for both RCPs) show harmony till mid-century with an increasing trend followed by divergence with the continued increase in RCP8.5 till the end of the century whereas RCP4.5 tend to follow a downward trend after mid-century in case of RCP4.5. An overall decrease of 2.1^0C has been projected for RCP 4.5 and that of RCP 8.5 goes down to -5.8^0C in case of minimum temperatures, whereas in case of maximum *Kharif* temperatures and increase of 1^0C is predicted for RCP 4.5 while RCP 8.5 suggest an increase of 5.8^0C for the whole projection period.

Due to rise in temperatures an overall increase of 1000 Growing Degree Days (GDDs) between past and late century extreme scenarios (RCP8.5) has been observed in case of wheat, implying that South Eastern side of Pakistan is likely to become unsuitable for wheat production due to temperature extremes after mid-century.

Temperatures in the South-Eastern part of Pakistan have shown to exceed the thresholds at the times of flowering and ripening thereby causing wheat yield losses. Further increase in temperature is projected to have serious implications for these growing areas.

APSIM Crop Simulation Model studies disclose that wheat production in the arid areas of Pakistan is likely to suffer to the tune of 17% in the 2020s for RCP4.5, whereas 21% and 40% in case of RCP8.5 for 2020s and 2080s, respectively. AquaCrop model projects 34% and 41% decline in Maize yields in case of scenario RCP8.5 by the end of the century in the KPK province, respectively. Ahmed et al. (2015), studied that due to climate change, there is a mean reduction of 15.2 and 17.2% in rice yield by DSSAT and APSIM, respectively. In wheat, mean yield reduction was 14.0% in DSSAT and 13.76% in APSIM with five GCMs, respectively.

The results suggest that the aggregate impact of climatic parameters, i.e., changes in temperature and rainfall exerted an overall negative impact on cereal crop yields, given that the management practices and use of technology remain unchanged. Studies suggest an imminent need of adaptation interventions to cope with the negative impacts of climate change.

Sri Lanka

The future projections for average maximum temperature indicate an increase of 3^0C for *Yala* season under both RCPs i.e. 4.5 and 8.5 for mid-century simulations while for end century results a distinctive increase of 4^0C is expected for *Maha* season under RCP 8.5. The average minimum temperature simulations show a marked increase of 3^0C in *Maha* season under RCP 4.5 as well as RCP 8.5 for the 2050s and the results for 2080s show a 2.5^0C rise for RRCP 8.5. AquaCrop model calibration results showed good skills in simulating crop growth and yield parameters over the selected period.

The effects of future climatic variations on the yield of medium and short duration rice varieties under locations representing the wet zone, dry zone and intermediate zone, for both *Maha* and *Yala* seasons were assessed using the biophysical simulation model APSIM (Amarasingha et al., 2018). The model simulated a decrease in the wet zone rice yield of Bg300 for Maha season by 18% in 2050 and 31% in 2100 under RCP 8.5, whereas, for Bg359, the Dry Zone rice, model simulations suggested a decrease of 17% in 2050 and 42% in 2100. These results imply that serious adaptation measures are essential to overcome the effects of climate change on yield.

Climate-Smart Agriculture Adaptations

South Asia is still predominantly an agrarian society where a majority of the population is dependent on agriculture for their livelihoods. Due to burgeoning population pressures, complex geographical features and the heavy dependence on natural resources that are directly influenced by changes in weather and climate, Agriculture production systems are facing great challenges. Water for agriculture is rapidly becoming a limiting factor due to population growth, competition from other water users, drought and water quality degradation. Thus, it is critical to ensure that every drop of water (either from rainfall and irrigation) counts for crop water use. Evapotranspiration (ET), is a significant component of water use in agriculture can help irrigation managers to find ways to improve water use efficiency by increasing transpiration and reducing evaporation.

Change in precipitation pattern and atmospheric temperatures can result in water and heat/cold stresses in many crops. Many practices and technologies such as water management measures in the form of conservation and harvesting options and optimized water requirement technologies and practices, can benefit to overcome the water-related stresses in agriculture and improve optimized used of water under conditions of water scarcity.

Farmers have experienced that the adoption of a single technology or a set of them for rice and wheat crops had a significant impact on yield. Use of zero-tillage in rice may reduce its yield, but a combination of minimum tillage with other technologies such as nutrient and water management has been shown to improve rice yield.

There is a wide variety of possible response options for adapting to climate change. Such choices can be related to policies, investments, institutions, water management, field management practices, farming practices and capacity development, both within the water and agriculture sectors and beyond. It is thus vital to consider the appropriate scale, the options are needed to be applied: on fields and farms; in irrigation schemes; in watersheds or aquifers; in subnational and transboundary river basins; and at the national level. Table 5.1 presents a list of potential response options (source, FAO) and indicates their relevance for different scales. To have optimal impact, these options must be used in combinations that are tailored to different contexts. The focus should be placed on major systems at risk. Their implementation depends on the local conditions and the specific climate change risks that need to be addressed (e.g. water scarcity, changes in water availability, extreme events, increased irrigation requirements, water quality).

Adaptations – Agriculture water management					
Options	**Field/Farm**	**Irrigation Schemes**	**Watershed /Aquifer**	**River Basin**	**National**
Land, water and crop management					
Enhancing soil moisture retention capacity	×				
Changing cropping pattern and diversification	×				
Adapting cropping calendar	×				
Supplementary irrigation	×	×			
Deficit irrigation		×			
Alternate wet and dry rice production system	×	×			
Drainage and flood management		×	×	×	
Policies, institutions and capacity building					
I&D infrastructure management		×	×	×	
Reallocation of water (between or within sectors)	×	×	×	×	×
Strengthening land/water right access	×	×	×	×	×
Crop insurances	×				
Improved weather forecasting capacity	×	×	×	×	×
Improved hydrological monitoring flood/droughts			×	×	×
Investments- Climate Financing					
On-farm water storage: water harvesting	×				
Groundwater development	×				
Modernization of irrigation infrastructure		×			
Breeding for resistance to droughts and floods	×				
Dam construction /enhancement		×	×	×	×
Drainage	×		×	×	

Potential options for climate change adaptation in the water at different scales (Source, FAO)

FUTURE DIRECTIONS

This work can be extended in the following directions:

- Food security, vulnerability and impact assessment for districts selected under phase-II in site selection of this project can be done.
- Exploring community-based pursuit of climate-smart agriculture by active collaboration between stakeholder communities and technical professionals
- Developing climate services which draw upon the best available climate science to qualify likely climatic changes and their probable impacts

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Appendix

Regional Project Inception Workshop

CAF2015-RR12-NMY-Shaheen

"Climate smart agriculture through sustainable water use management: Exploring new approaches and devising strategies for climate change adaptation in South Asia"

10-12 Nov, Islamabad, Pakistan

Inception Workshop Summary

Project inception workshop under APN project "Climate smart agriculture through sustainable water use management: Exploring new approaches and devising strategies for climate change adaptation in South Asia" (CAF2015-RR12-NMY-Shaheen) was held in Islamabad, Pakistan during 10-12 November, 2015. This workshop kick started two years, APN awarded project under its Climate Adaptation Framework.

Inception Workshop with the Inaugural session on 1st day (10 Nov.), was attended by a number of participants including 5 participants from regional collaborating countries of Bangladesh, Cambodia and Sri Lanka, senior representatives of Government departments, representatives of non-Government organizations, FAO and World Food Program representatives, Climate change, alternate energy and water resources research institute representatives, and Scientists from GCISC.

Inaugural session began with the welcome remarks by Muhammad Arif Goheer, Head, Agriculture and Coordination, GCISC. He thanked the honorable guests for their presence and expected the proactive involvement of participants in the workshop proceedings. The Guest of Honor Dr. Arshad Muhammad Khan (former Executive Director, GCISC) congratulated GCISC for organizing this workshop. He briefly talked about the GCISC's association with APN and appreciated the efforts of GCISC scientists for carrying out worthwhile studies. FAO deputy representative Francisco Gammaro appreciated GCISC for timely addressing the issue of Climate Smart Agriculture. A comprehensive overview of the project highlighting concept and significance of climate smart agriculture, objectives and other planning related aspects of this project was presented by Ms. Nuzba Shaheen in the capacity of project leader. This was followed by remarks by worthy chief guest Dr. Muhammad Hashim Popalzai, Additional Secretary Ministry of National Food Security & Research. He commended GCISC's research efforts in climate change related studies and assured his Ministry's full support.

After project inaugural ceremony, First session tilted "Climate Change & Food Security: Emerging Challenges & New Concepts" included 2 presentations" first presentation was made by FAO deputy representative, Francisco Gammaro, highlighting Threats of Climate Change to Food

Security in Pakistan and FAO's Adaptation Framework & Climate Smart Agriculture" second presentation was made by Sara Hamidi (on behalf of Krishna Pahari) on the issue of "Climate Change, Livelihoods and Food Security in Pakistan".

Second session "adapting to climate change" also included two presentations. First presentation was made by Dr. Mohsin Iqbal, national Food Security expert and former head Agriculture section GCISC. He shed light on "Climate Change & its Impacts on Agriculture in Pakistan". Second presentation was delivered by Dr. Munir Ahmad, Director Climate Change Alternate energy and water resources institute. The presentation comprehensively explained "Climate Change Impact on Agriculture and Adaptation Strategies".

Third session was dedicated for county presentations. Counterparts from each collaborating country made their country presentations, sharing their countries' Geographic Location & Climatology, Agriculture sectors' Contribution to GDP, Dependence on crops (Cereal crops, Cash crops etc.), Irrigated / Rained agriculture, Agricultural Institutions, Data Availability & Sources of data (with special reference to this project).

Second day of inception workshop started with a scholarly session titled, "Responding to Climate Change" in which 4 GCISC scientist delivered comprehensive quite informative presentations".

First presentation was made by Mr. Shahbaz Mahmood on "Climate Change: Simulating Future for Impact Studies , second was delivered by Dr. Shaukat Ali on, Twenty First Century Climatic and Hydrological Changes Over North Pakistan Third presentation was made by Dr. Zia Hashmi titled "Climate Change threat to Pakistan's Water Resources and Impact modeling needs", fourth and last very important presentation was made by Mr. Arif Goheer "Ensuring Food Security under Climate Change : A Simulation Modeling Perspective"

Second session which was the most important session from project planning point of view, started with the presentation of project plan and Framework, by Ms. Nuzba Shaheen (Project Leader) and it was followed by the most interactive and brainstorming discussion which was moderated by Muhammad Arif Goheer. After a mutual discussion on different project planning aspects and after getting views of country collaborators, a common framework was agreed upon by all the partners. This framework consisted of agreement of all partners on a proposed common project methodology, models to be used, site selection criteria, data needs and acquisition, achievement of milestones and deliverables and roles and responsibilities.

During second half of the day, project team (including regional participants and GCISC scientists) visited Fatehjang field station, a climate smart Agriculture village. At the Field station demonstrations on climate smart agricultural practices including Solar Powered High Efficiency Irrigation System provided an insight to participants on state of the art agriculture water management adaptation strategy under rising impacts of climate change. This visit was of great interest and significance as is acknowledged by all the participants.

Third day of the meeting started with country specific plans preparations based on previous days' standard common project framework followed by the presentations. At the end a session to foresee and mange Research Problems/ Limitations and way forward was conducted. Mr. Arif Goheer played the role of moderator during last but very important session.At the end, project inception workshop summary was presented by Ms. Nuzba Shaheen (Project Leader) and GCISC shields were presented to the regional country participants.

Training Workshop Brief Report

Background and Objective:

This training workshop was organized by Global Change Impact Studies Center, under APN (Asia Pacific Network for Global Chang Research) awarded project, titled “Climate smart agriculture through sustainable water use management: Exploring new approaches and devising strategies for climate change adaptation in South Asia”, led by Ms. Nuzba Shaheen, Senior Scientific Officer, GCISC. The main theme of the project is to model how the projected climate change scenarios will spatially and temporally impact cereal production, a dietary staple for billions of people in South Asia. Climate change scenarios of temperature and precipitation will be constructed using state of the art weather generator approach for the first time for South Asia. Impact assessment with climate smart approaches using simulation models and devising climate change adaptation strategies for integration in policy making will help build resilience in water efficient agriculture and food security.

Objective of this training workshop was to build capacity of south Asian countries in the use of Statistical Downscaling and AquaCrop Crop Simulation Modeling Tools for the assessments of food and water security in South-Asia Region and in devising plausible measures for adaptation and mitigation. All the expenses of this workshop including travel cost, accommodation and DSA expenses, as per the APN financial regulations, were covered out of funds of APN Project (CAF2015-PR12-NMY-Shaheen project).

Workshop Organization:

6-day regional capacity building workshop on the “Use of Statistical Downscaling and AquaCrop Simulation Modeling Tools for Climate Change Impact Studies was successfully organized by Global Change Impact Studies Center (GCISC). This training program was attended by 20 participants including six participants from Pakistan, 2 project participants from Bangladesh and Cambodia each and 10 participants from Sri Lanka.

Training workshop consisted of two back to back trainings: one on the use of statistical downscaling of climate change scenarios using weather generator approaches and another one on the use of AquaCrop model for farm management practices.

Inaugural session of the Training workshop started on the first day with the oil lamp lightening ceremony followed by welcome remarks by the organizers and guest of honor, Dr. A de Silva (Director, Department of Agriculture, Sri Lanka) who welcomed all the guests, foreign delegates and training participants to this training workshop and emphasized on the need of such capacity building trainings for building up scientific capabilities of regional scientists in the use of climate change simulation modeling tools and techniques.

The first 2-day segment of this training workshop was focusing on generating local scale statistically downscaled climate change scenarios through the use of a weather generator suite namely Rainsim-CRU WG. The resource person for this segment was Dr. Nathan Forsythe, who is a post-doc at School of Civil engineering and Geosciences at New Castle University, UK. During this part of workshop, Dr. Forsythe started with the basic concepts and theories of climate change, climate modeling and scenario generation and use of statistical downscaling tools and techniques including various weather generator approaches.

He also conducted different learning exercises about accessing, downloading, point extraction and visualization of Regional Climate Model data available through CORDEX South Asia data repositories and using RainSim and CRU WG models for generating future climate data through Change Factor application.

During practice session, for conducting hands on exercises, participants were divided into three groups; each group was mentored by a scientist from GCISC having expertise in the use of weather generator tools. Mentors from GCISC were Dr. Zia ur Rehman Hashmi, Ms. Nuzba Shaheen and Ms. Nadia Rehman. Participants showed great interest in learning all these useful techniques.

Third day i.e. 1 June began with the training on AquaCrop Simulation Model. The main objective of this 4-day capacity building workshop was to train participants in the practical applications of AquaCrop in order to improve their skills in strategic farm management practices.

The emphasis was on increasing crop water productivity in rainfed and irrigated production systems under changing climate and dwindling water scenarios. Prof. Dirk Raes, University Leuven, Belgium trained the participants in the use of AquaCrop Simulation model. And in this effort he was facilitated by his colleague Ms. Hanne. During the first session Prof. Dirk introduced the participants to the Aquacrop model interface and about the model's data requirements followed by hands on session by Haana. During the first session Prof. Dirk introduced the participants to the Aquacrop model interface and about the model's data requirements followed by hands on session by Haana.

The 2nd session was dedicated for training on soil characteristics and soil database management followed by the practical session. The topics of crop characteristics, crop database management, crop development and production and rainfed farming were practical sessions.

On the 3rd day detailed presentations on irrigation and field management were delivered by the trainers. The participants were introduced to the concepts of Net irrigation requirement; Irrigation scheduling; Generation of Irrigation schedule; Deficit irrigation Field surface practices; Soil fertility and crop responses; mulches and calibration of fertility stress. Workshop participants devoted a longer portion of their time on the hands-on sessions led by Ms. Hanna. Fourth and final day was dedicated for potential application of Aquacrop applications including conducting climate change studies using the model. The participants showed keen interest in the training modules. They were not only able to grasp many new concepts but also shared their local farming practices and identified possible paths of action towards implementation of the tool for carrying out project activities.

In the concluding session, Ms. Nuzba Shaheen presented a brief summary of training workshop and acknowledged the role of all the individuals and organisations for their support in conducting this capacity building training workshop. She also expressed gratitudes to FAO (Food and Agriculture organisation of United Nations) whose earnest support (FAO Pakistan office and FAO-Head Office) facilitated arrangement of an expert trainer of the AquaCrop model developers group. Local organisers from SriLanka thanked project lead country for holding this workshop in Sri Lanka and thereby providing a useful training opportunity to train Sri Lankan scientists in the use of state of the art climate change modelling tools for Impact assessment studies

Finally, GCISC shields were presented to Trainers and guests and certificates were given to all the participants of this training workshop

Expected outcomes of the training

In order to investigate climate change impacts on global food and water security issues, professional knowledge and expertise in the use of climate change scenario generation and impact assessment tools and techniques are highly desirable and needed to be enhanced at national and regional levels. The two training programs jointly addressed both these aspects and provided regional scientists with a comprehensive platform and opportunity for learning innovative and well tested approached in the fields of climate scenario generation and impact assessment studies. Training workshop on the use of statistical downscaling tools and techniques was believed to enable all the partner countries to produce future scenarios of their local climate data. Moreover, training on the use of AquaCrop not only enabled participants to grasp many new concepts about crop water management under the wake of rising impacts of climate change but also provided a chance to the participants for sharing their local farming practices and identifying possible paths of action towards implementation of the tool for carrying out future research activities. This training program is going to help a great deal not only in achieving the ultimate project objectives but also in building technical capabilities of the regional scientists in conducting research on climate change impacts and devising climate change adaptation and mitigation strategies for informed policy making.

REGIONAL TRAINING WORKSHOP

"Use of Statistical downscaling and AquaCrop Simulation Modelling Tools for Climate Change Impact Studies"

Kandy, Sri Lanka, May 30 – June 04, 2016

PROGRAMME

Day – 1	**Monday, 30th May , 2016**
***Session* – I** 08.30 - 10.00	***"Inaugural session with dignitaries"***
	Dr. Punya and Dr. Nissanka
Tea Break (10.00-10.30)	
Training on Statistical Downscaling Tools (RainSim & Weather Generator) Resource Person: Dr. Nathan Forsythe	
***Session* – II**	***"RCM theory, data extraction & interpretation"***
10.30 - 11.30	• Introduction to RCMs • relationship between GCMs and RCMs, capabilities/limitations
11.30 - 12.00	• RCM data downloading, clipping and Extraction of RCM climate information from model output files, e.g. CORDEX
12.00 - 12.30	• Analysis of RCM climatology Part 1: Calculation of key statistics and validation of control/historicalpresent and future time slices
Lunch Break (12.30-13.30)	
13.30 - 14.00	• Analysis of RCM climatology Part 2: Comparison of present and future time slices (spatial & seasonal patterns of change)
14.00 - 15.00	• Theory of change factors and their calculation
15.00 - 15.30	• Understanding limitations of change factor (CF) estimates & Evaluation of CFs
Tea Break (15.30-16.00)	
***Session* – III**	***"RainSim and Weather Generator (WG) usage"***
16.00 - 16.30	• Introduction to the weather generators and their applications & limitations
16.30 - 17.00	• How RainSim and the WG work
17.00 - 17.30	• Data needs and preparation for RainSim and the WG

17.30 - 18.30	• Review of Day 1, further Q & A on RCMs and (RainSim and) the WG
Day – 2 Tuesday, 31st May , 2016	
Session **–** III (Cont.)	***"RainSim and Weather Generator (WG) usage"***
08.00 - 09.00	• Review of Day 1, further Q & A on RCMs and (RainSim and) the WG relationship between GCMs and RCMs, capabilities/limitations
09.00 - 09.30	• Preparation of input and running the WG (background)
09.30 - 10.00	• Calculation of missing variables in input observations
10.00 - 10.30	• Error checking of meteorological records (Handling of missing values in case of large gaps)
Tea Break (10.30-11.00)	
11.00 - 11.30	• Running Rainsim to generate precipitation time-series
11.30 - 12.30	• Post-processing and analysis of RainSim output time-series (control & perturbed)
Lunch Break (12.30-13.30)	
Session **–** III	***"RainSim and Weather Generator (WG) usage"***
13.30 - 14.30	• Running the WG and analysing its output (control)
14.30 - 15.30	• Preparing to run the WG for a future scenario: Intro to CF application to WG
Tea Break (15.30-16.00)	
16.00 - 17.00	• Generation & analysis of WG perturbed outputs
17.00 - 18.00	• Review of Day 2, Q&A
Day – 3 Wednesday, 1st June , 2016	
Training: Capacity Development for Farm Management Strategies to Improve Crop – Water Productivity using Aqua Crop Trainer: Dr. Dirk Raes	
Session **–** I (Theoretical) 09.00 - 10.30	***"Introduction to AquaCrop and Climatic data"*** • Introduction to AquaCrop and Presentation of AquaCrop user-interface • Required weather data for AquaCrop • Reference ET (ETo) • Determination of ETo
Tea Break (10.30-11.00)	
Session **–** II (Practical)	***"Introduction to AquaCrop and Climatic data"*** • Input of climatic data and calculation of ETo • Database management (Climate)

11.00 - 12.30	
Lunch Break (12.30-14.00)	

***Session* – III**
(Theoretical)
 	
14.00 - 15.30
	"Soil characteristics"
	• Soil Physical Characteristics;
	  ○ soil water content,
	  ○ soil water balance, and
	  ○ soil water movement
	• Specification of soil characteristics in AquaCrop

Tea Break (15.30-16.00)	
***Session* – IV** (Practical) 16.00 - 17.30	***"Soil characteristics"*** • Database management (Soil) • Creating and updating projects
18.30- 20.00	***Dinner*** ***Dr. Punya & Dr. Nissanka***
Day – 4	**Thursday, 2nd June , 2016**
***Session* – I** (Theoretical) 09.00 - 10.30	***"Crop characteristics"*** • Tuning of crop characteristics to local environment
Tea Break (10.30-11.00)	
***Session* – II** (Practical) 11.00 - 12.30	***"Crop characteristics"*** • Database management (Crop) • Fine tuning of crop characteristics to the environment
Lunch Break (12.30-14.00)	

***Session* – III**
(Theoretical)
 	
14.00 - 15.30
	"Crop development and production; Rainfed farming"
	• Modelling of:
	  ○ Crop development;
	  ○ Crop Transpiration;
	  ○ Biomass production; and
	  ○ Crop yield
	    a. Rainfed farming:
	    b. Initial soil water content
	    c. Start of growing cycle

Tea Break (15.30-16.00)	
***Session* – IV** (Practical) 16.00 - 17.30	***"Crop development and production; Rainfed farming"*** • Initial soil water content • Start of the growing cycle (rainfed agriculture)

	Field Visit ***Dr. Punya & Dr. Nissanka to decide***
Day – 5	**Friday, 3rd June , 2016**

***Session* – I**
(Theoretical)
09.00 - 10.30
	"Irrigation management"
	• Water Productivity and Irrigated farming:
	  ○ Net irrigation requirement;
	  ○ Irrigation scheduling;
	  ○ Generation of Irrigation schedule;
	  ○ Deficit irrigation

Tea Break (10.30-11.00)	
***Session* – II** (Practical) 11.00 - 12.30	***"Irrigation management"*** • Database management (Irrigation) • Irrigation scheduling • Deficit irrigation
Lunch Break (12.30-14.00)	

***Session* – III**
(Theoretical)
14.00 - 15.30
	"Field management"
	• Field management:
	  ○ Field surface practices;
	  ○ Mulches;
	  ○ Soil fertility and crop responses
	  ○ Calibration of soil fertility stress

Tea Break (15.30-16.00)	
***Session* – IV** (Practical) 16.00 - 17.30	***"Field management"*** • Database management (Field Management) • Limited soil fertility
Day – 6	**Saturday, 4th June , 2016**
***Session* – I** (Theoretical) 09.00 - 10.30	***"Evaluations Applications"*** • Evaluation of simulation results • Presentation of case studies
Tea Break (10.30-11.00)	
***Session* – II** (Theoretical) 11.00 - 12.30	***"Evaluations Applications"*** • Presentation of case studies • Effect of climate change • Formulation of guidelines • Soil salinity stress

	Lunch Break (12.30-14.00)
***Session* –** III (Theoretical) 14.00 - 15.30	***“Follow-up”*** • Discussions with participants: ○ Specific topics ○ Follow-up
***Session* –** III	***Closing Ceremony***

REGIONAL PROJECT INCEPTION WORKSHOP

10-12 Nov, Islamabad, Pakistan

PROGRAMME

S. No.	Name	Designation/Affiliation	Email
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REGIONAL INCEPTION WORKSHOP UNDER APN PROJECT

"Climate smart agriculture through sustainable water use management: Exploring new approaches and devising strategies for climate change adaptation in South Asia"

(CAF2015-RR12-NMY-Shaheen)

Best Western Hotel Club Road-Islamabad Dated: 10-12 November2015

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Global Change Impact Studies Centre

REGIONAL TRAINING WORKSHOP UNDER APN PROJECT

"Climate smart agriculture through sustainable water use management: Exploring new approaches and devising strategies for climate change adaptation in South Asia"

(CAF2015-RR12-NMY-Shaheen)

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Global Change Impact Studies Centre

REGIONAL TRAINING WORKSHOP UNDER APN PROJECT

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University of Peradeniya Dated: May 30-June 04, Kandy, Sri Lanka

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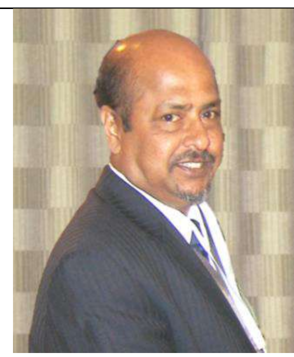
14	Dr. B. V. R. Punyawardena	Senior Research Officer Natural Resources Management Center, Department of Agriculture, Peradeniya, Sri Lanka batugedara_vrp@yahoo.com	
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An In kind support (along with estimated amount) was provided by following institutes

- **Global Change Impact Studies Center (GCISC)**: Administrative, Research and personnel support and Resource person/trainer support with an estimated amount US $ 15,000
- **School of Civil engineering and Geosciences at New Castle University, UK**: Technical expertise, resource person/trainer and research support including climate model downloading and acquisition support with an estimated amount of US $ 10,000
- **FAO-Pakistan**: Resource person/trainer support for organization of AquaCrop training workshop with an estimated amount of US $ 5000
- **Natural Resource Management Centre, Department of Agriculture and university of Peradeniya, Sri Lanka:** Administrative and research support with an estimated amount of US $ 2000
- **CAWERI-NARC** Research and field visit to climate smart agriculture sites support with an estimated amount US $2000

Young Scientists Trained in the Project

1. Ambreen Jahandad (amberjahandad29@gmail.com)

I am currently working as a research assistant, performing the responsibilities of a crop modler, in the APN project (CAF2016-RR07-CMY-Shaheen). The project has appeared to be a perfect platform to enhance my skills as a professional crop modelling student. The broad horizons of the project have opened a new spectra of knowledge for me and is playing a vital role in achieving a firm command over the applications of AquaCrop and APSIM using different climate scenarios for future predictions. Apart from the technical skills this project has provided me with the opportunity to work in a highly professional environment and get familiarized with work ethics. By working on this project I got a chance to improve my management and writing skills under a given format.

As a research assistant (crop modeller) I have assisted in the activities mentioned below.

- Application of APSIM and AquaCrop using downscaled data for future periods
- Post processing of downscaled climate data
- Technical Report writing
- Financial report preparation

2. Sahibzada Saadoon Hammad

I am Currently studying as an Erasmus Mundus student in the Master of Science in Geospatial Technologies at Universitat Jaume I, Castellon, Spain (saadoon1122@gmail.com).

The project was a very good learning opportunity. As a graduate from GIS background, the project opened a new spectrum of using GIS for applications in agriculture. Working with climate scenarios now enables me to use GIS effectively in this field more than ever. I worked with the basics of R statistical languages and it is helping me in my master studies here in UJI, Spain. Other than technical skills I have learnt project management skills, collaboration, cooperation and coordination needed to progress in a work environment. I have worked on following project activities:

- Statistical downscaling using two weather generators, CRU WG and Rain Sim
- Handling and post processing of climate model outputs
- Validation Analyses of Climate Change Scenario Data on selected study Sites
- Bias Correction of Global Climate Models (GCMs) and Regional Climate Model (RCMs) data using various Techniques

3. Khadija Haider

“I, Khadija Haider, worked as Research Assistant in this project. I am currently pursuing my Ph.D. in Marine Biology and Ecology from University of Miami, Florida. My current study focuses on how corals are impacted by climate change and ocean acidification.

My email address is khadija.haider@rsmas.miami.edu . Working on this project not only familiarized me with the climate of South and South East Asia but also polished my skills on a variety of tools especially R, ArcGIS, panoply and last but not the least Climate Data Operators (CDO). Now, I can handle huge datasets and run the statistical analysis with the techniques learned while working with my amazing mentor - Ms. Nuzba Shaheen. In a nutshell, this project empowered me with the tools and skills which have been helping me in my Ph.D. research and opening new doors of success for me. I would conclude with my belief that we need to change before the climate changes to a point of no return."

4. Muhammad Bilal (mbilal4949@hotmail.com)

I, Muhammad Bilal, am very thankful to Global Change Impact Studies Centre (GCISC) to give me an opportunity to work in this APN-funded project. Currently, I am enrolled as a PhD Scholar in National Engineering and Technology Centre, Agriculture University Nanjing, China. During my research work in the project, I got a chance to enhance my intellectual capabilities, achieve professional maturity, and learn a remarkable set of technical skills. The hard work nature, commitment to the assigned tasks, methodical approach and ability to work under pressure are some special assets of the project. Further, I availed the outstanding opportunity to learn new techniques and a solid practical background of Agriculture, Crop Modelling and Climate Change. Last but not the least, working in this project and the environment provided by the GCISC helped me to polish my personality and to achieve my future life endeavours.

GLOSSARY

AGB	Aboveground biomass
APN	Asia-Pacific Network for Global Change Research
APSIM	Agricultural Production System Simulator
ArcGIS	Aeronautical *Reconnaissance* Coverage Geographic Information System
CAWERI	Climate, Energy & Water Research Institute
CC	Canopy Cover
CDO	Climate Data Operators
CMIP5	Coupled Model Inter-comparison Project Five
CORDEX	Coordinated Regional Downscaling Experiment
CRU	Climate Research Unit
CSIRO	Commonwealth Scientific and Industrial Research Organization
CSU	Consecutive Summer Day Index
CVRMSE	Normalized Root Mean Square Error
D	Wilmot's index of Agreement
DTR	Diurnal temperature Range
EF	Nash-Sutcliffe model efficiency coefficient
ERA-Interim	ECMWF ReAnalysis
ESD	Empirical Statistical Down-scaling
FAO	Food and Agriculture Organisation
GCISC	Global Change Impact Studies Centre
GDD	Growing Degree Days
GPCC	Global Precipitation Climatology Centre
GraDS	Grid Analysis and Display System
HI	Harvest Index
IITM	Indian Institute of Tropical Meteorology
KPS	Kampong Speu
MERRA-2	Modern-Era Retrospective analysis for Research and Applications, version 2
MPI	Max Planck Institute for meteorology

NARC	National Agriculture Research Centre
NASA	National Aeronautics and Space Administration
NCEP	National Centres for Environmental Prediction
NCO	netCDF Operators
NetCDF	Network Common Data Form
Precip	Precipitation
r	Pearson's coefficient of correlation
RMSE	Root mean square error
SCPF	Standard Common Project Framework
SMHI	Swedish Meteorological and Hydrological Institute
SSE	Sum of Square Error
SWC	Soil Water Content
Tmax	Maximum Temperature
Tmin	Minimum Temperature
WD	Watch Forcing

- **Actual data or access to data used in the study**
  The details of data acquisition and use are given in section 2.3 (Data sets) of report.

- **Abstracts, Power Point Slides of conference/symposia/workshop presentations**
  The power point slides of conference/symposia/workshop presentations are separately attached (as Annex-I, II, III) due to the already large size of the given file.