Agriculture Resilience: linking Insurance and Technology

Consultant's Final Report

on

Crop yield assessment using remote sensing and crop simulation models

TA 6663-PAK: Strengthening Food Security Post-COVID-19 and Locust Attacks

STRENGTHENING POST-COVID-19 FOOD SECURITY AND LOCUST ATTACKS, IN PAKISTAN IN COLLABORATION WITH PATCO AND RDF

Sustainable Agriculture Resilience: Linking Insurance and Technology (Pakistan)

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REPORT

PREPARED FOR THE ASIAN DEVELOPMENT BANK

BY

International Crops Research Institute for the Semi-Arid Tropics

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Abbreviations

ADB	Asian Development Bank
DSSAT	Decision Support System for Agro technology Transfer
CSM	Crop Simulation Models
GEE	Google Earth Engine
GIS	Geographic Information System
GP	Gram Panchayat
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
LGP	Length of Growing Period
NDVI	Normalized Difference Vegetation Index
PATCO	PARC Agrotech Company (PVT) LTD
RDF	Research and Development Foundation

1 INTRODUCTION

1. The Government of Pakistan, with the support of the Asian Development Bank [1], plans to assess crop yields using different technologies including satellite technologies and other biophysical parameters.

2. This study mainly focusses on linking insurance and technology. The study will use existing environment, weather and management data along with satellite-derived crop spatial data in crop models to assess crop yields at gram panchayat (GP) level together with spatial information generated from near real time high resolution satellite images.

3. As part of this objective, a first training was conducted on crop classification maps and mapping geospatial products during 27 to 29 July 2021. A second training during 8 to 12 November mainly focused on DSSAT crop modelling and on integration of the crop model with remote sensing.

4. This document is the Final Report on these activities undertaken by ICRISAT to support the linking of insurance and technology.

2 PROJECT BACKGROUND

5. This project was undertaken as part of the support towards Strengthening Post-COVID-19 Food Security and Locust Attacks, Pakistan, in collaboration with PATCO (ADB consultant under TA 6663-PAK, Islamabad, Pakistan) and RDF (Research and Development Foundation, an NGO, Hyderabad, Pakistan). The trainings were conducted in the study district of Gujranwala district and conducted crop modelling and integration. This was followed by training local government officials on the use of crop models, mainly DSSAT and geospatial applications.

3 ACTIVITIES

6. The activities included an introduction to various Crop Simulation Models (CSM) and DSSAT Crop Model, preparation of soil and weather inputs for CSM, running the crop model and output generation, remote sensing-based Leaf Area Index (LAI) and other indices and the integration of remote sensing with the crop model.

4 INTEGRATION OF CROP MODEL WITH REMOTE SENSING

7. Figure 1 shows the methodology used to integrate remote sensing-derived LAI with crop model LAI for yield estimation.

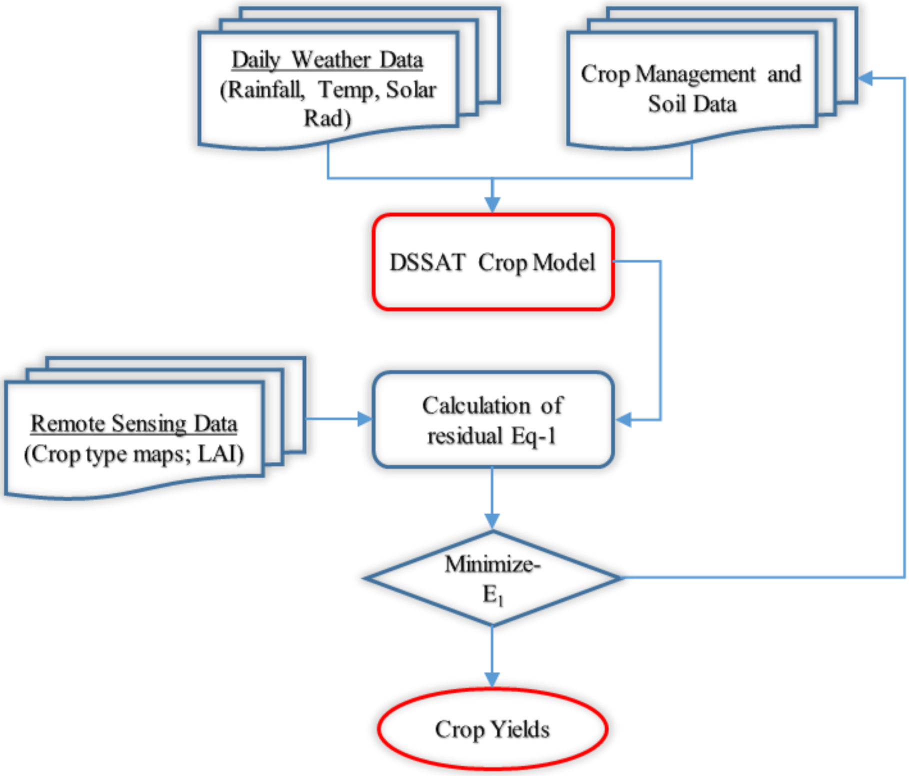

Figure 1: The methodology of integrating remote sensing-derived LAI with crop model LAI for yield estimation.

4.1 Introduction to CSMs and DSSAT Crop Model

8. An overview of Crop Simulation Models and introduction to the DSSAT crop model was given [Jones W 2003], focusing on the need for crop modelling, users of crop models and their application, an introduction to DSSAT and reasons to adopt it.

4.2 DSSAT Crop Model - Parameters

9. The process began with downloading DSSAT (DSSATv4.7.5) from the official website (http:dssat.net).

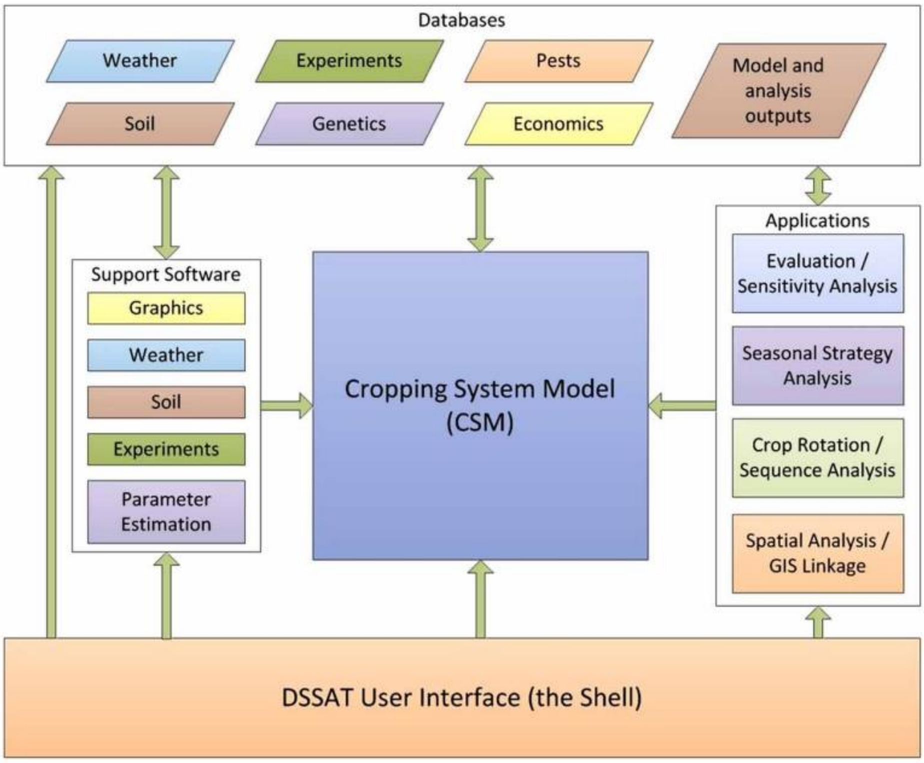

Figure 2: DSSAT model ecosystem (Source: http:dssat.net).

10. The DSSAT model contains the following data management tools (Figure 2):
    - X Build: Input crop management information in standard format
    - S Build: create and edit soil profiles
    - G Build: Display graphs of simulated and observed data
    - AT create: create and edit observations from experiments formatted correctly
    - ICSim: Introductory tool to demonstrate potential yield concepts
    - Sensitivity analysis: soil, weather, management, or variety characteristics
    - Seasonal analysis: Multiple-year simulations to evaluate uncertainty in biophysical and economic responses
    - Rotation/ sequence analysis: long term simulations to analyse changes in productivity and soil condition associated with cropping system
    - Spatial analysis: defines spatially variable soil, weather, management characteristics across a field or region for analysis

11. The DSSAT experiment starts with preparing files for major input parameters like soil, weather and cultivar
12. Using “S Build”, soil files are prepared by providing information that defines the soil, such as texture, depth, organic carbon, etc.

13. Using Weatherman, weather files are created mainly by giving parameters like minimum temperature, maximum temperature, rainfall and solar radiation
14. The cultivar file is prepared by knowing the genetic coefficients as well as length of growing of such seed
15. Then the experiment file is prepared using “X Build” by giving various input parameters, mainly in the following categories:
    - Experiment name, institute code, site code, experiment number (only 2 digits) and crop
    - Environment - Fields, Initial Conditions, Soil Analysis, and Environmental Modifications
    - Management - Cultivars, Planting, Irrigation, Fertilizer, Organic Amendments, Tillage, Harvest, and Chemical Application.

16. Treatments - Select treatments and select levels for all parameters
17. Simulations – Simulation start state, crop module, and adjusting the management parameters and output parameters

18. Then X Build file will be saved in default extension (.RIX for Rice)
19. The output file contains LAI and yield for the respective treatments.

4.3 Remote Sensing – Leaf Area Index

20. The remote sensing-based LAI is derived based on the fact that the spectral response of leaves is unique compared to that of other parts of the plant.
21. Vegetation indices – NDVI, EVI, SAVI, etc. – have shown high positive correlation to LAI.
22. With limited field data consisting of LAI values at a few locations, regression equations can be arrived at, relating LAI to spectral vegetation indices.
23. METRIC (Measuring Evapotranspiration at high Resolution with Internalized Calibration) model has developed a relation between LAI and Sentinel 2-derived Soil Adjusted Vegetation Index (SAVI). According to the METRIC model (Equation 1),

$$LAI = \frac{-\ln\left(\frac{0.69-SAVI}{0.59}\right)}{0.91} \text{.......... (1)}$$

24. For images used in this study, SAVI was computed using the formula (Equation 2):

$$SAVI = \frac{(1+L)\,(B8-B4)}{L+B8+B4} \text{.......... (2)}$$

Where, L is a soil factor, taken to be 0.1, B8 is the spectral reflectance in band 8 (Near Infrared) and B4 is the spectral reflectance in band 4 (Red).

25. MODIS-derived LAI is also available, but at 500 m resolution (Myneni et al., 2015).

4.4 CCEs data optimization

26. The optimization of CCEs was carried out using the methodology in Figure 3. The process began with the collection of sentinel 2 NDVI Maximum data (available), climate data and soil map.

27. The NDVI data with crop mask and respective climate and soil data were combined into homogenous strata and collected random points using stratified sampling. By multiple regression techniques, the number of samples were reduced to half of the random samples.

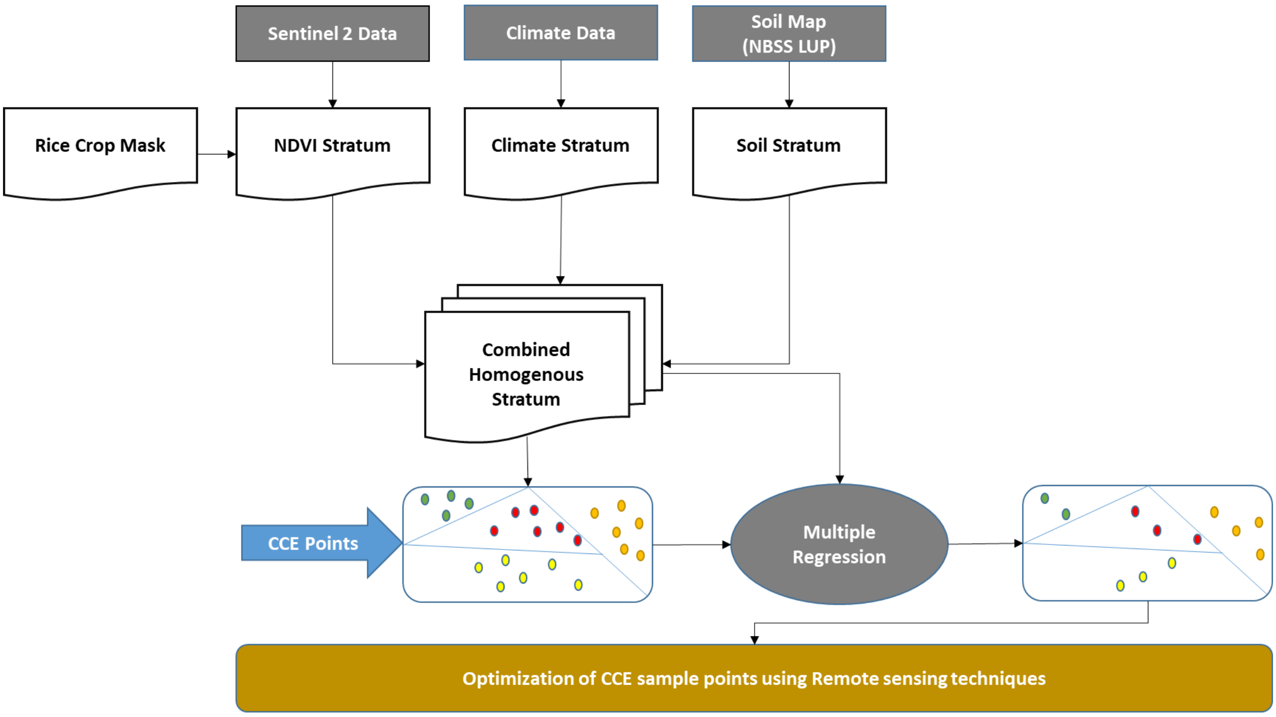

Figure 3: Optimization of Crop Cutting Experiments using remote sensing techniques.

28. Using the optimization, instructions will be given to field staff to collect the samples.

4.5 Integration of Remote Sensing LAI with Crop Model LAI

29. The simulation of cropping systems is often hindered by the lack of accurate input data such as parameter values for soil, management, cultivar and meteorological inputs. However, a combination of remote sensing-based LAI and crop model LAI has the potential to update and, where necessary, rectify cropping system model simulations for more certain outcomes. To assimilate LAI into the crop growth model in the process of yield estimation, the methodology of Gumma et al. (2021) was used

to assess crop yield assessment at the village level using remote sensing, field data and crop simulation models.

30. The optimization process starts with initial model parameterization by adjusting the free parameters so that the model-simulated LAI is in agreement with the Satellite LAI observations (Eq. 3). The simulated LAI values depend on the values of the free variables (e.g., planting date, nitrogen dose, soil profile parameters) that are generated by minimizing the value of the following cost function (equation 3) (Myneni et al., 2002). The remote sensing LAI data were collected during crop growth period based on availability.

$$\sum_{i=1}^{m} \frac{abs[LAI_s(t_i) - LAI_M(t_i)]}{LAI_M(t_i)} \qquad \ldots\ldots\ldots\ldots (3)$$

Where, LAI_M and LAI_S are the leaf area index measured and leaf area index simulated at time t_i, respectively.

31. By adjusting the free input variables in order to minimize residuals between Satellite LAI and simulated LAI at each corresponding period, an optimized set of input parameters were obtained. The free variables were adjusted sequentially based on the cost function (Eq. 1) for each location. After completing the maximum number of iterations with minimum merit function value, the free parameters were finalized. Finally, with the optimized parameters, the model was executed to update the crop yields.
32. Calibration: Crop yields were estimated for each CCE location and compared with the observed yields of that particular CCE's yield data.

5 TRAINING PROGRAM ON CROP YIELD ASSESSMENT USING REMOTE SENSING AND CROP SIMULATION MODELS

5.1 Overview

33. The virtual hands-on training (8-12 November) on integration of crop model with remote sensing for yield estimation to support insurance products as a part of "Strengthening Post-COVID-19 Food Security and Locust Attacks, Pakistan, in collaboration with PATCO (ADB consultant under TA 6663-PAK, Islamabad, Pakistan) and RDF (Research and Development Foundation, an NGO, Hyderabad, Pakistan) was conducted by the Geo-spatial and Big Data Sciences Cluster, ICRISAT. This course is for those interested in remote sensing and GIS technology and its application in the areas of natural resources, water resource management, agriculture, and social sciences. Participants from the Technical group of PATCO, Pakistan and Crop Reporting Service – Punjab and Sindh, Pakistan attended the training.

5.2 Objectives

- To introduce crop models and their application
- To familiarize with DSSAT crop model and preparation
- To integrate remote sensing with crop models for yield estimation

5.3 Participants and training activities

34. Participants from the Technical group of PATCO, Pakistan and Crop Reporting Service – Punjab and Sindh, Pakistan attended the training program (Figure 4). The mix of participants comprised those with knowledge of the subject and some with minimum knowledge; hence the training started from the basics.

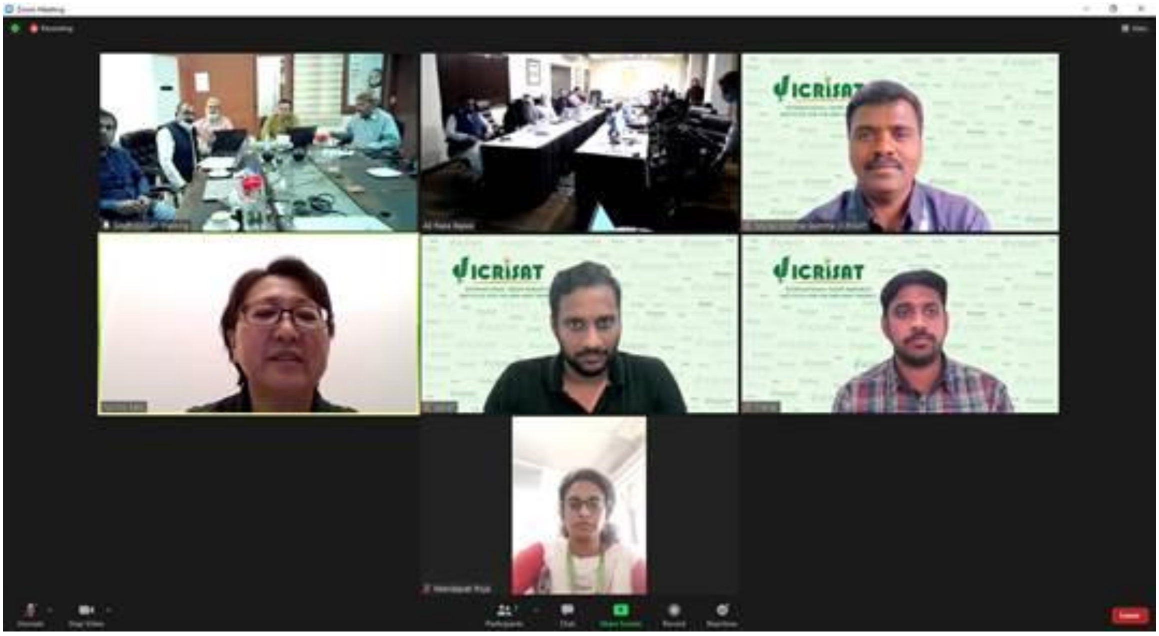

Figure 4: The PATCO technical team and crop reporting service teams from Punjab and Sindh in Pakistan at the virtual training on developing remote sensing products.

35. **Day wise activities:**

Day1: Overview: Remote sensing applications and crop yield assessment, and introduction to Crop Simulation Models (CSM)

Day2: Input parameters for DSSAT and weather data and soil data preparation

Day3: DSSAT CSM - Simulations - Output files and optimization of CCEs using geospatial technology

Day4: Calculation of LAI using satellite imagery and integration of RS LAI with Model LAI

Day5: Challenges, limitations and recommendations

36. Participants provided with copies of recommended reading material
37. **Trainers:** Dr. Murali Krishna Gumma, Dr. Roja Mandapati, Mr. Pavan Kumar Bellam and Mr. Pranay Panjala.

5.4 Results

38. With the knowledge gained in the training program, participants generated soil and weather parameters for their study area, ran crop models and extracted output files. The Google Earth Engine (GEE) code was shared to generate LAI values for particular locations, with participants extracting the LAI values. The methodology behind the integration of the remote sensing LAI with the Crop model was understood well by the participants.

5.5 Participants' feedback on training

39. A semi-structured questionnaire was used to obtain feedback on the training design, logistics and facilities, execution, and relevance to the participants work and utility, and aspects that need improvement. Participants were also asked to highlight what they liked /didn't like about the training and additional support they foresee to take the training learnings further.

40. In terms of training design, we received very positive feedback in terms of objectives but negative feedback on time allocation from 12 out of 16 members. Training execution got very positive feedback (14 out of 16) and reaching of objectives got neutral feedback (4 out 16). Very positive feedback was obtained on training relevance, work and utility, and logistics and facilities. Overall, training objectives were met to some extent. The training aspects most liked were the DSSAT model followed by the integration of RS with the model LAI. Almost 80% of the participants opined that less time was allocated to remote sensing sessions with more focus on DSSAT.

6 KEY FINDINGS AND NEXT STEPS

41. Physical hands-on training is highly recommended with sufficient time allocation.

- Inputs from the training will feed into processes that provide comprehensive insurance coverage against crop losses on account of non-preventable natural risks, thus helping stabilize farmer incomes and encouraging them to adopt innovative practices.

- Notified Insurance unit has been reduced to Village/Village Panchayat for major crops. With the help of approaches discussed, village level yield assessment is possible.

42. Next steps will include of identifying crop stress across the crop season and also crop type mapping

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8. Annex 1: List of Participants

List of Participants in the ICRISAT Training (08 – 12 November 2021)
Virtual through Tokyo – ICRISAT in Hyderabad Deccan – Luxus Grand Hotel in Lahore – RDF in Hyderabad Sindh

Lahore: Luxus Grand Hotel Conference Room
Hyderabad: RDF Conference Room

No.	Name	Sex	Position Title / Expertise	Email Address / Mobile Phone umber	Confirmation of Attendance by email					City to attend
					08 Nov	09 Nov	10 Nov	11 Nov	12 Nov	
		A. Technical								
		Punjab CRS								
1	Muhammad Usman Saleem	Male	Research Office (BS-17) / RS & GIS	osman.geomatics@gmail.com / 03217579429	✓	✓	✓	✓	✓	Lahore
2	Muhammad Shahid Mushtaq	Male	Assistant Director (BPS-18) / RS & GIS	Shahid6550@gmail.com / 03224481959 /	✓	✓	✓	✓	✓	Lahore
3	Raqia Shabir	Female	Research Office (BS-17) / RS & GIS	Ruqaia3@gmail.com / 03214216430	✓	✓	✓	✓	✓	Lahore
4	Zulfiqar Ali Mayo	Male	Statistical Officer	zulfiqaralimayo@gmail.com / 03336241814	✓	✓	✓	✓	✓	Lahore
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6	Shahid Mahmood	Male	Statistical Officer	ranaaltaf123@gmail.com	✓	✓	✓	✓	✓	Lahore
7	Mudassar Jamil Shera	Female	Statistical Officer	muddasarjamilshera@gmail.com	✓	✓	✓	✓	✓	Lahore
8	Faran Farooq	Male	Statistical Officer	faranfarooq@yahoo.com	✓	✓	✓	✓	✓	Lahore
9	Faiza Ali	Female	Research Office (BS-17) / RS & GIS	afaiza4@gmail.com	✓	✓	✓	✓	✓	Lahore
10	Rukhsana Naik	Female	Statistical Officer	rukh.naik7@gmail.com	✓	✓	✓	✓	✓	Lahore

No.	Name	Sex	Position Title / Expertise	Email Address / Mobile Phone umber	Confirmation of Attendance by email					City to attend
					08 Nov	09 Nov	10 Nov	11 Nov	12 Nov	
11	Muhammad Shahid	Male	Statistical Officer	econshahid@gmail.com	✓	✓	✓	✓	✓	Lahore
12	Mirza Waseem Abbas	Male		cipunjabcrs@agripunjab.gov.pk	✓	✓	✓	✓	✓	Lahore
13	Muhammad Iltaf	Male	Statistical Officer	copcell.crs@gmail.com	✓	✓	✓	✓	✓	Lahore
	Sindh CRS									
14	Adnan Ahmed Sheikh	Male	Assistant Director (BPS-17) / Statistician	adnanmusharaf@gmail.com / 03452421636	✓	✓	✓	✓	✓	Hyderabad
15	Sarfaraz Ali Bhutto	Male	Statistical Officer (BPS) / RS & GIS	saify.bhutto@yahoo.com / 03332772746	✓	✓	✓	✓	✓	Hyderabad
	PATCO									
16	Nauman Ul Huq	Male	Remote Sensing Specialist / GIS / Programing	naumanulhaq88@gmail.com / 03349122348	✓	✓	✓	✓	✓	Lahore
17	Dr. Muhammad Fahad	Male	Agronomy / Remote Sensing	fahadagr@outlook.com / 03346607341	✓	✓	✓	✓	✓	Lahore
18	Hannan Mehmood	Male	GIS Developer / RS & GIS	hannanmehmood@yahoo.com / 03236120031	✓	✓	✓	✓	✓	Lahore
	B. PATCO Administration / Coordination									
1	Dr. Abdul Qureshi	Male	Team Leader / Economist	drabdulhqureshi@gmail.com / 03005286574	✓	✓	✓	✓	✓	Lahore
2	Saira Maryam	Male	Admin. Assistant	sairamaryam6@gmail.com / 03344399817	✓	✓	✓	✓	✓	Lahore
3	Aziz Channa	Male	Sindh Provincial Coordinator for CRS	aziz.channa1@gmail.com / 03443807838	✓	✓	✓	✓	✓	Hyderabad
4	Khawaja Muhammad Ali	Female	TA Sindh Coordinator	engr.alikhawaja@gmail.com / 03323015920	✓	✓	✓	✓	✓	Hyderabad
	C. ADB									

No.	Name	Sex	Position Title / Expertise	Email Address / Mobile Phone umber	Confirmation of Attendance by email					City to attend
					08 Nov	09 Nov	10 Nov	11 Nov	12 Nov	
1	Noriko Sato	Female	Natural Resources Specialist	nsato@adb.org +63 917 512 7863 (WhatsApp)	Stand by					Tokyo
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