WP3: Water Productivity Analysis

Cai, Bharat, Upali, Gias, Susana, Asad

Water Productivity

- **Basin performance on agril. water utlisation**

- Crop (livestock, fish) water productivity kg/m^3

- Water value-adding \$/m^3

- Net value/costs

Factors affecting water productivity

Scope for WP Improvement

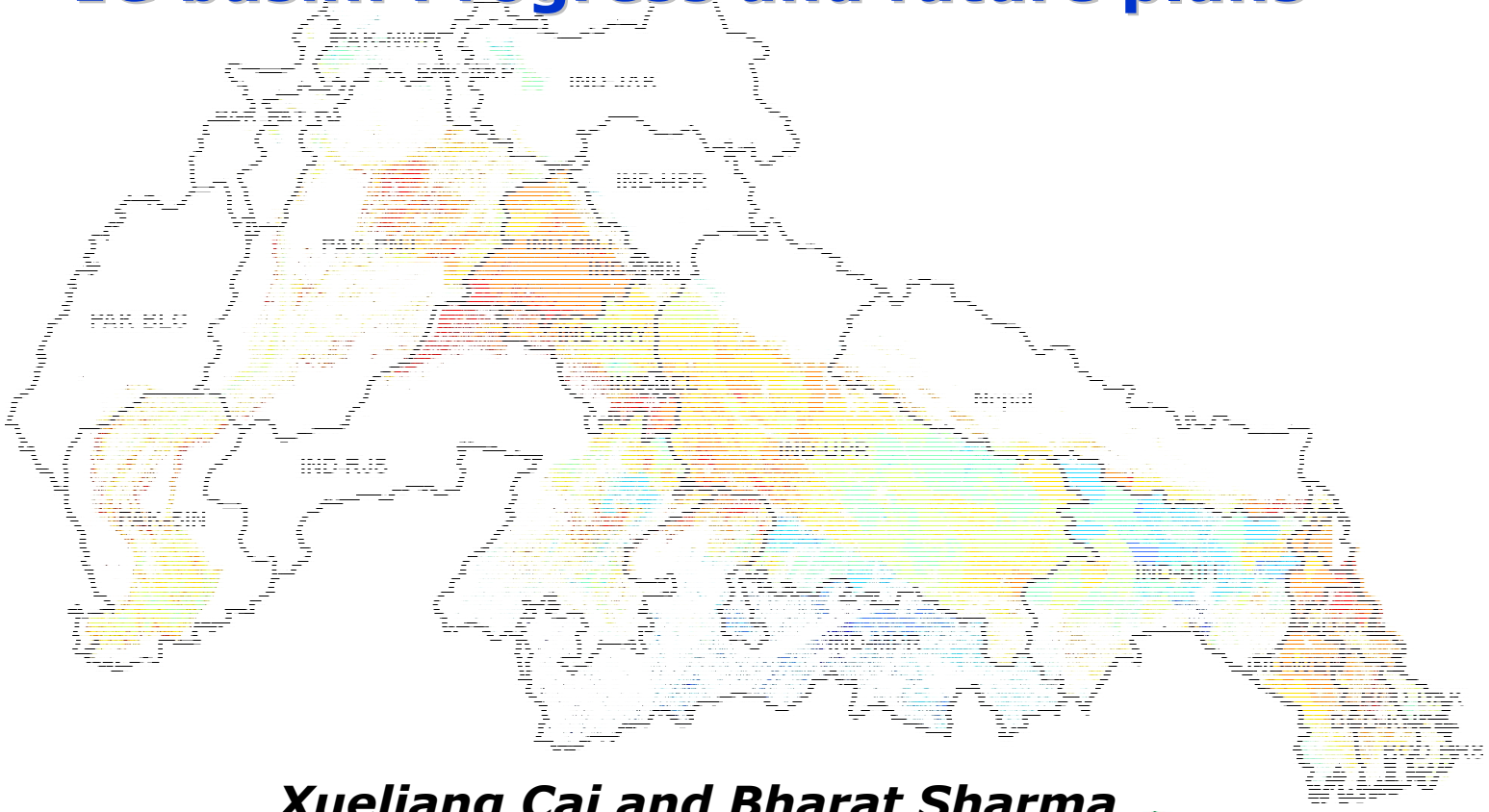
How well is the water used?

Levels of Analysis

- **RS/GIS based water productivity analysis of the IG basin (whole basin)**
- **Agro-hydrological modeling using OASIS performance assessment and strategic planning tool (Sub-Basin scale)**
- **Fish-productivity analysis for eastern Gangetic basin (Bangladesh)**
- **District –level water productivity analysis using census-data and field surveys (Basin/ country level analysis)**
- **District-level rice water productivity analysis for Bangladesh (Completed)**

International Water Management Institute

RS/GIS based water productivity analysis of the IG basin: Progress and future plans



Xueliang Cai and Bharat Sharma

24-2-2009

CGIAR Challenge Program on WATER & FOOD

Structure of the Presentation

Introd.	**Introduction**
Data	**Data collection**
LULC	**Crop dominance map synthesizing**
Prod.	**Land productivity mapping**
Water	**Water use mapping**
Results	**The water productivity mapping results**
Plan	**Action plan for 2009**

Water productivity – the concept

Water productivity (WP) is "*the physical mass of production or the economic value of production measured against gross inflow, net inflow, depleted water, process depleted water, or available water*" (Molden, 1997, SWIM 1). It measures how the systems convert water into goods and services. The generic equation is:

$$Water\ Productivity\,(kg/m^3\ or\ \$/m^3) = \frac{Output\ derived\ from\ water\ use\,(kg/m^2\ or\ \$/m^2)}{Water\ input\,(m^3/m^2)}$$

Why mapping water productivity

The overarching goal of Water Productivity assessment is to identify opportunities to improve the net gain from water by either

- increasing the productivity for the same quantum of water; or

- reduce the water input without or with little productivity decrease.

Basin WP Analysis – What to Care?

- Magnitude – what's the current status?
- Spatial Variation – how does it vary within and among regions?
- Causes – why is WP varying (both high and low)?
- Scope for improvement – how much potential for, where?
- Irrigated vs. rainfed – what's the option for sustainable development under water scarcity and food deficit condition?
- Crop vs. livestock and fisheries – how is livestock and fisheries contributing to water use outputs?

The Methodology

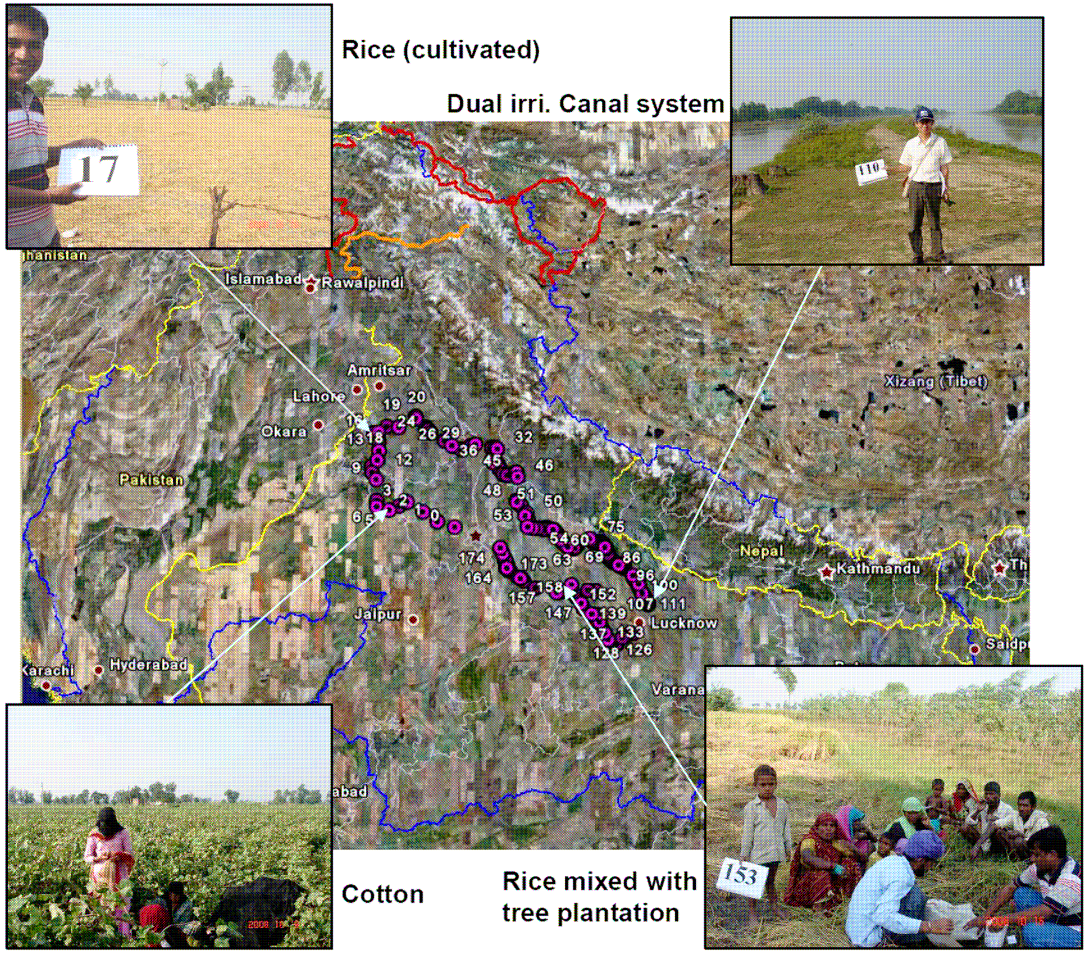
1. Data collection: production, weather data, MODIS NDVI and Land Surface Temperature (LST) products, existing LULC maps and GIS layers, GT points;
2. Crop dominance map synthesizing;
3. Land productivity:
   1. district/state wise agricultural productivity map from census;
   2. Interpolating to pixel wise productivity using MODIS NDVI indices;
4. ET mapping:
   1. Potential ET map with FAO approach;
   2. Actual ET estimation using SSEB model;
5. Water productivity mapping.

Data Collection

1. **Census data:** district wise crop area, yield and production, state wise livestock and fisheries production;
2. **Satellite sensor data:** MODIS 250m 16 day NDVI mosaic of the basin, MODIS 1km 16 day Land Surface Temperature (LST) products: Nov 2005 – Oct 2006;
3. **Weather data:** daily temperature, humidity, sea level pressure, precipitation, wind speed collected for 58 stations: 2005 – 2007;
4. **LULC maps**: USGS GLC 1992-93, IWMI IG basin LULC map 2005, IWMI GIAM 10km (1999) and 500m (2003);
5. **Other data layers**: basin boundary, administrative boundaries, road, railway, and river networks, DEM
6. **Ground truth data:** see continued…

Data collection

A ground truth mission was conducted in India from 8th -17th Oct, 2008



- Across Indus and Gangetic river basin
- >2700km covered
- 175 samples
  - LULC
  - Cropping pattern
  - Agricultural productivity (cut and farmer survey)
  - Water use (rainfed, surface/GW)
  - Social-economic survey

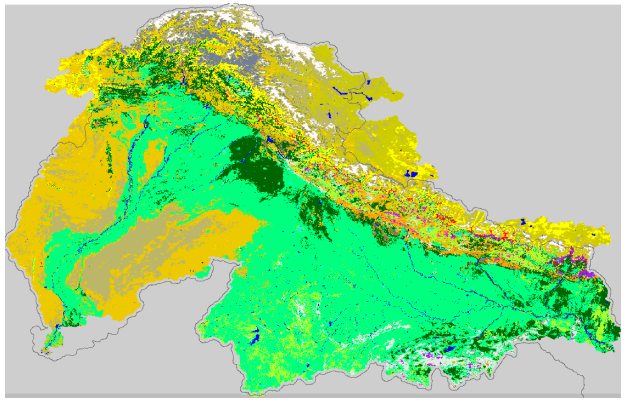
Intro | Data | LULC | Prod. | Water | Results | Plan

CGIAR Challenge Program on WATER & FOOD

Crop Dominance Map

Synthesizing existing maps to a crop dominance map with GT data

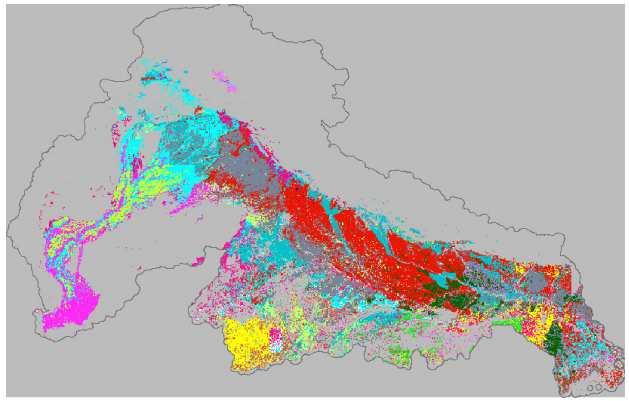
1km, USGS, 1992-1993



Legend

- IGB_bb_10kmbuffer
- INTERRUPTED AREAS (GLOBAL GOODES
- Urban and Built-Up Land
- Dryland Cropland and Pasture
- Irrigated Cropland and Pasture
- Mixed Dryland/Irrigated Cropland
- Cropland/Grassland Mosaic
- Cropland/Woodland Mosaic
- Grassland
- Shrubland
- Mixed Shrubland/Grassland
- Savanna
- Deciduous Broadleaf Forest
- Deciduous Needleleaf Forest
- Evergreen Broadleaf Forest
- Evergreen Needleleaf Forest
- Mixed Forest
- Water Bodies
- Herbaceous Wetland
- Wooded Wetland
- Barren or Sparsely Vegetated
- Herbaceous Tundra
- Wooded Tundra
- Mixed Tundra
- Bare Ground Tundra
- Snow or Ice

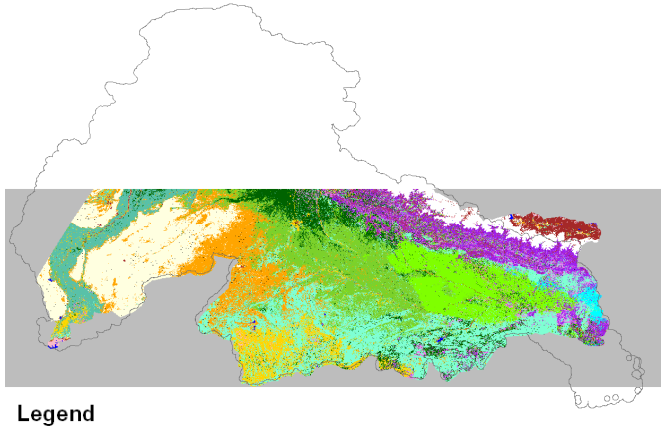
500m, IWMI, 2003



Legend

- 01Irrigated, surfacewater, rice, single crop
- 02 Irrigated, surfacewater, rice, double crop
- 03 Irrigated, surfacewater, rice-other crops, single crop
- 04 Irrigated, surfacewater, rice-other crops, double crop
- 05 Irrigated, surfacewater, rice-other crops, continuous crop
- 06 Irrigated, conjunctive use, mixed forest, rice-other crops, continuous crop
- 07 Irrigated, surfacewater, wheat-other crops, single crop
- 08 Irrigated, surfacewater, wheat-other crops, double crop
- 09 Irrigated, surfacewater, wheat-other crops, continuous crop
- 10 Irrigated, surfacewater, sugarcane-other crops, single crop
- 11 Irrigated, surfacewater, mixed crop, single crop
- 12 Irrigated, surfacewater, mixed crops, double crop
- 13 Irrigated, groundwater, rice-othercrops, single crop
- 14 Irrigated, groundwater, rice-othercrops, double crop
- 15 Irrigated, groundwater, cotton-other crops, single crop
- 16 Irrigated, groundwater, cotton, wheat-other crops, double crop
- 17 Irrigated, groundwater, cotton, soyabean-other crops, continuous crop
- 18 Irrigated, groundwater, sugarcane-other crops, single crop
- 19 Irrigated, groundwater, mixed crops, single crop
- 20 Irrigated, groundwater, plantations-other crops, continuous crop
- 21 Irrigated, conjunctive use, rice-other crops, single crop
- 22 Irrigated, conjunctive use, rice, wheat-other crops, double crop
- 23 Irrigated, conjunctive use, wheat, rice-other crops, double crop
- 24 Irrigated, conjunctive use, rice, sugarcane-other crops, continuous crop
- 25 Irrigated, conjunctive use, wheat-other crops, single crop
- 26 Irrigated, conjunctive use, cotton-other crops, single crop
- 27 Irrigated, conjunctive use, cotton, wheat-other crops, double crop
- 28 Irrigated, conjunctive use, sugarcane-other crops, single crop
- 29 Irrigated, conjunctive use, soyabean, wheat-other crops, double crop
- 30 Irrigated, conjunctive use, mixed crops, single crop
- 00 Ocean and other areas

500m, IWMI, 2005

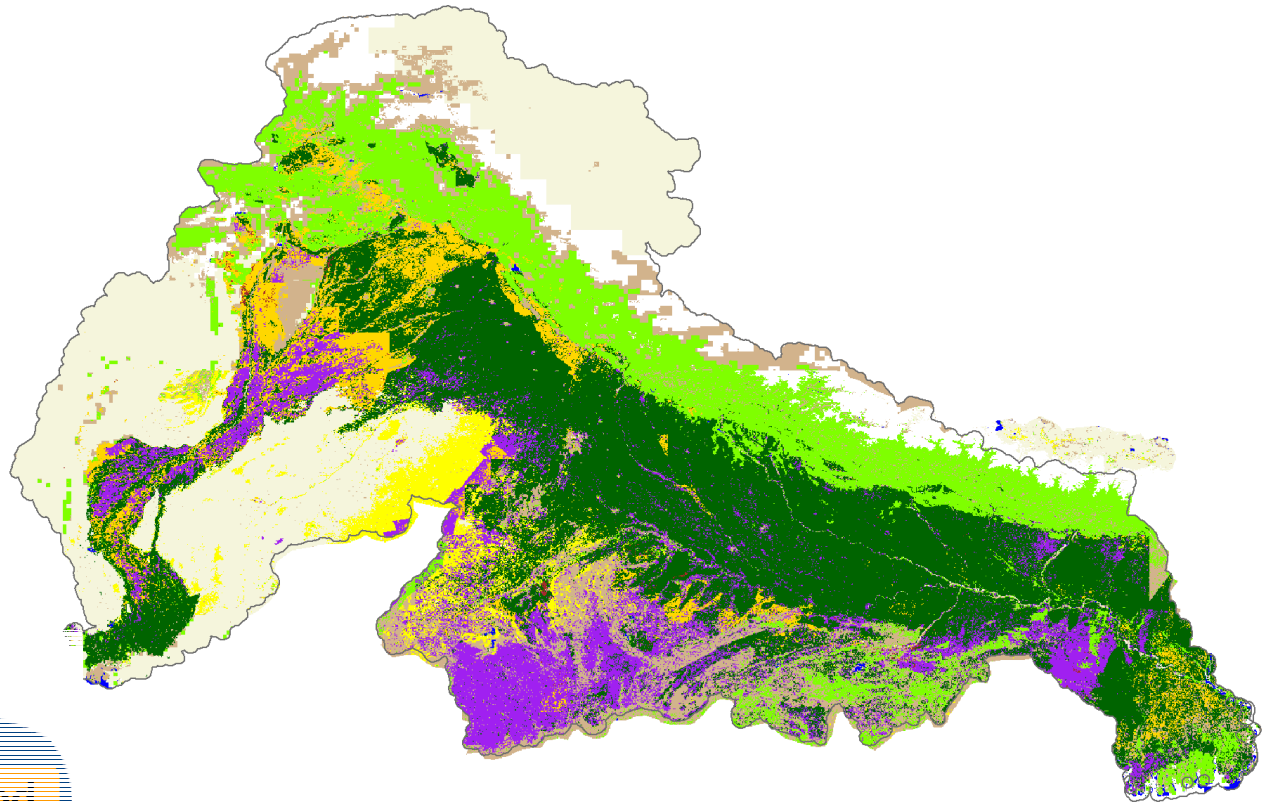


Legend

- IGB_bb_10kmbuffer
- unclassified
- water
- wetlands
- snow
- barren lands
- desert lands
- Mixed: Marshlands/ Himalayan
- Mixed: Rice, other c & wetlands
- Mixed: Rangelands, rain crops
- Rainfed crops and rangelands
- Irrigated: rice, sugarcane
- irrigated: rice and other crops
- irrigated: other crops, fallow f
- Irrigated: water logged(Indus)
- Forests (open): rice, other c/ n
- Forests (Himalayan): Young
- Forests (Himalayan): Mature
- Striping: Noise

AR Challenge Program on WATER & FOOD

Crop Dominance Map



Legend

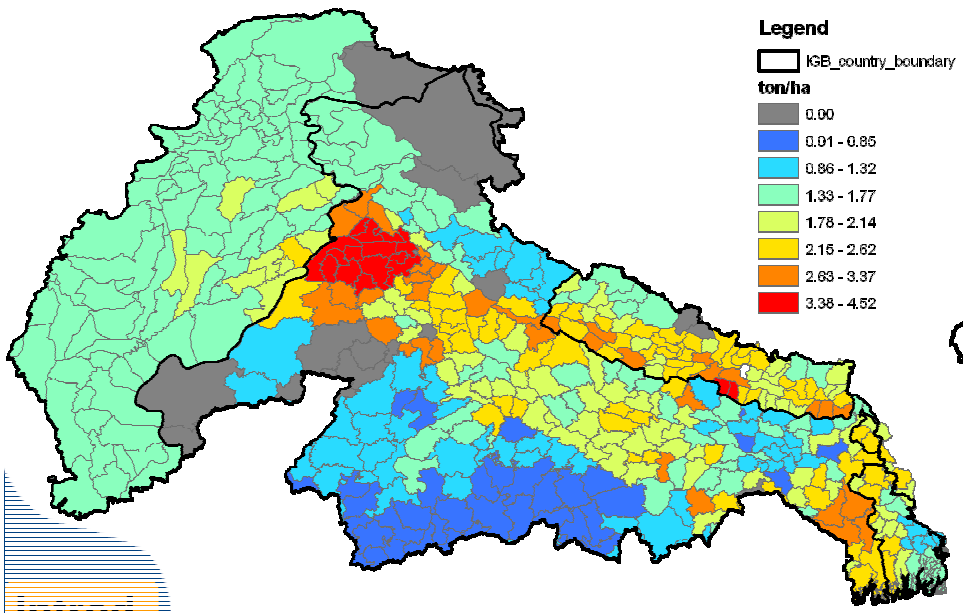
- water
- snow
- scrubland
- desert, barren land
- rainfed (crop and rangeland)
- forest
- surface water, rice, single crop
- surface water, rice-wheat, double crop
- surface water, rice, other crops, single
- surface water, rice, other crops, double
- surface water, rice, other crops, continuous
- surface water, wheat, other crops, single
- surface water, wheat, other crops, double
- surface water, wheat, other crops, continuous
- surface water, sugarcance, other, single
- surface water, mixed crops, single
- surface water, mixed crops, double
- ground water, rice, other crops, single
- ground water, rice, other crops, double
- ground water, cotton, other crops, single
- ground water, cotton, wheat, other crops, double
- ground water, sugarcance, other crops, single
- ground water, mixed crops, single
- conjunctive use, rice-wheat, other crops, double
- conjuctive use, rice, sugarcane, other crops, single
- conjunctive use, cotton, other crops, single
- conjunctive use, soyabean, wheat, other crops, double
- conjunctive use, mixed crops, single

A “crop dominance map” of namely year 2008 shows major crops rice and wheat area, and other mixed croplands. Watering sources are also given for IGB map.

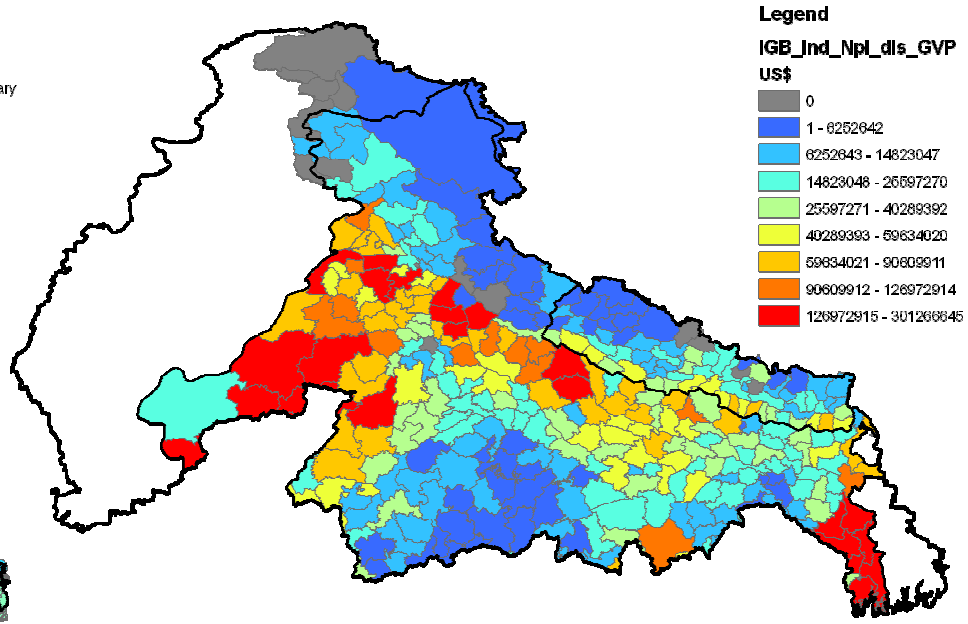
International Water Management Institute
CGIAR Challenge Program on WATER & FOOD

Crop Productivity

Step 1. District wise productivity map using census data



IGB paddy rice yield map of 2005

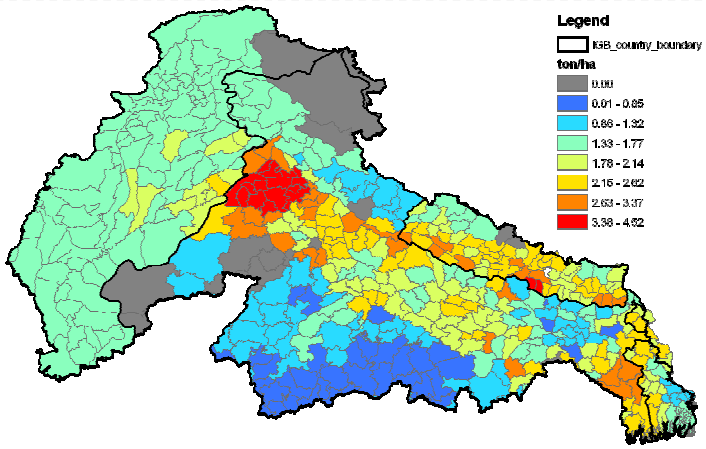


Crop GVP map of India and Nepal for 2005 Kharif season

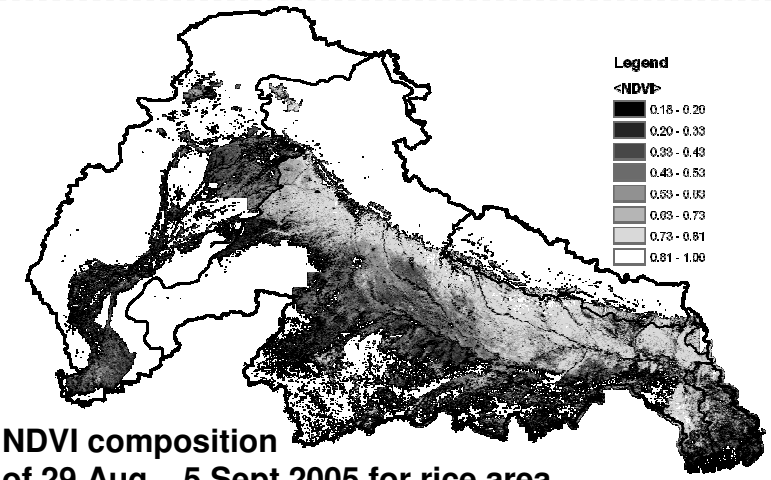
Introd.
Data
LULC
Prod.
Water
Results
Plan

Crop Productivity

Step 2. Pixel wise rice productivity map interpolation using MODIS data

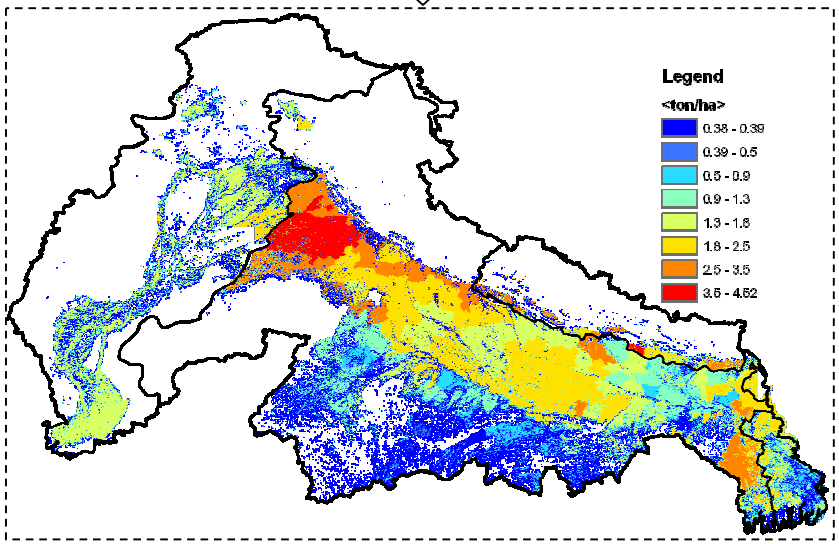


paddy rice yield map of 2005



NDVI composition of 29 Aug – 5 Sept 2005 for rice area

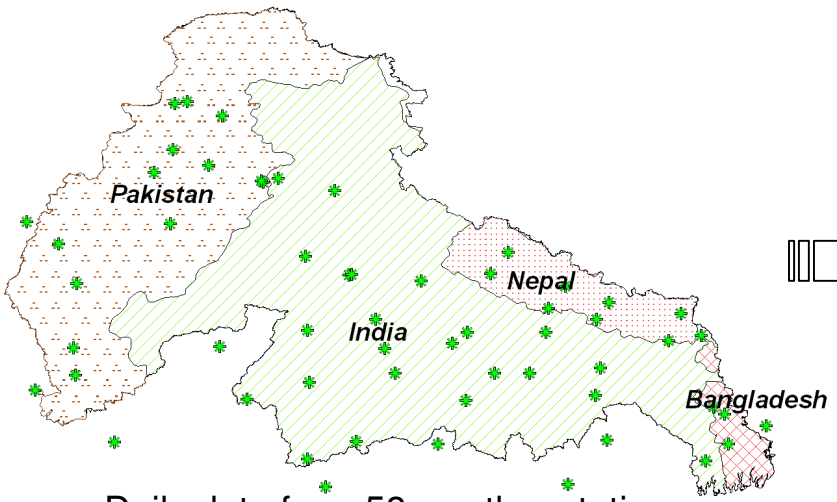
MODIS 250m NDVI at rice heading stage was used to interpolate yield from district average to pixel wise employing rice yield ~ NDVI linear relationship.



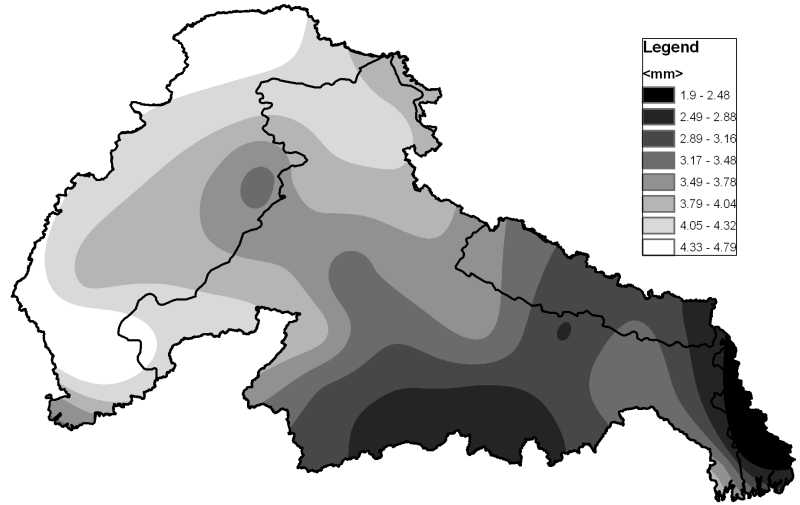
Interact.
Data
LULC
Prod.
Water
Results
Plan

Actual ET Estimation

Step 1. Potential ET calculation (2005-09-21 as example)



Daily data from 58 weather stations



potential ET map (2005 Sept 21)

Steps:

1. Hargreaves equation for reference ET.
2. Kc approach for potential ET.

Note: Kc (FAO56) was determined by maximum Kc values of major crop of the month

Introd.
Data
LULC
Prod.
Water
Results
Plan

CGIAR Challenge Program on WATER & FOOD

Actual ET Estimation

Step 2. Actual ET calculation by Simplified Surface Energy Balance (SSEB) approach

SSEB

$$ET_f = \frac{T_H - T_x}{T_H - T_C}$$

$$ET_a = ET_p * ET_f$$

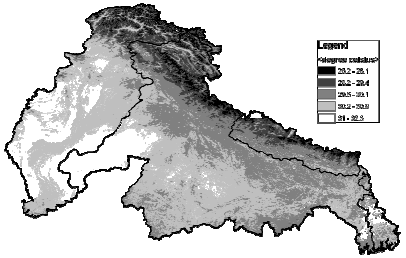
ET_a – the actual Evapotranspiration, mm.

ET_f – the evaporative fraction, 0-1, unitless.

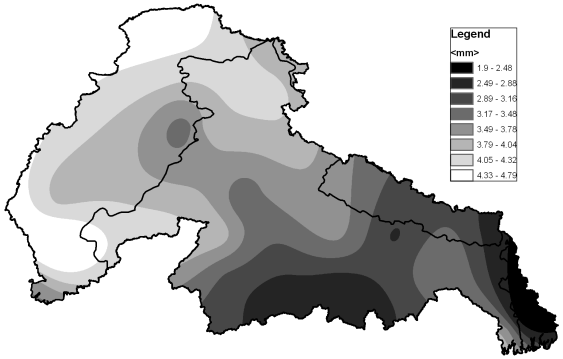
ET_0 – Potential ET, mm.

T_x – the Land Surface Temperature (LST) of pixel x from thermal data.

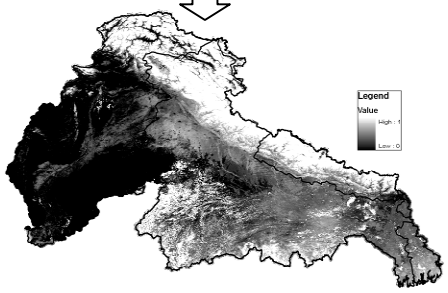
T_H/T_C – the LST of hottest/coldest pixels.



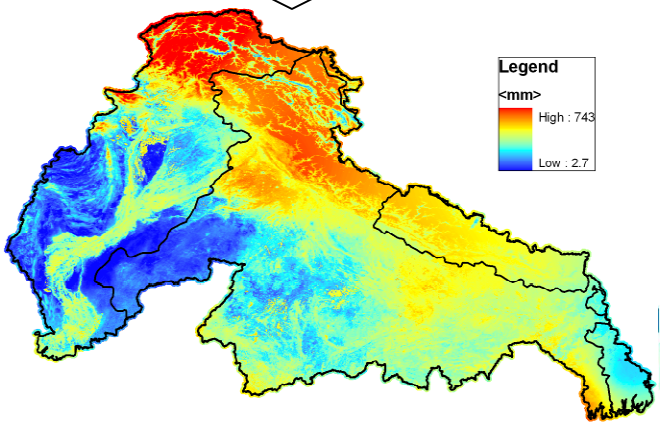
MODIS LST 2005 Sept 21



potential ET map (2005 Sept 21)



ET fraction map (2005 Sept 21)



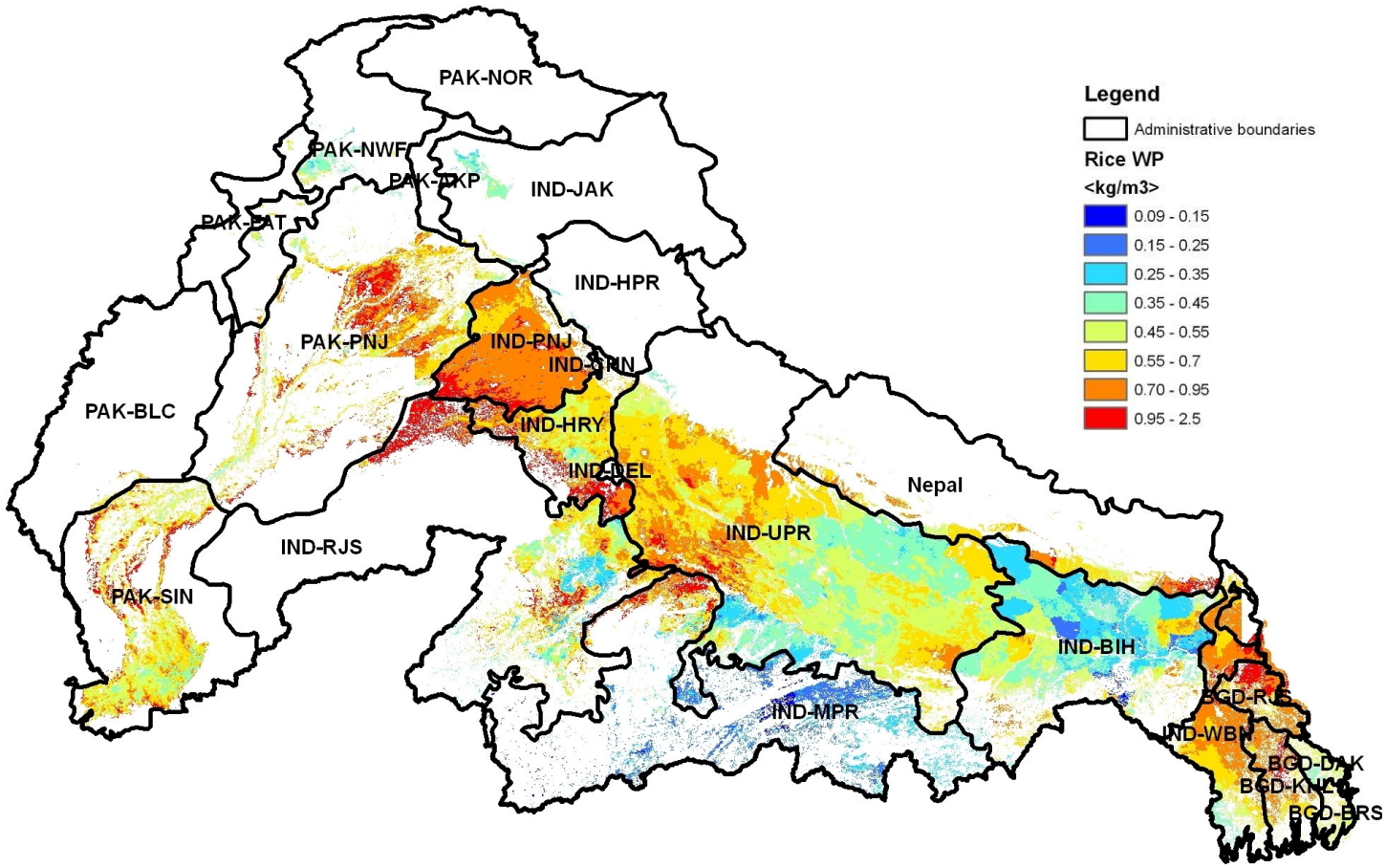
Seasonal actual ET map
(2005 Jun 10 – Oct 15)

Intro.
Data
LULC
Prod.
Water
Results
Plan

llenge Program on
R & FOOD

Water Productivity Maps

Rice productivity (kg/m^3)



Mean	AVG	SDV	Min	Max
0.618	0.618	0.306	0.09	2.5

Introd.
Data
LULC
Prod.
Water
Results
Plan

Water Productivity Maps

Rice productivity (kg/m^3)

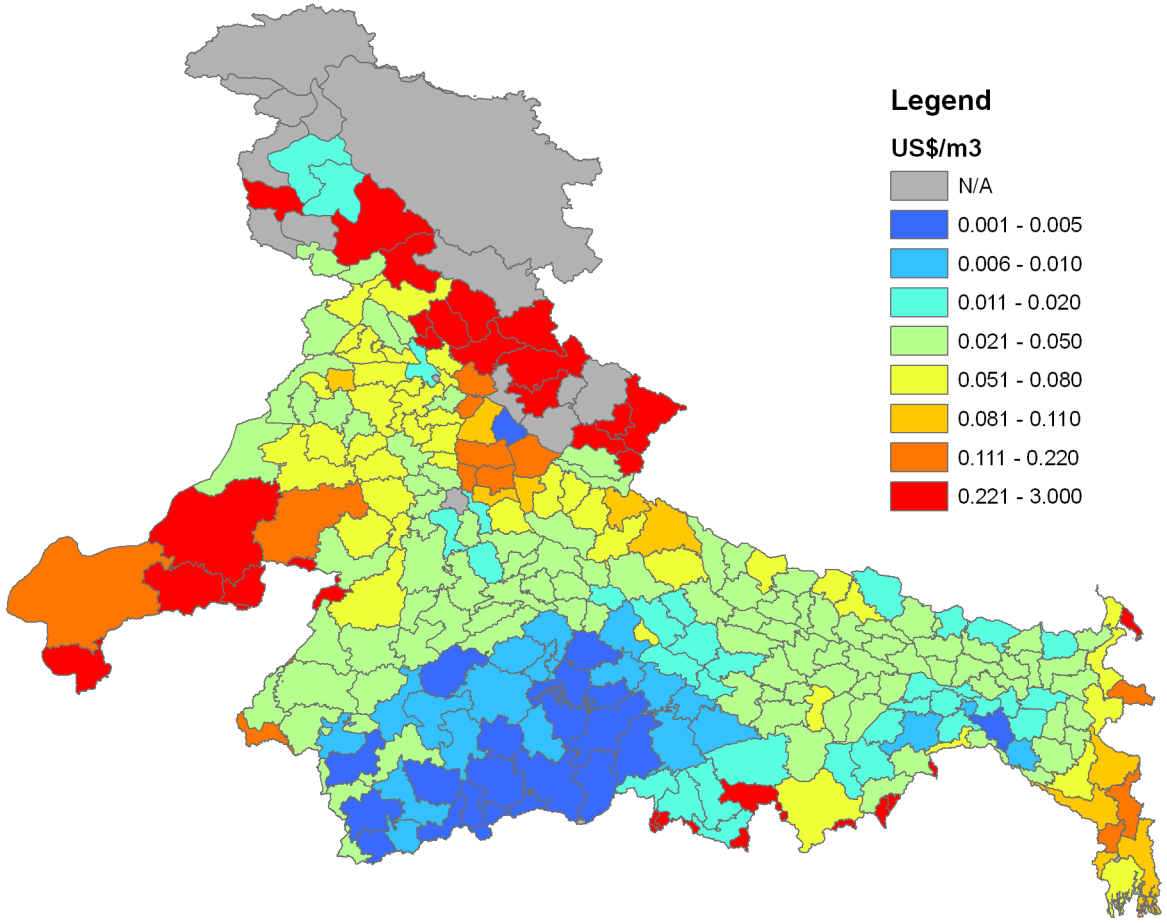
Rice water productivity for 4 major IGB countries (unit: kg/m^3)

Country	ADMIN_NAME	WP_MEAN	Country	ADMIN_NAME	WP_MEAN
Bangladesh	Chittagong	0.445	Pakistan	North-west Frontier	0.451
Bangladesh	Dhaka	0.496	Pakistan	FAT	0.525
Bangladesh	Barisal	0.533	Pakistan	Azad Kashmir	0.580
Bangladesh	Khulna	0.796	Pakistan	Baluchistan	0.657
Bangladesh	**Rajshahi**	**0.856**	Pakistan	Sind	0.732
			Pakistan	**Punjab**	**0.755**
Average		**0.625**	**Average**		**0.617**
Nepal	Lumbini	0.542	India	Madhya Pradesh	0.393
Nepal	Sagarmatha	0.556	India	Himachal Pradesh	0.407
Nepal	Janakpur	0.578	India	Bihar	0.408
Nepal	Bagmati	0.583	India	Jammu & Kashmir	0.430
Nepal	Gandaki	0.607	India	Uttar Pradesh	0.560
Nepal	Seti	0.699	India	West Bengal	0.718
Nepal	Bheri	0.713	India	Rajasthan	0.720
Nepal	Rapti	0.715	India	Haryana	0.746
Nepal	Narayani	0.754	India	**Delhi**	**0.818**
Nepal	Mahakali	0.792	India	**Punjab**	**0.833**
Nepal	**Kosi**	**0.904**			
Nepal	**Mechi**	**0.964**			
Average		**0.701**	**Average**		**0.603**

International Water Management Institute
allenge Program on
ER & FOOD

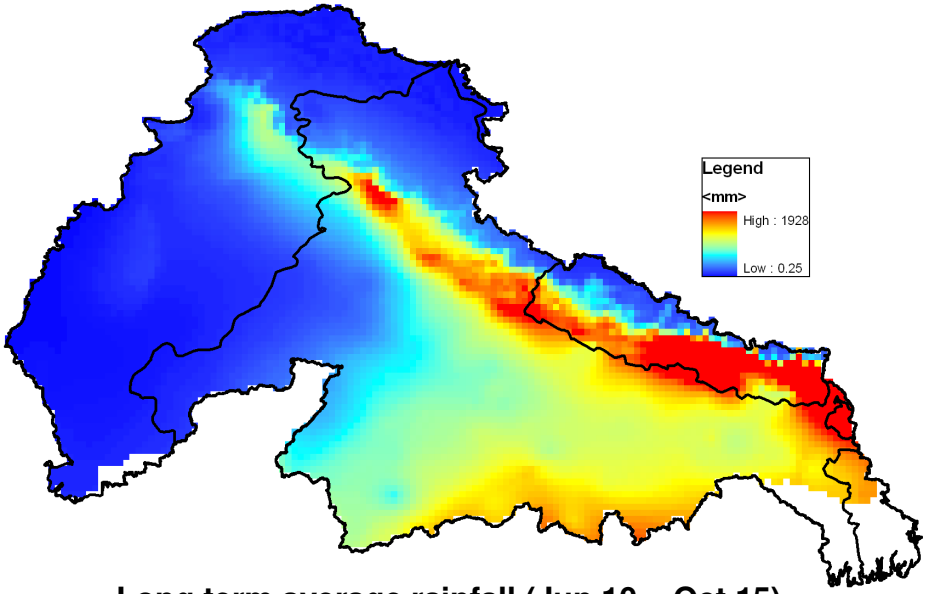
Water Productivity Maps

Crop water productivity (US$/m^3)

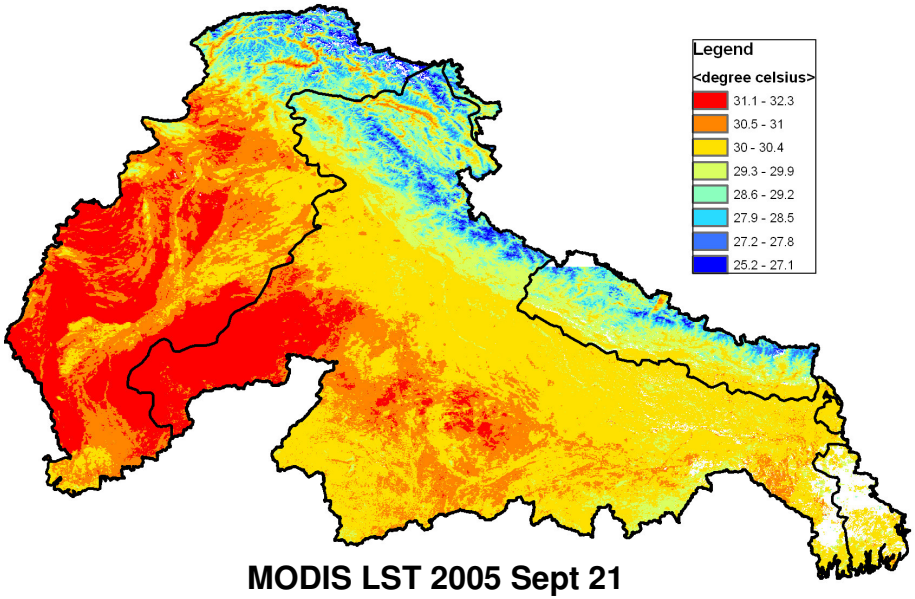


Crop WP varies significantly to rice WP although rice is the predominant crop in Kharif season

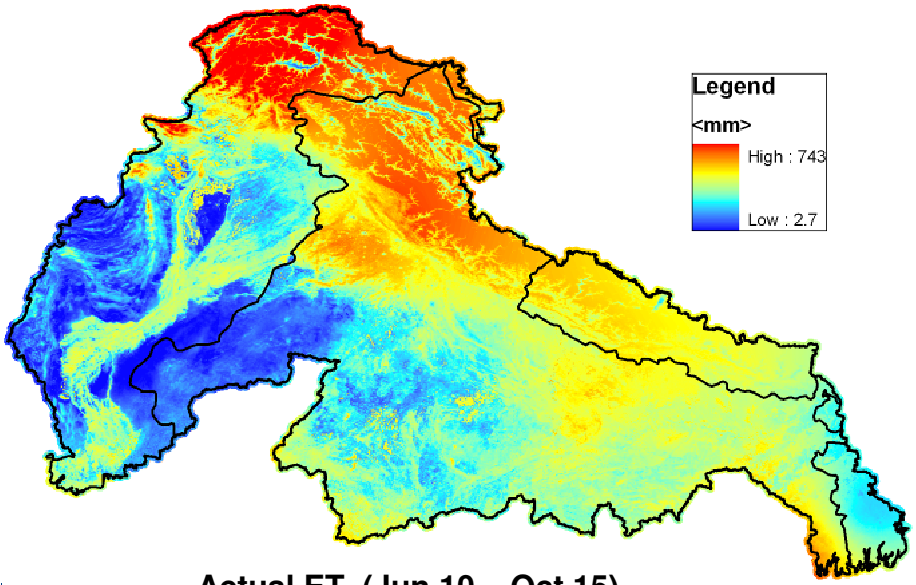
WP, ET and climate conditions



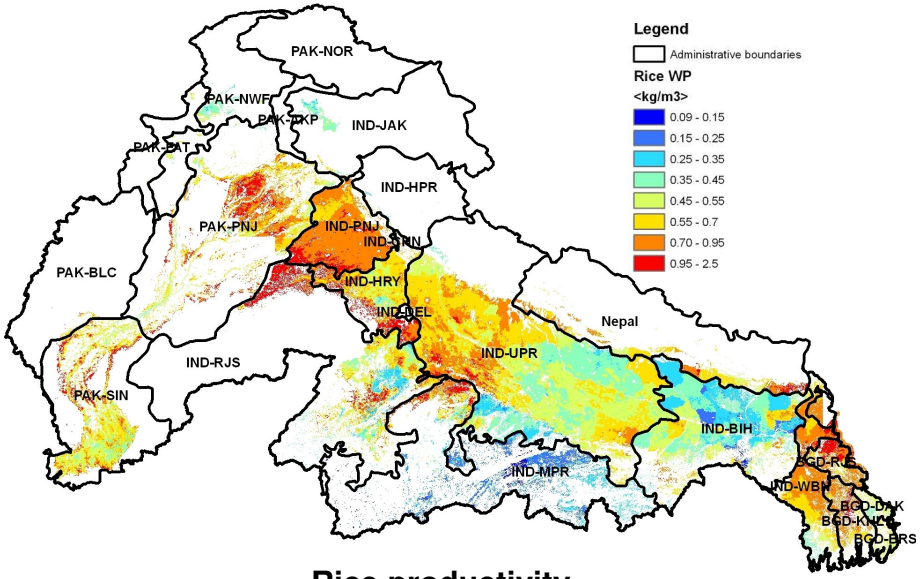
Long term average rainfall (Jun 10 – Oct 15)



MODIS LST 2005 Sept 21



Actual ET (Jun 10 – Oct 15)

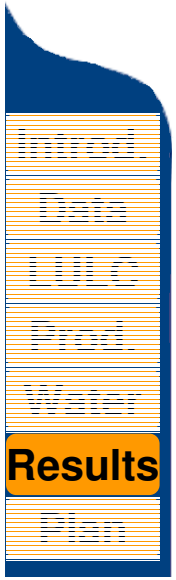


Rice productivity

Water Productivity Maps

Preliminary findings:

1. Basin average evapo-transpiration (328mm) is close to long term average precipitation (323mm) for the rice growing period;
2. Water productivity in Indo-Gangetic river basin is generally low, meaning great scope for improvement;
3. Significant variability exists across fields and regions. General decline from North-west to South-east could be observed;
4. The variability shows no direct relationship with climate conditions, implying the significance of irrigation;
5. Sugarcane, pulses and millet make significant contributions to the overall productivity of water.

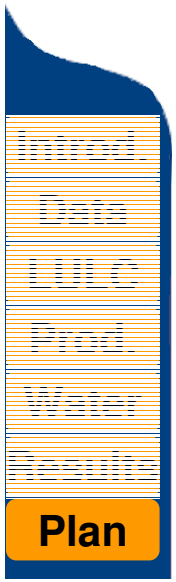


Work Plan for 2009

2008 – basin water productivity assessment (done)

2009 – Sub-basin analysis

1. ET and yield mapping using higher resolution Landsat images to study water consumption pattern and yield distribution;
2. Agro-hydrological modeling
3. Scaling up to basin
4. Write up



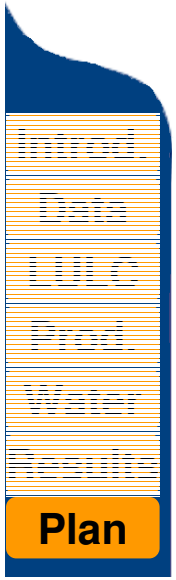
Work Plan for 2009

1. ET and yield mapping using higher resolution Landsat images to study water consumption pattern and yield distribution;

   Same approach as conducted in 2008

   However,

   It provides better spatial resolution maps to separate crops, agricultural and non agricultural water use for command areas, and provide unique yield map for model calibration.

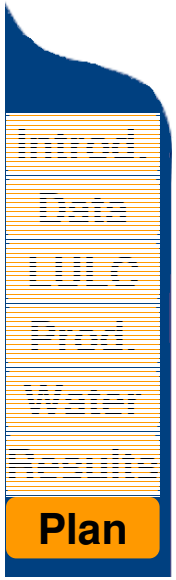


Work Plan for 2009

2. Agro-hydrological modeling using OASIS performance assessment and strategic planning tool.

- ***Planning level model – rapid assessment of strategic options for integrated Irrigation water management***
  - **Structural interventions** (reservoirs, irrigation and drainage canals…);
  - **Alternative water management practices** (water delivery, reservoir operation, surface-ground water conjunctive use…);
  - **Water availability changes** under climate change and competitive water use situation;
  - **Land use and cropping pattern changes**.

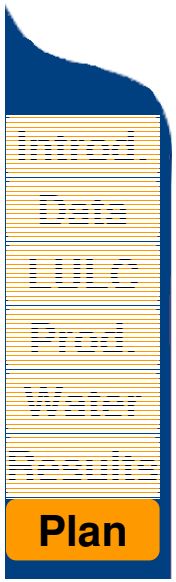
- ***Emphasis on water balance***
  - Water balance components (inflow, outflow, depletion…);
  - Diversion;
  - sources and benefits of depletion;
  - fate of return flows (non-consumed water).



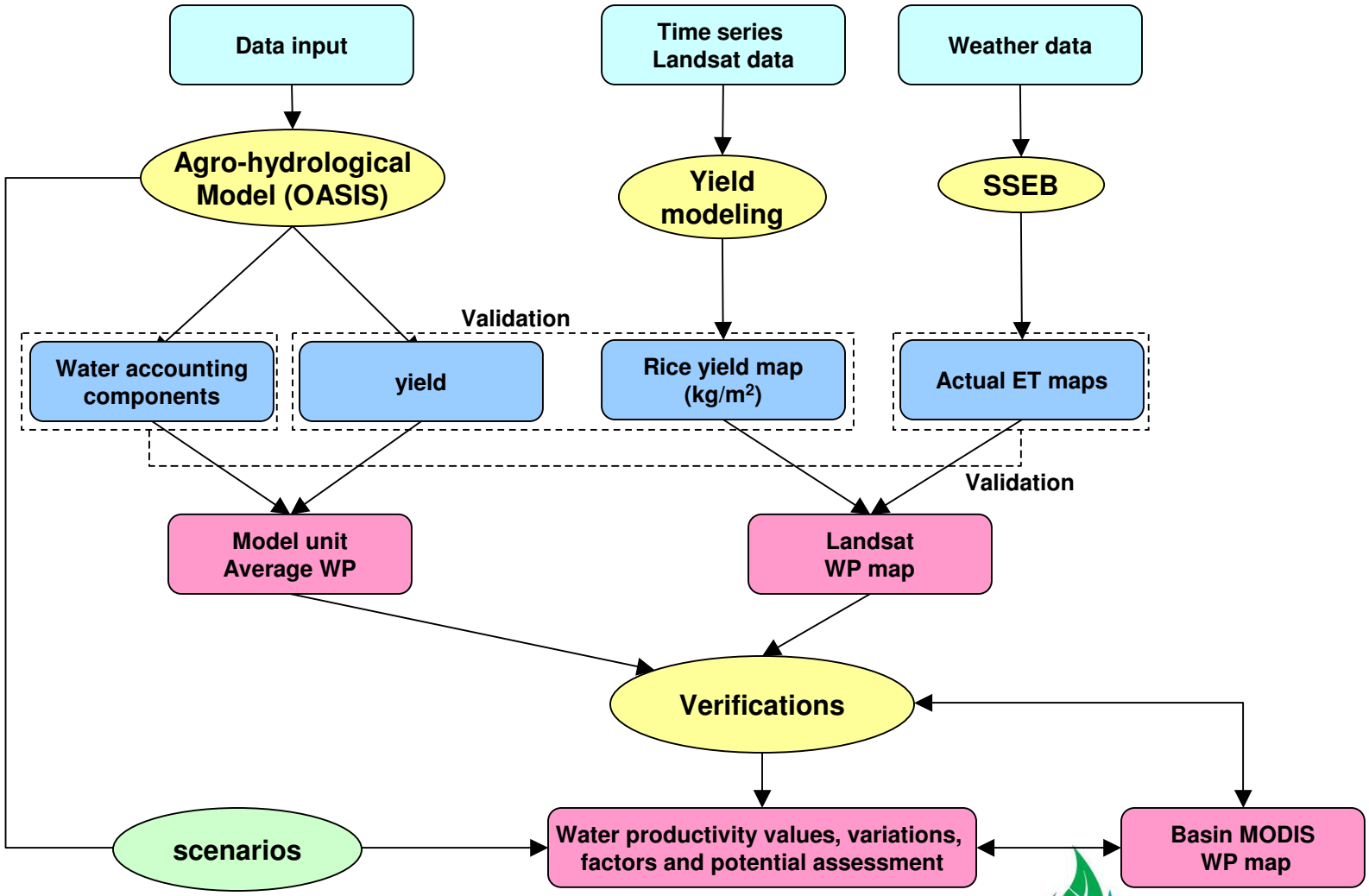
Work Plan for 2009

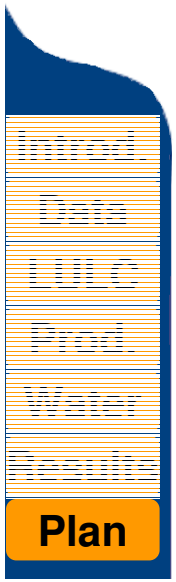
2. The modeling exercises help to to address:

   - ***(sub-) surface water cycling processes under various water demand – supply scenarios;***
   - ***crop responses to the water, and causes for yield and WP;***
   - ***System potential (more yield and/or less water diversion);***
   - ***Possible interventions.***



Sub-catchment modeling and links to basin WP assessment





Work Plan for 2009

	Tasks	*Activity*	Date	*Output*
1	Write up for 2008 works	▪ arranging outputs ▪ draft a paper for submission	31 Mar 2009	Paper for submission
2	Sub-catchment data collection and pre-processing	▪ ground data collection ▪ Landsat images download and normalization	31 Jul 2009	Data base for BFP-IGB sub-catchement
3	RS based WP analysis	▪ Rice yield modeling ▪ Rice productivity map ▪ Accuracy assessment ▪ Reference ET calculation ▪ ET mapping based on reference ET and Landsat LST data ▪ WP map	31 Aug 2009	ET map, Rice yield map, WP map
4	Model setup and calibration	▪ System layout conceptualization ▪ Input data ▪ Calibration using ground and RS data	31 Aug 2009	Model setup
5	Baseline performance assessment	▪ Supply – demand analysis ▪ Water consumption analysis ▪ WP assessment ▪ Scope for improvement	30 Sept 2009	System water balance, WP indices
5	Scenarios analysis	▪ analyze and identify scenarios ▪ Factors evaluation ▪ Intervention assessment	15 Oct 2009	Factors, local intervention recommendation
6	Scaling up	▪ Identify basin and sub-basin WP link, ▪ Identify common factors for both scales ▪ Basin intervention recommendation	31 Oct 2009	Basin intervention recommendation
9	Final report		31 Dec 2009	report
10	1-2 Scientific papers	Papers submitted	31 Dec 2009	papers

Results

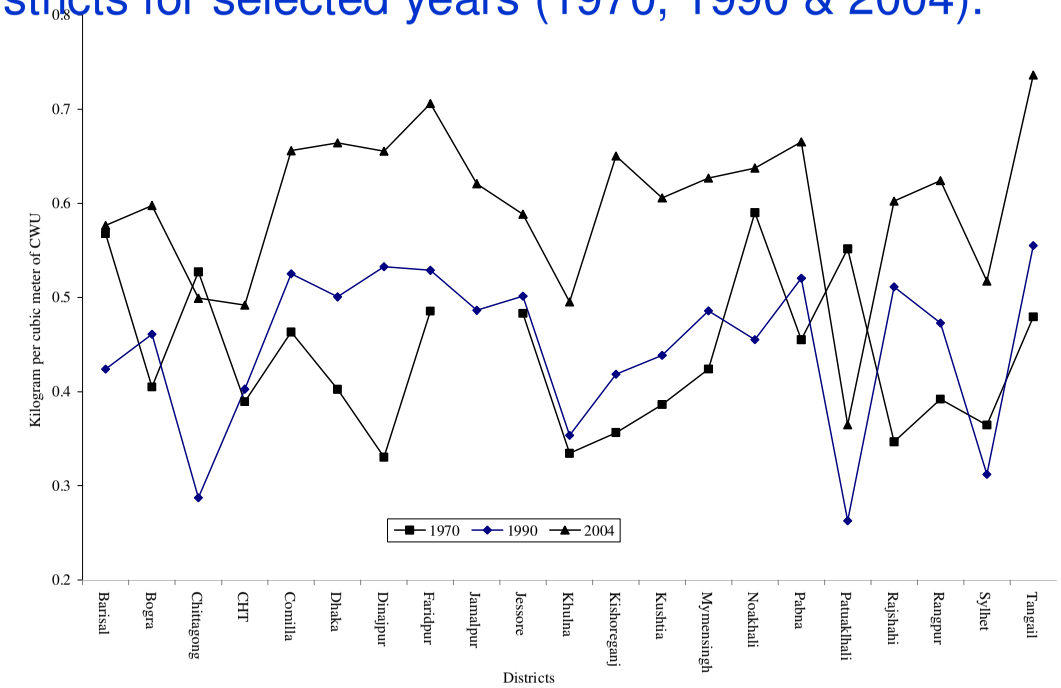
Plan

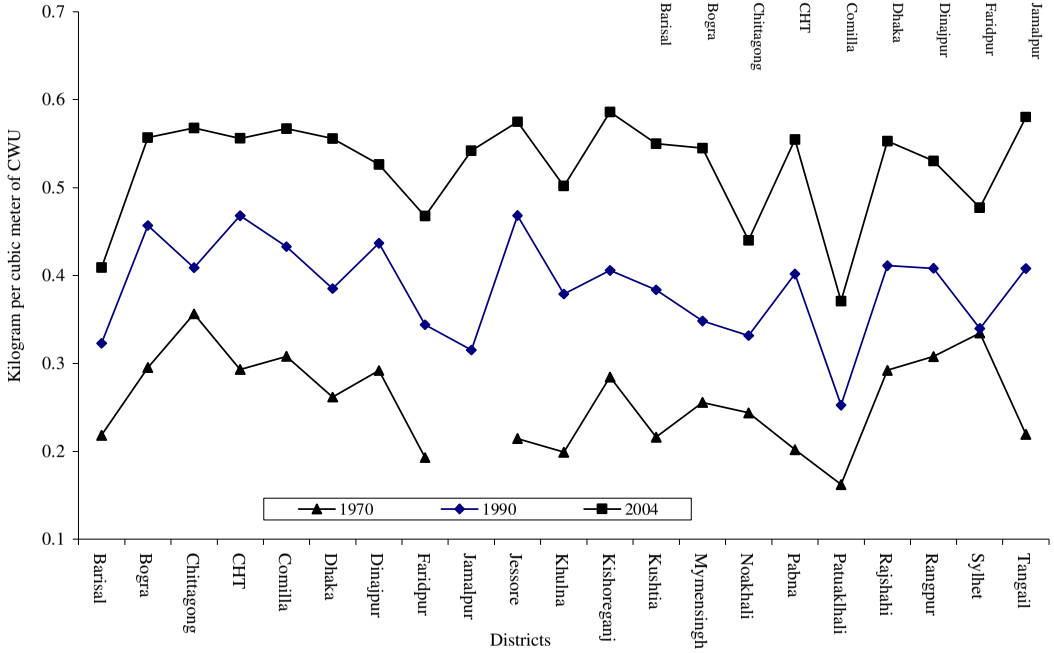
CGIAR Challenge Program on WATER & FOOD

International Water Management Institute

Levels of water productivity of kharif and rabi rice crops for Bangladesh districts for selected years (1970, 1990 & 2004).

Rabi crop: Rice





Kharif crop: Rice

CGIAR Challenge Program on WATER & FOOD