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HIGHLIGHT

Irrigation and India's Crop-Milk Agrarian Economy

A simple recursive model and some early results

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Irrigation is central to India's crop-milk mixed farming system. This explains why over three-quarter of public investments in accelerating agrarian growth are devoted to irrigation. Despite massive investments in irrigation development, there are hardly any systematic assessments of irrigation impact on aggregate output. Our eight-equation recursive model is one such effort that uses district-level data to outline the impact of water applied under different irrigation regimes – canals, groundwater, and others – on crop and dairy output. We find that while India's ₹10 trillion crop-milk economy remains significantly rainfed (45%), groundwater accounts for about 38% of the economy while despite cornering bulk of the public investments, canals contribute less than 10%. Our model also shows that groundwater irrigation is associated with higher area under high value crops and herd-efficiency ratio. Thus, addition of one groundwater structure adds close to ₹215,000 to the gross value of crop-milk output of a district. This Highlight describes the model and, under a set of assumptions, simulates different scenarios.

Irrigation and India's Crop-Milk Agrarian Economy*†

A simple recursive model and some early results

Research highlight based on paper with the same title (Goswami *et al.* 2017).

1. Irrigation and Agricultural Productivity

The relationship between irrigation and agricultural productivity has been well established. While some researchers have focussed on the relative importance of irrigation vis-à-vis other inputs in the productivity calculus (Chand and Srivastava, 2016); institutions like IFPRI and IWMI have developed water productivity models (IFPRI's IMPACT model; IWMI's PODIUM model) which employ consumptive water use (rather than water applied) to estimate water productivity in Kg/m³ or $/m³. These represent *average water productivity* and therefore, solutions to improve water productivity focus on shifts in cropping patterns, improved water delivery and rationing of water supply. Some studies (Kumar *et al.* 2009; Amarasinghe *et al.* 2009) also focus on spatial variability in water productivity. Similar studies have established that *average* water productivity is higher when farmers have greater *'water control'*, as is the case with well irrigation, as opposed to canal irrigation (Dhawan 1988). However, none of these studies estimate the *marginal value product* of irrigation water applied by the farmers on the value of crop and milk output. Understanding this is important for several reasons: [1] consumptive water use is difficult to directly measure and is often derived based on theoretical equations and assumptions; [2] improving average productivity of consumptive water use without reduction in water application does not necessarily improve profitability of agriculture for farmers because high water application rate is associated with high energy costs; and [3] average water productivity does not differentiate between water from rainfall, canals, wells, tanks etc.

In this paper, we report on a simple eight-equation architecture that avoids simultaneity through a recursive model specification. The model is designed to estimate

Table 1: Variables used in the 8-equation recursive model

Category	Variables	Definition	Units
Exogenous Variables	GWS	*Number of Groundwater Structures in the District*	*Number*
	CaAr	*Canal Irrigated Area in the District*	*Hectares (Ha.)*
	OthAr	*Area Irrigated by Tanks and Other Sources in the District*	*Hectares (Ha.)*
	RaAr	*Rainfed Area in the District*	*Hectares (Ha.)*
	ToBov	*Total Bovine Population in the District*	*Number*
Endogenous Variables	NPK	*Fertilizer Consumption in the District*	*Kilograms (Kg.)*
	GCA-F	*Gross Cropped Area under Field Crops in the District*	*Hectares (Ha.)*
	GCA-H	*Gross Cropped Area under High Value Crops in the District*	*Hectares (Ha.)*
	InMBov	*In-Milk Bovine Population in the District*	*Number*
	ToBov	*Total Bovine Population in the District*	*Number*
Regional Dummy Variables (see Figure 2)	D1	*Dummy variable for Hard Rock districts*	
	D2	*Dummy variable for Hilly districts*	
	D3	*Dummy variable for districts in the Indo-Gangetic Plains*	
	D4	*Dummy variable for Coastal districts*	
Groundwater Development Dummy Variables (see Figure 3)	E1	*Dummy variable for districts with 'Safe' Groundwater development (<70%)*	
	E2	*Dummy variable for districts with 'Semi-Critical' Groundwater development (70 – 90%)*	
	E3	*Dummy variable for districts with 'Critical' Groundwater development (90 – 100%)*	
	E4	*Dummy variable for districts with 'Over-Exploited' Groundwater aquifers (> 100%)*	

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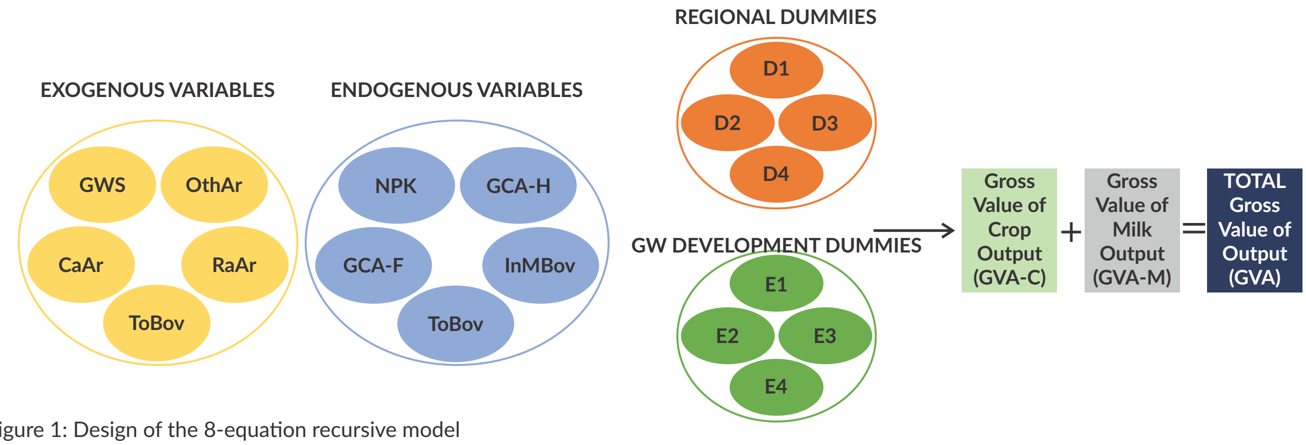

Figure 1: Design of the 8-equation recursive model

impact of irrigation under different regimes on gross value of crop and milk output at the district level. Against its many limitations, our model has the advantage that it can generate 'marginal value product' for water delivered through rainfall, public canals, groundwater wells, tanks and other sources of irrigation. The variables used in the model are described in Table 1 and the model design is shown in Figure 1. Gross values of crop and milk output are the target variables that are explained by irrigation variables and bovine stock through a set of intermediate variables such as crop choice[1], bovine herd efficiency[2] and stocking density[3].

1.1 Data and Sources

We compiled district-level data from various sources, as indicated in Table 2. The data sets we have used do not pertain to a single year; and this does pose an issue; however, we believe this is an acceptable limitation of our analytical approach. The advantage is that other researchers can challenge our conclusions by trying alternative

Table 2: Sources of district-wise data for different parameters

Variables	Data Source
District-wise number of Groundwater Structures (GWS)	Fourth Minor Irrigation Census (GoI 2014)
Gross Cropped Area under Field Crops (GCA-F) Gross Cropped Area under High Value Crops (GCA-H) Gross Value of Crop Output (GVA-C)	Directorate of Economics and Statistics, Ministry of Agriculture (2009)[¥]
Groundwater Irrigated Area (GWIA) Surface Water Irrigated Area (SWIA) Canal Irrigated Area Tank Irrigated Area Area Irrigated by Other Sources Net Sown Area (NSA) Net Irrigated Area (NIA)	Ninth Agricultural Census of India (MoA 2015)
Fertilizer Consumption (NPK)	Fertilizer Statistics (2010-11) (FAI 2011)
Groundwater Development (GWD)	Central Groundwater Board (CGWB 2011)
Total Bovine Population (ToBov) In-Milk Bovine Population (InMBov) Herd Efficiency Ratio (HER) Stocking Density	Nineteenth Livestock Census of India (MoA 2014)
Daily Milk Production	National Dairy Development Board (NDDB 2010)
Market Price of Milk	Rajeshwaranet *al.* (2014)[†]
Gross Value of Milk Output (GVA-M)	Calculated from milk production and liquid milk price

[¥] Data compiled from statistical abstracts of different states
[†]As per Rajeshwaran *et al.* (2014), the price of milk fat in 2010-11 was ₹401/Kg. Assuming an average fat content of 5% in liquid milk, we calculate the price of liquid milk in 2010-11 to be ₹20.05 per litre.

[1]Captured through Gross Cropped Area under field crops (GCA-F) and under high value crops (GCA-H). It should be noted that GCA-H has been calculated by multiplying area under banana, sugarcane and fruit crops by a factor of 3 (since these are annual crops), and cotton by a factor of 2 (since cotton is a two-season crop).
[2]Herd efficiency is estimated as the ratio of '*In-Milk Bovine Population*' (InMBov) to '*Total Bovine Population*' (ToBov) and is used to ascertain the efficiency of the herd population.
[3]Stocking density is calculated by dividing Total Bovine Population (ToBov) by the Net Sown Area (NSA) of the district.

specifications or competing models using the same data sets, most of which are available in the public domain.

The district boundaries used in the paper relate to the 590 districts considered in the fourth Minor Irrigation Census (2006-07) (GoI 2014). District level data from the Ninth Agricultural Census (2010-11) (MoA 2015), Fertilizer Statistics (2010-11) (FAI 2011), Nineteenth Livestock Census (2012) (MoA 2014) and National Dairy Development Board (NDDB 2010) has been converted to the same 590 districts against the current 707 districts. Of the 590 districts covered by the Fourth Minor Irrigation Census, complete data set for 98 districts[4] was not available; thus, data for 492 districts has been used for most of our cross-district analyses. The 492 districts for which data was available cover more than 95 per cent of the country's net sown area (NSA) and 93 per cent of the country's bovine population.

1.2 Methodology

Our methodology may be divided into two parts. The first part involves a set of eight regression equations that constitute the recursive model (Figure 1). The model attempts to trace the impact of input usage and dairy intensification on crop and milk outputs under different irrigation regimes.

The eight equations can be represented as follows:

[1] GWS = m (CaAr; OthAr; NSA; GWR; D2; D3; D4; E1; E2; E3; E4)
[2] InMBov = k (ToBov; GWS; CaAr; OthAr; RaAr; D1; D2; D3; D4)
[3] ToBov = l (GWS; CaAr; OthAr; RaAr; D1; D2; D3; D4)
[4] GCA-F = i (GWS; CaAr; OthAr; RaAr; D1; D2; D3; D4)
[5] GCA-H = j (GWS; CaAr; OthAr; RaAr; D1; D2; D3; D4)
[6] NPK = h (GWS; CaAr; OthAr; D1; D2; D3; D4)
[7] GVA-C = f (NPK; GCA-F; GCA-H; D1; D2; D3; D4)
[8] GVA-M = g (InMBov; ToBov; GCA; D1; D2; D3; D4)

The use of regional dummies (D1, D2, D3 and D4; Figure 2) takes into consideration the variability in agro-climatic conditions across the country. Another set of dummies (E1, E2, E3 and E4; Figure 3) correspond to CGWB's groundwater development categories: *safe*, *semi-critical*, *critical* and *over exploited* (CGWB 2011). These indicate overall groundwater availability and current use; and are also used to determine the potential for further groundwater development in the district through the addition of new irrigation wells.

The metric coefficients in the model are used to predict the dependent variable value while the standardized coefficients are used to ascertain the relative impact of the different modes of irrigation, where the metric of groundwater proxy (number of groundwater structures) is different from that of surface irrigation proxies (canal and other irrigated area) and rain-fed area. The standardized coefficients, thus, explain the relative influence of independent variables on the dependent variable.

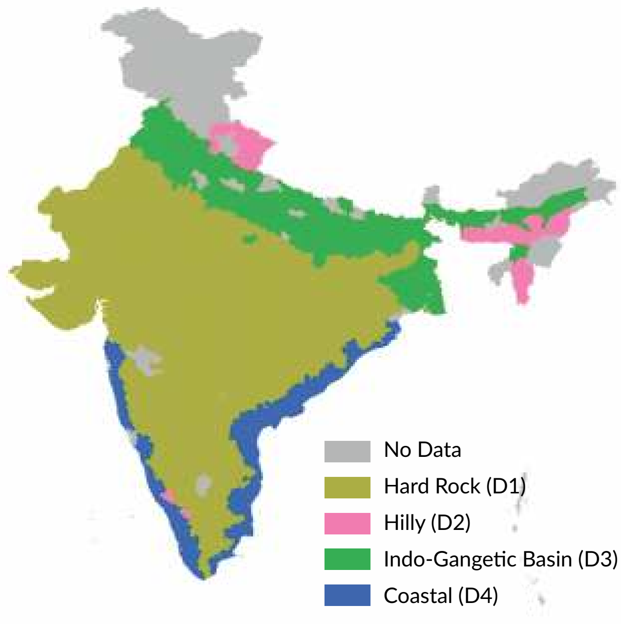

Figure 2: Regional Dummy Variables

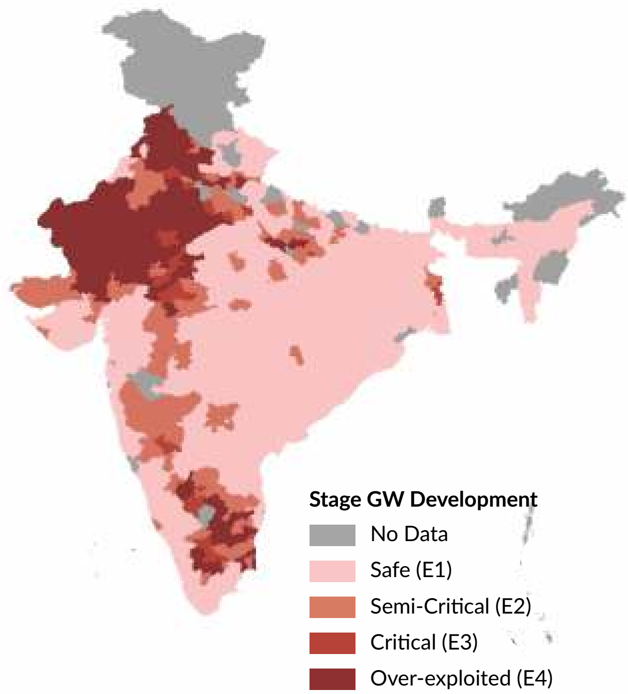

Figure 3: Groundwater Development Dummy Variables

In the second part, we then use the predicted values of the model to ascertain the size of contribution made by groundwater, canal and other sources of irrigation to the country's crop and dairy outputs. We also use our model to simulate the impact on crop and dairy outputs under five scenarios: [a] absence of groundwater irrigation; [b] absence of canal irrigation; [c] absence of tank and other sources of

[4]The 98 districts for which data on several parameters was missing include 57 districts in six hill states (*all districts of Jammu & Kashmir, Himachal Pradesh, Manipur, Sikkim, Tripura and Arunachal Pradesh*), 19 union territories, 9 urban districts, 7 districts in Uttar Pradesh (*Budaun, Faizabad, Gautam Buddha Nagar, Kaushambi, Kheri, Kushinagar and Mahoba*), both districts of Goa (*North Goa and South Goa*) and one district each in Assam (*Kamrup*), Bihar (*PurbiChamparan*), Maharashtra (Ahmednagar) and Orissa (Baleshwar).

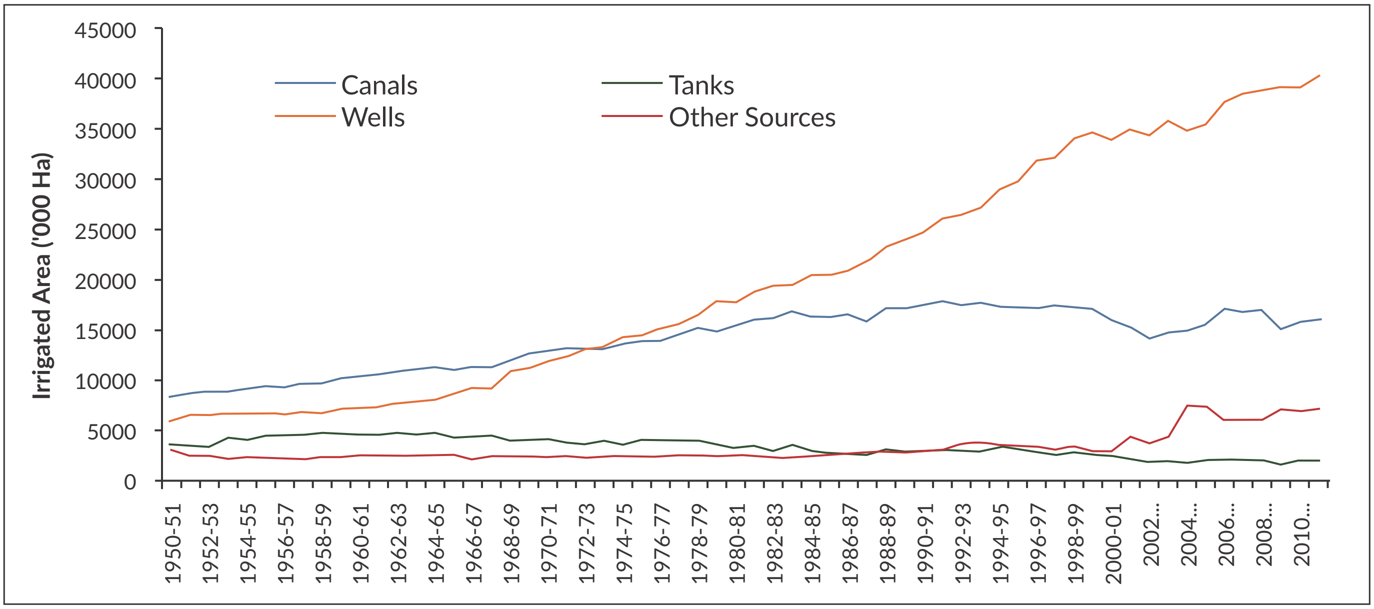

Figure 4: Irrigated area by source, 1950-51 to 2010-11

irrigation; [d] absence of all sources of irrigation; and [e] addition of new wells to recharge-fortified districts, in accordance with groundwater availability.

2. Crop and Milk Output under different Irrigation Regimes

For the purpose of our analysis, we classify Indian agriculture into four categories: [a] rain-fed / unirrigated agriculture; [b] agriculture serviced by canal irrigation; [c] agriculture serviced by groundwater irrigation; and [d] agriculture serviced by tanks and other sources of irrigation. Roughly one-third of category [d] is agriculture serviced by tank irrigation while the other two-third includes lift irrigation from streams and surface water bodies. We recognize that categories [b], [c] and [d] will have some overlap in the form of conjunctive use of groundwater and surface water from multiple sources.

In recent years, India's irrigation economy has been dominated by groundwater. As can be seen in Figure 4, almost all the new area brought under irrigation after 1990 can be attributed to expansion of groundwater irrigation. Over the same period, area irrigated by canals and tanks has either stagnated or declined (Shah *et al.* 2016). Researchers have argued that the spread of groundwater irrigation over India's vast countryside corresponds positively with population density, rather than resource availability. The highest concentration of groundwater structures (GWS) can be found in the densely populated Indo-Gangetic plains. Contrary to hydrologic expectations and despite the limited storage capacity of hard-rock aquifers, a large number of

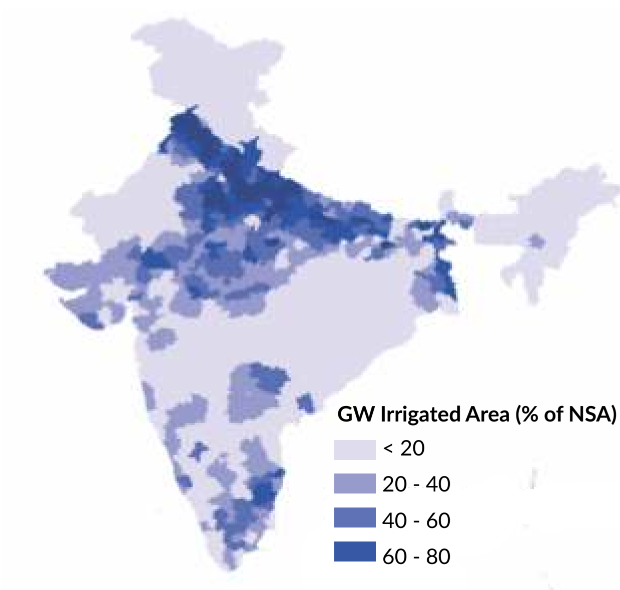

Figure 5: Concentration of groundwater irrigated area

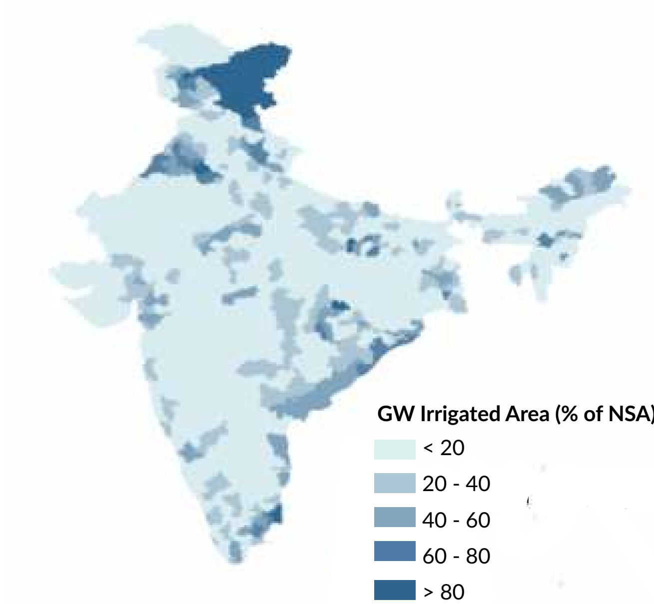

Figure 6: Concentration of surface water irrigated area

groundwater irrigation structures can also be found in peninsular India. Deb Roy and Shah (2003) termed groundwater a "*democratic resource*" which offers farmers far greater 'water control' than other sources of irrigation due to its year-round, on-demand availability. This reduces the farmers' risk in their investments in seed, labor, fertilizer, pesticides and other agricultural inputs; it also helps farmers achieve higher productivity in crop cultivation (Bhaduri *et al.* 2009). Though not that widely studied, groundwater also has a positive correlation with the dairy economy through its contribution to irrigated green fodder production. Shah (2009) has argued that irrigated green fodder is one of the key drivers of growingmilk production in semi-arid Gujarat and Rajasthan.

About 29 and 17 per cent of the net sown area is irrigated by groundwater and surface water respectively. Groundwater dominant areas are concentrated in the plains of Indo-Gangetic basin (IGB), Tamil Nadu, Andhra Pradesh and parts of Gujarat and Madhya Pradesh (see Figure 5). Around 90 of the top 100 most productive districts of the country in terms of crop production count among these groundwater dominant districts. Domination of surface irrigation is spread across districts in Jammu & Kashmir, Punjab and Haryana, along with some coastal districts of Andhra Pradesh and Odisha, and some parts of Chhattisgarh (see Figure 6).

A district's '*per hectare value of crop output*' (GVA-C) shows a close association with the extent of groundwater irrigation in the district. As one moves from less groundwater irrigated districts to more, average fertiliser consumption (NPK; in Kg./Ha.), cropping and land use intensity, and average gross value of crop output (in ₹/Ha.) witness a gradual increase (Table 3). A similar association can be seen among dairy parameters of Herd Efficiency Ratio *(InMBov/ToBov)* and gross value of milk output (Table 4).

3. Contribution of Irrigation Regimes to Gross Value of Output

Table 5 summarizes the results of our recursive model. The key points that emerge are:

[a] We saw earlier (in Table 3 and Table 4) that groundwater irrigation shows significant positive impact on both agrarian and dairy value of output through its correlation with fertilizer consumption (NPK), cropping intensity, land use intensity and herd efficiency ratio (HER). Our model results also reflect the same. The relatively higher crop productivity associated with groundwater irrigation can be explained by the higher degree of '*water control*' available to groundwater irrigators vis-à-vis canal irrigators, tank irrigators and, of course, rainfed farmers. This, in turn, creates incentives for farmers to invest their land, labor and capital into higher productivity agriculture including higher value crops (GCA-H) and higher intensity of fertilizer use (NPK).

[b] Fertiliser consumption (NPK) has a higher impact on the value of crop output (GVA-C) of a district than other variables like gross cropped area under field and high value crops (GCA-F; GCA-H). Gross Cropped Area under High Value crops (GCA-H) adds seven times more value to the district's crop output (₹60,338 per hectare) compared to area under Field crops (GCA-F; ₹8,434 per hectare).

[c] Despite a low R^2 (0.21) – which indicates low overall goodness of fit – equation [5] shows the importance of groundwater (GWS); and other irrigation (OthAr) to the gross cropped area under high value crops (GCA-H). Expectedly, rainfed agriculture (RaAr) is not significant for area under high value crops (GCA-H) but interestingly, canal irrigation (CaAr) also does not show up as a significant variable for high value agriculture (GCA-H). This indicates the low degree of "water control"

Table 3: Groundwater irrigated area, canal irrigated area, fertilizer consumption, cropping intensity, land use intensity and gross value of crop output per hectare of net sown area (492 districts)

GWIA (% of NSA)	No. of Districts	NPK (Kg./Ha.)	Cropping Intensity	Land Use Intensity	GVA-C (₹/Ha. NSA)
Less than 20%	239	155	1.12	1.28	₹44,325
Between 20% and 40%	95	194	1.04	1.23	₹56,221
Between 40% and 60%	72	232	1.21	1.33	₹77,084
Between 60% and 80%	50	312	1.52	1.74	₹1,01,134
More than 80%	36	375	1.68	1.95	₹1,12,998
TOTAL / AVERAGE	**492**	**200**	**1.21**	**1.35**	**₹60,378**

Table 4: Groundwater irrigated area, canal irrigated area, bovine density, in-milk bovine density, herd efficiency ratio and gross value of milk output per hectare of net sown area (492 districts)

GWIA (% of NSA)	No. of Districts	ToBov Density per 100 Ha. NSA	InMBov Density per 100 Ha. NSA	Herd Efficiency Ratio (HER)	GVA-M (₹/Ha. NSA)
Less than 20%	239	181	40	0.22	₹9,940
Between 20% and 40%	95	200	54	0.27	₹13,783
Between 40% and 60%	72	226	67	0.30	₹18,251
Between 60% and 80%	50	286	89	0.31	₹26,912
More than 80%	36	288	103	0.36	₹39,834
TOTAL / AVERAGE	**492**	**207**	**55**	**0.27**	**₹16,212**

Table 5: Recursive Model Results

Dependent /Independent variables	GWS [1]	InMBov [2]	ToBov [3]	GCA-F [4]	GCA-H [5]	NPK (in kg) [6]	GVA-C [7]	GVA-M [8]
GWS	--	0.70$^{1\%}$ (0.25)	2.78$^{1\%}$ (0.30)	2.04$^{1\%}$ (0.28)	0.83$^{1\%}$ (0.40)	699$^{1\%}$ (0.52)	--	--
CaAr	-0.05$^{5\%}$ (-0.08)	0.13$^{1\%}$ (0.06)	0.85$^{1\%}$ (0.14)	1.28$^{1\%}$ (0.27)	0.09 (0.06)	287$^{1\%}$ (0.32)	--	--
OthAr	-0.11$^{10\%}$ (-0.06)	0.09 (0.02)	4.85$^{1\%}$ (0.28)	0.61$^{10\%}$ (0.04)	0.47$^{1\%}$ (0.12)	469$^{1\%}$ (0.18)	--	--
NSA	0.02$^{1\%}$ (0.14)	--	--	--	--	--	--	--
GWR	0.39$^{1\%}$ (0.57)	--	--	--	--	--	--	--
RaAr	--	0.01 (0.02)	0.55$^{1\%}$ (0.29)	0.98$^{1\%}$ (0.70)	0.01 (0.02)	64$^{1\%}$ (0.23)	--	--
NPK	--	--	--	--	--	--	155$^{1\%}$ (0.48)	--
ToBov	--	0.22$^{1\%}$ (0.72)	--	--	--	--	--	-3557$^{1\%}$ (-0.33)
InMBov	--	--	--	--	--	--	--	33537$^{1\%}$ (0.94)
GCA	--	--	--	--	--	--	--	2073$^{1\%}$ (0.12)
GCA-F	--	--	--	--	--	--	8434$^{1\%}$ (0.14)	--
GCA-H	--	--	--	--	--	--	60338$^{1\%}$ (0.28)	--
D2	-4584	19898$^{5\%}$	-208868$^{1\%}$	-39515	30845$^{5\%}$	6984640	-448000000	35700000
D3	-17174$^{1\%}$	23357$^{1\%}$	136630$^{1\%}$	52338$^{1\%}$	25570$^{1\%}$	21600000$^{1\%}$	4520000000$^{1\%}$	1230000000$^{1\%}$
D4	-4419	15871$^{10\%}$	-184263$^{1\%}$	-87150$^{1\%}$	38396$^{1\%}$	4593953	7360000000$^{1\%}$	1850000000$^{1\%}$
E2	30882$^{1\%}$	--	--	--	--	--	--	--
E3	33672$^{1\%}$	--	--	--	--	--	--	--
E4	33635$^{1\%}$	--	--	--	--	--	--	--
Constant	-776	-17068$^{1\%}$	277458$^{1\%}$	46446$^{1\%}$	-13344$^{10\%}$	-4937986	449000000	1733958
R^2	0.50	0.57	0.47	0.72	0.21	0.78	0.56	0.66

Note: $^{10\%}$,$^{5\%}$ and $^{1\%}$ denote that the coefficients are significant at the 10%, 5% and 1% levels for two-tailed t-tests. Figures in parentheses '( )' are the standardized coefficients.

Table 6: Predicted values for rain-fed, groundwater, canal and other irrigation dependent crop and milk output

	Actual	Predicted	Rain-fed	GW	Canal	Other
GVA-C (₹ trillion)	8.11	8.38	3.70	3.25	0.83	0.53
GVA-M (₹ trillion)	2.18	2.00	0.99	0.74	0.14	0.12
TOTAL	10.29	10.38	4.69	3.99	0.97	0.65

under rainfed and purely canal irrigated conditions; and vice-versa under groundwater and other modes of irrigation.

[d] The dairy output equation (equation [8]) suggests that the number of in-milk bovine (InMBov) has a significant and positive impact on gross value of milk output (GVA-M). The addition of one in-milk bovine (InMBov) adds ₹33,537 to the district's value of milk output (GVA-M). However, number of total bovine (ToBov) has a negative sign, highlighting the importance of herd efficiency ratio (InMBov/ToBov). This also explains why several dairy promotion programs which focus exclusively on distributing cattle heads to poor farmers have failed to produce the desired results in terms of boosting dairy output. Improved herd management – rather than merely adding (unproductive) bovine heads – should be the focus of dairy promotion initiatives.

[e] Several scholars including Dhawan (1988) have written about a strong complementarity between surface and groundwater irrigation arising from canal or tank irrigation induced regular recharge of shallow aquifers. However, our model (equation [1]) suggests a negative or substitutive relationship between the two – suggesting that as groundwater irrigation expands, it crowds-out canal irrigation. By offering superior irrigation service and much greater "water control", groundwater

structures (GWS) erode the importance of canal irrigation in the local agrarian economy. Deb Roy and Shah (2003) showed a high correlation between density of groundwater structures and population density – terming groundwater a "democratic" resource, not necessarily driven by 'hydrologic opportunity' like in the case of surface irrigation. Our model, however, suggests a positive and significant correlation between number of groundwater structures (GWS) and groundwater resource availability (GWR).

[f] Our model also estimates the marginal values of crop and milk output delivered under different irrigation regimes. The marginal value of crop output is estimated at ₹175,631 per groundwater structure (₹87,816 per hectare of groundwater irrigated area), ₹60,710 per hectare of canal irrigated area and ₹106,199 per hectare of land irrigated by tanks and other sources. The marginal value of milk output stands at ₹40,048 per groundwater structure (₹20,024 per groundwater irrigated hectare), ₹10,448 per canal irrigated hectare and ₹23,790 per hectare of land irrigated by tanks and other sources. Therefore, adding a hectare of groundwater irrigation contributes significantly more to the values of both crop and milk output vis-à-vis addition of a hectare of canal irrigation. This also explains the demand pull for wells and other pumps (both surface and groundwater).

[g] Finally, our model predicts the size of the groundwater irrigation economy to be roughly ₹4.00 trillion (₹3.25 trillion for crop and ₹0.74 trillion for milk). The canal irrigation economy is estimated at less than a quarter of this – ₹0.97 trillion (₹0.83 trillion for crop; 0.14 trillion for milk output). The economy dependent on tank and other sources of irrigation is even smaller at ₹0.65 trillion (₹0.53 trillion for crop; 0.12 trillion for milk output). The largest chunk of the economy is rain-fed, estimated at ₹4.69 trillion (₹3.70 trillion and ₹0.99 trillion for gross value of crop and milk output respectively) (see Table 6).

4. Regional Variations and Policy Simulations

The estimated values of the model show that the hard rock region, which covers almost 67% of the total NSA in the country, accounts for the lowest levels of per hectare gross values of crop and milk output. The region is characterised by low land use intensity, fertiliser consumption and bovine density and herd efficiency ratio. The agro-climatically favourable farming systems of the hilly region are associated with relatively higher gross values of milk and crop output. The region has higher land use intensity for high value crops, above average fertilizer use, high total and in-milk bovine density but low HER. The coastal and Indo-Gangetic plains have the highest predicted gross values of crop and milk output. The regions have high land use intensity, high fertilizer use and high HER (Table 7). Figure 7 and 8 and respectively depict the district-wise gross value of crop and milk output, as predicted by our model.

We have earlier seen that groundwater is the biggest contributor to India's irrigated economy. What would happen to the various crop and dairy parameters if the different

Table 7: Recursive model-predicted average values of crop and dairy indicators

Regions	GVA-C (₹/Ha.)	GVA-M (₹/Ha.)	LUI-F*	LUI-H**	FERT (Kg./Ha.)	ToBov density (per 100HaNSA)	InMBov density (per 100HaNSA)	HER (InMBov/ToBov)
D1: Hard Rock	₹42,606	₹11,075	1.16	2.49	167	171	43	25
D2: Hilly	₹83,404	₹18,026	1.10	2.57	285	263	69	26
D3: Indo-Gangetic	₹102,561	₹22,692	1.10	2.29	325	170	57	34
D4: Coastal	₹107,425	₹23,419	1.23	2.80	274	185	55	30
ALL INDIA	**₹62,303**	**₹14,860**	**1.14**	**2.45**	**215**	**173**	**48**	**28**

*Land Use Intensity – Field Crops (Predicted Values), **Land Use Intensity – High Value Crops (Predicted Values)

Table 8: Predicted percentage change in all-India crop and milk parameters under different policy scenarios

Parameters	Values		Percentage Change in Parameters			
	Actual	Predicted	No Oth	No Canal	No GW	No Irrigation
GWS* (million)	18.93	18.52				
NPK (million metric tonnes)	26.96	28.88	-8%	-14%	-45%	-67%
GCA-F (million hectares)	159.90	159.17	-1%	-12%	-24%	-37%
GCA-H (million hectares)	21.43	21.02	-11%	-4%	-73%	-91%
GVA-C (trillion ₹)	**8.12**	**8.38**	**-6%**	**-10%**	**-39%**	**-56%**
InMBov (million)	74.23	64.46	-10%	-6%	-38%	-56%
ToBov (million)	278.74	232.79	-12%	-5%	-22%	-40%
GVA-M (trillion ₹)	**2.19**	**2.00**	**-7%**	**-7%**	**-37%**	**-52%**

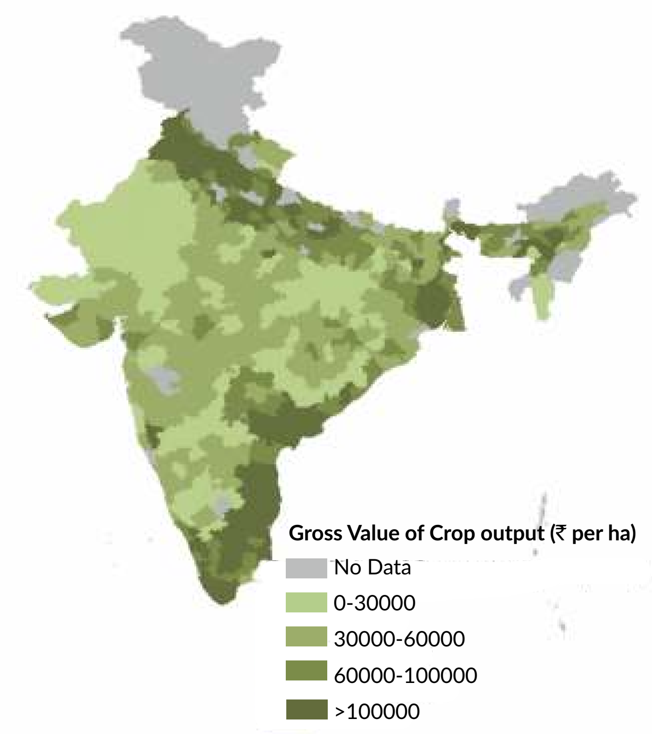

Figure 7: Gross Value of Crop Output (Predicted)

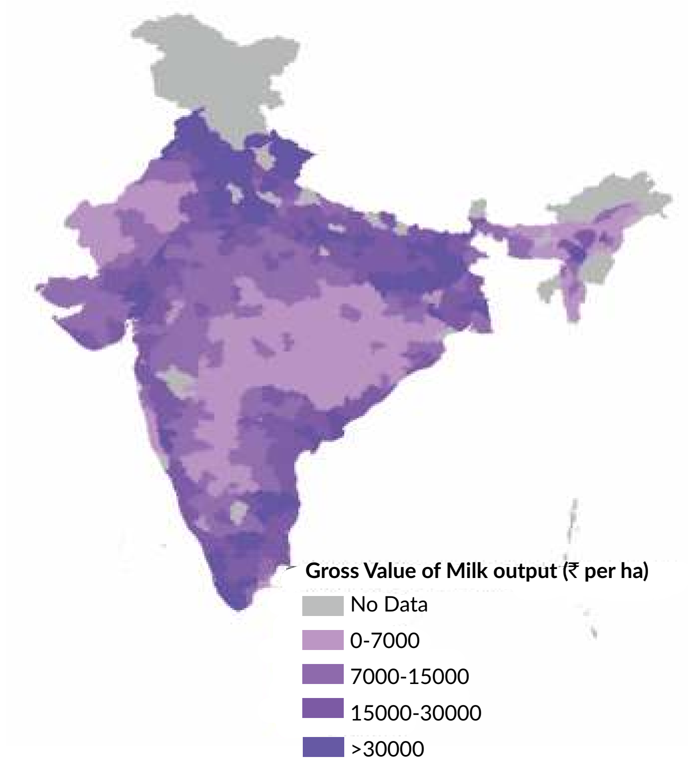

Figure 8: Gross Value of Milk Output (Predicted)

Table 9: Predicted impact of 2.5 million new groundwater structures in 112 most irrigation-deprived districts

	Actual	Predicted	With New Structures	Percentage Change
GWS (million)	2.72	3.68	6.17	68%
NPK (million metric tonnes)	4.35	5.46	7.21	32%
GCA-F (mHa)	40.45	41.35	46.43	12%
GCA-H (mHa)	2.33	3.11	5.18	67%
GVA-C (₹ trillion)	**1.17**	**1.58**	**2.02**	**28%**
InMBov (million)	12.40	14.03	17.30	23%
ToBov (million)	64.45	55.35	62.28	13%
Herd Efficiency Ratio	0.19	0.25	0.28	12%
GVA-M (₹ trillion)	**0.25**	**0.40**	**0.51**	**25%**

irrigation regimes were to (theoretically) disappear? Table 8 shows the percentage change in fertilizer consumption (NPK); gross cropped area under field and high value crops (GCA-F and GCA-H); total and in-milk bovine population (ToBov and InMBov); and the gross values of crop and milk output (GVA-C and GVA-M) under different scenarios.

We find that removing tanks and other sources of irrigation would lead to a 6 per cent decline in value crop output and a 7 per cent decline in milk output. Similarly, removing canal irrigation would result in a 10 per cent decline in crop output and 7 per cent decline in milk output. However, removing groundwater irrigation would deplete both the crop and milk output by 35-40 per cent. The most drastic decline can be seen in area under high value crops (GCA-H), fertilizer consumption (NPK) and in-milk bovine population (InMBov). This shows the strong correlation between groundwater irrigation and high value agriculture. Further, if India's agriculture economy was deprived of all irrigation and left entirely dependent on rainfall, cultivation of high value crops would almost disappear (decline by 91 per cent); fertilizer consumption would fall (to one-third its current value); bovine population would reduce (by 40 per cent); in-milk bovine population would fall (by 56 per cent); and the crop and milk outputs would decline significantly (decline of 56 and 52 per cent of current values, respectively).

While several districts, especially in western and peninsular India, are facing problems associated with groundwater depletion, there are 245 districts where groundwater resource is currently under-utilized. We estimated how many new groundwater structures can be constructed in these districts without threatening the long-term sustainability of groundwater irrigation[5]. At current levels of withdrawal per groundwater structure, we estimate that more than 6 million new groundwater extraction structures can be supported.

Of the 245 districts where new groundwater structures are possible, 112 have been classified as India's most irrigation-deprived districts (see Shah *et al.* 2016). Our model estimates that investing ₹250 billion for financing 2.5 million new groundwater structures in these irrigation-deprived districts (assuming average cost of ₹1,00,000 per structure) would lead to an additional crop output of ₹0.44 trillion and milk output of ₹0.11 trillion per year – a growth of 28 per cent (Table 9).

5. Conclusion

Chandeli tanks in Bundelkhand and the Kakatiya tanks in Telangana are prime examples of rulers investing in irrigation development for agricultural development. In British India, the desire to maximize land revenue was the primary driver of irrigation investments as provision of irrigation ensured the production of surplus over subsistence needs. However, there is little literature to compare the relative share of different irrigation modes to the gross value of output from agriculture. This paper is an attempt to quantify the relative shares of canal, groundwater and other modes of irrigation to the gross value of crop as well as milk output. We use our eight-equation recursive model to not only quantify the marginal value of additional canal, well and other irrigation but also to simulate the likely impact of new irrigation investments.

Our recursive model can be refined further in a number of ways. The equations derived from data from 492 districts at the national level can be nuanced by developing regional equations for hilly, hard rock, Indo-Gangetic plains and coastal areas. Our results suggest that especially in hilly areas where rainfall is plentiful and climatic conditions favor rain-fed high value agriculture, the provision of irrigation is neither necessary nor a sufficient condition for high agricultural productivity. Almost everywhere else, we find that provision of well irrigation results in the highest returns.

Despite low productivity, rain-fed conditions represent the largest share of the crop-milk mixed economy (45.2%) followed by groundwater dependent (38.4%), canal dependent (9.3%) and other irrigation dependent (6.3%) crop cultivation and dairying (Figure 9). The relatively low share of

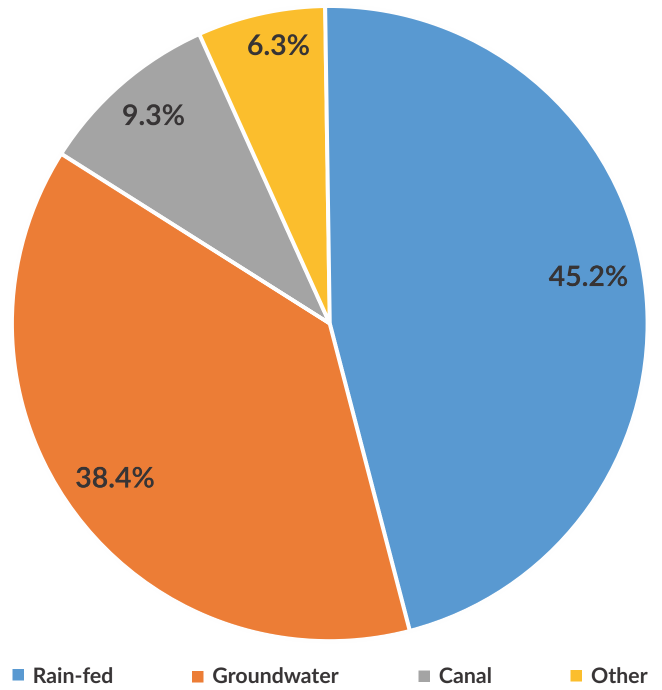

Figure 9: Share of different irrigation regimes in India's crop-milk mixed

canal dependent agricultural economy reflects the lop-sided nature of public irrigation investments in India. While bulk of public expenditure continues to build and maintain canal irrigation systems, it contributes less than 10 per cent to the gross value of crop and milk output. Groundwater irrigation, on the other hand, is almost entirely privately funded and poorly managed. Yet, it contributes nearly 40 per cent to India's gross value generation in agriculture. This suggests a need to divert precious public resources into equitable and sustainable groundwater management. Our results also show that the most effective way of expanding irrigation access and improving agricultural incomes is by investing in groundwater irrigation. The creation of one new groundwater extraction structure (classified as 'minor irrigation') adds nearly ₹215,000 to the gross value of crop and milk output of a district, ceteris paribus. This is primarily because groundwater irrigation offers greater reliability and water control, leading to expansion of area under high value crops and improved bovine herd management.

Finally, our model shows that if the objective of the Government of India is to deliver *Har Khet ko Pani*, as promised under the *Pradhan Mantri Krishi Sinchai Yojana* (PMKSY), the government should prioritize investments in 2.5 million new groundwater structures in the 112 most irrigation-deprived districts of the country. Doing this will expand irrigated area by roughly 5 mHa and enhance gross value of output from crops and milk by more than ₹0.5 trillion. A similar investment in adding new canal irrigated area is unlikely to return even a tenth of this value.

[5]We used the classification used by the Central Groundwater Board (CGWB) and based on average water extraction per structure per year in each of the 245 identified districts, we estimated the potential for new structures within the 'Safe' category (less than 70% groundwater development).

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About the IWMI-Tata Program and Water Policy Highlights

The IWMI-Tata Water Policy Program (ITP) was launched in 2000 as a co-equal partnership between the International Water Management Institute (IWMI), Colombo and Sir Ratan Tata Trust (SRTT), Mumbai. The program presents new perspectives and practical solutions derived from the wealth of research done in India on water resource management. Its objective is to help policy makers at the central, state and local levels address their water challenges – in areas such as sustainable groundwater management, water scarcity, and rural poverty – by translating research findings into practical policy recommendations. Through this program, IWMI collaborates with a range of partners across India to identify, analyze and document relevant water management approaches and current practices. These practices are assessed and synthesized for maximum policy impact in the series on Water Policy Highlights and IWMI-Tata Comments.

Water Policy Highlights are pre-publication discussion papers developed primarily as the basis for discussion during ITP's Annual Partners' Meet. The research underlying these Highlights was funded with support from International Water Management Institute (IWMI), Tata Trusts, CGIAR Research Program on Water, Land and Ecosystems (WLE) and CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). However, the Highlights are not externally peer-reviewed and the views expressed are of the author/s alone and not of ITP or any of its funding partners.

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