Shifts in Irrigation Water Demand and Supply Patterns during Critical Crop Growth Stages under Changing Impacts of Climate and Socio-Economic Dynamics in South Asia

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Abstract

Changing irrigation water demand (IWD) and supply (IWS) patterns (size and time) under increased climate variability and socio-economic development is significantly effecting the water and food production in the densely populated South Asia (SA). Considering food security paradigm of SA, where rice and wheat are major staple and water-intensive crops, this study aims to investigate the linkages in IWD by crops and IWS by sources (surface and groundwater) using integrated climate and socio-economic projections. The novel aspect of this study is to explore IWD and IWS pattern shifts during critical crop growth stages (CW's), which is previously less studied with no remarkable research evidence for IGB region. Quantification of shifts in IWD and IWS patterns in future is crucial for long-term integrated water resources and agricultural planning. For this, LPJmL crop-water model is forced with an ensemble of eight state of the art downscaled GCM at 5 arc-min resolution. To assess the combined impacts of climate and socio-economic changes, RCP-SSP framework is used. Our statistical analysis results show that IWD is higher in vegetative stage (CW1) than the reproductive stage (CW2) during both Rabi and Kharif cropping seasons. Water demand is decreasing in future for wheat while increasing for rice. IWS is decreasing substantially from surface while increasing largely from groundwater resources during Rabi. Though, IWS during kharif season is increasing largely from both surface and groundwater resources. There is mismatch in demand and supply as evident from the results suggesting 10 days early wheat planting reduces IWD by 8.0% in F1, 18.7% in F2 and 28.4% in F3 during CW1 with a decrease of 7%, 30 % and 62.56% during F1, F2 and F3 in CW2. Increased IWS with larger contribution from groundwater resources is projected for both crops in future. Water gap between demand and supply during both CW's in future is increasing for Rabi and Kharif suggesting 10 days early planting of wheat while 20 days delay in kharif planting. Estimation of IWS by sources helped in assessing shifts in percent (%) dependency of water supply from different sources. Moreover, Spatio-temporal mismatch between water demand and supply help exploring geospatially driven water gap trends consequently, highlighting water stress hotspots during CW's in future.

Shifts in Irrigation Water Demand and Supply Patterns during Critical Crop Growth Phases under Changing Impacts of Climate and Socio-Economic Dynamics in South Asia (582753)

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Highlights

Future cryosphere changes on **land** are projected to **affect water resources** and their uses, such as hydropower and **irrigated agriculture** in high mountain areas {2.3, 2.3.1} **(SROCC-IPCC, 2019).**

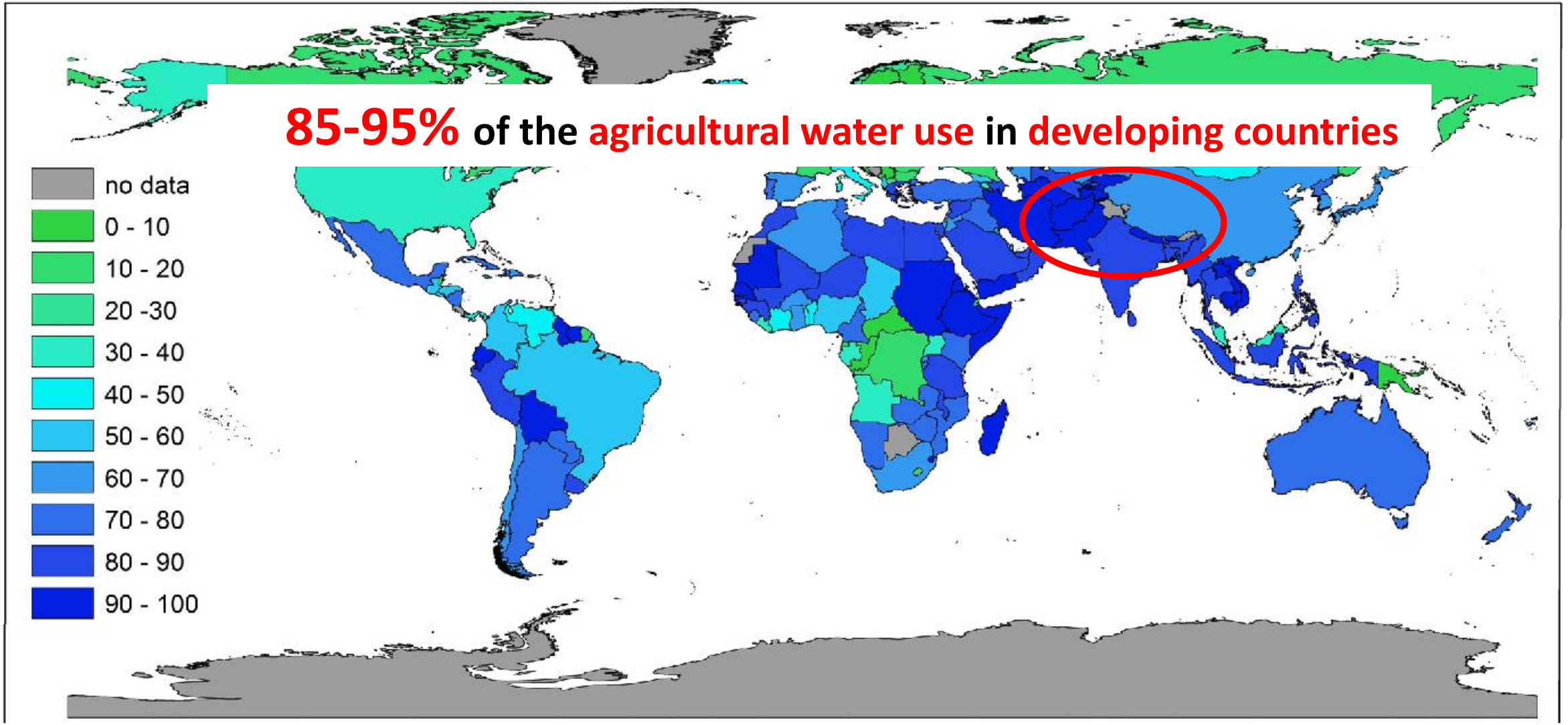
Since the mid-20th century, the **shrinking cryosphere** in the Arctic and **high-mountain areas** has **led to predominantly negative impacts on food security, water resources,** health etc...(high confidence) {1.1, 1.5, 1.6.2, 2.3, 2.4, 3.4} **(SROCC-IPCC, 2019).**

Pathways with **higher demand for food,** feed, **water** and **technological improvements in agriculture yields** are at **higher risks from water scarcity** … (high confidence). {5.1.4, 5.2.3, 6.1.4, 7.2} **(SRCCL-IPCC, 2019).**

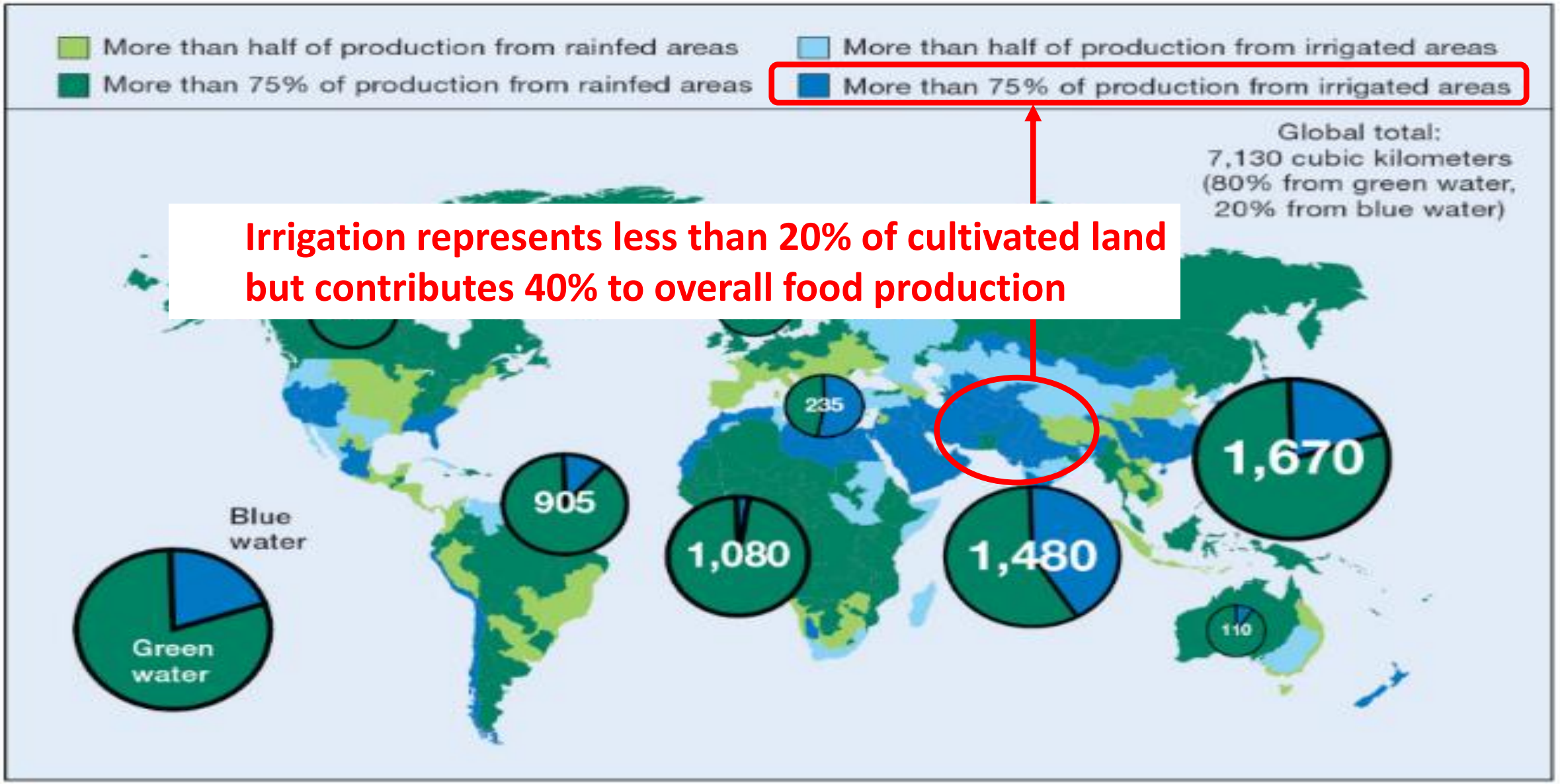
Socioeconomic changes have been identified as the **main driver of water scarcity** **(Rene et al., 2018)**.

Water demand for **agriculture**, industry, and households will **increase** by **30-40%** by **2050** and **projected water demands** will be **largest** for **Asia** than the world put together **(2018,IIASA).**

Annual fresh water withdrawals in agriculture per country (%)



(Noemi Mansocu et al., 2015)


More than half of production from rainfed areas
More than 75% of production from rainfed areas
More than half of production from irrigated areas
More than 75% of production from irrigated areas
Global total:
7,130 cubic kilometers
(80% from green water,
20% from blue water)
Irrigation represents less than 20% of cultivated land
but contributes 40% to overall food production
235
905
1,080
1,480
1,670
110
Blue
water
Green
water

Research Rationality

A number of research studies are available on **estimating irrigation water demand** and **changes** associated with **changing climate**

BUT!!!

This study is **unique** enlightening **linkages** between **changing irrigation water demand** and **supply** pattern during **critical crop growth phases** and identified **spatial distribution of irrigation watergap** in **IGB** river basins under **mixed RCP-SSP** scenarios

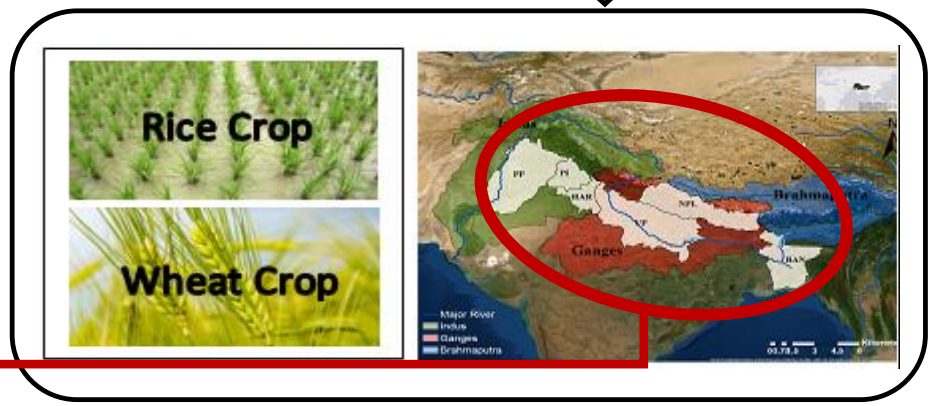
Study Flowchart

Climate Variable
(Temp, Prec, SW & LW Radiation)
8 GCM (CMIP5), 2 RCP-SSP at 5 min

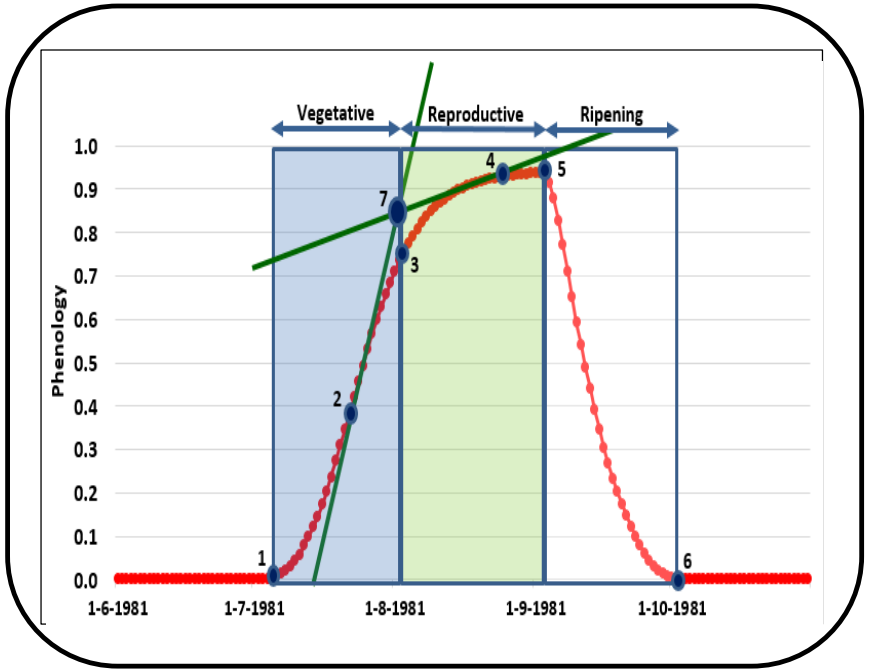
Non Climate Variable
(Landuse, Soil, Co_2, DEM etc.)

Lund Potsdam Jena managed Land Model (LPJmL)

- Sowing and Harvest dates
- Crop Yields, - Phenology, - LAI
- Irrigation water demand (IWD) by crop
- Irrigation water supply (IWS) by sources (Surf, Res & GW)



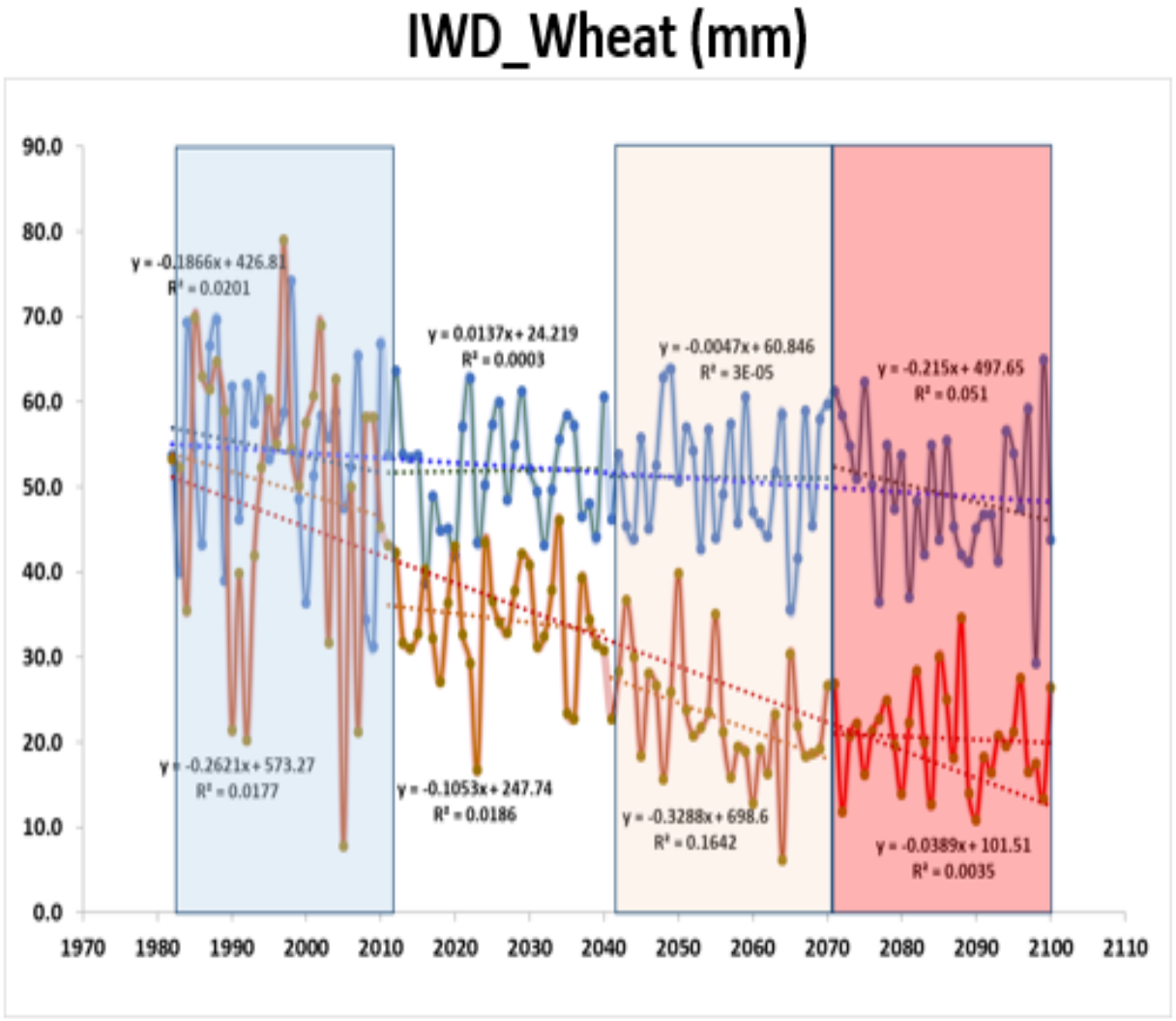
Punjab, Pakistan (PP)
Punjab, India (PI)
Haryana (HAR)
Uttar Pradesh (UP)
Nepal (NPL)
Bangladesh (BAN)

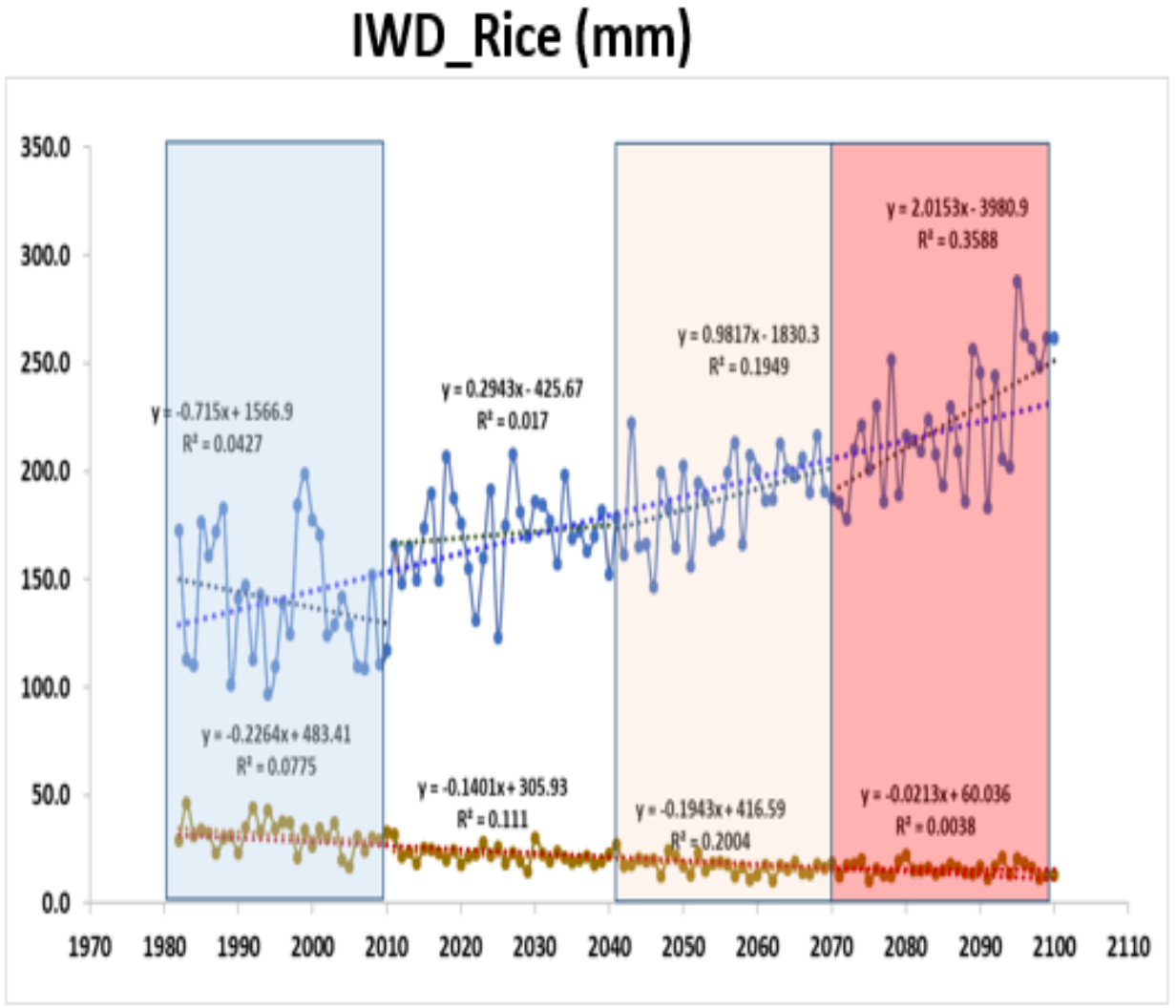


Results

- Irrigation water demand **(IWD)** by crops
- Irrigation water supply **(IWS)** by sources (surface, reservoir and groundwater)
- **% change** by IWD and IWS in future
- **Spatial** distribution of **watergap**

Irrigation Water Demand_Punjab, Pakistan (1981-2100)

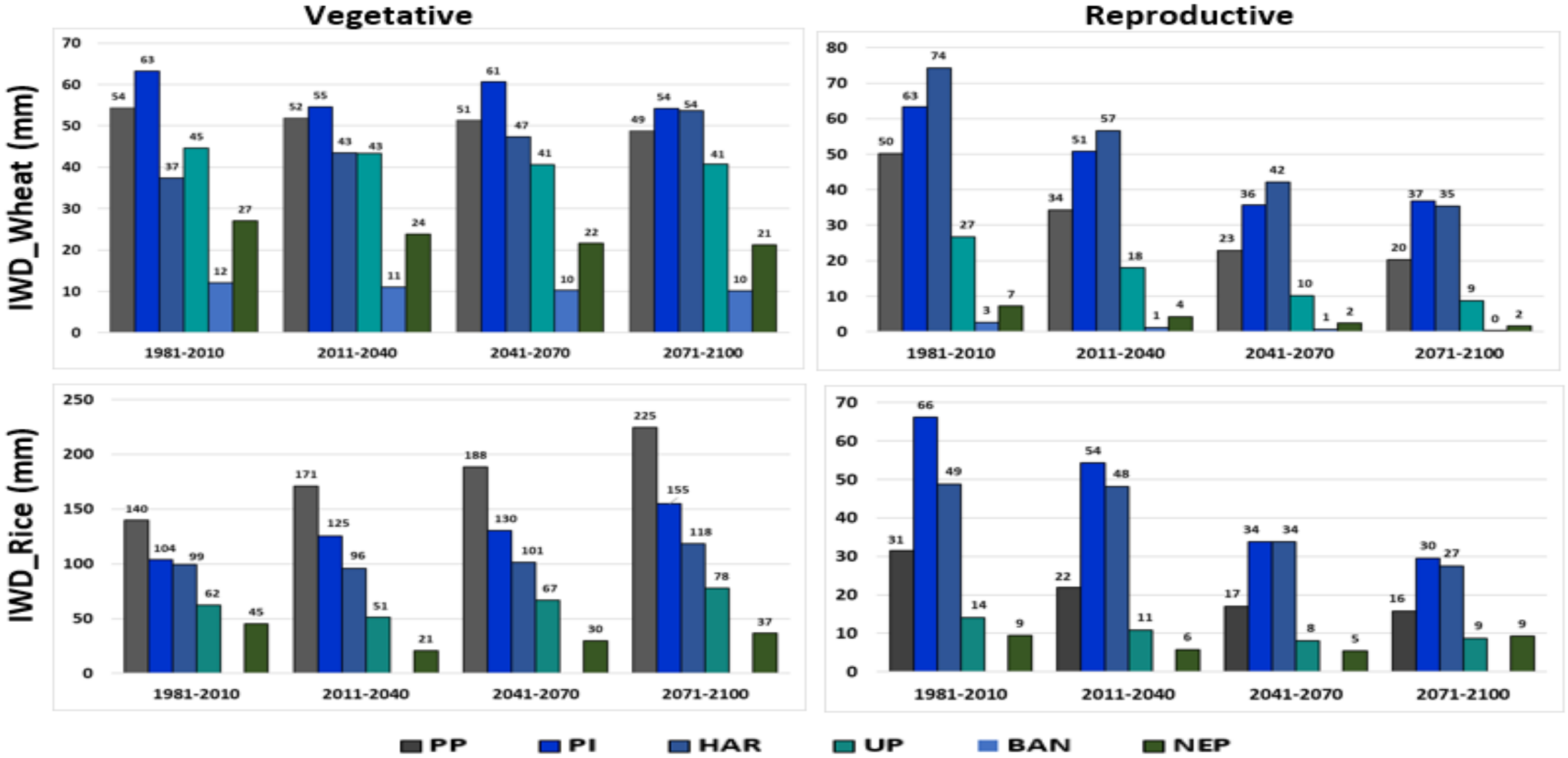




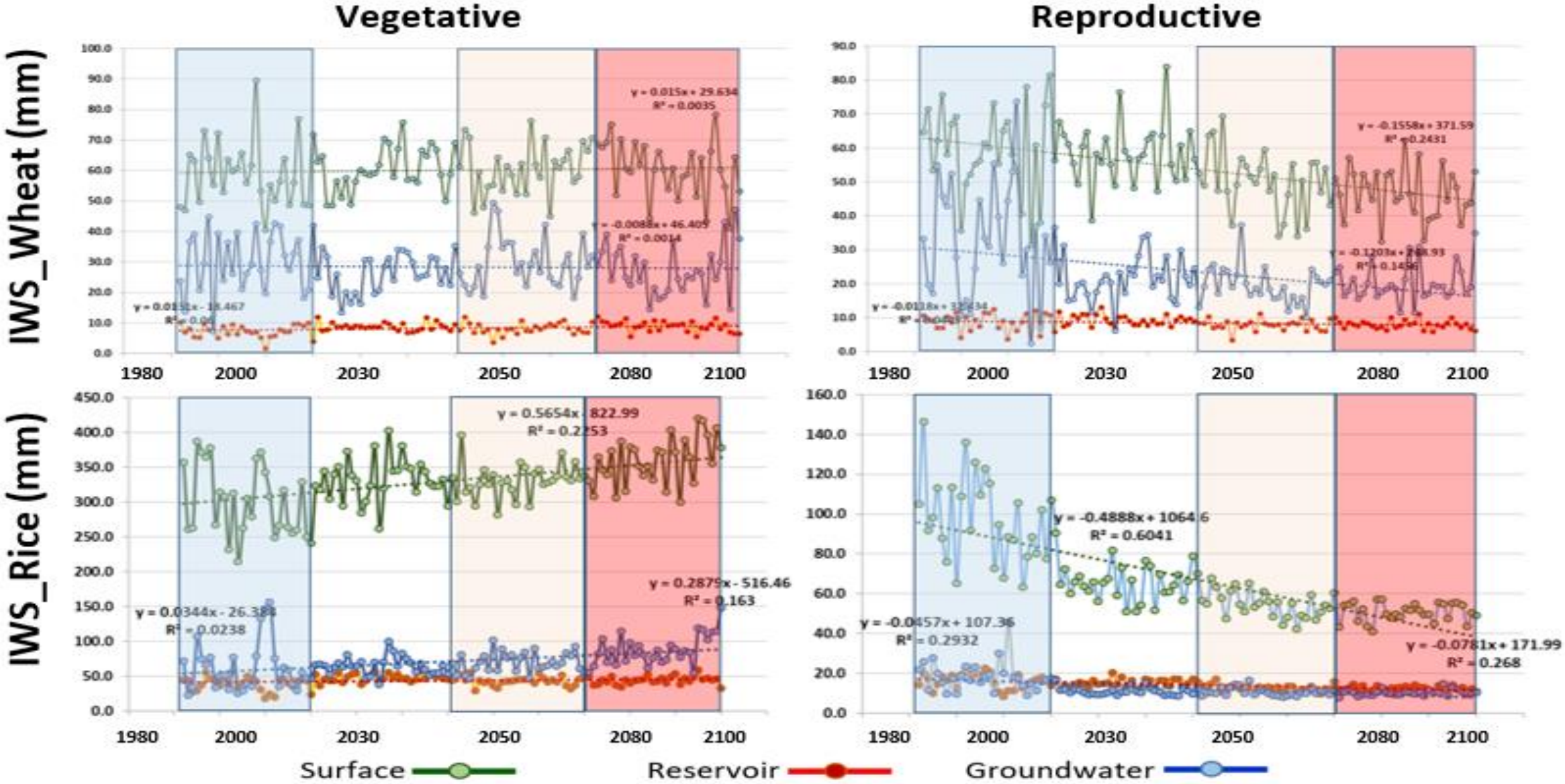
Vegetative

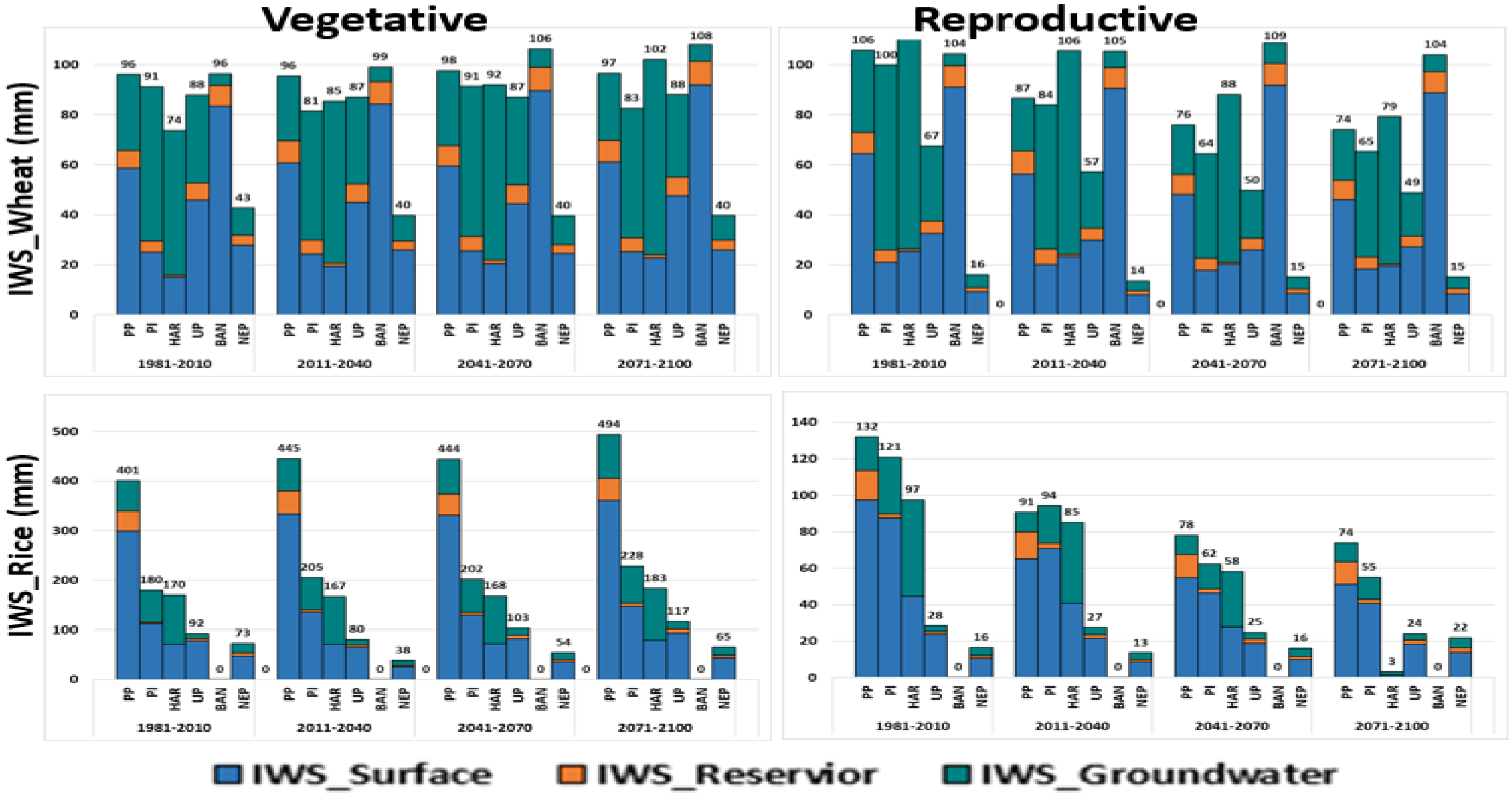
Reproductive

Irrigation Water Demand by six study sites

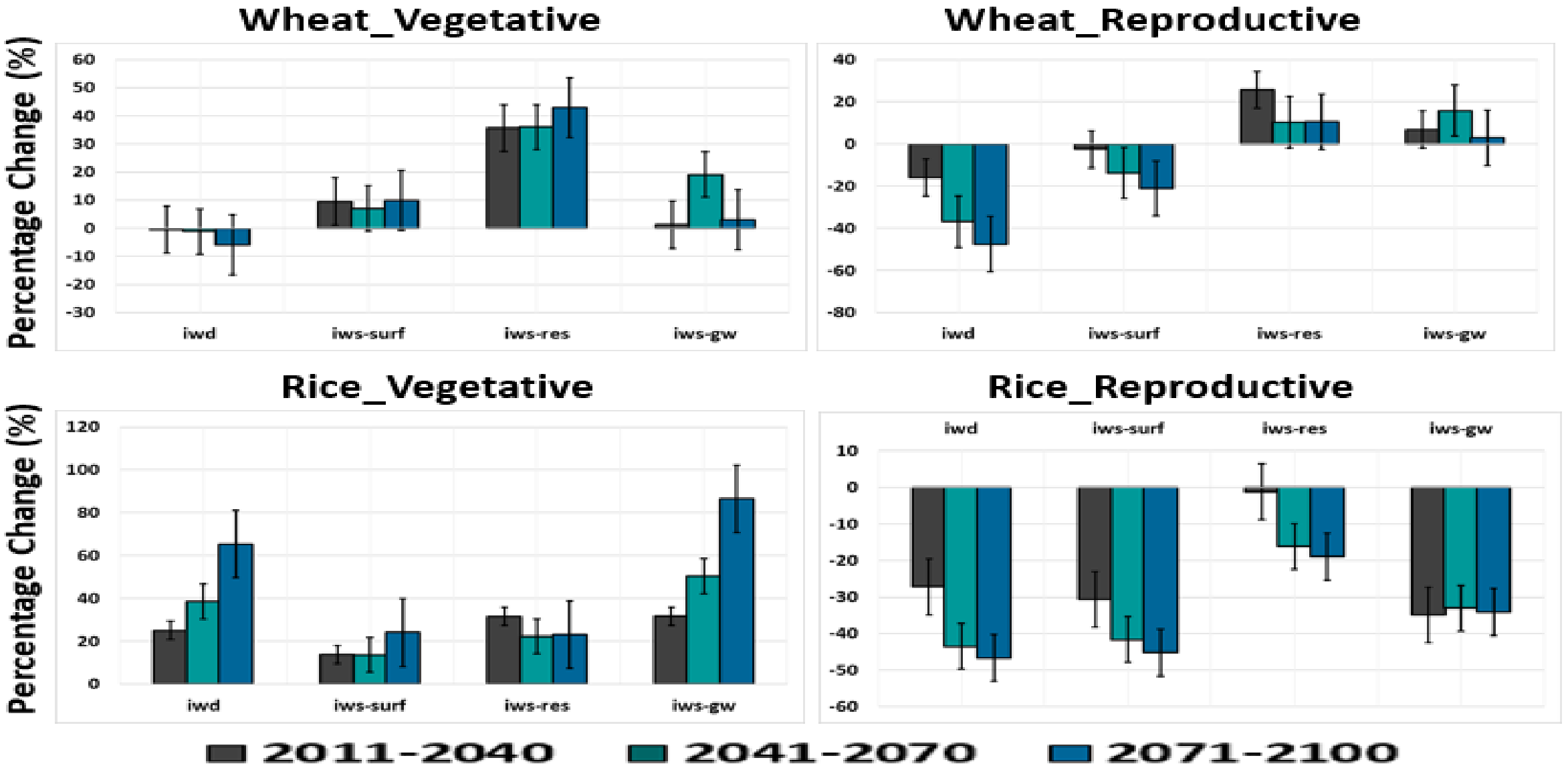


Irrigation Water Supply projections for Punjab, Pakistan (1981-2100)




Vegetative
Reproductive
IWS_Wheat (mm)
IWS_Rice (mm)
PP
PI
HAR
UP
BAN
NEP
1981-2010
2011-2040
2041-2070
2071-2100
IWS_Surface
IWS_Reservior
IWS_Groundwater

% Change in IWD and IWS in Punjab, Pakistan in Future



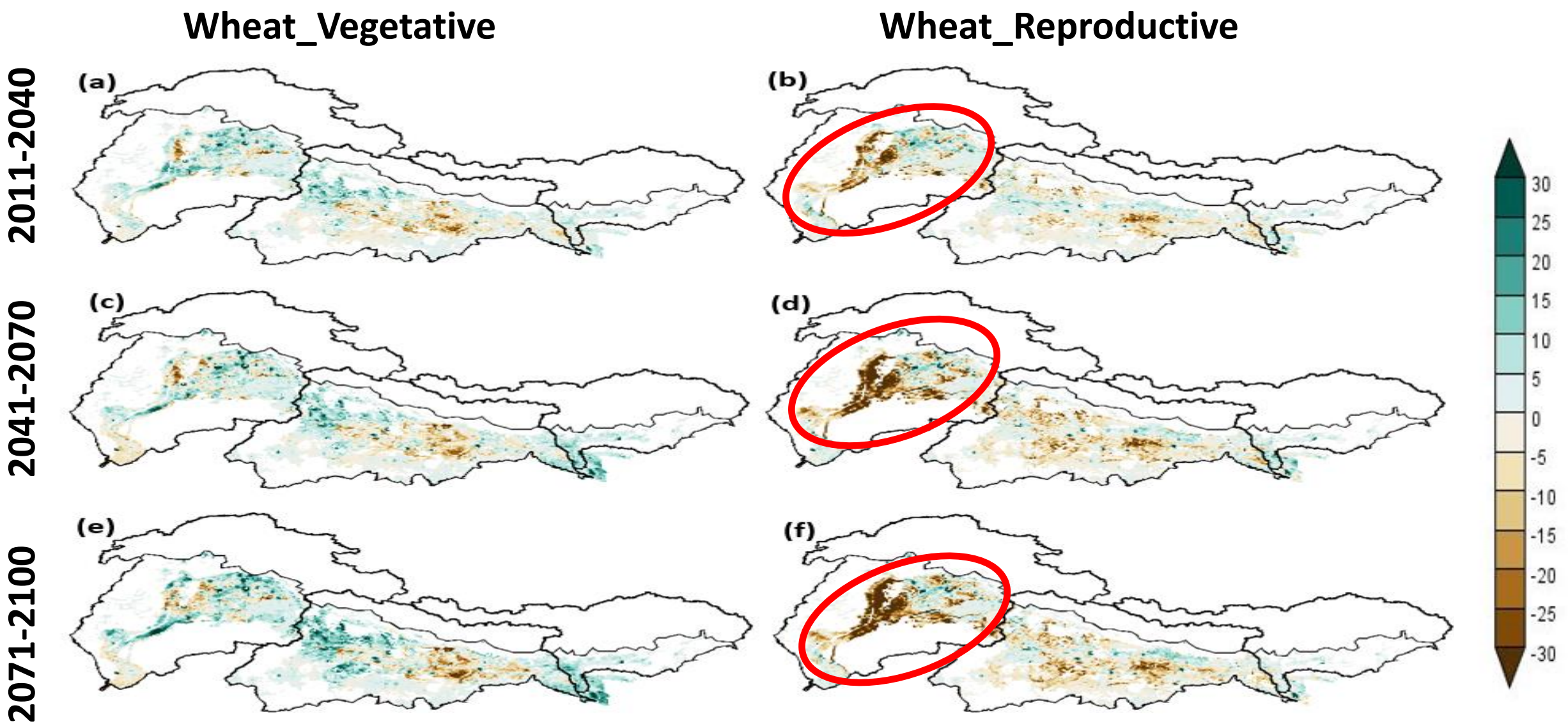
Irrigation watergap

e.g. Water for agriculture

Supply < Demand = Stress

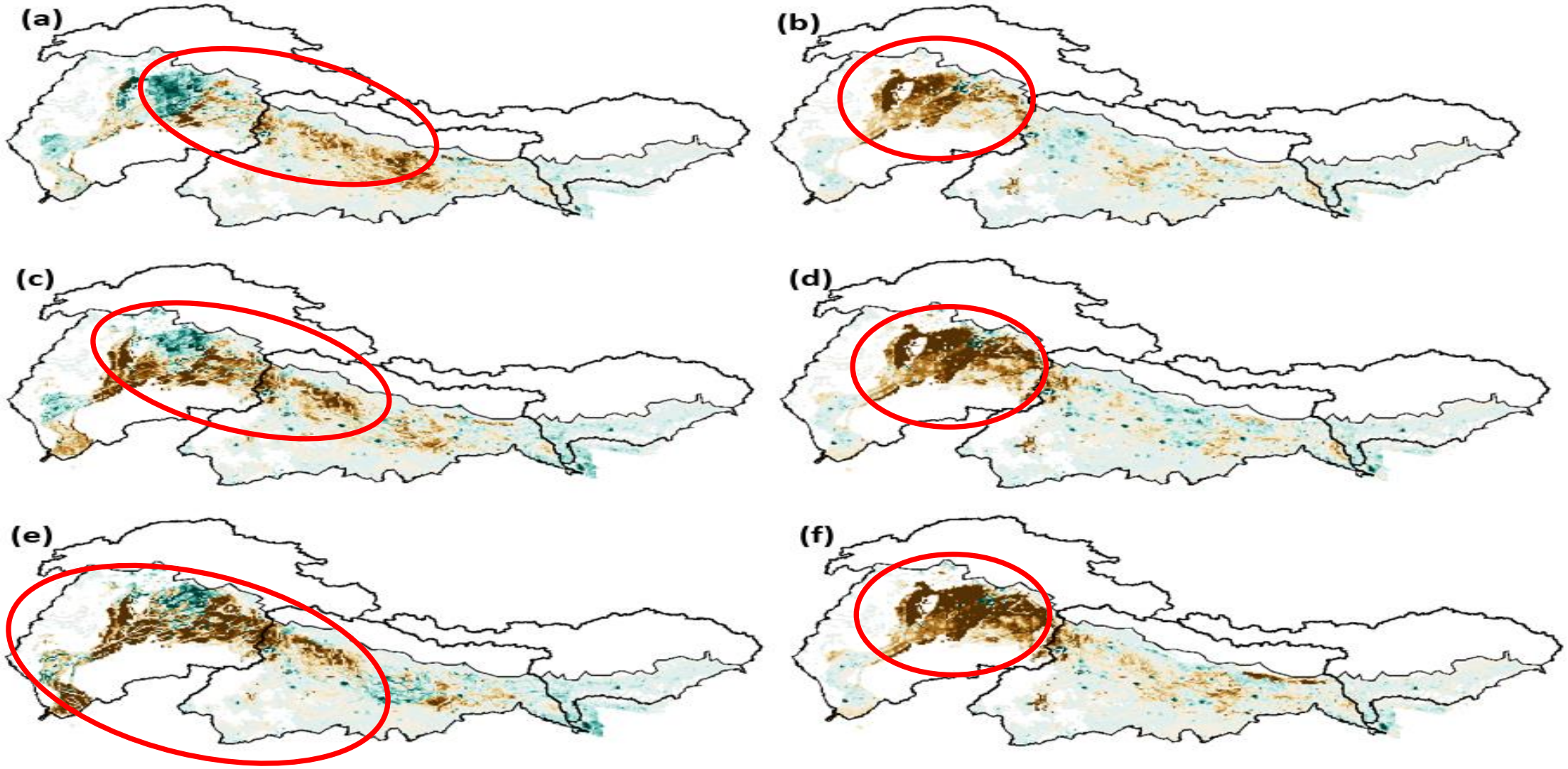
Irrigation Watergap = $Supply_{Surf+Res}$ - Demand

Irrigation watergap



Rice_Vegetative

Rice_Reproductive



Conclusion:

- **IWD** is **higher** during **vegetative phase** than **reproductive phase**
- **IWS is increasing** during **vegetative phase but reducing during reproductive phase in both cropping season**
- **IWD and IWS** are **changing** in **space and time (magnitude and sign of change varies in region)**
- **Changes in contribution of irrigation water supply** from **(Surface and groundwater resources)** are **not consistent** in future
- There is **large mis(match)** between irrigation water demand and supply (**quantity and timing**) causing stress on more **groundwater withdrawals**
- **Watergap is large** during **reproductive crop growth phase (flowering**) in both seasons
- **Watergap/ stress** is **large in north-western Ganges** and **central** and **south** part of **Indus basin**

- Rice being water intensive crop, IWD is projected to increase by 60 % till 2100 during veg- stage in PP, also has an increasing trend for all study states. But a declining trend is also evident during rep- stage for all states, PI with highest decrease of 54 % till end century
- Irrigation water supply available through reservoir during wheat veg- phase will increase in future (42%)
- An overall increase is expected in IWS through all sources during veg- stage as compared to rep- stage of Rice crop showing overall decrease.
- Ground water supplies for irrigation during rice veg- stage show 86 % more water, on the other hand during rep- stage these sources will face deficiency to the tune of 34 % and even 45 % less water available through surface.

Take-home Message

Crop water assessment *during critical crop growth phases (rather whole cropping season) are curial to understand the linkages between (mis)match of irrigation water demand and supply (quantity and timing) for devising appropriate strategies for sustained water resources and food production systems management under climate change and socio-economic stressors*

Feedback, questions, discussion
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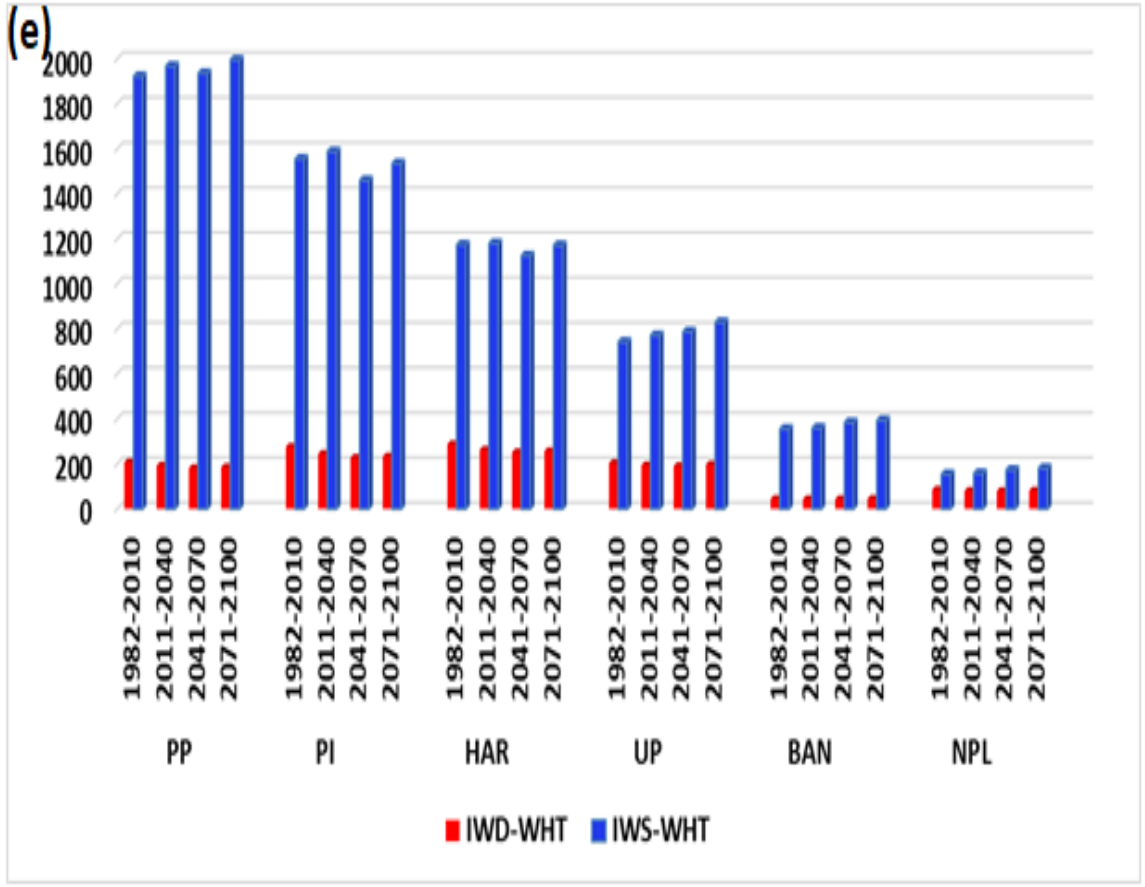
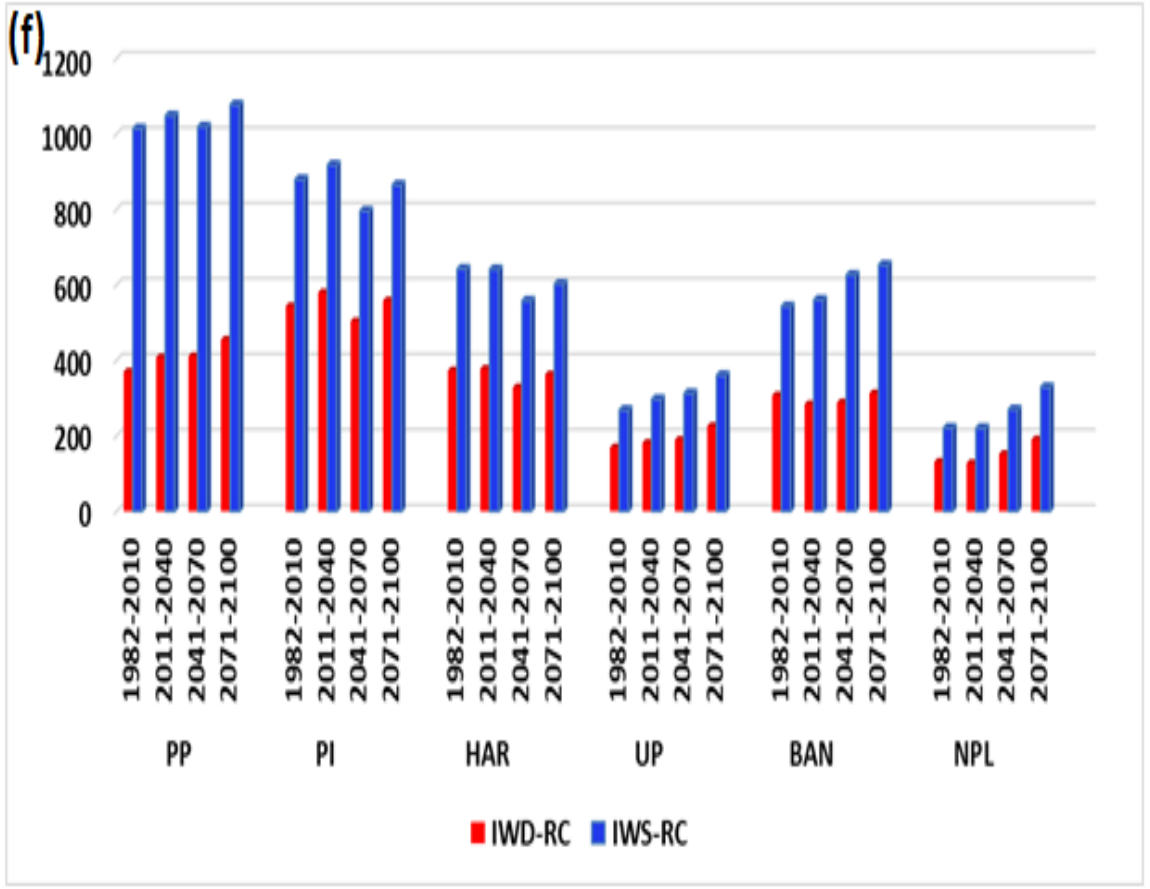
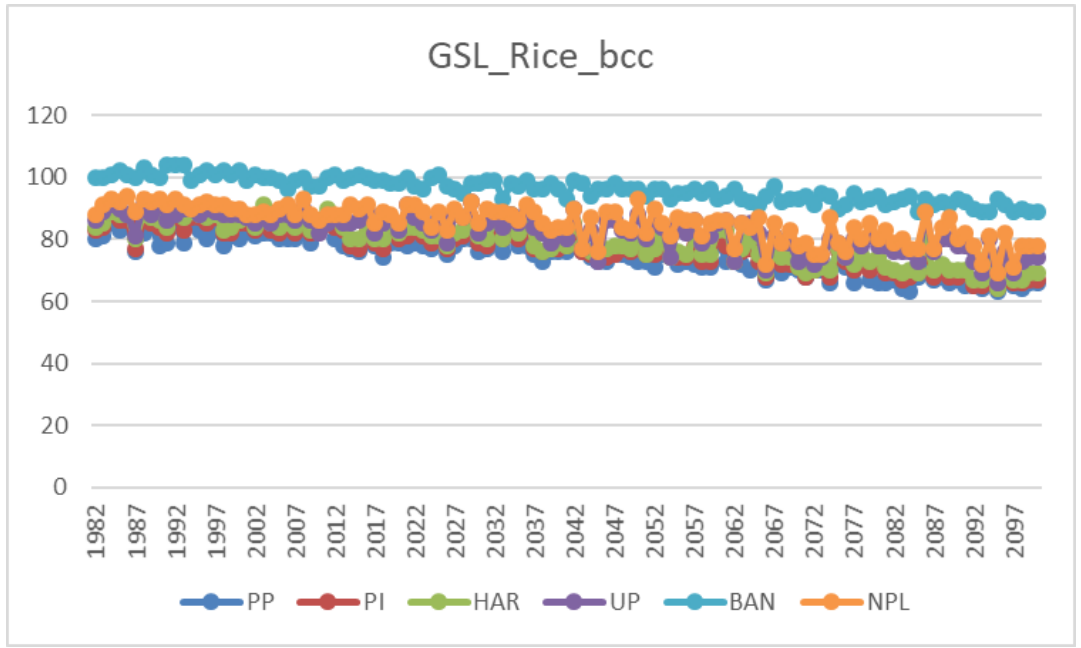
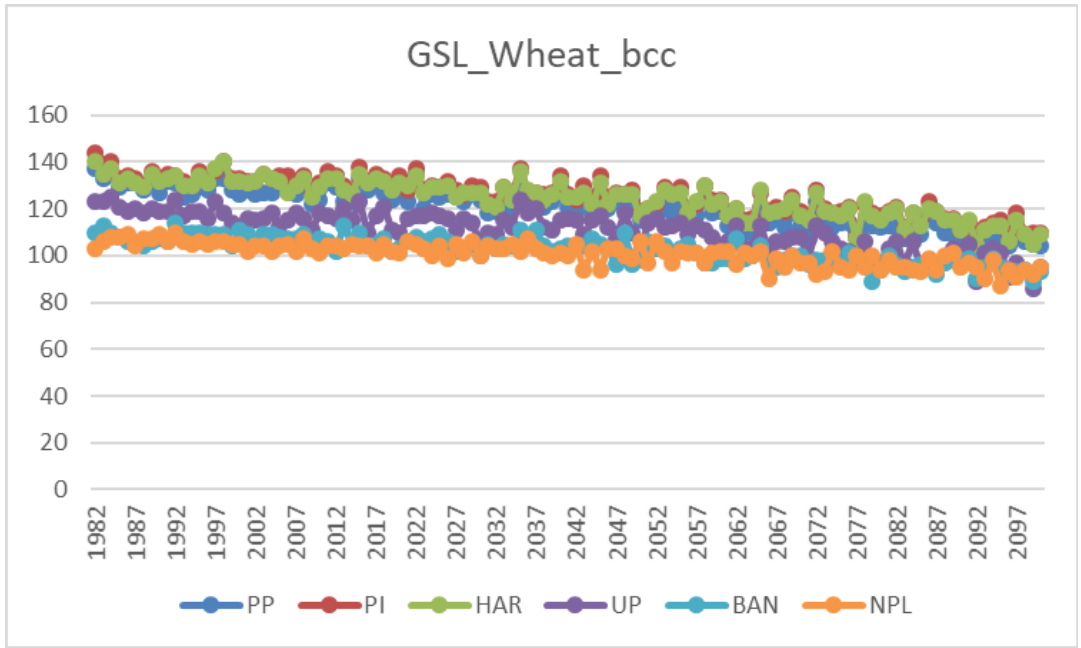
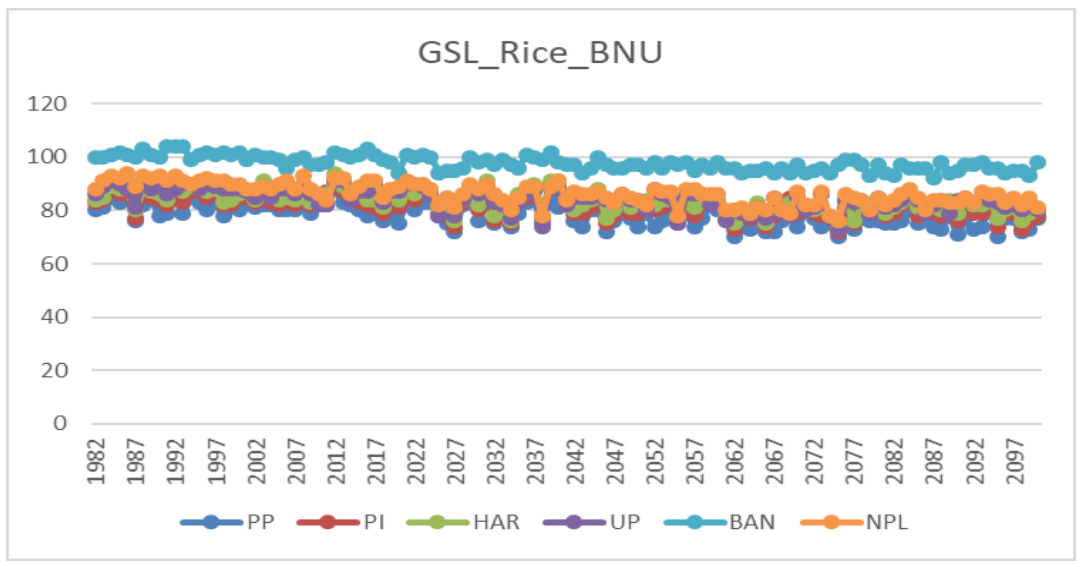
IWD and IWS at Seasonal level

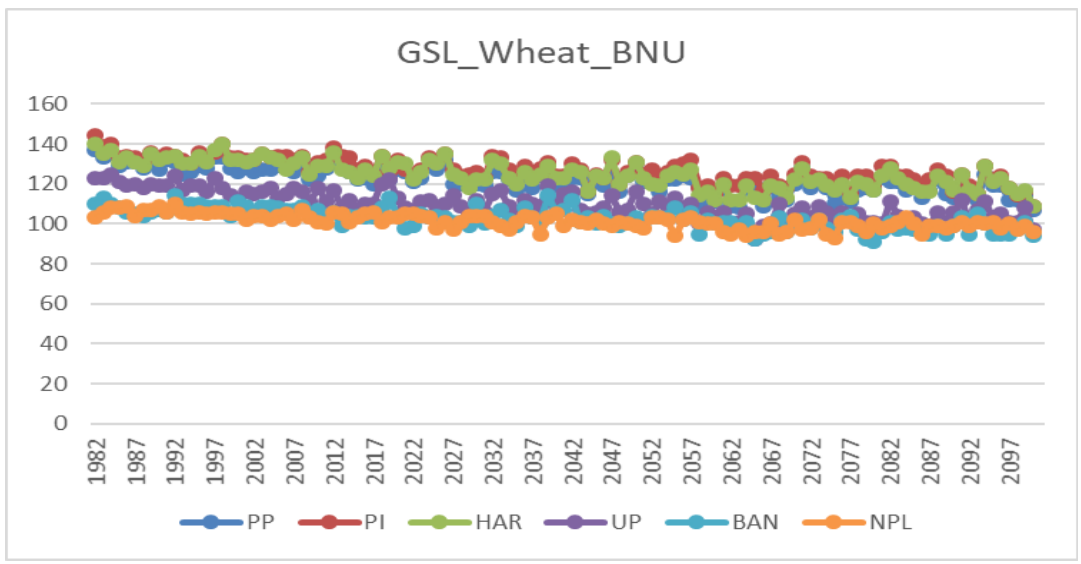


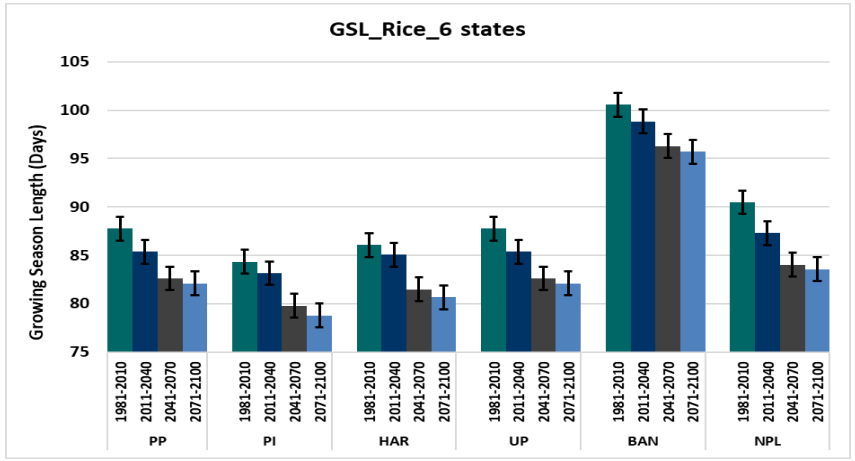


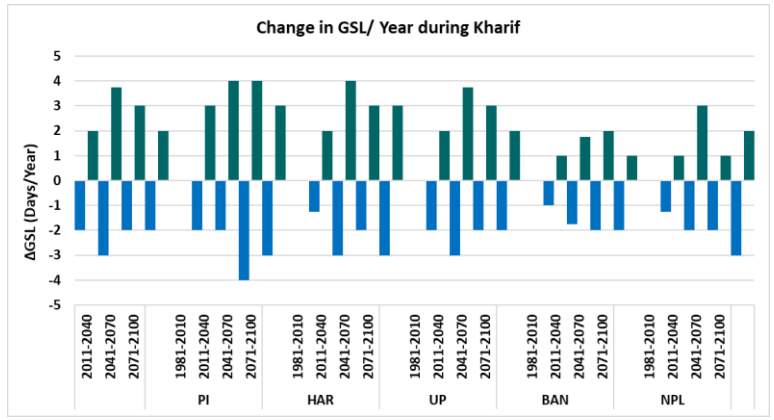

GSL_Rice_bcc
120
100
80
60
40
20
0
1982 1987 1992 1997 2002 2007 2012 2017 2022 2027 2032 2037 2042 2047 2052 2057 2062 2067 2072 2077 2082 2087 2092 2097
PP PI HAR UP BAN NPL

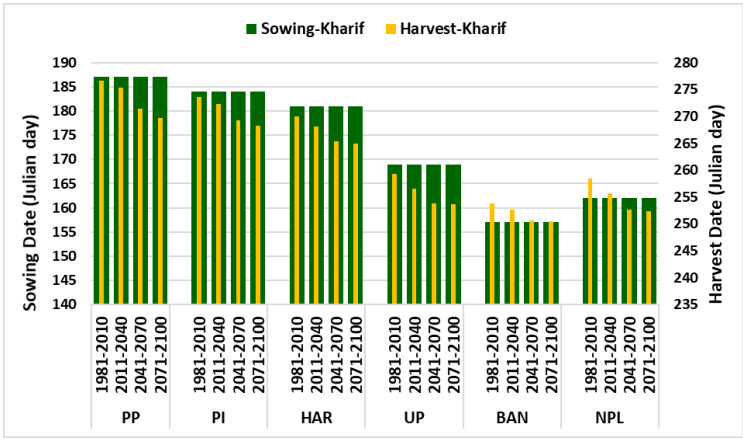

GSL_Wheat_bcc
160
140
120
100
80
60
40
20
0
1982 1987 1992 1997 2002 2007 2012 2017 2022 2027 2032 2037 2042 2047 2052 2057 2062 2067 2072 2077 2082 2087 2092 2097
PP PI HAR UP BAN NPL

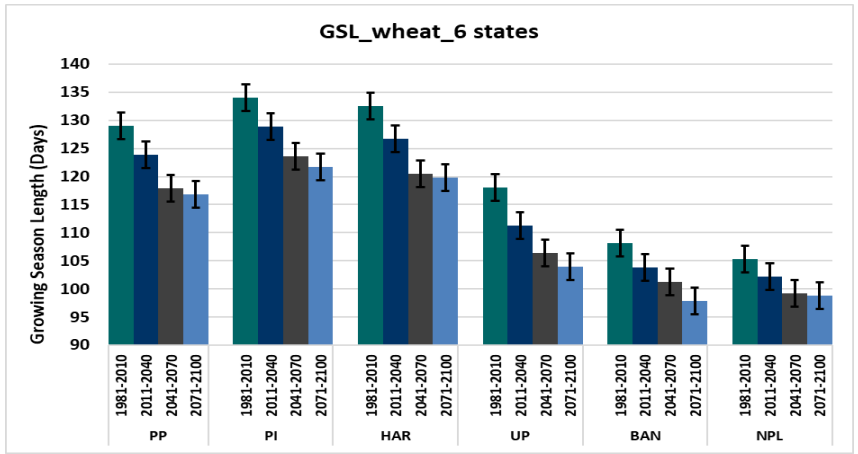

GSL_Rice_BNU
120
100
80
60
40
20
0
1982 1987 1992 1997 2002 2007 2012 2017 2022 2027 2032 2037 2042 2047 2052 2057 2062 2067 2072 2077 2082 2087 2092 2097
PP PI HAR UP BAN NPL

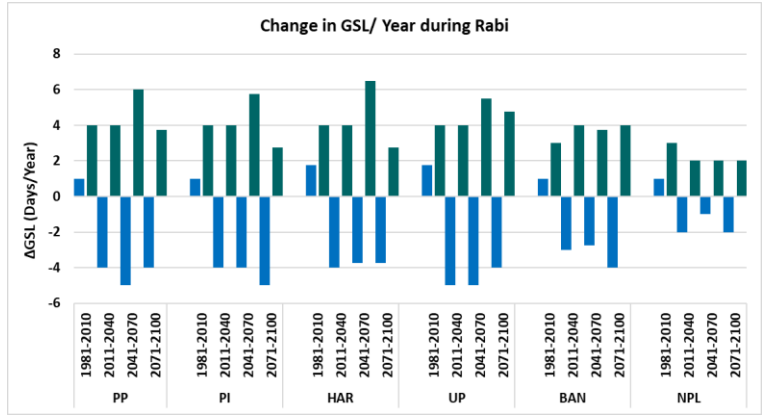

GSL_Wheat_BNU
160
140
120
100
80
60
40
20
0
1982 1987 1992 1997 2002 2007 2012 2017 2022 2027 2032 2037 2042 2047 2052 2057 2062 2067 2072 2077 2082 2087 2092 2097
PP PI HAR UP BAN NPL

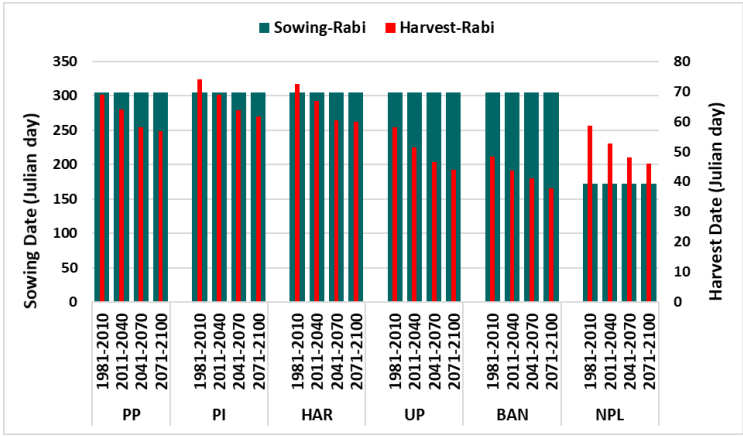

GSL_Rice_6 states
Growing Season Length (Days)
105
100
95
90
85
80
75
1981-2010
2011-2040
2041-2070
2071-2100
PP
PI
HAR
UP
BAN
NPL


Change in GSL/ Year during Kharif
ΔGSL (Days/Year)
5
4
3
2
1
0
-1
-2
-3
-4
-5
2011-2040
2041-2070
2071-2100
PI
HAR
UP
BAN
NPL


Sowing-Kharif
Harvest-Kharif
Sowing Date (Julian day)
Harvest Date (Julian day)
190
185
180
175
170
165
160
155
150
145
140
280
275
270
265
260
255
250
245
240
235
1981-2010
2011-2040
2041-2070
2071-2100
PP
PI
HAR
UP
BAN
NPL


GSL_wheat_6 states
Growing Season Length (Days)
140
135
130
125
120
115
110
105
100
95
90
1981-2010
2011-2040
2041-2070
2071-2100
PP
PI
HAR
UP
BAN
NPL


Change in GSL/ Year during Rabi
ΔGSL (Days/Year)
8
6
4
2
0
-2
-4
-6
1981-2010
2011-2040
2041-2070
2071-2100
PP
PI
HAR
UP
BAN
NPL


Sowing-Rabi
Harvest-Rabi
Sowing Date (Julian day)
Harvest Date (Julian day)
350
300
250
200
150
100
50
0
80
70
60
50
40
30
20
10
0
1981-2010
2011-2040
2041-2070
2071-2100
PP
PI
HAR
UP
BAN
NPL