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UNRAVELLING THE SPATIO-TEMPORAL PATTERN OF IRRIGATION DEVELOPMENT AND ITS IMPACT ON INDIAN AGRICULTURE[†]

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ABSTRACT

Irrigation, the dominant use of water resources, has always remained a decisive factor in agricultural growth and development. The present study provides a critical analysis of inter-regional variations in water resources and irrigation development over successive plan periods (1950–2007) and ascertains the long-term impact of irrigation development on Indian agriculture using tabular, growth and econometric analysis. With impressive irrigation development over successive five-year plans, India possesses the largest irrigated area in the world. However, the positive impact of irrigation development could not be achieved equally across different geographical regions, and unsustainable water resource development in one part coexists with its underutilization in other parts of the country. The Northern region of India showed better performance both in irrigation and agriculture while the Eastern region was found to be poorest in spite of a rich water resource base. Panel data analysis revealed a positive correlation between irrigation and crop yield though with varying degree. The findings of the present study provides a platform for institutional restructuring, policy reframing and technological interventions to improve water use efficiency and develop water resources in a equitable, holistic and sustainable manner. Copyright © 2013 John Wiley & Sons, Ltd.

KEY WORDS: water resources; irrigation development; spatial and temporal variations; impact on agriculture; India

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RÉSUMÉ

L'irrigation, le principal utilisateur des ressources en eau, a toujours été un facteur déterminant dans la croissance et le développement agricole. La présente étude fournit une analyse critique des variations interrégionales des ressources en eau au cours des plans de développement successifs (1950–2007), et détermine l'impact à long terme du développement de l'irrigation sur l'agriculture indienne à l'aide de tableaux de croissance et d'analyse économétrique. Les plans quinquennaux successifs ont fait que l'Inde possède la plus grande superficie irriguée dans le monde. Toutefois, l'impact positif du développement de l'irrigation ne pourrait pas être atteint si certaines régions géographiques développaient les ressources en eau de façon non durable, alors que d'autres régions coexisteraient avec des ressources sous-utilisées. La région du Nord de l'Inde a montré de meilleures performances à la fois en termes d'irrigation et d'agriculture tandis que la région de l'Est est parmi les plus pauvres en dépit de ressources en eau abondantes. L'analyse des données du panel a révélé une corrélation positive entre l'irrigation et le rendement des cultures, mais avec des degrés divers. La présente étude résulte en une plateforme pour la restructuration institutionnelle et le recadrage des politiques ainsi que des interventions technologiques pour améliorer l'efficacité d'utilisation de l'eau et développer les ressources en eau de manière équitable, globale et durable. Copyright © 2013 John Wiley & Sons, Ltd.

MOTS CLÉS: ressources en eau; développement de l'irrigation; variations spatiales et temporelles; impact sur l'agriculture; Inde

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[†]Démêler les motifs spatio-temporels du développement de l'irrigation et de leur impact sur l'agriculture indienne.

INTRODUCTION

Historically, irrigation has played a crucial role in agricultural growth and development and will continue to be important due to its direct (Saleth, 1996; Vaidyanathan, 1999; Hasnip *et al*., 2001) as well indirect (Saleth *et al*., 2003; Narayanamoorthy and Bhattarai, 2004; Narayanamoorthy, 2007) positive impact on the rural economy. Although ascertaining the precise contribution of irrigation to food production is difficult (World Bank, 1998), various estimates point to a significant contribution from irrigated agriculture to overall agricultural production in India (60% estimated by Seckler and Sampath, 1985; 55% by World Bank, 1991; 58% by Government of India, 1999). Because of its yield-augmenting impact, irrigation development has always been the priority area of India's agricultural development strategy in successive five-year plans (FYPs), with massive financial support given to the irrigation sector. Consequently, irrigation potential has increased from 22 million hectares (Mha) during the pre-plan period to 123 Mha up to the 10th FYP, making India the world leader in the irrigation sector (Central Water Commission, CWC, 2010). Many studies have noted that the performance of India's irrigation sector has remained unsustainable, leading to declining utilization of the irrigation infrastructure created so far (Selvarajan and Roy, 2004; Narayanamoorthy, 2011). Not many studies have analysed the physical and financial performance of irrigation projects and its long-term impact on the agricultural sector across different regions over successive plan periods in India. A region-wise as well as project category-wise examination of irrigation development in terms of created potential, gaps in utilization, the changing dynamics of irrigation sources and financial performance in the recent past would provide feedback for framing appropriate policies and financial allocation in the irrigation sector across the regions in future plans. Therefore, the present study was conducted to analyse regional variations in available water resources, irrigation development and utilization patterns under major, medium and minor irrigation projects,[1] expenditure in creating irrigation infrastructure, financial recovery in irrigation projects during the recent past and the long-term impact of irrigation development on the agricultural sector to provide an impetus to stakeholders towards sustainable irrigation development in India.

MATERIALS AND METHODS

The study is based on the data collected from published sources such as *Financial Aspects of Irrigation Projects in India, Water and Related Statistics* (2000 and 2010), *Estimates of Area and Production of Major Crops in India* (various issues), *Agricultural Statistics at a Glance* (various issues), etc. Time series data on different aspects such as investment in irrigation, land use statistics, source-wise irrigated area, ultimate irrigation potential (UIP), irrigation potential created (IPC), irrigation potential utilized (IPU), etc. were collected for different states of India. Subsequently, the states were categorized into different geographical regions, viz. Northern (Chandigarh, Delhi, Haryana, Himachal Pradesh, Jammu and Kashmir, Punjab, Uttar Pradesh and Uttarakhand), Southern (Andhra Pradesh, Karnataka, Kerala, Pondicherry and Tamil Nadu), Western (Gujarat, Madhya Pradesh, Maharashtra and Rajasthan) and Eastern (Bihar, Chattisgarh, Jharkhand, Odisha, West Bengal and Assam) for inter-regional comparison (Figure 1).

Spatial and temporal irrigation development was examined by analysing physical and financial aspects of irrigation projects in the country using tabular and growth analysis. These include regional trend and variations in IPC and its utilization, structural shift in sources of irrigation, allocation of financial resources in the irrigation sector, cost of creation of irrigation infrastructure, financial recovery, etc. The impact of irrigation on agriculture was examined by studying the trend in irrigation coverage (the share of irrigated area in the sown area) and estimated cropping intensity (net sown area/gross sown area × 100) over successive FYPs. Further, panel data regression analysis (fixed-effect model) was attempted to establish the irrigation–yield relationship incorporating spatial variations in explanatory variables. Panel data analysis has advantages over ordinary least square (OLS) regression models in terms of increased precision in estimation (due to the increase in the number of observations because of combining or pooling several time periods of data for each individual) and capturing unobserved individual heterogeneity that may be correlated with regressors. In the present study, the panel data set was prepared using 14 major states (cross-section units) over 13 years (time series units) and the fixed-effect model was used which allows each cross-section unit (state) to have a different intercept term though all slopes are the same. The specification of the model is given below:

$$\begin{aligned} Y_{it} &= \alpha_i + \beta_1 X_{1\,it} + \beta_2 X_{2\,it} + \beta_3 X_{3\,it} + e_{it} \\ e_{it} &\sim IID\left(0, \sigma_e^2\right) \end{aligned} \quad (1)$$

where

Y_{it} = yield (kg ha^{-1}) of cereals/pulses/foodgrains/oilseeds in the *i*th state ($i = 1$ to 14) and *t*th year ($t = 1$ to 13)

X_1 = irrigation coverage (the share of gross irrigated area in gross sown area)

X_2 = rainfall index (ratio of actual to normal rainfall multiplied by 100)

X_3 = trend variable (proxy for technological improvement)

e_{it} = error component

α_i, β_1, β_2, β_3 = parameters to be estimated.

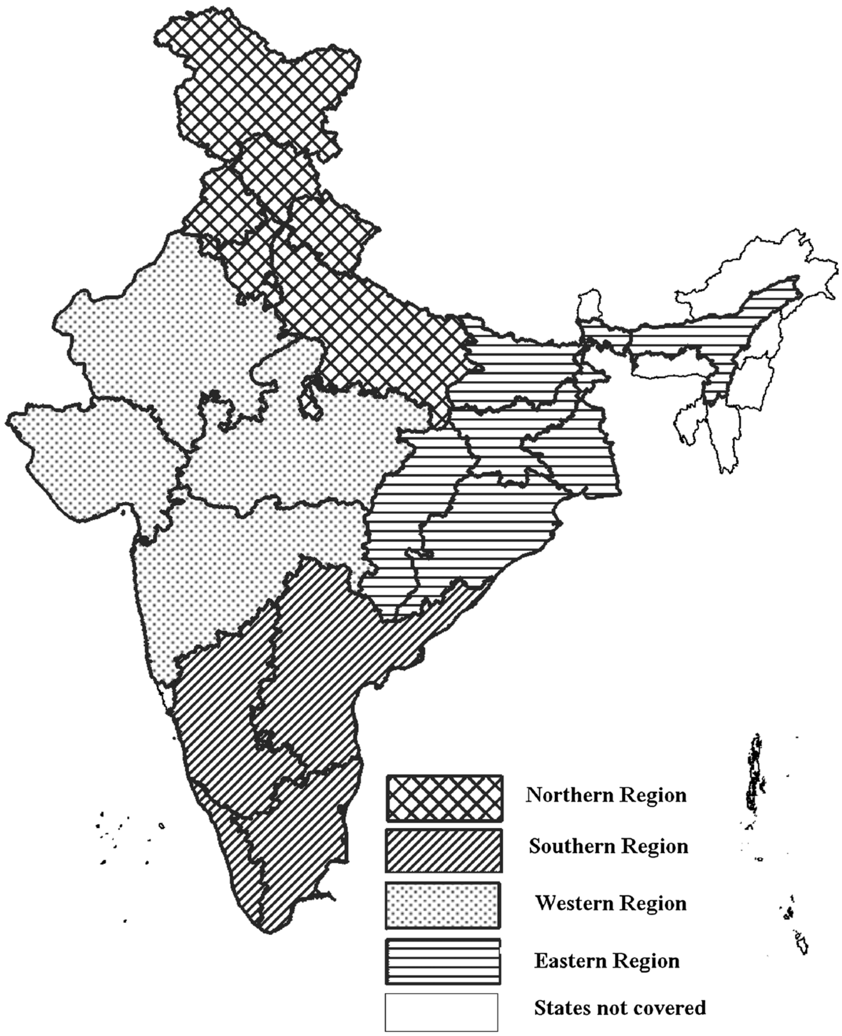

Figure 1. Demarcation of geographical regions of India

In the above model, irrigation coverage, rainfall index and trend variable (to capture technological improvement) were regressed with crop yield. The model treats α_i as an unobserved random variable that is potentially correlated with the observed regressors ($X_{z\ it}$ z: regressors) and picks up the fixed effects that differ among the states (cross-section units) but is constant over time. The fixed-effect estimators were obtained by subtraction of the time-averaged model (Equation 2) from the original model (Equation 1) as follows:

$$\overline{Y}_i = \alpha_i + \beta_1 \overline{X}_{1\ i} + \beta_2\,\overline{X}_{2\ i} + \beta_3 \overline{X}_{3\ i} + \overline{e}_i \qquad (2)$$

where

$$\overline{Y}_i = T^{-1}\sum_{t=1}^{13} Y_{it},\ \bar{X}_{z\ i} = T^{-1}\sum_{t=1}^{13} X_{z\ it}$$

$$\left(Y_{it} - \overline{Y}_i\right) = \beta_1\left(X_{1\ it} - \overline{X}_{1\ i}\right) + \beta_2\left(X_{2\ it} - \overline{X}_{2\ i}\right) + \beta_3\left(X_{3\ it} - \overline{X}_{3\ i}\right) + \left(e_{it} - \overline{e}_i\right) \qquad (3)$$

Using OLS estimation yields the fixed effect estimator $\hat{\beta}_z$ and $\hat{\alpha}_i$ as follows:

$$\hat{\beta}_z = \left[\sum_{i=1}^{14}\sum_{t=1}^{13}\left(X_{z\ it} - \overline{X}_{z\ i}\right)\left(X_{z\ it} - \overline{X}_{z\ i}\right)'\right]^{-1} \qquad (4)$$

$$\sum_{i=1}^{14}\sum_{t=1}^{13}\left(X_{z\ it} - \overline{X}_{z\ i}\right)\ \left(Y_{it} - \overline{Y}_{\ i}\right)$$

$$\hat{\alpha}_i = \overline{Y}_{\ i} - \overline{X}_{z\ i}{}'\hat{\beta}_z \qquad (5)$$

RESULTS AND DISCUSSION

Water resources scenario

The water resource potential in India, as estimated by different agencies, varies from 1440 to 1950 BCM (billion cubic metres) (11th FYP, Government of India) with a currently accepted estimate of 1870 BCM. Within the limitations of physiographic conditions, sociopolitical environment, legal and constitutional constraints and the technology available, the utilizable water resources of the country have been assessed as 1123 BCM, of which 690 BCM are from surface water and 433 BCM from groundwater sources (Central Water Commission, CWC, 2010). Total water resources are spread over 20 river basins with a catchment area of 3.2 million km^2. The Ganga–Brahmaputra–Meghna is the largest river basin in India with 34, 59.4 and 39.7% share in the total catchment area, total water resources potential and total utilizable surface water resources, respectively. However, there exists spatial and seasonal variation in the endowment of water resources. More than 90% of the annual runoff in peninsular rivers and more than 80% in the Himalayan rivers occur during the monsoon (June–September) season. Consequently, several areas with high rainfall also experience water shortage in other seasons. In the geographical regions, the estimated utilizable surface water, considering live storage capacity and runoff of about 250 river schemes, is greatest in the Northern region (295 BCM) (Chopra and Bishwanath, 2000). On the other hand, in the Eastern region, the utilizable surface water is lowest (69 BCM), although these states receive plenty of rainfall during the monsoon season. The spatial and seasonal variations in water resource endowment necessitate the creation of storage capacity in reservoirs and tanks. The total storage built up in projects completed up to 2010 is about 225 BCM in the country, which may increase up to 396 BCM once the projects under construction or consideration are completed, against the utilizable water resources of 1123 BCM in the river basins of the country.

Total replenishable groundwater potential in India has been estimated as 433 BCM yr^{-1}, of which 399 BCM (105, 92, 76 and 120 BCM in the Northern, Western, Southern and Eastern regions, respectively) groundwater can be made available for different uses annually, keeping aside 34 BCM for natural discharge. The annual replenishable groundwater resource comes from two major sources: rainfall (67%) and other sources (33%) that include canal seepage, return flow from irrigation, seepage from water bodies and artificial recharge due to water conservation structures. Further, the south-west monsoon being the most prevalent source of rainfall in the country, about 7% of the country's annual replenishable groundwater recharge takes place during the *kharif* (July–October) period of cultivation. With an annual groundwater draft of 231 BCM (irrigation constituting 92% of the total draft), overall groundwater development in the country is 58%. Thus, groundwater can be developed further in the country as a whole.

Ultimate irrigation potential (UIP): source- and region-wise distribution

UIP, which limits the expansion of irrigation in a region, is the gross irrigated area (GIA) that theoretically could be irrigated if all available land and water resources were used for irrigation (Ministry of Water Resources). Total identified UIP of the country is 140 Mha without inter-basin sharing, and 175 Mha with inter-basin sharing (Table I). Major and medium (M&M) irrigation sources can utilize 42.1% (59 Mha) of total UIP, while the remainder (57.9%) can be utilized by minor irrigation (MI) sources. Further, groundwater with 79% (64 Mha) share in UIP from MI sources is the most important source of irrigation in the country. Due to topographical, hydrological and other constraints, there exist striking inter-regional variations in UIP and therefore inequitable irrigation development (Narayanamoorthy, 2011). The Northern region contributes 30.5% (43 Mha) to total UIP in the country, followed by the Western region. Source-wise UIP revealed that UIP from M&M and MI (groundwater) sources are highest in the Northern region (32.2 and 34.3%, respectively) followed by the Western region. On the other hand, UIP from MI (surface water) is highest in the Eastern region of the country. However, abundant water resources in the Eastern region are not accessible to farmers at the right time and place because of poor irrigation infrastructure development, making it a high-potential but poor-performing region. Thus, better irrigation infrastructure development in the Eastern region would bring scope for better agricultural growth. UIP is least in the Southern region compared to other regions of the country. This could be one of the most important reasons why some of the South Indian states are seriously pressing for implementation of a national river-linking project at the earliest opportunity (Narayanamoorthy, 2011).

It is to be noted that UIP estimates are questionable. Seasonal imbalance in flow of rivers, geographic incongruity

Table I. Region-wise ultimate irrigation potential (UIP) (million ha)

Region	Major and medium surface water	Minor irrigation			Grand total
		Surface water	Groundwater	Total	
North	19 (32.2)	1.9 (11.2)	22 (34.3)	24 (29.3)	43 (30.5)
West	15 (25.4)	4.3 (24.7)	17 (27.2)	22 (26.7)	37 (26.4)
South	10 (16.9)	5.2 (30.0)	10 (16.0)	15 (19.0)	25 (18.2)
East	14 (23.7)	5.3 (30.4)	14 (21.6)	19 (23.5)	34 (24.1)
India	59 (100)	17 (100)	64 (100)	81 (100)	140 (100)

Figures within parentheses are share of respective region in total UIP.
Total may not tally due to exclusion of a few states in the regional aggregation.

between regions with undeveloped water potential and those with irrigable lands; increasing competition for land and water from the non-irrigation sector and non-conjunctive assessment of surface and groundwater are some of the factors leading to probable over-assessment (World Bank, 1998). The interlinked nature of groundwater and surface water is not recognized in India. Exploitation of one affects the potential development of the other, yet each is measured independently (World Bank, 1991). Also, for many of the states, irrigation potential created (IPC) has been observed to be higher than UIP (Dhawan, 1993). The figures for UIP are not based on any river basin-wide planning or survey and, thus are ad hoc figures based on sites identified for various sizes of dams and similar ad hoc estimates of groundwater development potential based on a water balance formula (Thakkar, 1999). Therefore, assessment of UIP needs to be reviewed, keeping the above-mentioned factors in mind.

Irrigation development in India: temporal and spatial trends

Physical performance of irrigation projects. Examination of the physical performance of irrigation projects revealed that total IPC (total gross area proposed to be irrigated under different crops during a year by a scheme) in India has increased from 22 Mha during the pre-plan period to 123 Mha (42 Mha through M&M and 81 Mha through MI projects) up to 10th FYP because of public as well as private investment in irrigation. On the other hand, the IPU (the gross area actually irrigated during the reference year out of the gross proposed area to be irrigated by the scheme during the year) has increased from 22 Mha during the pre-plan period to 91 Mha (34 Mha through and 57 Mha through MI projects) up to the 10th FYP. Thus, although the irrigation infrastructure in the country has improved, it is accompanied by inefficient utilization of the already created potential as shown by the widening gap between IPC and IPU in successive FYPs (Figure 2). Presently, the gap between IPC and IPU is about 32 Mha (26%).

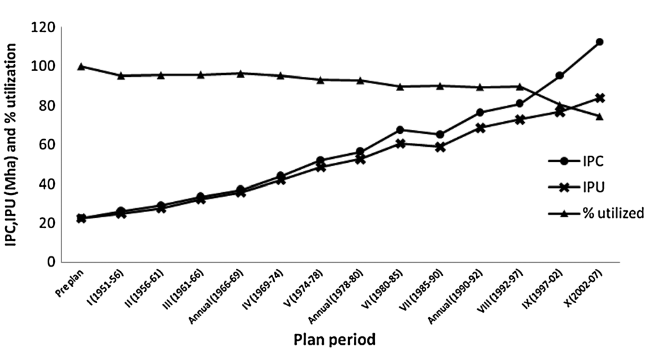

Figure 2. Plan-wise IPC, IPU and utilization of created irrigation potential in India

The underutilization of already created irrigation facilities is due to the slow pace of the Command Area Development Programme (initiated in 1973–74 to bridge the gap between IPC and IPU), depletion of professional staff in state irrigation agencies and paucity of non-plan funds available for irrigation departments, resulting in decline in operation and maintenance of irrigation projects and growing default maintenance (Government of India, 2011). Further, the potential area which can be irrigated in a system depends on several variables, including availability of distribution networks, volume and seasonal pattern of water availability, conveyance losses, distribution and application to fields, extent to which conjunctive use is developed and actual cropping pattern practised on the ground. There is considerable evidence showing that the cropping pattern actually adopted by the farmers is often much more water intensive than assumed and this is one important reason why the actual area irrigated is smaller than the designed potential (Vaidyanathan, 1999). For the country as a whole, about 88% of the UIP has already been developed, which limits further expansion of irrigation infrastructure on a large scale (Table II). Thus, emphasis may be given to improve utilization of the already created irrigation infrastructure. For the 12th FYP (2012–2017), the government has fixed the target to reduce the gap between IPC and IPU by 10 Mha by strengthening CAD programme and removing existing operational and maintenance inefficiencies through effective implementation of participatory irrigation management which in turn would contribute positively to agricultural growth in the country.

Irrigation development has not been uniform across different regions of the country, as shown by the varying share of IPC in UIP from 64.8% in the Eastern region to 106% in the Northern region (Table II). The relative contribution of different sources (surface/groundwater) of irrigation (which itself is determined by various hydro-geological, resource endowment, socio-economic and policy-related factors) was found to be an important determinant of regional variation in irrigation development. In the Northern and Western regions, groundwater was the major source of irrigation, constituting 82 and 66% share of total IPU, respectively, at the end of the 10th FYP. On the other hand, in the Southern and Eastern regions surface irrigation predominated, with 68 and 58% share of total IPU, respectively. The impact of groundwater as a source of irrigation, which is more reliable and efficient than surface water (Sharma, 2009), is reflected through better irrigation development in the Northern and Western regions of the country. However, the groundwater-driven irrigation development in the North-Western region was not found to be sustainable, as shown by more than 100% of IPC (groundwater) in UIP (groundwater) at the end of the 10th FYP (Table II). Although the higher value of IPC than the ultimate potential might be the outcome of under/overestimation

Table II. Zone-wise irrigation development (million ha) and its utilization (%) at the end of the 10th FYP

Particulars	North	West	South	East	India
Ultimate irrigation potential (UIP)	43	37	25	34	40
Irrigation potential created (IPC)	45	34	22	22	123
Irrigation potential utilized (IPU)	37	23	17	14	91
% of IPC (total) to UIP (total)	106	91.9	86.8	64.8	88.1
% of IPC (M&M) to UIP (M&M)	74.9	68.4	85.2	65.1	72.3
% of IPC (MI_total) to UIP (MI_total)	130	108	87.9	64.7	99.5
% of IPC (MI_surface) to UIP (MI_surface)	66.6	76.0	100	72.4	81.4
% of IPC (MI_ground) to UIP (MI_ground)	135	116	81.5	61.8	104
% of IPU (total) to IPC (total)	82.4	67.3	75.0	65.5	73.9
% of IPU(M&M) to IPC (M&M)	83.4	76.1	88.3	77.5	81.3
% of IPU (MI_total) to IPC (MI_total)	81.9	63.5	66.7	56.4	70.0
% of IPU (MI_surface) to IPC (MI_surface)	76.0	50.3	65.0	52.5	59.1
% of IPU (MI_ground) to IPC (MI_ground)	82.2	65.7	67.8	58.1	72.3

Total may not tally due to exclusion of a few states in the regional aggregation.

of UIP/IPC (Dhawan, 1993), the overexploitation (higher extraction than replenishment) of groundwater in the North-Western states goes on unabated. Groundwater development in many North-Western states such as Delhi (170%), Punjab (145%), Rajasthan (125%) and Haryana (109%) is at more than its sustainable level (Central Ground Water Board, CGWB, 2010) because of overexploitation and injudicious use raising several sustainability issues. From 2002 to 2008, three North-western states (Punjab, Haryana and Rajasthan) together lost about 109 km^3 of groundwater due to decline in the water table to the extent of 0.33 m yr^{-1} (Rodell *et al.*, 2009). As public expenditure per unit area was least in the Northern region (Table II), it is unregulated private investment in groundwater irrigation which has played a crucial role in this negative externality in the region. The third minor irrigation census (2000–01) revealed that about 80% dug wells and 60% tubewells were constructed investing farmers' own savings, while only 4% dugwells and 14% tubewells were constructed using bank/other loans and 2% tubewells were government funded (http://wrmin.nic.in/micensus/mi3census). Government policies providing free/subsidized electricity and pumps in many states are adding fuel to the water crisis. Reduced farm profitability through increasing pumping costs, deceleration in productivity of irrigation water (Kumar *et al.*, 2003) and equity issues (Nagaraj *et al.*, 2003) in groundwater distribution are also considered major challenges in this context.

The overexploitation of groundwater in the north-western part of the country coexists with relatively low levels of development in the Eastern region (27%). The lower groundwater exploitation of irrigation in the Eastern region has a bearing on the lower impact of irrigation development on the agricultural performance, poverty and living scenario (Rijsberman, 2003). Thus, acceleration in investment by private farmers in groundwater irrigation may have a larger impact in enhancing agricultural production and income in the Eastern region. Further, the utilization of already created irrigation potential was also least (65.5%) in the Eastern region at the end of the 10th FYP (Table II). The lowest share of IPC in UIP (64.8%), least utilization of already created potential (65.5%) and least groundwater development (27%) in the Eastern region sets out a strong case to reframe new policies and regulations that facilitate better irrigation infrastructure in the region.

The irrigation sector in India has also witnessed a structural shift in the relative contribution of different sources of irrigation over the years (Figure 3). The share of canals in the net irrigated area (NIA) in India has declined from about 41% in the 1st FYP to 26% in the 10th, although the absolute area under canal irrigation has increased with a growth of 1.3% yr^{-1}. On the other hand, the share of tubewells in NIA has increased significantly from less than 1% to about 41% during the same period due to an 8% annual growth in tubewell-irrigated area. The significant growth in tubewell-irrigated area re-emphasized the growing importance of groundwater as a source of irrigation because of its reliability and higher irrigation efficiency of 70–80% compared to 25–45% in canal irrigation (Sharma,

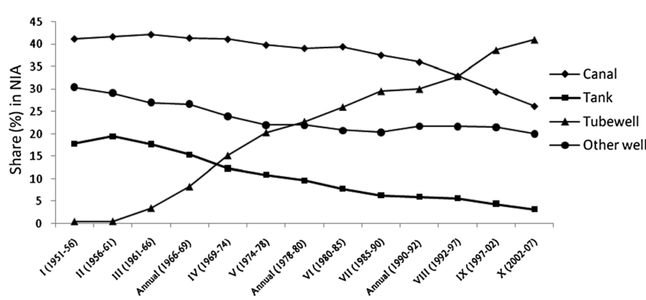

Figure 3. The share (%) of different sources in net irrigation area in India in successive FYPs

2009). The deceleration in growth of the area under canals in recent years despite increased investment is mainly because of three things (Raju, 2004). First, the relatively easier potential had already been utilized, and further development was more difficult, with the result that there was inevitably a decline in the rate of growth of the area under irrigation. Second, the investment costs of the irrigation projects that were taken up from the 7th Plan onwards were much higher, and a given order of investment could only create a lower order of irrigation potential than was possible in earlier plan periods. Thirdly, budgetary allocation could not be made in adequate measure for the large number of M&M projects taken up, and this inevitably resulted in slower completion of projects and therefore slower creation of irrigation potential.

Further, inefficient and unequal distribution of canal water into farmers' fields results in a shift from canals to more reliable tubewells as a source of irrigation. Tanks, with a long history and special significance to small and marginal farmers especially in Southern India, witnessed poor performance with negative growth (−1.4%) due to the weak institutional arrangements, property rights structures and breakdown of the local authority system (Marothia, 1992, 1993; Vaidyanathan, 1997). It has been observed that in a period of 10 years, tanks get a normal supply during the first to third year, a deficit supply during the fourth to eight year and fail completely the during ninth and tenth years (Palanisami, 2000). Thus the tubewell explosion, especially in the North-Western states during the early 1970s and later period, outstripped other sources of irrigation, raising sustainability issues over groundwater resources (Kumar *et al*., 2003).

Financial performance of irrigation projects. Irrigation projects in India are primarily financed by the government to create additional irrigation potential as well as to remove deficiencies of created potential and for optimal utilization of water resources. With the considerable government support, although absolute financial expenditure (planned) on irrigation development has increased from US$ 13 700 million[2] during the 1st FYP to US$11 100 million during the 10th FYP at 1993–94 prices, the share of irrigation expenditure in the total planned budget has instead decreased from 23 to 9% (Central Water Commission, CWC, 2010) during the same period, indicating increasing demand from other sectors of the economy. Moreover, allocation of financial resources to the irrigation sector exhibited significant inter-regional variations. The average share of irrigation in the total budget during 1992–2011 (8th to 11th FYP) in the Northern, Western, Southern and Eastern regions was 7, 20, 22 and 11%, respectively. The regional variation in irrigation investment was primarily due to varying number, composition, size, relative cost of the irrigation projects, time and cost overruns in the respective region in addition to hidden inefficiencies in the execution of projects.

The total number of completed and ongoing projects (major, medium and ERM projects) was highest in the Western region (972) followed by the Eastern (458), Southern (442) and Northern (302) regions up to the 11th FYP. The bulk of total irrigation investment was constituted by M&M projects (82%), followed by MI (14 %) and command area development (CAD) projects (4%) with interregional variations. Among the regions, the share of M&M projects inthe total irrigation budget was highest in the Southern region (91%), followed by the Western (81%), Northern (77%) and Eastern (60%) regions. The relatively higher share in the Southern and Western regions was due to more irrigation projects and higher cost of creation of irrigation potential as compared to the Northern and Eastern regions (Table III).

The estimated per hectare cost of creation of irrigation potential has increased substantially over successive FYPs (Dhawan, 1993; Government of India, 1999; Gulati *et al*., 1999). For M&M projects, it has increased from US$33.6 and US$520 during the 1st FYP (1951–56) to US$4230

Table III. Zone-wise financial expenditure on irrigation projects during the 10th FYP

Zone	Financial expenditure (US$ million)		IPC (000 ha)		Irrigation intensity (%)	Net IPC (000 ha)		Financial expenditure (US$/net IPC)		Financial return[a] (%)	
	M&M	MI	M&M	MI		M&M	MI	M&M	MI	M&M	MI
North	1 910	610	1061	2139	156	858	1369	2812	448	14.3	3.4
West	5 220	1030	1533	734	119	1292	618	4040	1668	25.7	14.8
South	4 950	730	939	1160	121	780	962	6349	755	2.9	3.9
East	2 040	790	1736	1455	148	1170	981	1745	808	23.9	4.6
India	16 440	3480	5296	5571	138	3887	4037	4284	862	14.5	6.1

[a]Share of gross receipt in total working expenditure.
M&M: major and medium irrigation projects; MI: minor irrigation project; IPC: irrigation potential created.
Total may not tally due to exclusion of a few states in the regional aggregation.

and US$2270 during the 10th (2002–07) at current and constant (1993–94) prices, respectively. Similarly, for MI projects, cost has increased from US$12.6 and US$195 during the 1st FYP to US$863 and US$463 in the 10th at current and constant (1993–94) prices, respectively. The increase in irrigation cost is substantial from the 6th Plan onwards, which is mainly due to introduction of the extension and distribution system up to 5–8 ha blocks, the cost of rehabilitation and resettlement, environmental and forest aspects, inclusion of the cost of catchment area treatment, inclusion of the drainage system in the command of irrigation projects, increase in establishment costs, etc. (Government of India, 1999). Among the regions, the Eastern region spent least (US$1745) to create additional irrigation potential, while the Southern region spent the most (US$6349), followed by the Western region (US$4040) under M&M projects during the 10th FYP (Table II). Under MI projects, per hectare irrigation investment was least in the Northern region (US$448) and highest in the Western region (US$1668) of the country. Thus, the Northern and Eastern regions incurred comparatively less expenditure than the Southern and Western parts of the country to create additional irrigation potential.

Time and cost overruns are major challenges in the irrigation sector in the country. The number of projects awaiting completion was about 200 up to the first four FYPs which has increased significantly in the range of 500–600 in successive FYPs (Government of India, 2011) with a present backlog of 553 (at the start of the 11th FYP). Part of the reason for time overruns is that too many projects are taken up in successive FYPs without emphasizing the completion of ongoing projects. Though all the plans, without exception, declared their intention to give priority to completing ongoing schemes, the addition of new schemes continued unabated (Dhawan, 1993). During the 11th FYP, 309 major, medium and ERM (extension, renovation and modernization) projects have been initiated with the spillover projects of 553 from the previous plan period. Across different regions, the number of new projects in the Eastern, Western, Northern and Southern regions is 113, 108, 58 and 22 in addition to 112, 254, 50, 125 spillover projects, respectively. It is to be noted that spillover projects are comparatively high in the Western and Southern regions, indicating inefficiency in the implementation of irrigation projects by the states of these regions. Another reason for time overruns is the inadequate allocation of funds for completing projects as per the implementation schedule envisaged at the time of planning (Government of India, 2011).

The immediate effect of time escalation is cost overruns of irrigation projects. A recent study has estimated the cost escalation of the order of about 138% in ERM projects, about 200% in major projects and about 500% in medium projects, with no significant regional trend in escalation value of different types of projects (Government of India, 2011). Untimely completion of irrigation projects affects creation and utilization of irrigation infrastructure. To accelerate the completion of ongoing irrigation projects, the Government of India launched an accelerated irrigation benefit programme (AIBP) in 1996–97 under which 109 M&M projects and 6584 MI projects were completed up to 2009–10 with cumulative expenditure of US$8350 million since inception. It is to be noted that the Western region constituted 43% (US$3580 million) of the total expenditure (US$8350 million) and 41% (2.5 Mha) of the total IPC (6.0 Mha) created under AIBP up to 2009–10. Higher expenditure under AIBP in the Western region might be due to the highest number of spillover projects (254 out of 553) in the 11th Plan in the region. Strengthening of such programmes (AIBP) along with adequate and time-bound provision of financial resources in the execution of irrigation projects would contribute positively to reducing time overruns.

The financial performance of the irrigation sector is also weighed down by poor cost recovery, which was found to be low as revenue could generate only 14.5% (M&M) and 6.1% (MI) of the total working expenditure incurred during the 10th FYP, keep aside returns from capital investment (Table III). Poor financial returns from a huge irrigation investment exert pressure on the government exchequer and set limits on further investment. Among the regions, financial returns were comparatively better in the Western region in both M&M (25.7%) and MI (14.8%) projects. In the Southern region, M&M projects generated least (2.9 per cent) return over working expenditure. The Northern region also lagged behind in return over working expenditure in MI projects. Eastern India showed relatively higher returns especially in M&M projects. Poor cost recovery of irrigation projects necessitates restructuring of the institutional set-up for better operation and management of irrigation projects to make them financially sound and self-reliant. In this context, participatory irrigation management/irrigation management transfer initiatives have been undertaken in many places. To date about 13.2 Mha of irrigated area is under the jurisdiction of 56 539 water users' associations (WUAs) in the country. However, these institutions need to be strengthened not only to improve the physical performance of irrigation projects but also in revenue generation for financial sustainability.

From the physical and financial performance, it is envisaged that in the Southern region, there seems little scope for further creation of surface water irrigation infrastructure (as 85.2% of UIP from M&M and 100% from MI surface have already been developed) or for groundwater development due to the predominance of hard-rock geology. Therefore, in the light of absence of techno-economically viable opportunities for new irrigation facilities in the Southern region, emphasis may be given to the completion of ongoing projects and improvement in utilization of already created potential, particularly small-scale irrigation systems such as farm ponds, tank irrigation, etc. which are presently suffering from institutional and financial constraints and need revival.

In the Western region, groundwater potential has already been exploited as shown by more than 100% share of IPC (groundwater) in identified available potential through groundwater (Table II). Therefore, this region will continue to be dependent on M&M irrigation in spite of its cost-intensive nature. However, the lowest utilization (76.1% in M&M and 50.3% MI surface) of already created potential especially in surface irrigation as compared to other regions offers opportunities for improving the existing irrigation infrastructure in the region. In Northern India, development and improvement of surface irrigation infrastructure should be prioritized in the backdrop of the low cost of creation and groundwater over-exploitation. Efforts should also be extended to groundwater recharge activities and its conjunctive use with surface water for sustainable development of water resources in the region. The Eastern region offers a great opportunity for creation of new irrigation facilities (low cost of creation and least development of M&M and groundwater potential), as well as improvement in utilization of already created potential (comparatively lower utilization than other regions). Thus, there is a need to set location-specific priorities for holistic water resource development and institutional reforms for the efficient operation of irrigation projects.

Impact of irrigation development on Indian agriculture

Ascertaining the precise contribution of irrigation in food production is difficult because there are no official Indian statistical data that give a breakdown of agricultural production under irrigated or rainfed conditions. However, irrigation has definitely contributed to increasing in cropping intensity from 111% in the 1st FYP to 136% in the 10th (Figure 4). Consequently, the gross sown area (GSA) has increased from 140 Mha in the 1st FYP to 190 Mha in the 10th with 0.6% growth per annum, in spite of almost stagnant net sown area (NSA) during the same period. Net irrigated area (NIA) and gross irrigated area (GIA) witnessed significant 2.1 and 2.5% annual growth during 1950–2007, respectively, leading to an increasing share of NIA and GIA in NSA and GSA in successive FYPs. At the end of the 10th FYP, about 42% of NSA as well as GSA was irrigated, making India a world leader in irrigated area. Irrigation intensity also witnessed an increasing trend during the period under consideration. Though these indicators (share of NIA in NSA, share of GIA in GSA, cropping intensity, irrigation intensity) witnessed overall improvement over the years, it is not uniform across different regions, indicating inter-regional disparity in irrigation and agriculture performance. The Northern region was ranked first among the other regions in all these four indicators during the 10th FYP, indicating comparatively better performance. The World Bank (1991) acknowledged tubewell irrigation for the high cropping intensity in the Northern region. Irrigation intensity and share of NIA and GIA in NSA in GSA, respectively, were lowest in the Western region in the 10th FYP, reflecting poor development of irrigation in the region.

The results of the panel data regression analysis showed irrigation to be a significant factor affecting crop yield positively, though to a varying degree except for pulses (Table IV). For pulses, irrigation was not found to be a significant factor because they are primarily grown under rainfed and residual moisture conditions. Estimated coefficients for the rainfall index were significant and positive for all the crops, indicating that higher rainfall than normal will improve crop yield. But less and uncertain rainfall would have an adverse impact on crop yield and thus food production in India where 58% of the GSA is still under rainfed conditions. However, the positive marginal effect of irrigation coverage on crop yield was stronger than rainfall, as shown by the higher value of the estimated coefficients. Therefore, improving irrigation infrastructure will not only improve crop yield but also reduce dependency of crop production on the monsoon. The development of irrigation infrastructure should be backed by technological

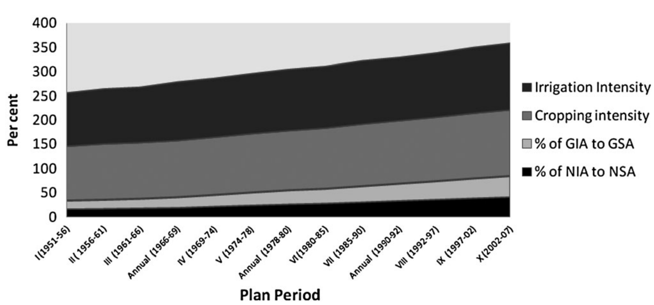

Figure 4. Plan-wise land use and cropping pattern in India

Table IV. Impact of irrigation on crop yield (panel data regression analysis)

Parameters	Cereals	Pulses	Foodgrains	Oilseeds
Constant	881***	365***	855***	500***
	(199)	(45.8)	(168)	(91.3)
Irrigation coverage	14.9***	−1.02	14.6***	3.33*
	(3.85)	(1.42)	(3.51)	(1.84)
Rainfall	1.74**	2.13***	1.39**	2.09***
	(0.71)	(0.31)	(0.63)	(0.60)
Trend	22.6***	7.79***	19.0***	13.1***
	(4.18)	(1.53)	(3.72)	(3.42)
Cross-section fixed effects (14)				
Andhra Pradesh	272	−56.4	135	−130
Bihar	−509	146	−406	−68.8
Gujarat	−309	3.44	−299	242
Haryana	648	151	686	250
Karnataka	−50.9	−230	−170	−314
Kerala	74.4	–	142	–
Madhya Pradesh	−560	129	−566	106
Maharashtra	−446	−57.5	−442	70.3
Odisha	−505	−222	−487	−436
Punjab	1 285	240	1 379	55.8
Rajasthan	−432	−194	−491	−6.13
Tamil Nadu	218	−244	109	535
Uttar Pradesh	−97.3	236	−74	−100
West Bengal	414	96.6	483	−204
R^2	0.950	0.817	0.961	0.774
D-W statistics	1.42	1.70	1.45	2.26
No. of observations	210	195	210	195
(time period)	(1996–2010)	(1996–2010)	(1996–2010)	(1996–2010)

Dependent variable: yield (kg ha^{-1}) of respective crop.
***, **, *: significant at 1, 5 and 10% level of significance, respectively.
Kerala, not being a major producer of pulses and oilseeds, was not included in the analysis for these crops.

improvement which was found to be significant (‘trend’ variable) and positively affecting yield of all the crops. In the analysis, fixed effects (deviation from the overall mean) were estimated (Table IV) for each cross-section unit (states) to capture spatial heterogeneity.

CONCLUSION

The approach used in this study enabled us to assess the effect of seasonal water resource availability, topographic, hydrological, poor irrigation infrastructure and other socio-economic factors on regional variations in irrigation potential and thus its development. Strengthening irrigation infrastructure especially in less developed regions opens up great scope to store and harness the potential of this precious natural resource for greater agricultural growth. The study stressed the need for an institutional set-up in the operation and maintenance of irrigation projects, especially at tertiary level integrating participatory irrigation management (PIM) under the umbrella of water users’ associations (WUAs) to face the challenge of escalating costs of creating irrigation and insufficient budget allocation. The physical performance of irrigation projects revealed substantial growth in irrigation development with groundwater as a predominant source of irrigation in the country. However, it coexists with the increasing gap between IPC and IPU (about 32 Mha at present), unsustainable groundwater exploitation and regional disparity in irrigation development and utilization. The increasing gap between IPC and IPU over the years indicates inefficiency in the execution of irrigation projects and water resource utilization. As about 88% of the UIP has already been developed for the country as a whole, improving utilization of already created irrigation infrastructure by removing existing operational and maintenance inefficiencies will contribute positively to agricultural growth in the country. Above all, the study stressed the need to switch from traditional (furrow, border and flood irrigation) to modern irrigation technologies (drip, sprinkler, etc.), along with institutional and policy support for improving irrigation efficiency in the country. Unsustainable groundwater development is the outcome of interregional disparities, provision of free/subsidized electricity and pumps and excessive private investment in groundwater without considering suitable recharge mechanisms. Thus, efficient groundwater governance, by regulating excessive withdrawal (in overexploited regions) and promoting its utilization (in the less developed Eastern region) through effective legislation and policy intervention, is of prime importance for maintaining food security in the future. These findings can inform dialogue and policy change aimed at reducing regional inequality in irrigation development for the sustainable and holistic development of water resources. This is particularly important in the light of the significant contribution of irrigation to agricultural growth and its positive impact on crop yield, though to varying degrees.

NOTES

[1]Major irrigation projects: irrigation projects with a command area of more than 10 000 ha.

Medium irrigation projects: irrigation projects with a command area of 2000–10 000 ha.

Minor irrigation projects (surface/groundwater): irrigation projects with a command area up to 2000 ha.

[2]US$1 = 50 Indian rupees.

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