Land use Changes in India's IGP: Contribution of Economics and Climate

(Drawn from FASAL model)

*Presented at "**International Workshop On Land Cover/Land Use Changes, Forestry, and Agriculture in South/Southeast Asia**"*
8, 9, 10th August, 2022 at Cambodia.

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FASAL Model from IEG:

- State level forecasts of Area (A) and Yield (Y) of crops with confidence intervals-
  - periodic submissions of forecasts from model estimates to MoA&FW, GOI
- Econometric modelling for supporting and complementing Remote Sensing (RS)
- Validation of Field estimates
- Can explain the reasons for variations in Area and Yield of crops

FASAL TO RTISA:

- **Partnership** of IEG (eco model), ISRO -later MNCFC (RS), and IMD (agromet-model) under umbrella supervision of DES, MOA&FW.
  - Submission (forecast A & Y) **in early season** (F0 F1) and also end season for assessing model
  - Major crops in main growing states in two broad seasons
  - Forecasts based on econometric model (prices/costs) corrected for in-season and past rainfall (storage).
- **Transition to RTISA from 2019 (September)-a milestone**
  - **More frequent** (monthly) submission,
  - Equation more **hybrid**
  - Use of **maps** of crops, weather, river basins, interventions-greater attention to water.
- Expansion of coverage
  - Kharif or Monsoon crops (13): Rice(C), Bajra (M), Jowar (M), Maize (Coarse C), Arhar (Pl), Moong(Pl), Urad (Pl), Groundnut (OS), Soybean (OS), Castor Seed (OS), Cotton(Cash), Sugarcane (Cash), Jute (Cash) Rabi or Winter/Summer crops (11): Rice (C), Wheat (C), Jowar (C), Maize (Coarse C), Barley ©, Moong (Pl), Urad (Pl), Masur (Pl-Lentil), Gram (Pl), Groundnut (OS), Rapeseed Mustard (OS)
  - Coverage towards **Minor producing states**
- Outlook from weekly CWWG meetings, frequent consultations and presentations with Senior officers
  - **Explain equations and factors for production/acreage variations**
  - Showing **performance**

India's Crops:

- Green Revolution- **Wheat and Rice** emphasis
  - Rice farming labour intensive and tedious, wheat farming more mechanized
  - Considered as staples- food security
  - India among largest producers- Self sufficiency- exports, public distribution (NFSA)
  - Enjoys Minimum Support Price (MSP) and Public Procurement as incentive for food production.
  - Susceptible to Climate Change- Temperature and Rainfall
  - **Traditional bastion of Rice is East but now spread to west- across all north India, Wheat concentrated in west**
- Coarse cereals, oilseeds, pulses- (modest in water demand)- ideal for drier western region
- Rice & Wheat (IGP): 32% of India's Gross Cropped Area: Haryana, Gujarat, Rajasthan, Punjab, Madhya Pradesh, Chhattisgarh, West Bengal, Jharkhand, Odisha, Bihar, Uttar Pradesh.

Rice

- Primarily Khari, Rice needs humidity, plenty of rainfall Hot weather, June to October (flexible with early and late sowing, double cropping of kh rice and **variation of calendar across states)**
- **Water demanding** (3000-5000 litres per kg of rice), labour (female labour) intensive.
- 3/4th of global rice is produced by **raising seedling in nursery then transplanted to puddled fields.**
  - Puddling causes methane emission => search for alternative methods like Direct Seeding(DS), Mid Season Wetting(MSW), System of Rice Intensification (SRI).
  - Need for chemical **nitrogenous fertilizers** (Urea)-also possible to harness bio-fertilizer from water logged soil.

Rice Production Scenario in India (Kg. per Capita)

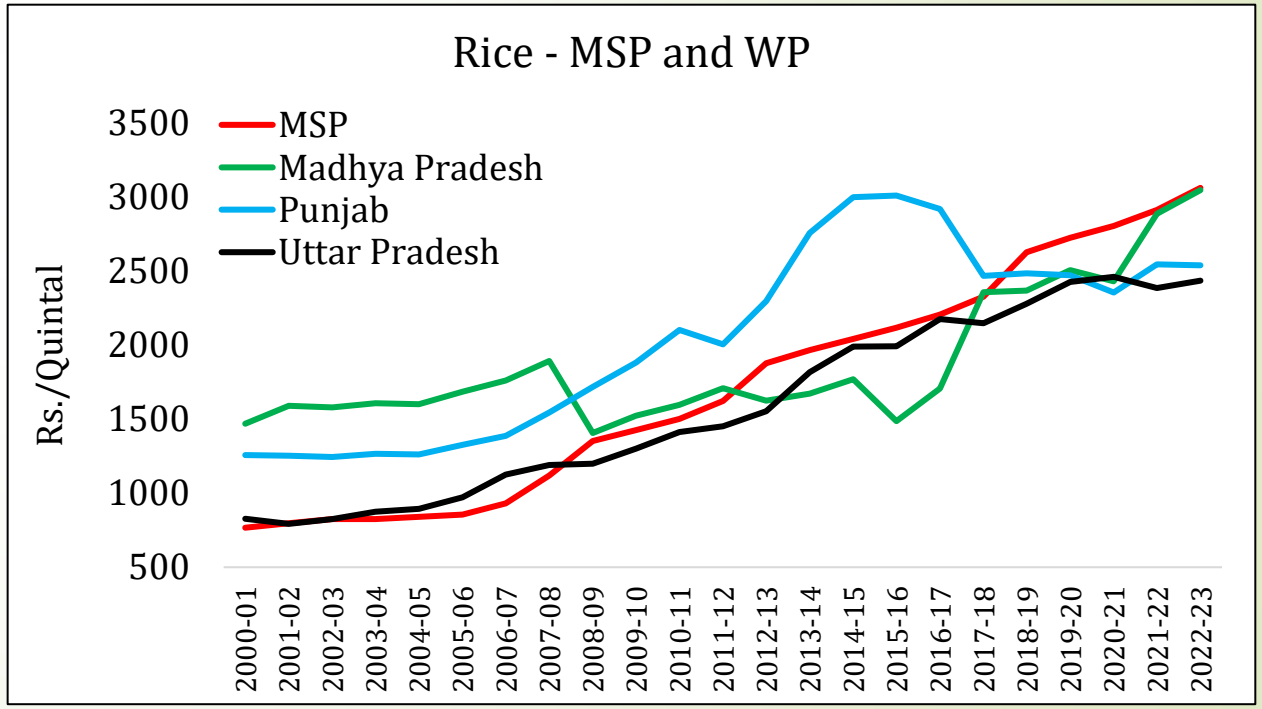
	Production	Consumption	Procurement	Stocks	Exports	Population (Billion)
1992-93	86.59	78.66	15.38	10.22	0.83	0.93
2000-01	80.43	74.89	20.14	19.59	1.45	1.06 (1.14)
2011-12	84.22	68.25	28.03	20.46	5.74	1.25 (1.18)
2019-20	86.58	-	38.06	13.39	6.95	1.37 (1.09)

Note: Consumption data is not available for 2019-20 (Jha, 2019). Figure in parenthesis is ratio to previous year.
Source: Computed from production data of DES (Website), Consumption data of NSSO (Various).

Economics: MSP and Market Price (WP) of Rice

- Land allocation between Rice and substitute crops in the region in the season
- Substitute crops differ among states depending on agro-climatic conditions
- Market price generally higher than support price and rise faster but came closer recently

States	Substitute Crops
Haryana	Cotton
Punjab	Cotton, CC, Horticulture
Madhya Pradesh	Oilseed, Pulses, Horticulture
Uttar Pradesh	SC, CC, Pulses, Horticulture



Note: WP: 2022-23 figure is 1st Quarter price only

Wheat

- **Moderate Water,** labour (female labour) demand.
- Need for timely controlled water, excess water harmful
  - Irrigation
- Rabi crop in winter Oct-November to March-April
- Cool climate ideal but need for sunshine and temp at specific growing stages
- Late harvest- exposure to heat-Timely sowing important
  - Long winter good

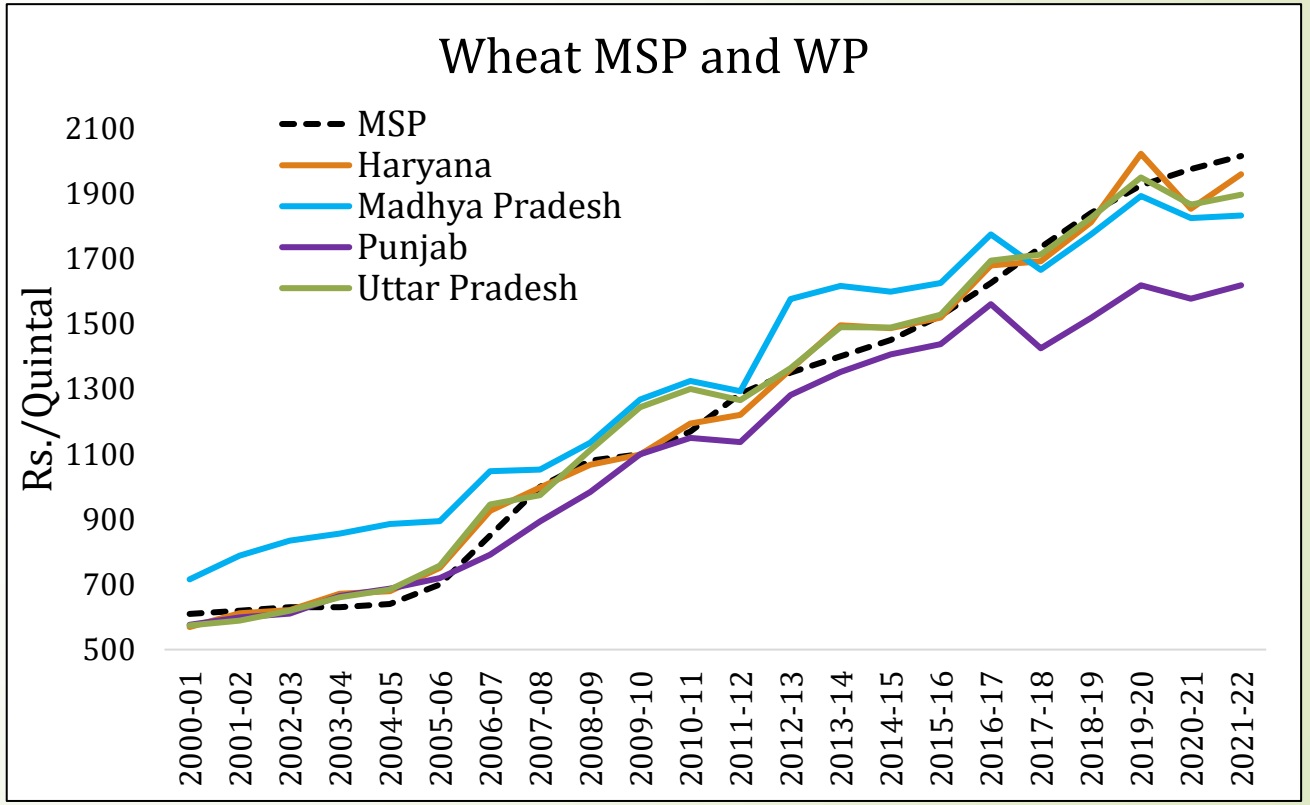
Wheat Production Scenario in India (Kg. per Capita)						
	Production	Consumption	Procurement	Stocks	Exports	Population (Billion)
1992-93	64.52	53.74	13.83	3.74	0.00	0.93
2000-01	65.95	55.01	15.47	16.25	1.05	1.06 (1.14)
2011-12	75.89	52.43	22.67	17.23	0.60	1.25 (1.18)
2019-20	78.94		24.98	19.85	0.16	1.37 (1.09)

Note: Consumption data is not available for 2019-20 (Jha, 2019). Figure in parenthesis is ratio to previous year.
Source: Computed from production data of DES (Website), Consumption data of NSSO (Various).

Economics: MSP and Market Price (WP) of Wheat

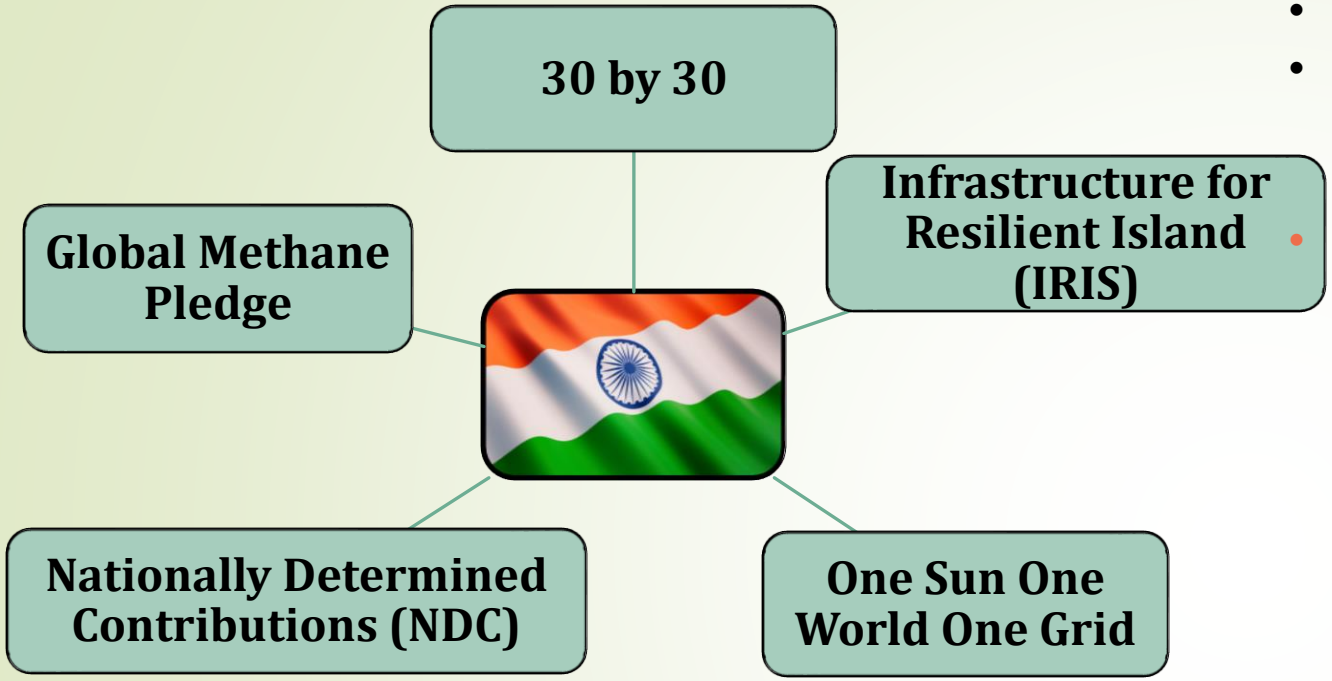
- Mostly north and northwest India. MP.
- Land allocation **between Wheat and substitute crops** in the region in the season
- Substitute crops differ among states
- Not all and always market prices are lower than support price, crossing. PJ wheat price falling lowest

States	Substitute Crops
Haryana	Pulses, Oilseeds
Punjab	Oilseeds, Sugarcane, horticulture
Madhya Pradesh	Pulses, Oilseeds
Uttar Pradesh	Pulses, Oilseeds, Coarse Cereals, Horticulture



Importance of Climate Change and Linkage with Farming

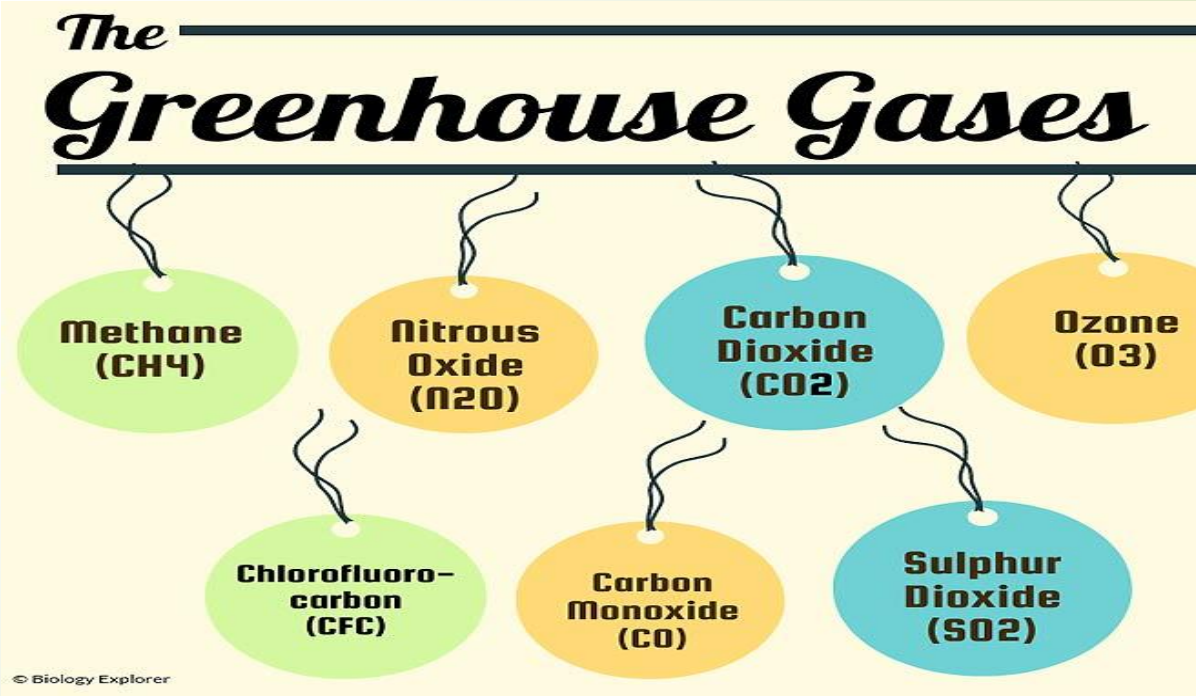
Climate Meets



Methane

- Byproduct of biomass, agriculture and livestock
- Takes a decade to convert to CO_2 or get cycled out Unlike CO_2 which persists for centuries in atmosphere,
- **Extraordinarily powerful heat absorber, causing about 80 times as much warming as the same amount of carbon dioxide.**

- Land use for cultivation **historically displaced forests, the critical sink of carbon**
- Modernization linked it to **both methane and nitrogenous emissions** HYV seeds –water chemical fertilizers.
- **Rice- major source of methane.**



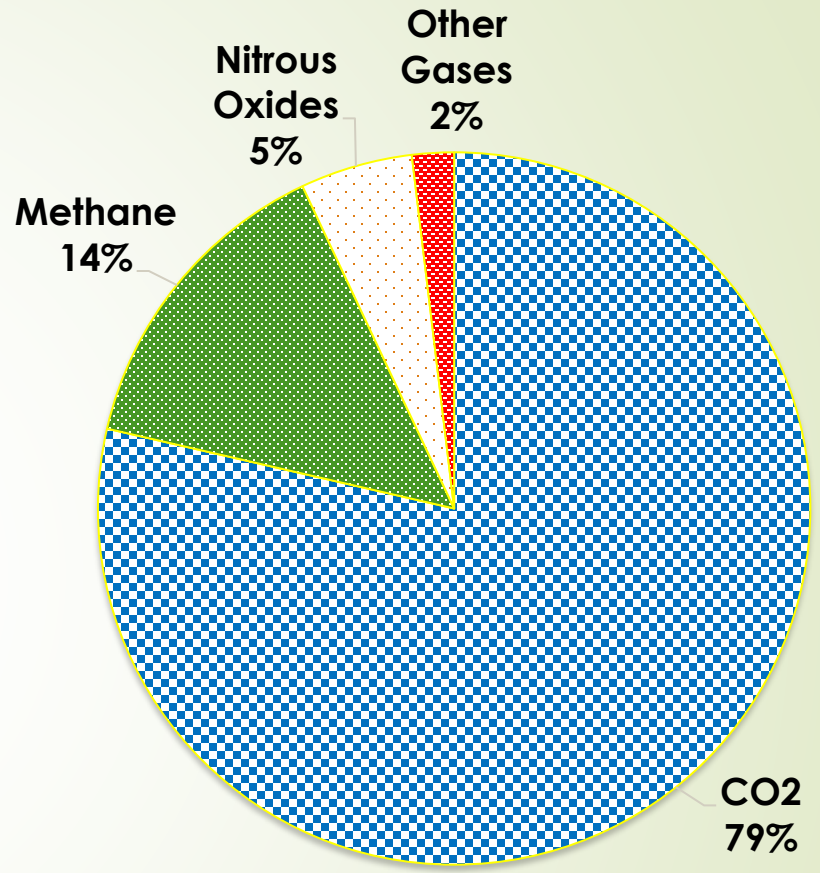
Land use and Global Warming in India

Sources in India:

- **Crop farming 14% of GHG emission**
- Other sources-
  - Livestock (14.5%)
  - Animal Products
  - Transport and Vehicles with Power Plants
  - Industrialization

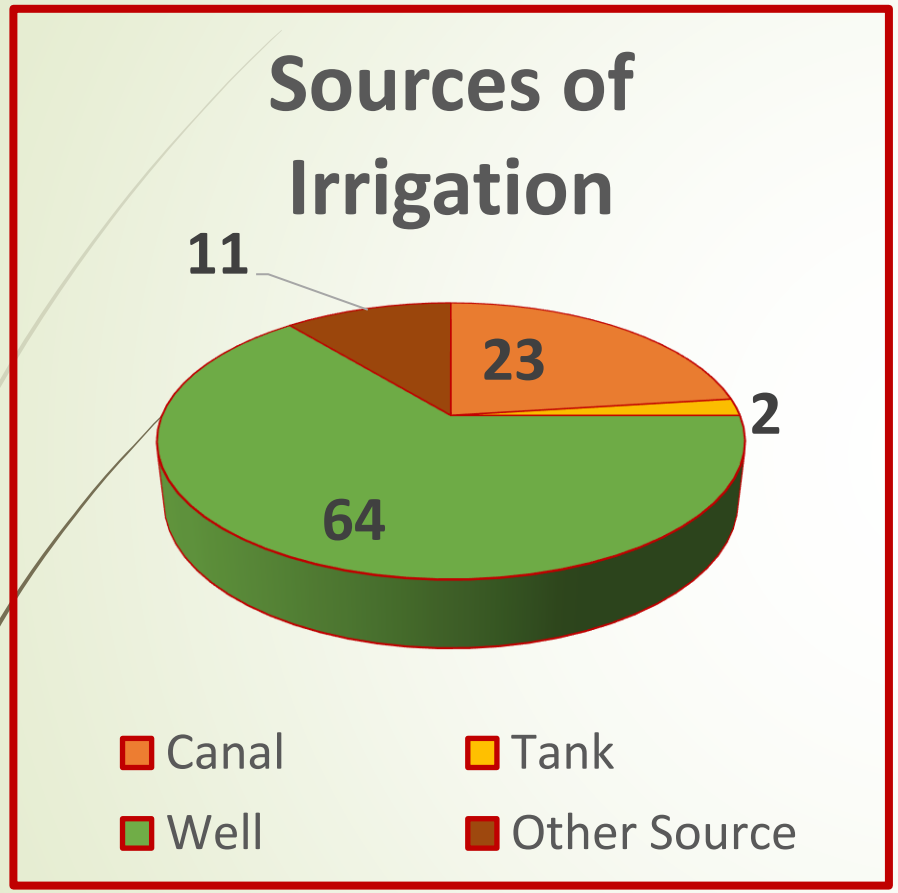
- **Agriculture: 63% Net sown area under commercially used land (CU)**
- Share of Rice, Wheat in GCA=38%, NSA=55% in India
- Rice, Wheat- Nitrogen and also CO_2 (crop burning), Rice- Methane,
  - Need for policy in balancing emission reduction, water saving ecological practices and food security.

Total Agricultural Emission



- **Farming:**
  - Livestock (54.6%)
  - Nitrous Oxide from Soils (19%)
  - Anaerobic rice cultivation in continuous flooded field(17.5%)
  - Burning of Crop Residuals (2.1%)

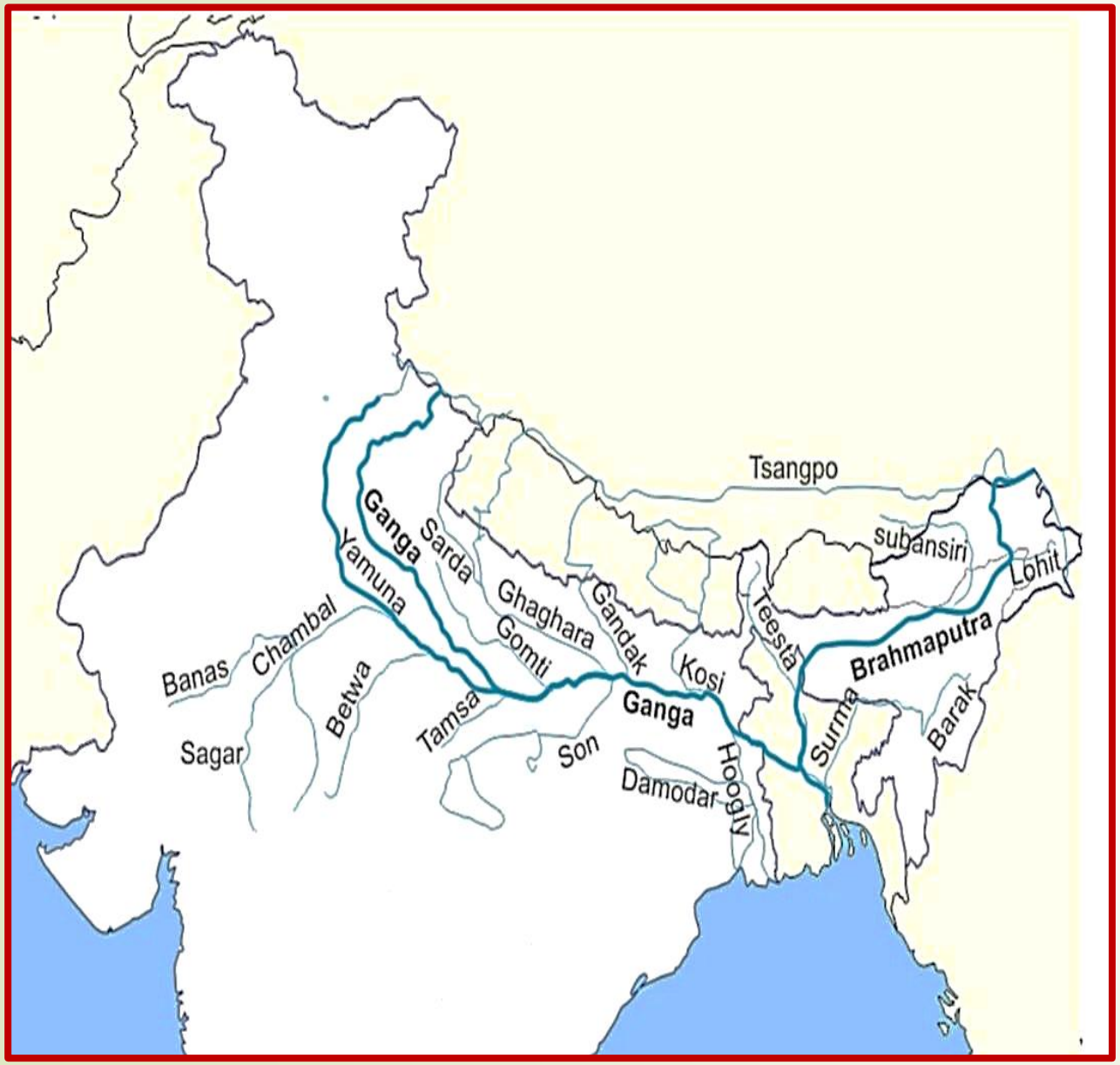
Water Scenario and River Basins



- Integrated basins- Importance of Rainfall: **past and present, MET level, proximate, upstream and water sharing states**.

- Major rivers of North India: Indus and Ganga, their tributaries and sub-tributaries. Other independent rivers in Rajasthan Gujarat
  - Proximate Basins
  - hydrologically linked basins.
- **Human interventions-** dams, reservoirs, canals, spillways, hydel power-plants- water redistribution administratively
- Rainfall in the past and trans-boundary states (and countries).
  - replenishes reservoirs, tanks and groundwater
- 50% Net Sown Area/GCA irrigated by canals, wells, tanks and other sources.
  - Canals (40% in 1980) surpassed by wells (64% in recent years).
  - Wells powered by hydel energy.

Ganga River and Tributaries



- Origin- Uttarakhand, India
- Flows South East through **Uttarakhand, UP, Bihar, West Bengal to Bay of Bengal in West Bengal and Bangladesh-**
- Catchment- **Uttarakhand, UP, MP, Rajasthan, Haryana, Chhattisgarh, Jharkhand, Bihar, West Bengal & Delhi.**
- Tributaries and sub-tributaries- from **northern snows/rains:** Yamuna (largest), Bhagirathi, Kosi, Ghagra, Teesta, etc, eastern Himalayas: Bhramaputra and **central Indian plateau**: Chambal, Ken, Betwa, Hindon, Son, Damodar, also distributaries.
- Interventions- Tehri Dam, projects on Chambal, Rihand, Damodar, Ganaga canal, Yamuna Canal, Power plants, etc.

Indus River and Tributaries

- Origin- Tibetan highland of western China near Lake Mansarovar.
- Many tributaries from Ladakh (India) flowing to Afghanistan etc
- Flows southwest to Arabian Sea in Pakistan.
- 5 tributaries in India (Jhelum, Chenab, Ravi, Beas and Satluj), 3 for Indian irrigation (Ravi, Beas, and Sutlej).
- **Indus Waters Treaty with Pakistan(1960)**
- Interventions- Indus Valley Project (IVP), Guru Gobind Sagar (Bhakra Dam), Thein Dam, Indra Gandhi (IG) canal etc
- Catchment- **Himachal Pradesh, Kashmir, Rajasthan (western desert also), Punjab, Haryana**

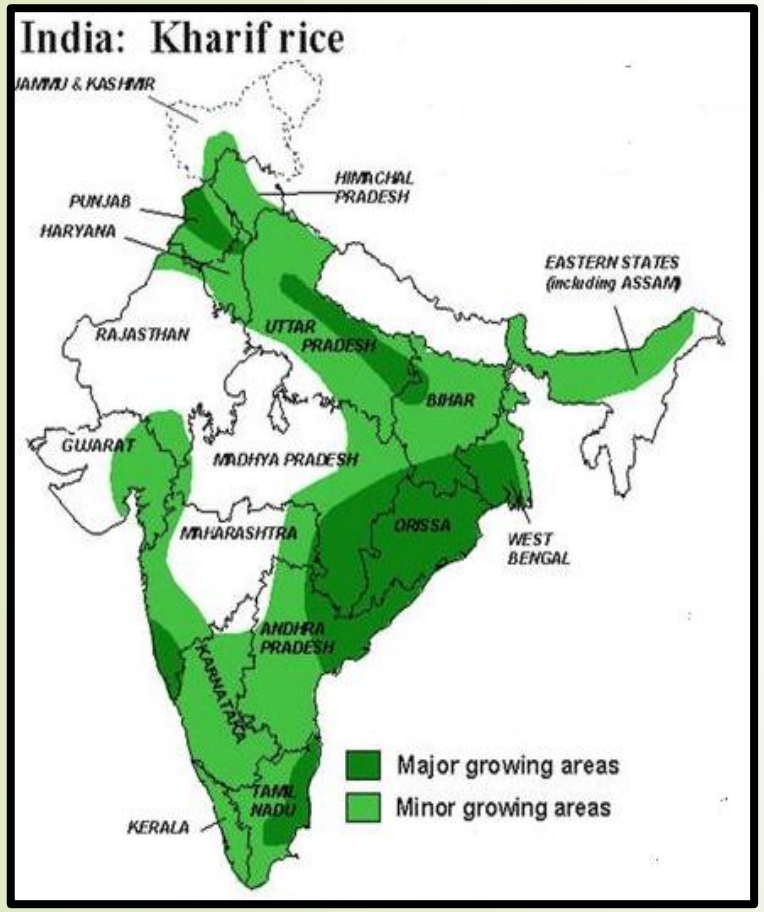
Objective

- To look at India's Land use in farming-**cropping pattern** changes with respect to **rice and wheat** acreage/yield changes in the recent times. Conducted in the backdrop of
  - evolving climatic conditions, this analysis takes a spatio-dynamic perspective of water specifically over the northern-western farm belt in the Indo-Gangetic plains (IGP): Climate change
  - Government policy for food security, diversification, trade and political economy
- To assess the **contribution of economic factors (prices) and weather** (rainfall distribution) to acreage/yield shifts from 2000 to 2019, a specific period as case study.
- Focus on North-west/Central India, specifically **4 states UP, MP, PJ and HR** where both rice and wheat grown.

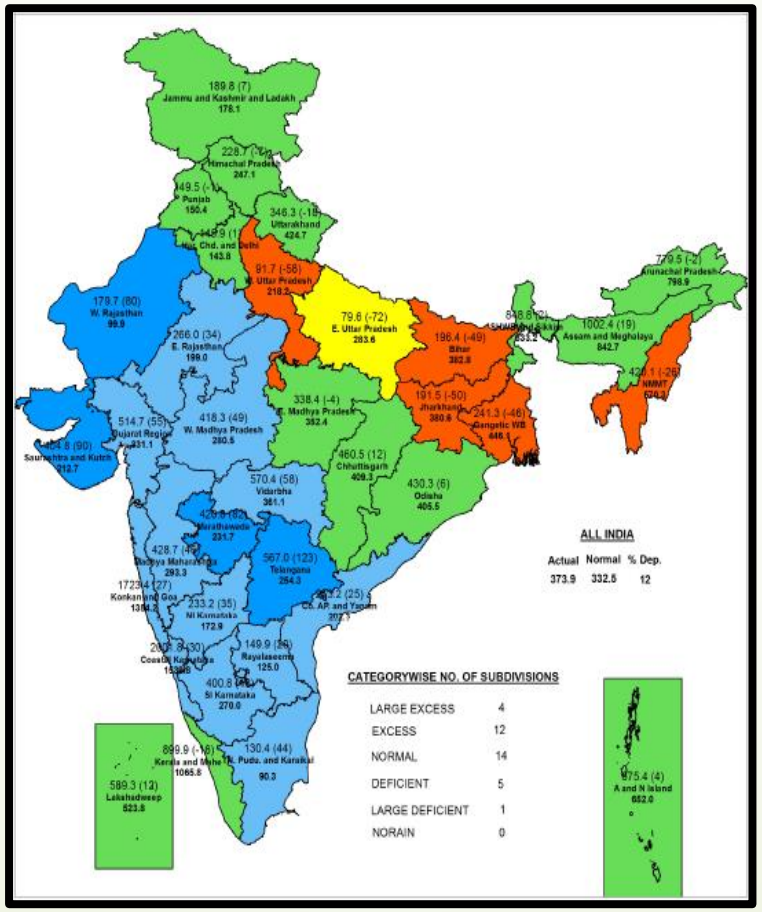
Methodology

(Quantitative and intensive use of crop cluster, river basin and weather maps)

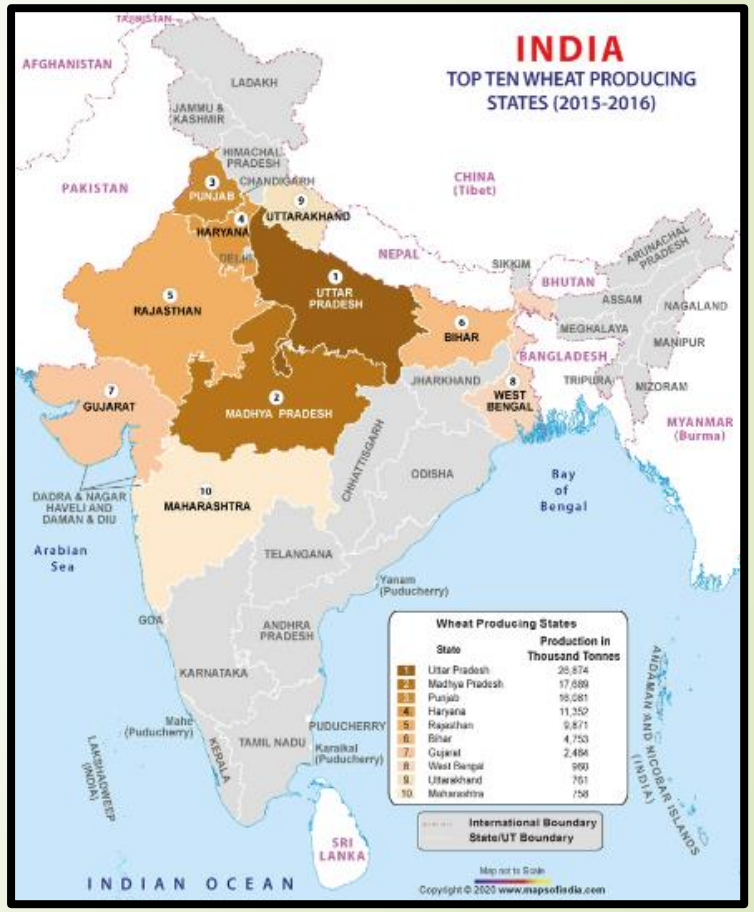
Major Rice growing Area



India Meteorological region: 36



Major Wheat growing Area



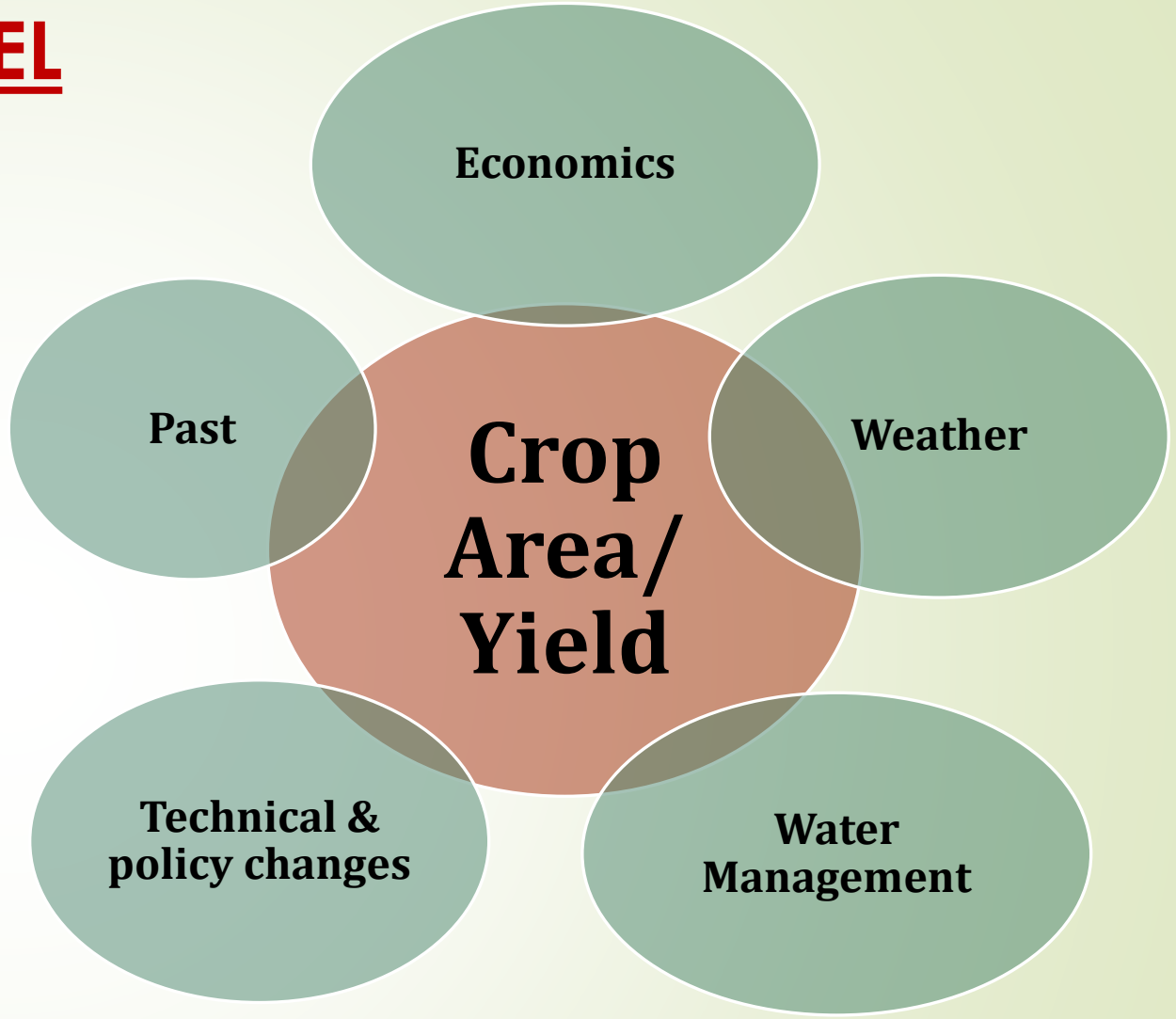
Data from Official Sources:

- Used rainfall data from 1990-91 to 2020- 2021.
- Crop acreage, yield and prices- (i) Rice, (ii) Wheat (iii) Coarse Cereals (Bajra, Jowar), (iv) Maize, (v) Pulses (Arhar, Moong, Urad), (vi) Oilseeds (Groundnut, Soybean), (vii) Cash Crop (Cotton, Sugarcane, Jute, Horticulture).
  - Bihar (BH), Madhya Pradesh (MP) and Andhra Pradesh (AP) underwent **bifurcations.**
  - For pre-2000 years, data for undivided MP (O) and Bihar (O) are reported for the older (O) states that included Chhattisgarh and Jharkhand respectively
  - Over the entire period, AP includes Telangana which was separated from undivided AP more recently in 2014.
- Considers post Green Revolution (1980) status.
- Model for acreage and yield of rice and wheat is estimated for 4 states in IGP
  - **Regression sample -2000-01 to 2019-20.**
  - **Both terminal years of regression happen to be years of normal monsoon.**

MODEL

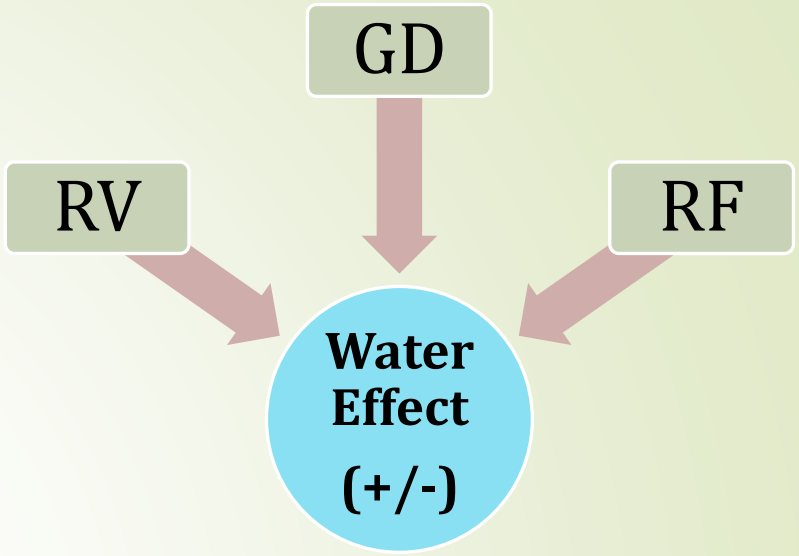
- ❑ Estimating in two stages: A & Y
- ❑ A*Y=Production
- ❑ Linear, squared rainfall and interactions.
- ❑ **All parameters statistically significant**

- EN, RF, RV, GD, IG, PT, TMP.
  - EN=Economic, RF=Rainfall, RV=water in Reservoirs in hydrologically linked METs, GD=depth of Groundwater, IG =Irrigation by sources in state, PT=Past trend, TMP= Temperature
- Economic incentives-
  - **Expected price- depends on MSP and past market prices**. Also price model to forecast.
  - Area: Relative to substitute crops: from crop calendar. Yield: relative to cost
  - Cost of inputs: NPK, Urea, DAP, Sulphur, PTD, ITD, Labour. (COC data also)
- GD and RV- water to supplement local seasonal rainfall
  - Utilization of water depends on the area under different sources of irrigation.
- **Interaction (INT) among water variables.**



- Crop calendars different among States- flexibility- delayed or early sowing possible

Water Resources



- More water can be beneficial or harmful (excess water/ diversion to water demanding crops/ poor drainage),
- METs: Meteorological Subdivisions- regions of **climatic homogeneity (IMD)**

Rainfall (delayed/early) Soil moisture effect	RF	**Pre-monsoon, monsoon and post-Monsoon** (local depressions, cyclones, western depressions) Rainfall of METs in study states/ neighbouring states/ upstream states	**Monthly:** January to November **Analysis:** Average, Coefficient of Variation and linear Time Trend
Reservoirs	RV	**Located in study state/ upstream states/ water sharing states**: Kh- May end, Ra- Sep end	**Total volume in one or more sets of Reservoirs in BCM**
Groundwater	GD	In METs of study states: Kh-May end, Ra-Aug end	The **depth (in metres)** averaged across constituent districts
Irrigation Soil moisture effect	IG	Study states- Year	Area under Canal, well, tank and others

Specification:

- **Diagnostic** are tested (Adj. R^2, t-stat, residual, signs, stability/Robust)
- **One period forward forecast is validated** with observed value. **Omitting of in-sample observations** for validation tried to avoid over-fitting (towards ML).
- **All parameters statistically significant** and satisfy intuitive and mathematical constraints.
- Check **for multicollinearity** (VIF), stationarity of error, robustness etc.
- **Programming for automatizing in process**

Contribution of variable Z_i to estimated acreage change (ΔY),

$$\Delta Y_i = (a_i \, X \, \Delta Z_i)$$

- $\Delta Z_i = Z_{i1} - Z_{i0}$, $\Delta Y_i = Y_1 - Y_0$
- With interaction variable (Z_i X Z_j), with a coefficient of a_{ij},

$$\Delta Y_i = [(a_i + a_{ij} \, Z_{j0}) \, X \, \Delta Z_i]$$

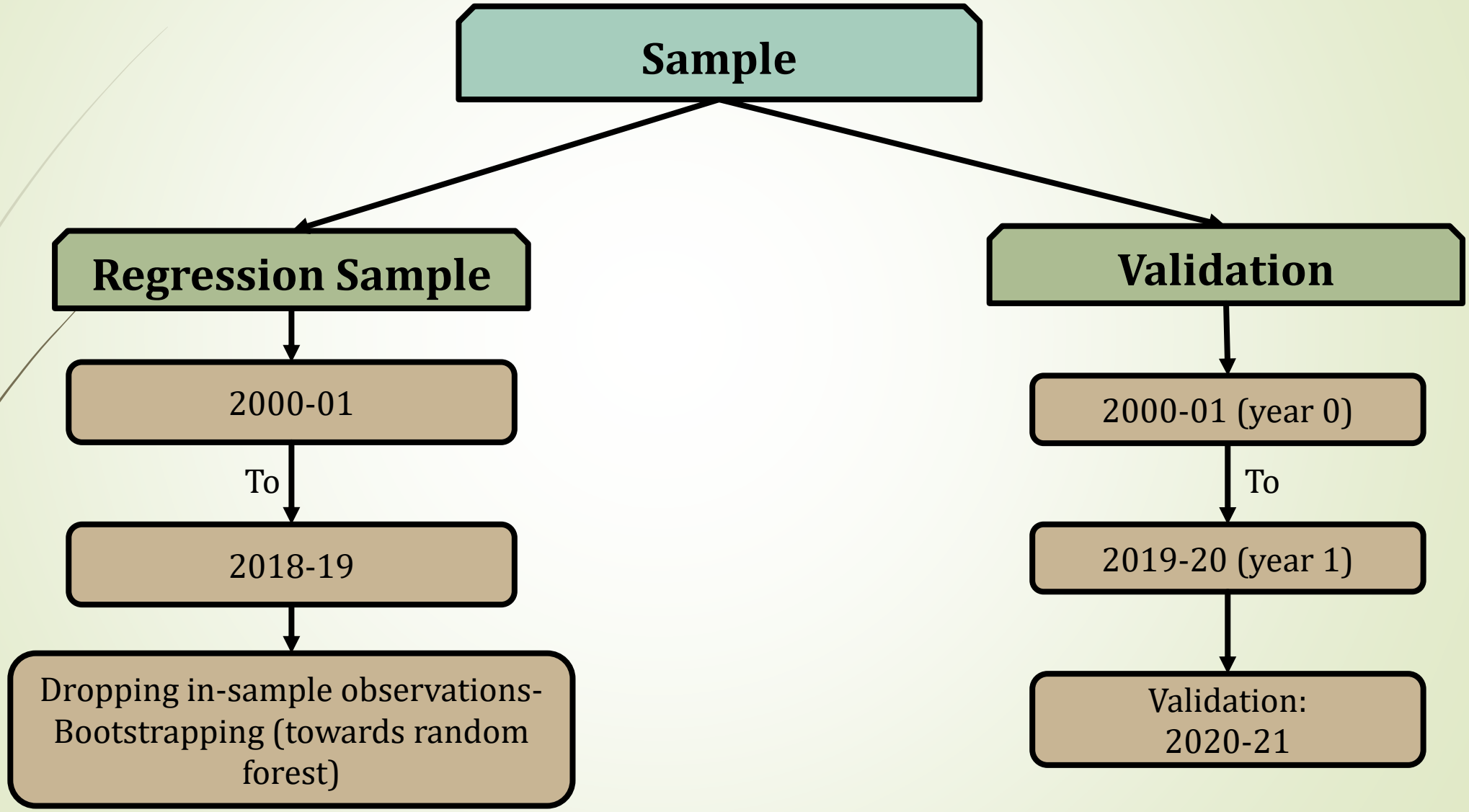
- Decomposition leads to a residual effect (ΔZ_{ij}) between the changes in either variable

$$\Delta Y_{ij} = [a_{ij} \, X \, (\Delta Z_i \, X \, \Delta Z_j)]$$

Computed:

1. Contribution of each Z_i,
2. the aggregate effect of the changes in each component including interactions and residual interaction effect of all changes add up to 100% (or -100% in cases of area decline).
3. For cases where the area declined, signs of contribution are reverse-adjusted to signify the direction of contribution towards the change in dependent variable.

Validation (Observed vs estimate) and stability (robustness)



Results Climate

Total Monsoon Rainfall (mm) :1991 – 2021

- Sum of average monthly rainfall of May to November
- Monthly distribution: Modal rainfall was either June-July or July-August.
- Source: Computed from IMD data, IMD (Website)

METs	May-Nov	METs	May-Nov	METs	May-Nov
CK	VH	BH	M	TP	L
KG	VH	EM	M	MT	L
AR	H	VD	M	RY	L
SW	H	CA	M	NI	L
AM	H	WM	M	WU	L
EH	H	GR	M	JK	L
GW	M	SI	M	ER	L
OD	M	TL	M	SK	D
UT	M	HP	M	PJ	D
CH	M	EU	M	HC	D
JH	M	MM	M	WR	D

Category	Rainfall Range (mm)	No. of METs
Dry (D)	< 600	4
Low (L)	600 – 800	7
Moderate (M)	800 -1500	16
High (H)	1500- 3000	4
Very high (VH)	>3000	2

Variability of Monsoon Rainfall CV (%) :1991 – 2021

Category	CV Range	No. of METs
High (H)	>30%	5
Medium (M)	20%-30%	15
Low (L)	<20%	13

METs	CV (%)	METs	CV (%)	METs	CV (%)
CK	L	BH	M	TP	L
KG	M	EM	L	MT	M
AR	H	VD	L	RY	M
SW	L	CA	L	NI	M
AM	L	WM	M	WU	M
EH	L	GR	H	JK	M
GW	L	SI	M	ER	M
OD	L	TL	M	SK	H
UT	M	HP	M	PJ	H
CH	L	EU	L	HC	H
JH	L	MM	M	WR	M

Source: Computed from IMD data, IMD (Website)

Time Trend of Monsoon Rainfall:1991 – 2021

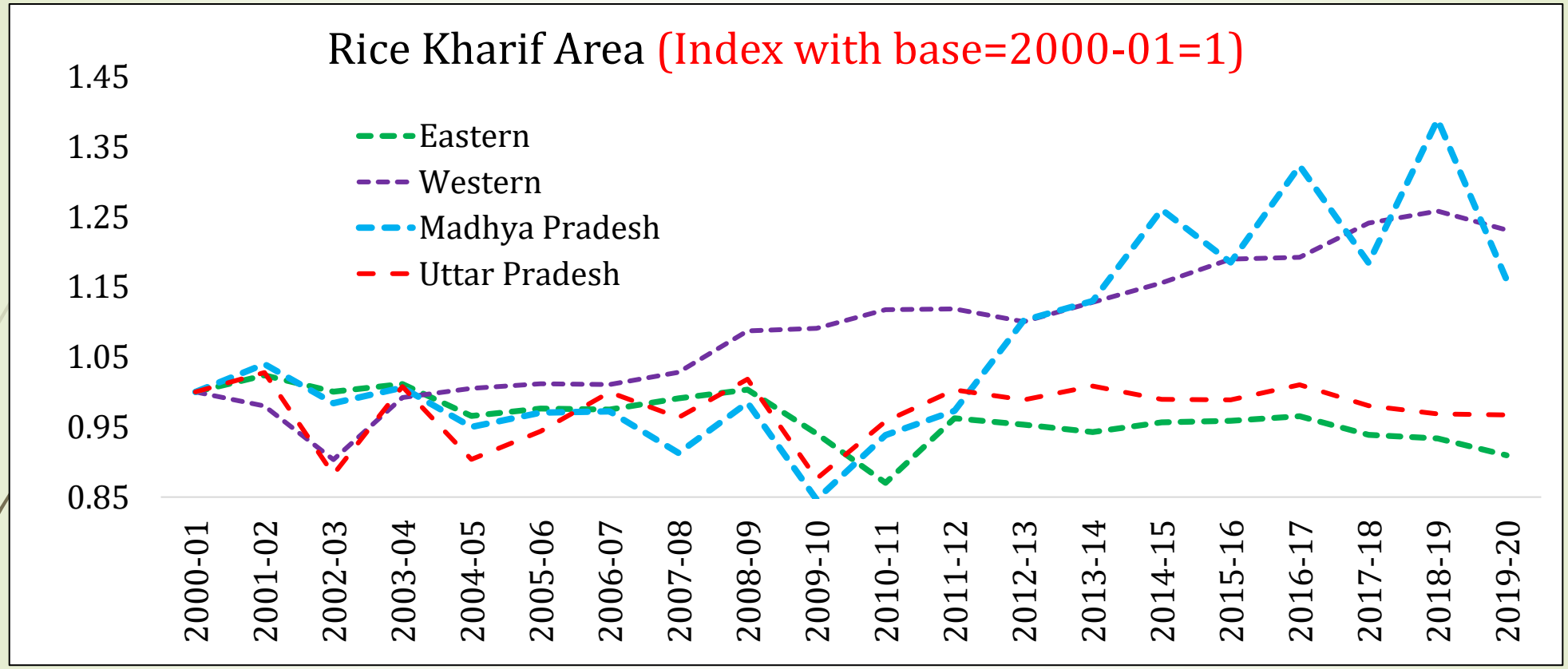
- Denotes significant trend at 10%.
- Source: Computed from IMD data, IMD (Website)

METs	Trend	METs	Trend	METs	Trend
CK	N	BH	N	TP	N
KG	P*	EM	N	MT	P
AR	N*	VD	P	RY	N
SW	N*	CA	N	NI	N
AM	P	WM	P*	WU	N*
EH	N*	GR	P	JK	N
GW	N*	SI	P*	ER	P
OD	N	TL	P	SK	P*
UT	N	HP	N*	PJ	N*
CH	P	EU	N	HC	N*
JH	N*	MM	P*	WR	P

Category	No. of METs
Positive (P)	8
Positive Significant (P*)	5
Negative (N)	11
Negative Significant (N*)	9

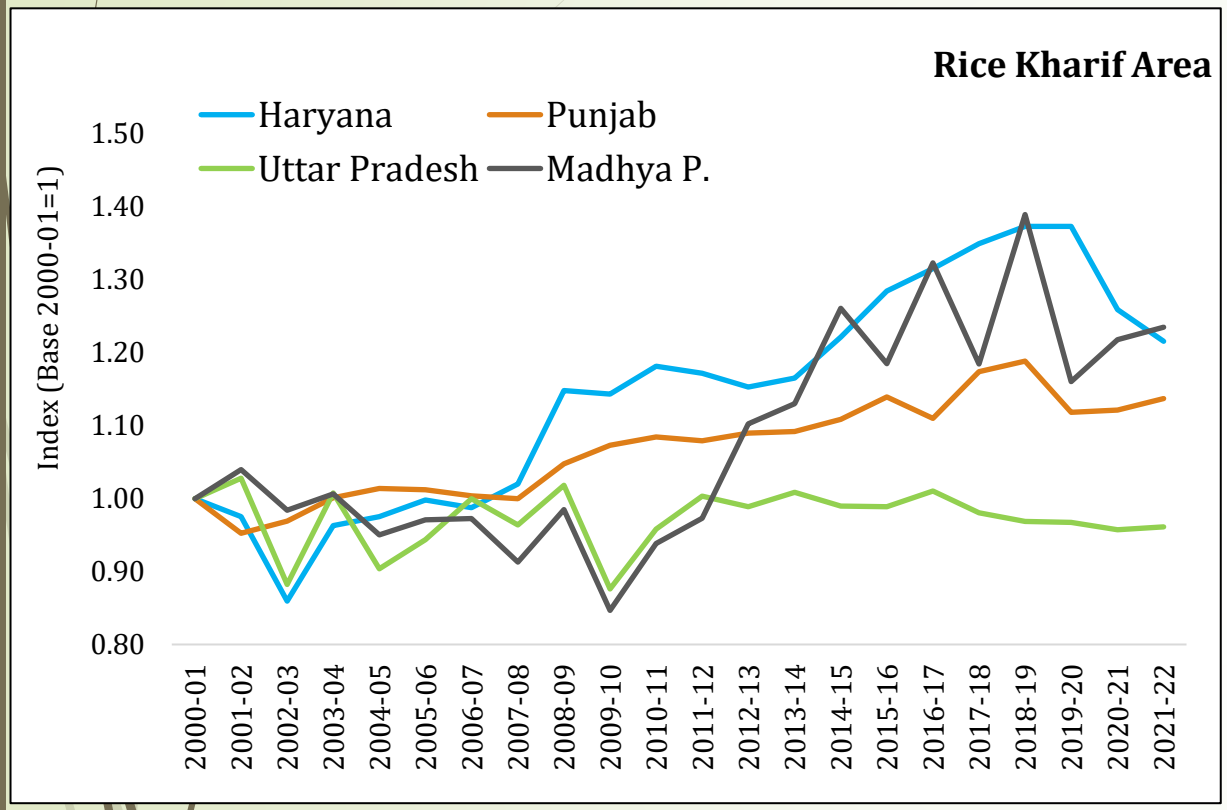
Rice

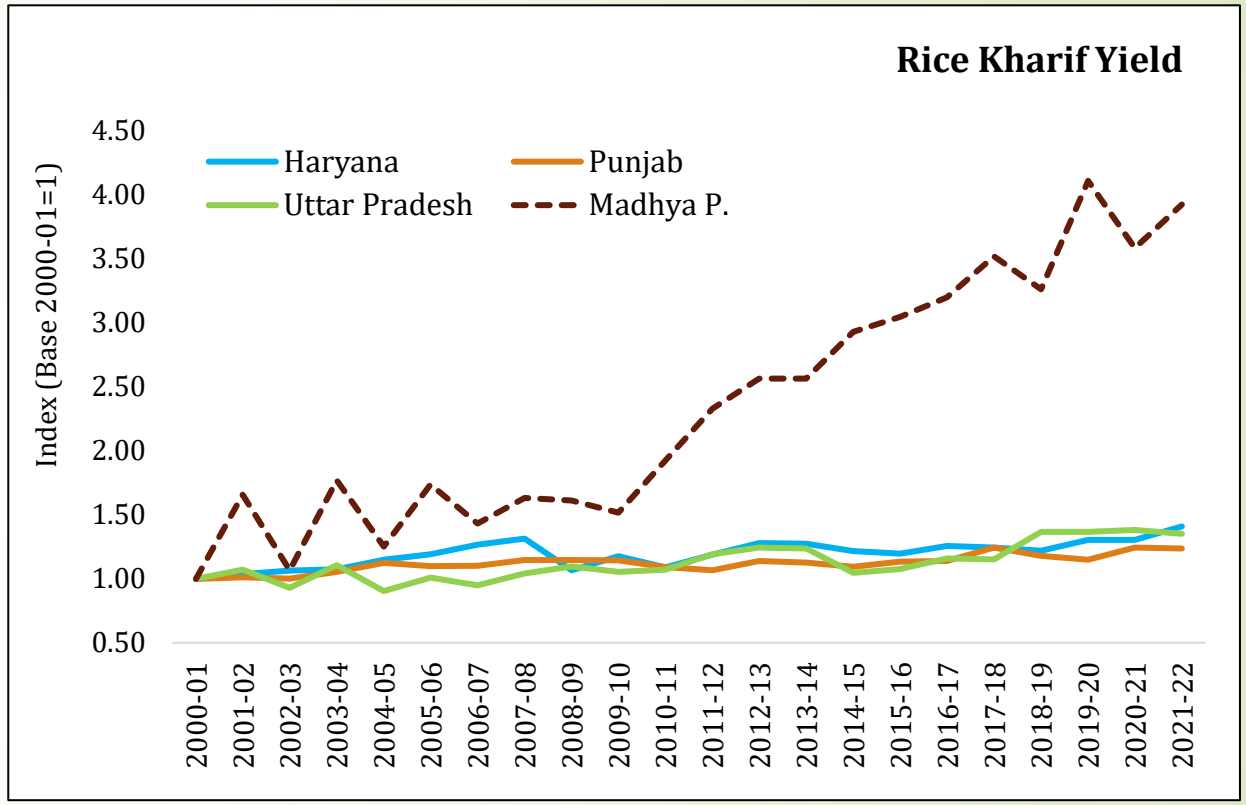
Kharif Rice Area Changes among Regions



- Eastern states (E): Assam, Bihar, Odissa, Jharkhand, West Bengal and Chhattisgarh
- Western states (W) states: Punjab, Haryana, Gujarat, Rajasthan
- Central states (C): Madhya Pradesh (MP) and Uttar Pradesh (UP)

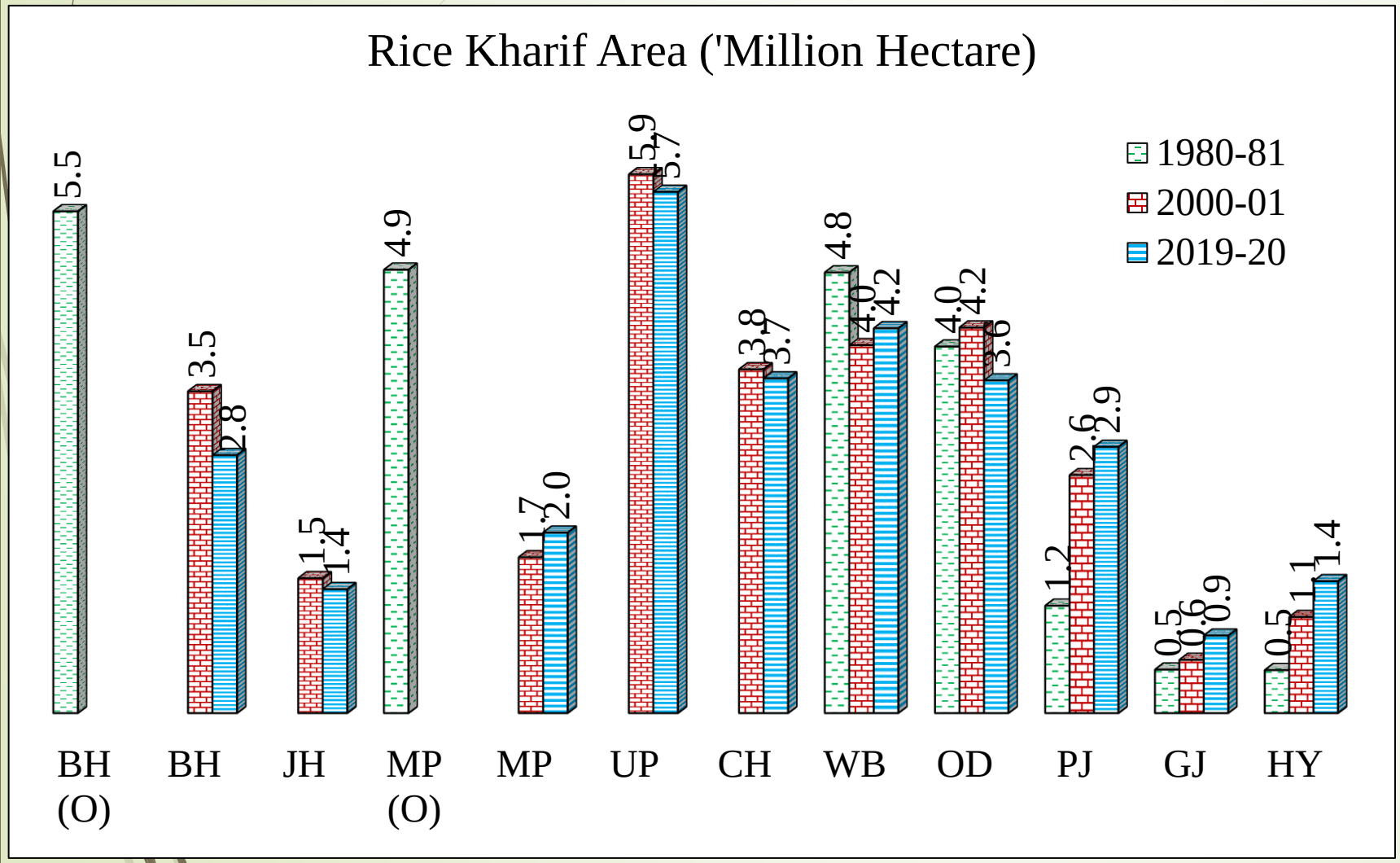
Rice Area and Yield





- MP performed highest in yield gains other states Yield near stagnation
- HR gained most in acreage followed by MP and PJ
- UP stagnated and lost acreage

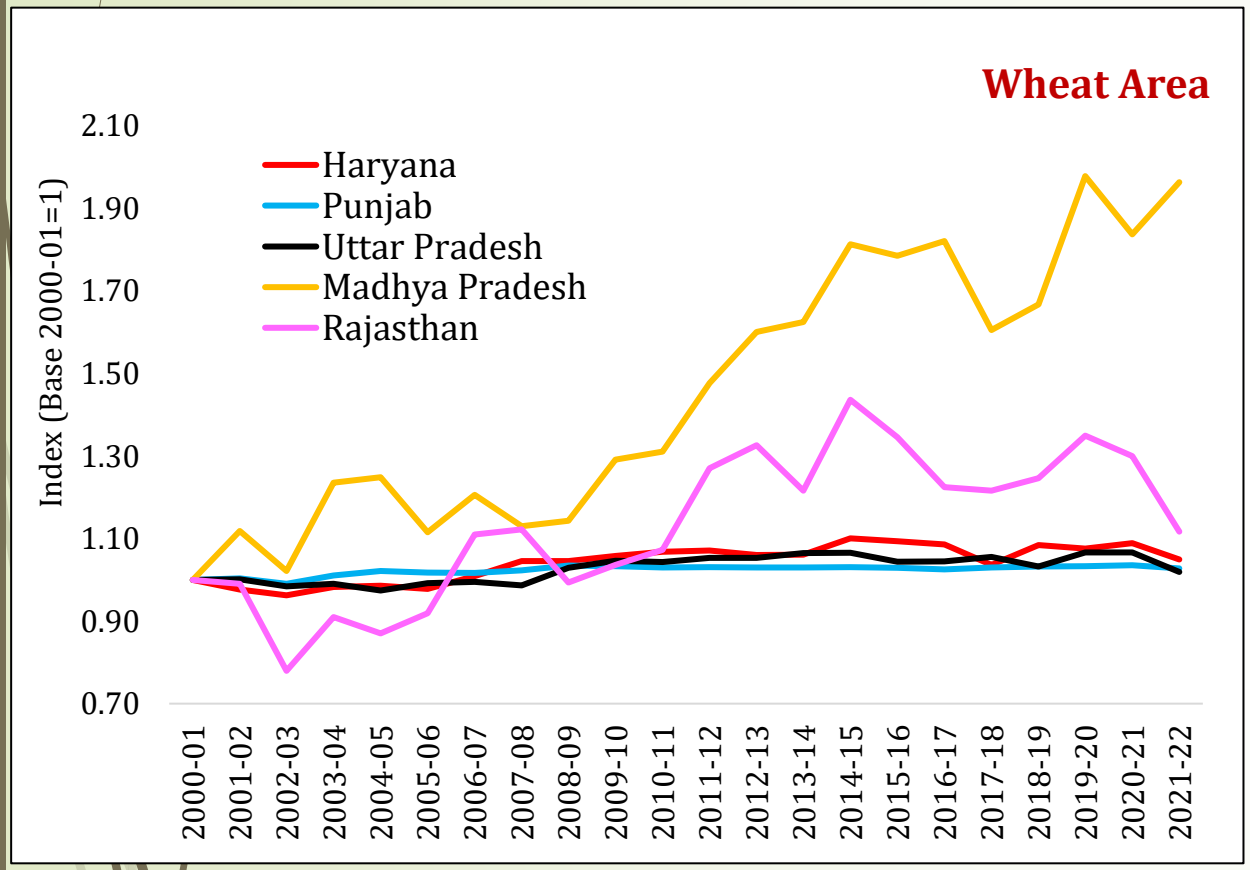
Dominance of Rice since Post GR

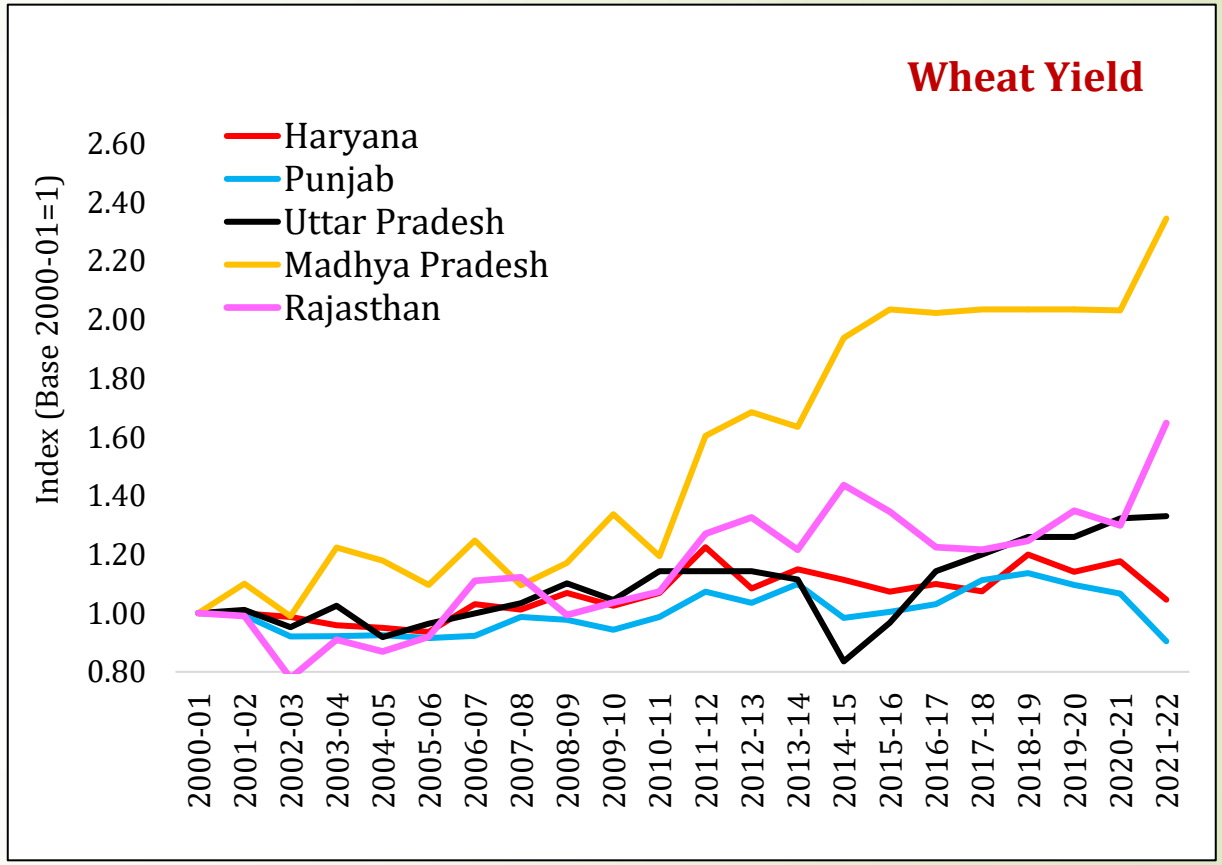


- Dominance in Eastern states and in undivided Madhya Pradesh in 1980.
- UP largest grower but lost acreage. All eastern states BH JH CH WB OD lost
- Western states gained, MP (w/o CH) gained in last 2 decades. GJ emerging grower.
- Bifurcation in 2000, CH in east was the rice bastion in MP in Central. CH follows pattern of its eastern partners.
- Over time, acreage in the two parts of MP(O) moved contrarily.

Wheat

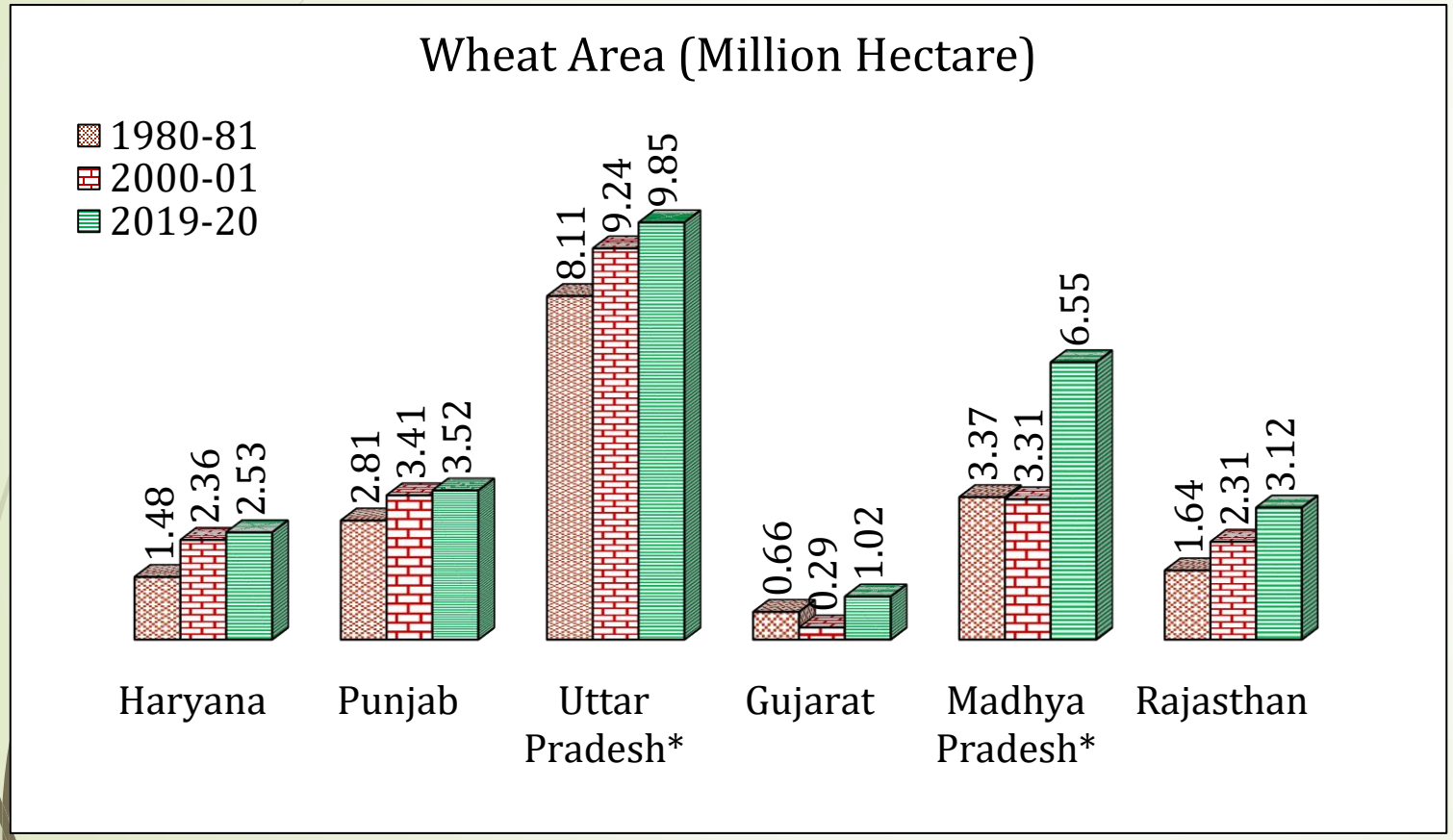
Wheat Area and Yield





- **MP performed far better both in acreage expansion and yield gain**, RJ followed
- PJ HR and UP showed no remarkable gain in area
- UP showed some improvement in yield but PJ HC did not

Dominance of Wheat since Post GR



- UP remains largest grower, still growing
- Western states HR, PJ. RJ growing
- GJ emerging as wheat grower
- MP lost as acreage in 2000 same as MP(O) incl CH in 1980 but made big gains in last 2 decades

Note: * denoted 1980-81 figures of old states (O)

Change in Cropped acreages under crop groups between 2000-01 and 2019-20

	Rice	Wheat	Maize	Millets	Pulses	Oilseeds	Cash Crops and Others	GCA
Gujarat	33.58	185.15	-5.12	-65.57	22.77	0.48	22.70	9.48
Rajasthan	32.24	34.98	-8.13	-5.58	166.93	104.86	-21.68	31.63
Uttar Pradesh	-2.88	6.65	-20.85	-19.69	-12.48	45.76	37.94	6.14
Punjab	11.79	3.32	-30.55	-82.37	-46.83	-55.39	-22.40	-1.14
Haryana	37.29	7.60	-60.00	-29.81	-55.63	59.18	-0.26	8.01
Madhya Prades	18.80	98.58	69.36	-61.32	34.01	35.18	108.53	46.14
All India	-2.45	21.55	40.62	-39.90	31.24	10.21	13.54	6.46

- **Rice:** Gained acreage more in **diversified sta**tes GJ, RJ, PJ, HR & MP. Lost in UP & All India.
- **Wheat:** Gained area in **all.**
- **Maize**: Gained area in MP and All India.
- **Millets:** Lost acreage wherever grown.
- **Pulses:** Gained area in GJ, RJ, MP & All India. Despite their promotion by policy, PB & HR showed no affinity to. Lost in UP.
- **Oilseeds:** Gained in all but lost in PJ.
- **Cash Crops & Other:** Gained in all but lost in RJ, PJ & HR.
- **GCA**: Loss of crop land in PJ.

Cropping Pattern Changes (2000-01 and 2019-20)

Difference	Rice	Wheat	Maize	Millets	Pulses	Oilseeds	Cash Crops and Others
Gujarat	1.43	5.49	-0.59	-9.46	0.85	-2.25	4.53
Rajasthan	0.00	0.31	-1.52	-8.16	12.69	7.66	-10.98
Uttar Pradesh	-1.98	0.17	-0.93	-1.51	-1.88	1.28	4.85
Punjab	4.30	1.93	-0.62	-0.39	-0.37	-0.62	-4.24
Haryana	4.67	-0.15	-0.15	-4.36	-1.51	3.21	-1.70
Madhya Prades	-1.78	6.62	0.74	-5.51	-1.65	-2.32	3.89
All India	-2.02	1.97	1.18	-5.64	2.68	0.47	1.36

- **Rice** lost 2.02 % points in GCA of all India, in W/C states in UP and MP, **gained share in non-trad states, GJ, PJ, HR**
- **Wheat winner** of share (HR excl)
- **Maize** mostly lost share though gained in all India and in MP
- **Millets only lost,** 5.6% points in all India
- Except GJ and RJ **pulses** lost share but gained at all India level, **spatially concentrated gain**
- **Oilseeds big gain in RJ** , share loss in MP, GJ

Broad Rainfall effect and Impact of Market & Price Policy Rice kharif (Area and Yield) in select IGP states

- **Water Effect**
  - **Differential importance of monthly, spatial rainfall.**
  - Receding GD constrained rice planting in HR. GD important in all yield equations
  - Water in the reservoirs of HP, PJ, UT, RJ, UP, CH, JH, GJ, MH and MP proved important.
  - Benefits from northern Himalayan METs (HP and JK, UT) rainfall.
  - Planting in PJ and HR – influenced by rain in W states including RJ.
    - Negative interaction of hill RF with IG in HR & PJ speaks of water use efficiency.
  - High rainfall is harmful in growing and harvest season
  - Irrigation- WELL, CNL in HY and PJ, OTH in UP and NIA in MP - Important

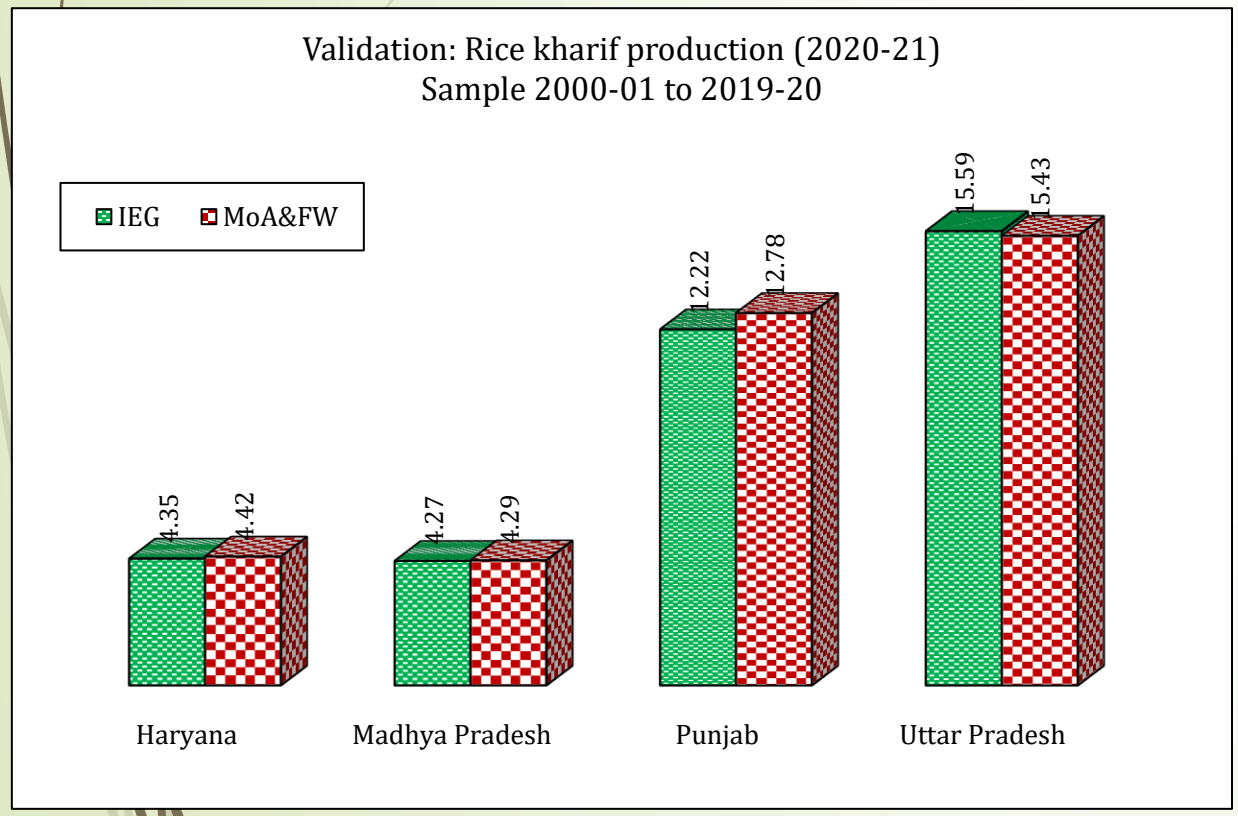
- **Economic**
  - MSP -incentive in all cases, being the only one in HR in acreage
  - Revenue in MP area only and all states in (HR,UP, PJ, MP) in Yield equation
  - Substitute crops are mostly Cotton, Maize, Tomato, Pulses(Moong, Urad, Arhar), Soybean, Jowar, Cabbage in western states. Past area is significant determinant of Area in PJ, HR.
  - Input- fertilizer (nutrients like dap, urea, sulf etc) , PTD, ITD and also wage - significant effect
- Temperature in some months/fortnights matter for productivity.

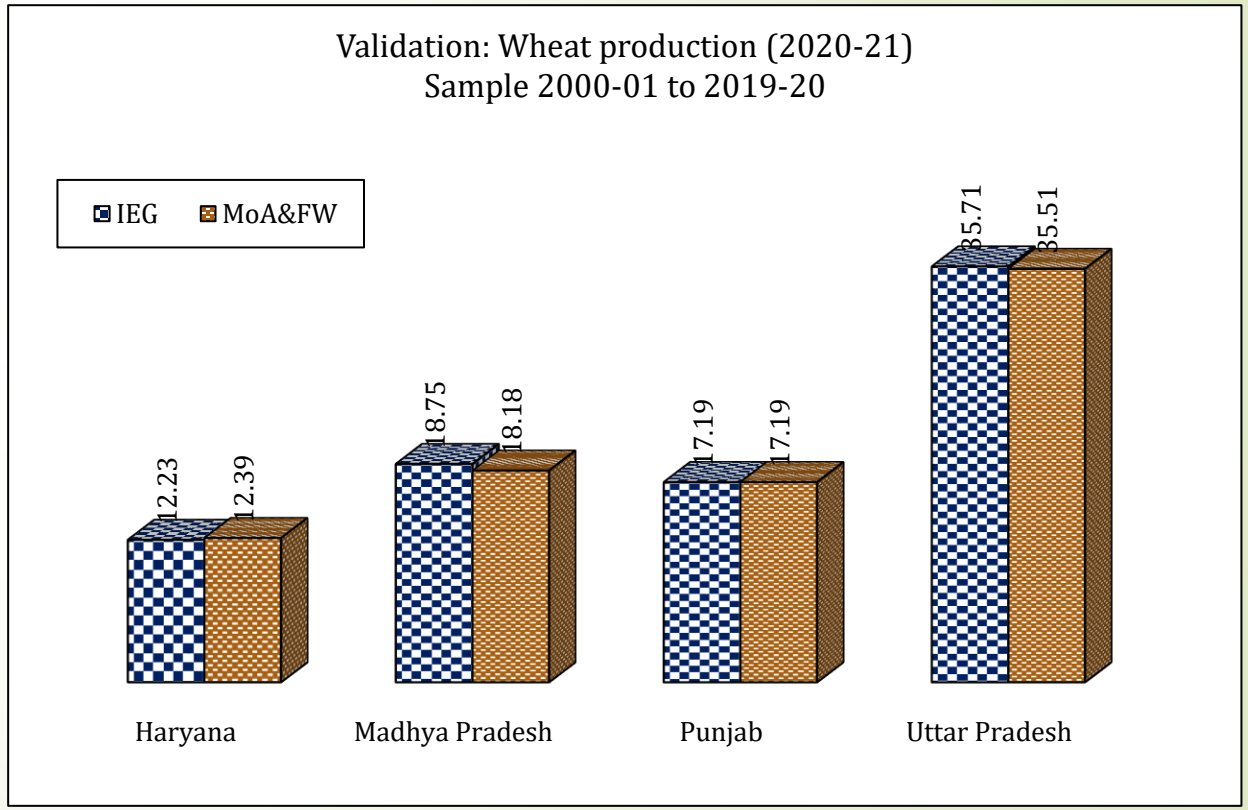
Broad Rainfall effect and Impact of Market & Price Policy Wheat (Area and Yield) in select IGP states

- **Water Effect**
  - **Differential importance of monthly, spatial rainfall.**
  - **GD is helping planting of wheat in MP and growing in UP.**
  - **Reservoirs water aiding in the area and yield from IGP and neighboring's states,** HP, PJ, UT, RJ, UP, CH, JH, GJ, MH and MP
  - Rainfall both help and hurt depending on place and time. High RV can also be harmful if accompanied by high RF (water release/floods) on rainfall.
  - Irrigation- Canal and well are important for planting and growing season but it can adverse effect when unseasonal rainfall with mismanagement of Dams.
- **Economic**
  - MSP -incentive in all cases
  - Revenue (P and Y) in PJ, HR in area and UP, HR in Yield equation
  - Substitute crops are mostly Maize, Potato, Jowar Pulses (Moong, Urad, Gram), onion in IGP states. Past area is significant determinant of Area in all states (MP, HR, PJ, UP).
  - Input – Fertilizer (nutrients like dap, urea, sulf etc), PTD, ITD – effective.
- Temperature in growing season important – fortnightly/monthly matters for productivity . Higher TMP can helps at some points in growing seasons and hurt in others.

Validation for 2020-21

Sample: 2000-01 to 2019-20





Contribution of Economics, Weather and Irrigation to Rice, Wheat - Area changes

	Increase Acreage(%)	Trend	Economic	Rainfall	Ground water	Reservoir	Irrigation	Interactions
RICE								
Uttar Pradesh	-5.38	-9.97	-34.36	99.01	-	26.44	23.21	-4.32
Punjab	17.00	45.90	-23.50	14.30	77.80	-14.90	7.70	-7.00
Haryana	40.20	57.90	43.20	12.30	-10.50	-14.70	11.90	-0.10
Madhya Pradesh	11.90	-9.17	30.39	-13.38	65.72	-2.00	30.80	-2.37
Wheat								
Uttar Pradesh	6.69	26.10	92.61	55.18	-	-22.79	-12.45	-38.61
Punjab	3.15	99.48	17.23	-7.40	-	-33.84	22.46	2.09
Haryana	11.90	30.42	-18.20	-12.04	-	84.97	31.02	-16.17
Madhya Pradesh	83.68	43.46	-9.68	63.44	10.29	22.30	-	-29.81

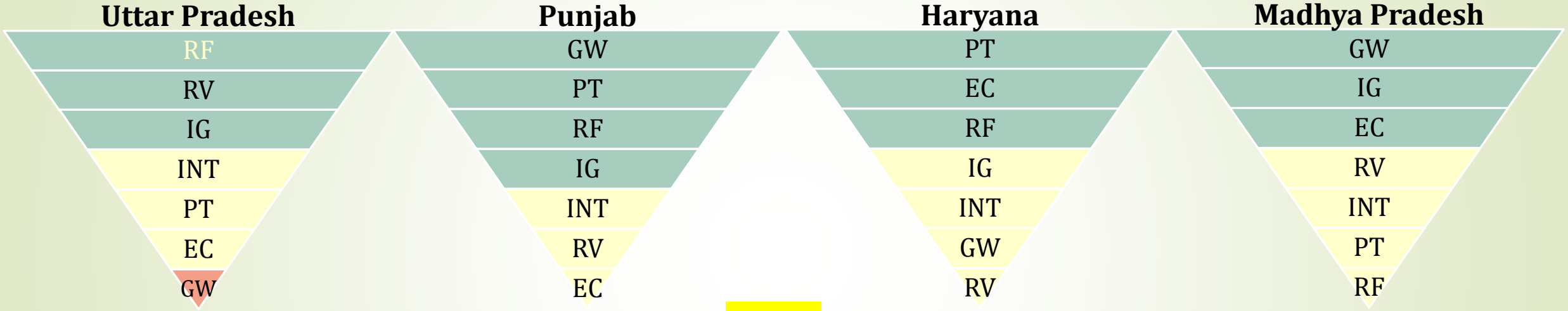
Contribution of Economics, Weather and Irrigation to Rice, Wheat - Yield changes

	Increase Yield (%)	Economic	Rainfall	Ground water	Reservoir	Irrigation	Temperature	Interactions
Rice								
Uttar Pradesh	28.48	175.25	-44.85	-14.59	-0.30	-13.63	-	-1.88
Punjab	15.24	46.99	34.20	-	26.21	-5.37	-1.07	-0.95
Haryana	19.60	44.24	21.91	-	75.80	-10.00	6.82	-38.77
Madhya Pradesh	104.49	68.03	-45.72	52.64	7.95	25.66	-	-8.56
Wheat								
Uttar Pradesh	25.66	163.35	-13.71	-20.95	-16.10	-5.79	-2.01	-4.79
Punjab	11.47	124.20	-112.26	-	29.30	-15.14	63.75	10.16
Haryana	13.31	37.29	-49.49	-	28.65	24.84	22.02	36.69
Madhya Pradesh	85.15	55.66	7.17	-21.86	72.21	-	7.38	-20.56

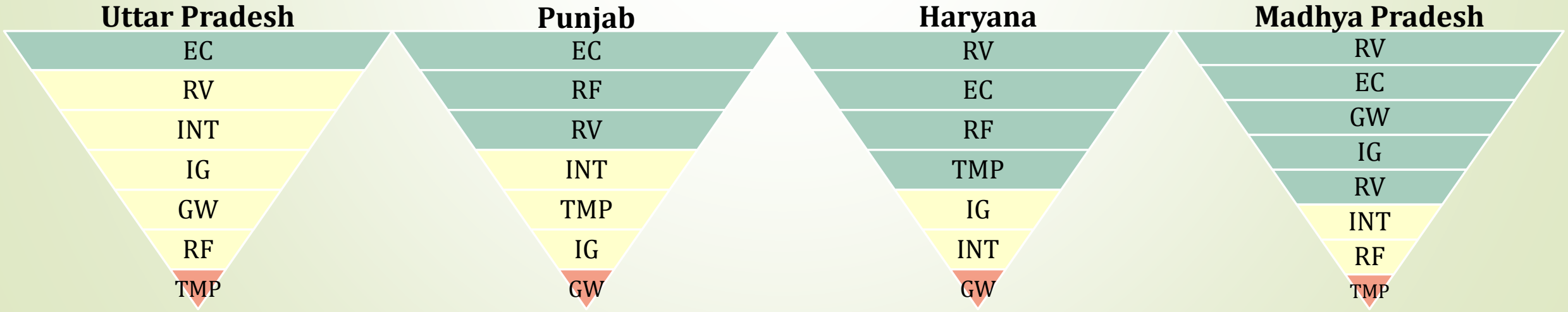
Contributions- Rice

Effects
Positive
Negative
No effect

Area



Yield

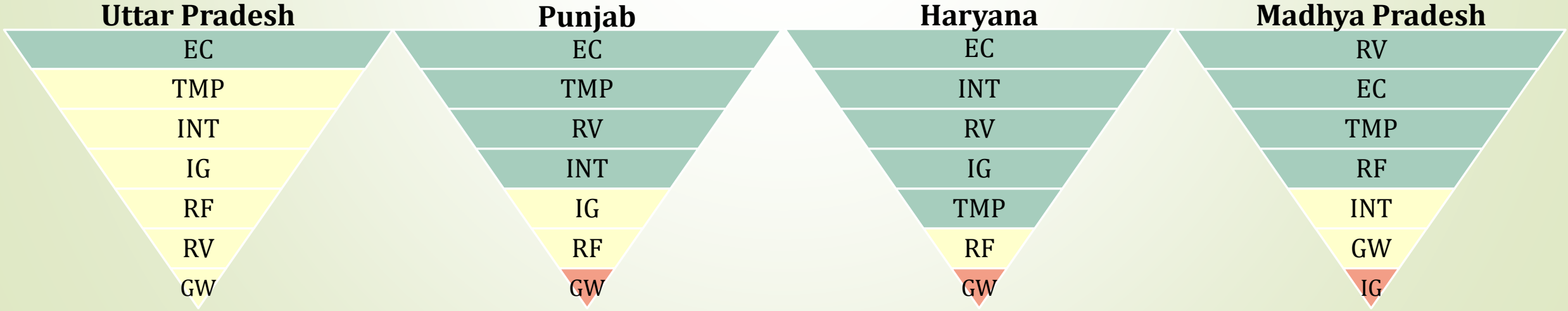


Contributions- Wheat

Effects
Positive
Negative
No effect

Area

Yield



Contribution of Economic and Water management policy, Weather and Past to Rice and Wheat (Area and Yield)

- Direct changes in **RF** contributed to
  - rice area expansion in UP, PJ and HR, little negative effect in MP
  - helped Rice yield only in HR, adverse yield effect on rice
  - Important for wheat area expansion in UP and MP, negative in others.
  - Helped wheat yield only in MP (positive trend)
- Temperature important for yield in some cases **helped rice in HR, wheat in PJ and HR but hurt Rice in PJ**
- By and large, **reservoir storage discouraged acreage expansion and yield rise**.
  - Helped rice area in UP, but hurt yield
  - Helped wheat area in HR MP
  - Most important contributor to wheat yield improvement in MP
  - RF and RV did not help wheat yield in UP
- **Economics** was an important contributor, did not help area expansion in PJ, rising cost of inputs fertilizer and labour.
  - Helped rice and wheat yield in all cases
- Effect of past-(marketing Infrastructure?) important for promoting rice area in PJ and HR
- Irrigation network not always helpful for yield. GD was a support to Rice in MP

Concerns and Need for thought

- Climatic changes happening at the **regional levels**, Rainfall getting less in important belts but gains for MP
- Migration of rice observed: is **rain-fed cultivation giving way to irrigated rice**. Move towards rice cultivation but also accompanying a migration of rice away from low-lying wetlands of the east to irrigated fields of the west, -thinking on land use policy.
  - Given that deep-water paddy located in eastern states are discredited for large emissions, Could the movements be seen as an adaptive solution?
- Cropping patterns moving away from millets, ineffectiveness of policy for promoting pulses or oilseeds in certain states.
- Wheat area pattern largely stabilized, **emergence of GJ, rise of Rice in western states- high performance of MP** in Rice Wheat A and Y
- **Economics** through market forces and limited government interventions in market **not always having positive** effect
- Rainfall hurt yield of rice/wheat in some cases. Temperature mostly helped.
- **Water management not best performance.**

Thank You

For Giving Your Valuable Time.

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- Gulati, Ashok (2021). Indian Agriculture @75. Volume 1, Issue 2- October, ICRIER, Agri-food trend and Analytic Bulletin (AF-TAB).
- Sources:
  - **Sources-DES, FAI, IMD, CGWB, CWC, OEA , considering COC.**
  - **Software : Eviews 12**

Uttar Pradesh Kharif Rice Area Equation (Sample: 2000-01 to 2020-21)

Dependent Variable: AREA11
Method: Panel Least Squares
Date: 07/27/22 Time: 12:34
Sample: 2000 2020 IF (SEASON=1 AND STATE=13)
Periods included: 20
Cross-sections included: 1
Total panel (balanced) observations: 20

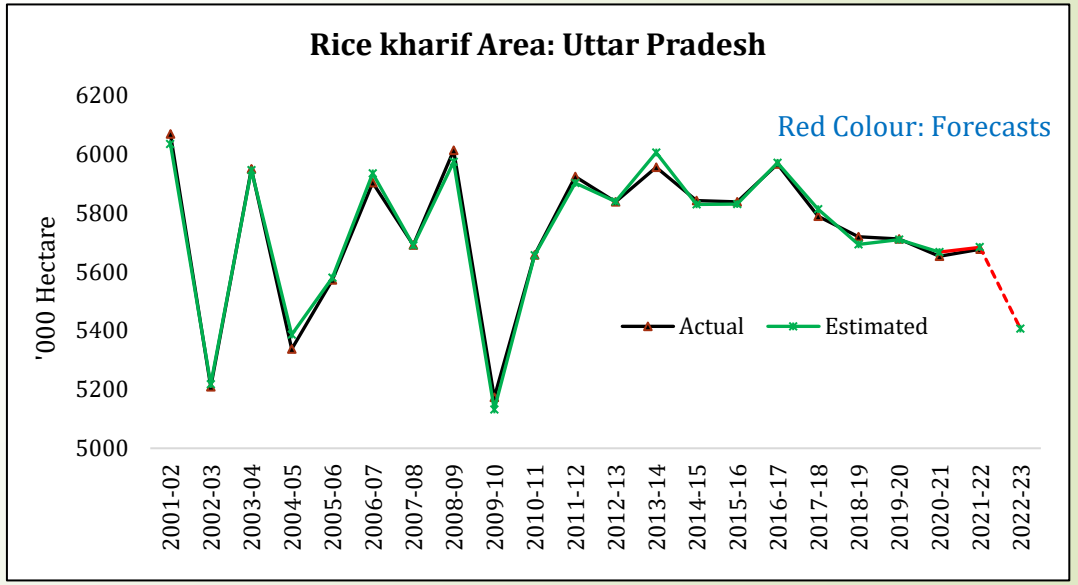
Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	4980.952	453.1019	10.99301	0.0000
AREA11(-1)	-0.155836	0.060743	-2.565504	0.0247
((MSP11+PRICE_CROP11M11(-1)+PRICE...	753.9404	85.89630	8.777332	0.0000
(UP_MAY_RD+UP_MAY_SD)*(IRR_CANAL...	0.057537	0.009534	6.035186	0.0001
(M11_RF6+M11_RF7)+(M10_RF8+M10_...	0.661905	0.026877	24.62748	0.0000
(M16_RF5+M11_RF4+M10_RF3)*IRR_C...	0.000433	0.000144	3.014025	0.0108
(M11_RF9)+(M10_RF5+M10_RF7)+(M15...	-0.365110	0.060753	-6.009689	0.0001
IRR_OTH_FCAST113N	0.789804	0.157373	5.018666	0.0003

R-squared	0.989605	Mean dependent var	5740.000
Adjusted R-squared	0.983541	S.D. dependent var	254.0858
S.E. of regression	32.59749	Akaike info criterion	10.09552
Sum squared resid	12751.15	Schwarz criterion	10.49381
Log likelihood	-92.95522	Hannan-Quinn criter.	10.17327
F-statistic	163.1961	Durbin-Watson stat	1.764855
Prob(F-statistic)	0.000000		

Multicollinearity Test

Variance Inflation Factors
Date: 07/27/22 Time: 12:35
Sample: 2000 2020 IF (SEASON=1 AND STATE=13)
Included observations: 20

Variable	Coefficient Variance	Uncentered VIF	Centered VIF
C	205301.4	3864.147	NA
AREA11(-1)	0.003690	2302.488	4.314782
((MSP11+PRICE_CR...	7378.175	44.49636	1.364457
(UP_MAY_RD+UP_M...	9.09E-05	7.897155	1.642257
((M11_RF6+M11_RF...	0.000722	57.76187	1.503893
(M16_RF5+M11_RF4...	2.06E-08	18.52602	2.037453
((M11_RF9)+(M10_...	0.003691	78.19806	2.166399
IRR_OTH_FCAST113N	0.024766	5.099008	1.262960



Explaining changes in 2021-22 to 2022-23

Uttar Pradesh – Rice Kharif Area

		Past Area	Economic	RF-Sowing (Apr-Sep)	RF-Sowing (Jul-Sep)	Irr	INT RV*Irr	INT RF*Irr (Mar-May)
Year	AREA	AREA(-1)	MSP, Past Market Price	(WU, HP, JK, HC, WR), (UT, BH, CH, EU, JH)	WU, EU, HP, UT	Other	UP(Rihand+ Sardasagar) *(Canal)	(JK, WU, EU)*(CANAL)
2020-21	5652.0	5711.0	0.281	138.4	180.4	86.5	2339.2	78805.6
2021-22	5676.0	5652.0	0.288	146.2	207.3	82.9	2784.4	42236.2
2022-23	**5403***	5676.0	0.323	113.9	194.2	76.1	2307.7	39244.4
Effect*		-ve	+ve	+ve	-ve	+ve	+ve	+ve

Note:

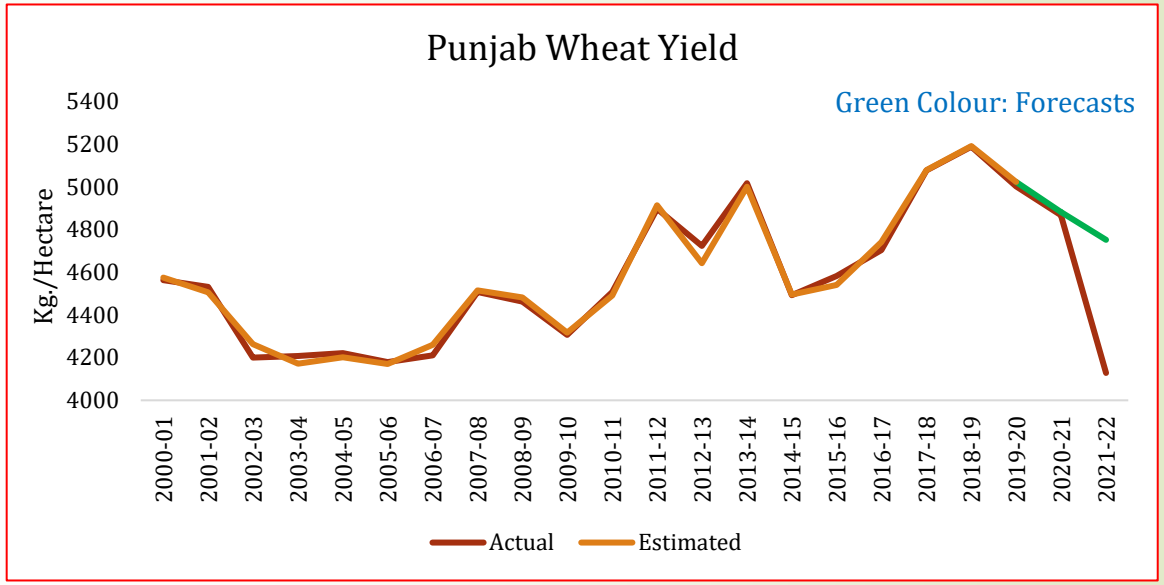
- * Estimated by model
- Rainfall is assumed normal from 25 July 2022
- Irrigation projected for 2019 onwards

Wheat Punjab Yield Equation (Sample 2000-01 to 2019-20)

Dependent Variable: YIELD13
Method: Panel Least Squares
Date: 07/30/22 Time: 10:27
Sample: 2000 2019 IF SEASON=2 AND STATE=10
Periods included: 20
Cross-sections included: 1
Total panel (balanced) observations: 20

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	7433.762	337.3712	22.03437	0.0000
((MSP13+PRICE_CROP2M13+PRICE_CR...	120.4257	12.65491	9.516129	0.0000
(UP_SEP_RD+PJ_SEP_TD+MP_SEP_IS+GJ_...	11.84163	4.093219	2.892987	0.0135
((HP_SEP_GS+HP_SEP_KL)+RJ_SEP_JK+GJ...	-38.05058	11.61899	-3.274861	0.0066
(((M16_RF6+M13_RF6+M12_RF6+M17_...	6.311897	0.457023	13.81089	0.0000
((M15_RF6)+(M14_RF10)+(M17_RF11+...	-2.074085	0.242805	-8.542177	0.0000
((NOV1_MAX_14)+(APR2_MAX_14(1)))...	-50.74731	3.871219	-13.10887	0.0000
(M16_RF9+M16_RF4(1))*IRR_CANAL_F...	-2.026426	0.392298	-5.165530	0.0002

R-squared	0.989377	Mean dependent var	4579.050
Adjusted R-squared	0.983181	S.D. dependent var	319.8155
S.E. of regression	41.47625	Akaike info criterion	10.57729
Sum squared resid	20643.35	Schwarz criterion	10.97559
Log likelihood	-97.77293	Hannan-Quinn criter.	10.65504
F-statistic	159.6679	Durbin-Watson stat	2.457966
Prob(F-statistic)	0.000000		



Explaining changes in 2020-21 to 2021-22

Punjab– Wheat Yield

		Economic	INT RV*Irr	INT RV*Irr	INT RF*Irr (June)	INT RF*Irr June-May(+1)	Temp	INT RF*Irr Sep-Apr(+1)
	YIELD	MSP, Past Market Price)/DAP,UREA, PTD	[UP(Rihand)+PJ(Thein)+MP(Indira Sagar)+GJ(Sardar Sarovar)]*(NIA)	[(HP(Govind Sagar+Kol)+RJ(Jhakam)+GJ(Hatmati+Sukhi)]*(NIA)	(JK, HC, UT, WR)*(WELL)	(HP, PJ, WR, ER)*(NIA)	Max(Nov, Apr)+Min(Mar)	(JK)*(CANAL)
2019-20	5003.0	13.259	23.927	6.789	43.582	269.294	72.436	35.943
2020-21	4868.0	13.899	25.600	5.928	57.822	298.511	78.322	36.527
2021-22	4750*	12.868	16.571	5.453	83.660	253.969	81.844	33.363
Effect*		+ve	+ve	-ve	+ve	-ve	-ve	-ve

Note:

- * Estimated by model
- Irrigation projected for 2019 onwards