Trends in Irrigation Development and its Impact on Agricultural Productivity in India : A Time Series Analysis

S. K. Srivastava*[1], Souvik Ghosh[2], Ashwani Kumar[2], P. S. B., Anand[2] and S. S. Raju[1]

Introduction

In India, irrigation has a crucial role in agricultural and rural development (Vaidyanathan *et al*., 1994; Hasnip *et al.*, 2001; Barker and Molle, 2004). Due to yield augmenting impact of irrigation, it has received high priority in the successive Five Years Plans (FYP). However, ascertaining precise contribution of irrigation in food production is difficult because there are no official Indian statistical data that provide the breakdown of agricultural production under irrigated or rainfed conditions (World Bank, 1998). Nevertheless, various estimates point to a significant contribution from irrigated agriculture to overall agricultural production [60% estimated by Seckler and Sampath (1985); 55% by World Bank (1991); 58% by Planning Commission (1999)]. The present paper has examined the temporal and spatial pattern in irrigation development and has assessed its impact on agricultural productivity to provide a feedback for the holistic development of water resources in India.

Methodology

Irrigation development was examined over successive FYP and across northern (Chandigarh, Delhi, Haryana, Himachal Pradesh, Jammu and Kashmir, Punjab, Uttar Pradesh and Uttarakhand), southern (Andhra Pradesh, Karnataka, Kerala, Pondicherry and Tamil Nadu), eastern (Bihar, Chattisgarh, Jharkhand, Odisha, West Bengal and Assam) and western (Gujarat, Madhya Pradesh, Maharashtra and Rajasthan) regions of India by estimating the share of gross irrigated area (GIA) in gross sown area (GSA), source-wise net irrigated area (NIA) and compound growth rate (CGR) in irrigated area. Further, the impact of irrigation on agricultural productivity was assessed by examining cropping intensity (gross cropped area/net cropped area*100) and crop diversification and by fitting time series regression models for different crops. The functional form of time series regression analysis was:

$$\ln Y_t = C_1 + C_2 * \ln X_{1t} + C_3 * \ln X_{2t} + C_4 * X_{3t}$$

where,

$\ln Y_t$ = Crop yield in the t^{th} year (kg/ha) in log form

C_1 = Constant/intercept

$\ln X_{1t}$ = Irrigated area under crop in the t^{th} year (Mha) in log form

$\ln X_{2t}$ = Rainfall in the t^{th} year (mm) in log form

X_{3t} = Trend, and

C_2, C_3, C_4 = Coefficients to be estimated.

Yield (kg/ha) of the crops (rice, wheat, sugarcane, pulses, oilseeds) was regressed with respective area of crops under irrigation (Mha) and rainfall. Additionally, the value of agricultural commodities per net sown area (₹/ha) at 2004-05 prices was also regressed with irrigation and rainfall to see their overall impact on the agricultural sector. The stationarity conditions of data series were checked using Augmented Dicky-Fuller (ADF) test in E-views 5.1 software. Irrigation and crop yield data series for all the crops were found to be trend-stationary after transformation into the logarithmic terms. Therefore, trend variable was also included in the regression analysis. In addition to making series stationary, trend variable also captures the effect of technological improvement over the years. In the case of wheat, time-series regression suffered with auto-correlation problem. To correct the problem of autocorrelation, two-step procedure was followed. Firstly, original series of wheat yield was regressed on the area under irrigation, rainfall and trend variable. Then, variance ($\hat{\rho}$) was estimated using Durbin-Watson statistics ($\hat{\rho}$=1–d/2). Subsequently, in the second step, $\hat{\rho}$ was used to transform the original series ($y_t - \hat{\rho}\, y_{t-1}$ and $x_{it} - \hat{\rho}\, X_{it-1}$) and ordinary least square (OLS) technique was applied on transformed variables (Gujarati, 2005). Transformation of the variables solved the problem of autocorrelation. Additionally, Prais-Winsten transformation { $Y_1\sqrt{1-P^2}$ and $X_i\sqrt{1-P^2}$} was applied to avoid the loss of one observation due to differencing (Gujarati, 2005).

Results and Discussion

Ultimate Irrigation Potential (UIP)

Ultimate irrigation potential (UIP), which limits the expansion of irrigation in a region, is the GIA that theoretically could be irrigated if all available land and water resources would be used for irrigation (Ministry of

[1] National Centre for Agricultural Economics and Policy Research (NCAP), New Delhi-110012.

[2] Directorate of Water Management (ICAR), Bhubaneswar, 751 023, Odisha.

Water Resources). UIP stands at around 139.89 Mha without inter-basin sharing and at 175 Mha with inter-basin sharing (CWC, 2010). Out of total UIP, 81.43 Mha (58.2 %) can be developed through minor irrigation (MI) projects, while the remaining 41.8 per cent can be utilized by the major and medium (M&M) irrigation sources in the country. Further, groundwater accounts for 78.7 per cent (64.09 Mha) of UIP from MI sources making it the most important source of irrigation in the country. The regional examination of UIP revealed striking variations in the potential of irrigation development across different regions due to topographical, hydrological and other constraints. Northern region constitutes the highest share (30.52 %) in the total UIP of the country, followed by western (26.08 %), eastern (24.06 %) and southern (18.19 %) regions.

Trend in irrigation development

With considerable government support, the absolute financial expenditure (planned) on irrigation development has though increased significantly from ₹ 6,840 crore during first FYP to ₹ 55,489 crore during tenth FYP at 1993-94 prices, the share of irrigation expenditure in total planned budget has rather decreased from 23 per cent to 9 per cent (CWC, 2010) during this period, indicating increasing demand towards other sectors of the economy. However, in recent years, trend is again shifting upward. Correspondingly, irrigation potential created (IPC) has increased from 22 Mha during pre-plan period to 123 Mha up to tenth FYP. Among the regions, IPC varied from 21.83 Mha in the eastern region to 45.08 Mha in the northern region at the end of tenth FYP. But, utilization of irrigation potential (IPU) was less than the created ranging from 65.52 per cent in the eastern region to 82.38 per cent in the northern region with the national average of 73.88 per cent during tenth FYP. Further, the utilization of already created irrigation potential witnessed a declining trend over the successive FYPs, raising several efficiency issues in the execution of irrigation projects.

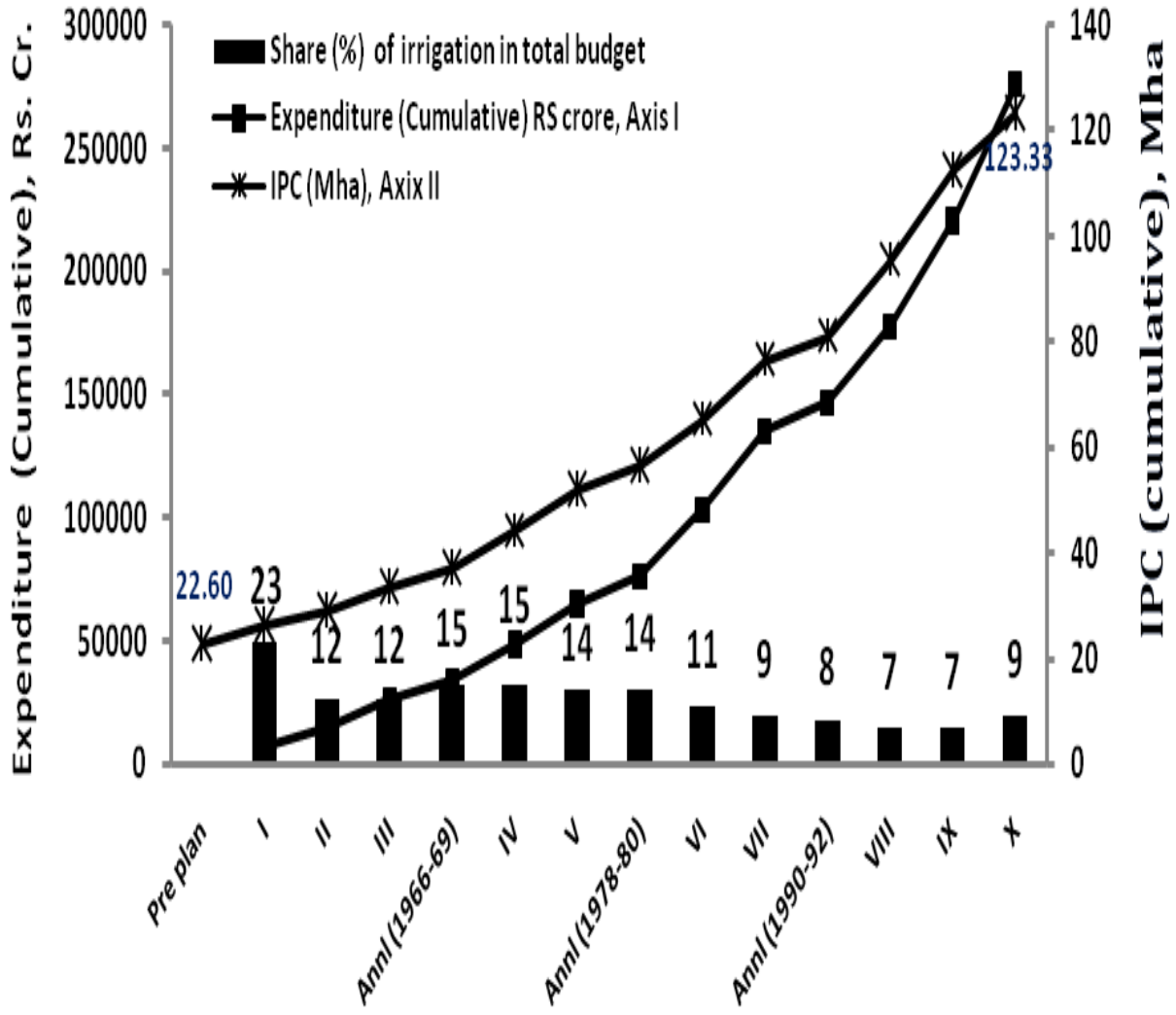

Figure 1. Five year plan wise trend in irrigation investment and its development in India

Improved irrigation infrastructure has resulted into increase in the net irrigated area (NIA) from 21.57 Mha in the first FYP to 58.81 Mha in the tenth FYP with the CGR of 2.08 per cent per annum (table 1). However, a structural shift has been observed in the relative contribution of different sources of irrigation in NIA over the years. The share of canal, which constituted 41 per cent in NIA in first FYP, declined to 26 per cent in tenth FYP, while the share of groundwater increased from less than one per cent to about 41 per cent during the same period. It was due to significantly higher annual growth of groundwater irrigated area (8.01 %) than canal irrigated area (1.26 %) during 1950-2007. Significant growth in the groundwater irrigated area indicated the growing importance of groundwater because of its reliability and higher irrigation efficiency of 70-80 per cent compared to 25-45 per cent of the canal irrigation (Sharma, 2009). Thus, the share of GIA in GSA increased from 17.09 per cent in first FYP to 42.77 per cent in tenth FYP.

TABLE 1—PLAN-WISE LAND USE PATTERN IN INDIA

(Million ha)

Plan	Net sown area (NSA)	Gross sown area (GSA)	Net irrigated area (NIA)	Gross irrigated area (GIA)	% of NIA to NSA	% of GIA to GSA	Cropping intensity (%)	Irrigation intensity (%)
First	125.95	140.01	21.57	23.93	17.13	17.09	111.17	110.98
Second	131.58	150.51	23.56	26.94	17.91	17.90	114.39	114.37
Third	136.51	156.89	25.88	29.85	18.96	19.03	114.93	115.34
Annual (1966-69)	138.14	160.21	27.70	33.79	20.05	21.09	115.98	121.97
Fourth	139.66	165.05	31.45	38.58	22.52	23.37	118.18	122.69
Fifth	140.06	168.76	35.00	43.68	24.99	25.88	120.49	124.81
Annual (1978-80)	140.94	172.20	38.29	48.76	27.17	28.32	122.18	127.34
Sixth	141.18	175.60	40.80	52.28	28.90	29.77	124.39	128.12
Seventh	139.76	178.03	44.03	57.81	31.50	32.47	127.38	131.29
Annual (1990-92)	142.32	183.99	48.83	64.08	34.31	34.83	129.28	131.23
Eighth	142.61	187.48	52.62	70.05	36.90	37.36	131.47	133.13
Ninth	141.64	189.70	56.06	76.46	39.58	40.31	133.93	136.37
Tenth	139.54	189.84	58.81	81.20	42.15	42.77	136.05	138.09
CGR (1950-07)	**0.18**	**0.58**	**2.08**	**2.52**				

CGR: Compound growth rate

Cropping intensity, irrigation intensity and share of NIA and GIA in NSA and GSA, respectively witnessed increasing trend in all the regions of the country over successive FYPs reflecting overall improvement in irrigation status and consequently, agriculture. However, rate of improvement in above indicators was not found to be uniform across different regions indicating inter-regional disparity between irrigation and agriculture sector. Northern region ranked first among the regions in terms of cropping intensity, irrigation intensity and share of NIA and GIA in NSA and GSA, respectively during tenth FYP. More than double share of NIA and GIA in NSA and GSA, respectively in Northern region as compared to other regions indicated better development of irrigation in the region. Irrigation intensity and share of NIA and GIA in NSA in GSA, respectively was lowest in Western region in tenth FYP reflecting poor development of irrigation in the region.

Impact of Irrigation on Agriculture

Manifestation of irrigation development was improvement in the cropping intensity and crop diversification towards water-intensive and high-value crops like fruits, vegetables, sugarcane, etc. over the years. Cropping intensity has increased from 111 per cent in first FYP to 136 per cent in tenth FYP (table 1), though not uniformly across the regions. Cereals and pulses, though still dominating with 63 per cent share in GSA (cropping pattern), have witnessed a declining trend over the planning period (table 2). On the other hand, fruits, vegetables, sugarcane, etc. which require assured irrigation, registered an increasing share in the GSA indicating irrigation as an important factor of crop diversification along with various other economic, policy and technological factors. Among the crops, fruits and vegetables witnessed maximum growth (3.36 per cent per annum) in their area during 1950 to 2007.

TABLE 2—PLAN-WISE AREA UNDER CROPS AND CROPPING PATTERN IN INDIA

Plan	Rice		Wheat		Cereals		Pulses		Oilseeds		Sugarcane		F & V		C& S	
	TA	CP	TA	CP	TA	CP	TA	CP	TA	CP	TA	CP	TA	CP	TA	CP
First	30.78	21.77	10.87	7.67	99.61	70.85	21.94	15.50	11.62	8.22	1.75	1.24	2.17	1.54	1.29	0.91
Second	33.16	22.03	12.86	8.54	89.90	59.73	23.94	15.91	12.88	8.56	2.16	1.44	2.52	1.67	1.44	0.96
Third	35.57	22.67	13.33	8.50	93.28	59.46	24.01	15.30	14.02	8.94	2.48	1.58	2.95	1.88	1.55	0.99
Annual plans (1966-69)	35.68	22.27	14.44	9.01	96.54	60.26	22.31	13.93	14.38	8.97	2.31	1.44	3.46	2.16	1.67	1.04
Fourth	37.49	22.72	18.30	11.09	101.04	61.22	22.80	13.81	14.90	9.03	2.63	1.59	3.66	2.22	1.78	1.08
Fifth	38.98	23.10	20.11	11.91	102.06	60.48	23.72	14.05	15.25	9.04	3.09	1.83	4.19	2.48	1.91	1.13
Annual plans (1978-80)	40.03	23.25	22.32	12.96	104.28	60.56	23.15	13.44	15.43	8.96	3.10	1.80	4.70	2.73	2.14	1.24
Sixth	40.42	23.01	23.15	13.18	105.03	59.81	23.24	13.23	17.34	9.87	3.28	1.87	5.21	2.97	2.16	1.23
Seventh	41.03	23.05	23.42	13.16	103.16	57.96	23.18	13.02	20.98	11.78	3.38	1.90	6.14	3.45	2.36	1.33
Annual Plans (1990-92)	42.67	23.20	23.77	12.92	101.51	55.17	23.67	12.86	25.46	13.85	3.90	2.12	7.63	4.15	2.41	1.31
Eighth	42.73	22.79	25.29	13.49	100.75	53.74	22.94	12.24	26.58	14.18	3.97	2.12	8.68	4.63	2.36	1.26
Ninth	44.61	23.52	26.76	14.10	83.22	43.88	21.97	11.58	24.41	12.86	4.19	2.21	9.80	5.17	2.79	1.47
Tenth	42.84	22.61	26.78	14.07	98.77	52.01	22.66	11.90	25.62	13.45	4.42	2.28	11.95	6.15	3.53	1.98
CGR(1950-2007)	**0.66**		**1.85**		**-0.24**		**-0.02**		**1.69**		**1.72**		**3.36**		**1.68**	

CGR: compound growth rate in respective category during 1950-2007

TA: Total area under respective crop (Million ha)

CP: cropping pattern (share of a crop's area in gross sown area)

F & V: fruits and vegetables, C&S: condiments and spices

TABLE 3—PLAN-WISE IRRIGATED AREA UNDER DIFFERENT CROPS IN INDIA

(Per cent)

Plan	Rice		Wheat		Cereals		Pulses		Oilseeds		Sugarcane		F & V		C& S	
	IA*	Yield	IA	Yield	IA	Yield	IA	Yield	IA	Yield	IA	Yield	IA	Yield	IA	Yield
First	33.40	8.74	35.21	7.08	17.74	5.67	9.15	4.68	1.20	4.66	67.75	327.70	11.71	—	6.17	—
Second	36.15	9.14	31.77	7.58	21.60	6.15	8.27	4.82	3.18	5.03	67.00	375.25	18.21	—	22.00	—
Third	37.15	9.86	35.98	8.31	22.83	7.01	8.87	4.87	3.56	4.87	69.72	440.50	18.43	—	27.34	—
Annual plans (1966-69)	38.31	9.90	47.06	10.53	25.38	7.14	9.76	4.67	4.96	4.77	74.11	434.12	22.01	—	27.80	—
Fourth	38.25	11.06	55.12	12.68	27.99	9.11	8.58	4.91	7.48	5.28	74.32	495.70	29.56	—	33.72	—
Fifth	39.03	12.01	63.38	13.57	31.54	9.90	7.65	4.84	8.81	5.60	77.80	501.12	33.79	—	37.77	—
Annual plans (1978-80)	42.22	12.46	67.13	14.95	34.27	10.73	8.31	4.70	11.76	5.40	77.51	512.71	37.47	—	39.82	—
Sixth	42.13	13.50	72.18	16.83	35.53	11.53	8.20	4.86	16.54	6.20	81.58	523.14	36.79	—	38.93	—
Seventh	44.51	15.85	77.48	20.16	38.77	14.05	9.37	5.39	20.20	6.74	85.77	518.89	37.50	—	44.56	—
Annual Plans (1990-92)	46.45	17.45	82.18	22.66	42.18	15.59	10.63	5.54	24.73	7.62	89.99	517.76	34.33	102.13	47.36	9.48
Eighth	50.07	18.44	85.63	24.33	46.15	16.78	12.41	5.73	25.86	8.43	93.04	531.41	34.61	116.73	59.33	10.32
Ninth	54.58	19.26	87.53	26.65	61.65	18.79	13.04	5.98	25.87	8.42	99.78	541.63	46.82	130.36	59.07	11.84
Tenth	55.42	21.02	91.08	26.50	52.50	19.33	15.39	5.93	29.13	9.91	99.57	542.07	49.09	128.54	52.89	13.41
CGR (1950-2007)	**1.65**	**2.32**	**4.10**	**2.49**	**2.27**	**2.51**	**0.96**	**0.74**	**8.24**	**1.93**	**2.58**	**1.00**	**6.56**	**1.03**	**5.70**	**2.50**

CGR: compound growth rate in respective category during 1950-2007.

* share of irrigated area under respective crop.

Yield: Quintals/ha, F & V: fruits and vegetables, C&S: condiments and spices.

For rice, wheat, cereals, pulses, oilseeds and sugarcane, CGR is estimated for the period 1969-2007. For fruits & vegetables and spices, CGR is estimated for the period 1990-2007.

Further, 99.57 and 91.08 per cent area under sugarcane and wheat, respectively had access to irrigation during tenth FYP in India (table 3). Irrigated area under sugarcane has increased from 67 per cent in first FYP to 99.57 per cent in tenth FYP with the annual growth of 2.58 per cent. Similarly, irrigated area under wheat increased from 35.21 per cent in first FYP to 91.08 per cent in tenth FYP with the annual growth of 4.1 per cent. More than half of the total area under fruits and vegetables, condiments and spices, cereals and rice was under irrigation during tenth FYP. Pulses and oilseed, which are primarily grown under rainfed conditions, occupied minimum area under irrigation. However, oilseeds witnessed maximum growth in irrigated area under them during 1950 to 2007 because of technological and policy boosts provided by government to increase the oilseeds production. Similarly, yield of these crops improved in the same direction with the annual growth of 2.32 per cent, 2.49 per cent, 1.00 per cent, 0.74 per cent and 1.93 per cent, respectively indicating positive impact of irrigation in synergy with other inputs.

Results of the time series regression analysis also showed irrigation as a significant factor affecting crop yield positively, though with varying degree except for pulses (Table 4). For pulses, irrigation was not found to be a significant factor because they are primarily grown under the rainfed and residual soil moisture conditions. Rainfall was found to be a significant factor affecting yield of pulses positively. Rainfall was also significantly affecting yield of all the crops, except sugarcane and wheat which are mainly grown in the irrigated conditions. About 94 per cent of the sugarcane and 91 per cent of the wheat are grown under irrigated conditions in India. For oilseeds, irrigated area has increased from less than one per cent during 1950s to 27 per cent in 2008 and was found significant in combination with rainfall and trend variable. Trend variable representing technological improvement was found to be significant and positive for all the crops. Overall, agricultural productivity, expressed in terms of value of agricultural commodities (₹) per net sown area at 2004-05 prices, was positively affected by irrigation, rainfall and technological improvements.

The estimated positive coefficients of the irrigated area, representing irrigation elasticities (log-linear production function), indicated scope to improve crop yield further by improving irrigation infrastructure. However, for the country as a whole, about 88 per cent of the UIP has already been developed which limits further expansion of irrigation infrastructure on a large scale. As utilization of irrigation potential is less than IPC, irrigation infrastructure can be improved by improving irrigation efficiency, institutional rearrangements in favour of water users association, sustainable groundwater development in the light of its over-exploitation and emphasizing completion of on-going irrigation projects rather starting new ones. This will lead to the improved crop productivity and thus livelihood of the Indian farming community.

TABLE 4—IMPACT OF IRRIGATION ON CROP YIELD (TIME SERIES REGRESSION)

Parameters	Rice	Wheat	Sugarcane	Pulses	Oilseeds	Agricultural productivity (₹/Ha)
Constant	1.803*	2.482***	10.319***	2.006	4.918***	6.043***
	(0.961)	(0.124)	(0.116)	(1.239)	(0.188)	(0.594)
Irrigated area	0.550**	0.506***	0.208**	0.024	0.084*	0.332**
	(0.231)	(0.127)	(0.099)	(0.128)	(0.049)	(0.134)
Rainfall	0.494***	-0.027	0.001	0.564***	0.001***	0.270***
	(0.143)	(0.035)	(0.000)	(0.176)	(0.000)	(0.086)
Trend	0.011***	0.005***	0.009***	0.007**	0.014***	0.018***
	(0.004)	(0.002)	(0.002)	(0.002)	(0.002)	(0.003)
R^2	0.959	0.868	0.929	0.708	0.921	0.990
D-W statistics	1.34	1.95	1.55	1.81	2.21	1.52
D_L-D_u(1%)	1.20-1.47	1.20-1.47	1.10-1.44	1.14-1.45	1.12-1.45	1.20-1.47
Time period	1965-2008	1965-2008	1965-2008	1970-2008	1971-2008	1965-2008

NOTES: Dependent variable: Yield (kg/ha) of respective crops.

Variables are expressed in logarithmic terms to make the series stationary.

Conclusions

In India, irrigation has played a catalytic role in providing food security to millions of people by positively affecting agricultural productivity. Therefore, irrigation has received massive government support in the successive FYPs and has witnessed significant growth during the past fifty years, though with inter-regional variations. The potential of irrigation development varies across geographical regions due to topographical, hydrological and other constraints. Consequently, different regions have performed differently in development of irrigation. Further, the increasing gap between irrigation potential created and its utilization over the years has raised efficiency issues in the execution of irrigation projects. As about 88 per cent of UIP has already been developed, irrigation infrastructure can be improved further by bridging this gap. Improved irrigation infrastructure has led to increased cropping intensity and crop diversification towards high-value crops. The irrigation exerts a positive and significant impact on crop yield with varying degree across different crops. The agricultural productivity can be improved further by increasing irrigation efficiency, evolving institutional rearrangements, developing sustainable groundwater supply and emphasizing on completion of the on-going irrigation projects efficiently rather starting new ones.

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