ENERGY PRODUCTIVITY OF INDIAN AGRICULTURE: ARE ENERGY GUZZLING DISTRICTS GENERATING HIGHER AGRICULTURAL VALUE?

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ABSTRACT

Groundwater irrigation has been central to India's irrigated agriculture. India is the largest extractor of groundwater, pumping nearly 250 km^3 every year for irrigation. The abstraction of groundwater is closely coupled with access to subsidized or free electricity in the country. Supply of free electricity has led to the perverse groundwater-energy nexus in the country. This nexus has resulted in grave economic and environmental repercussions. There is a mounting fiscal burden of energy subsidies in the country, which has led many power utilities at the helm of bankruptcy. At the same time, free power has attributed to the groundwater depletion at an alarming rate in many parts of the country. Hence, it becomes important to understand whether these economic and environmental costs of groundwater irrigation are commensurate with its benefits. This study takes a look at the energy productivity of groundwater irrigated agriculture in the districts of India and assesses its contribution to the agricultural output.

Keywords: Water-Food-Energy Nexus, Energy Productivity, Water Productivity, Sustainable Groundwater Use, India.

1. INTRODUCTION

Groundwater irrigation is the mainstay of Indian agriculture. It meets around 60% of India's irrigation needs and plays a crucial role in feeding 170-180 million populaces of the country (Zaveri et al. 2016). India's groundwater consumption dramatically increased from 50 km3 in 1970 to 250 km3 in 2010 [Shah 2014]. Of 250 km^3, more than 90% is used for irrigation alone. In terms of area, groundwater irrigated area increased from 12 million ha to 40 million ha in between 1970-2010 (MoSPI 2015). In between 1990-2010, 90% of the total incremental net irrigated area was contributed through groundwater alone. Some of the major drivers of this spectacular growth in groundwater irrigation have been: [a] the mounting population pressure on farmlands; [b] failure of canals in providing year-round, on-demand water supply in most places; [c] technological advancements leading to cheap and easy access to pumps and drilling equipment; and [d] most importantly, the availability of free or highly subsidized electricity for pumping (Shah 2009, Mukherji et al. 2012). The low or marginal cost of groundwater extraction due to highly subsidized energy played a major role in expanding groundwater irrigation in the country. Power utilities of India passed electricity subsidies worth Rs. 369 billion (~US$ 7 billion) to the farmers for groundwater pumping in 2012 (Gulati & Pahuja 2015). However, free or subsidized electricity has subsequently led to groundwater overexploitation due to inefficient and unregulated pumping in many parts of the country (Kumar 2005, Shah et al. 2003).

Since groundwater is a finite resource and a large amount of energy being used for its extraction on the expense of public money, it is important to understand the utilization of these resources and their contribution in agricultural production. This study attempts: a] to estimate the district-wise energy productivity of groundwater irrigation in India; [b]

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to do a comparative analysis of the most energy-efficient districts and the least energy-efficient districts; and [c] to discuss the contribution of energy use in India's agricultural output using a logarithmic input-output function.

2. DATA AND METHODS

2.1 Data

We compiled district-level data from various sources, as shown in Table 1. The datasets don't pertain to a single year. However, we assume this to be an acceptable limitation considering the scale and scope of the study. The district boundaries used in the paper relate to 593 districts in Census 2001. All the data has been converted to the same 593 districts against the current 707 districts. Of the 590 districts covered, data of 468 districts were considered for analysis.122 districts were left partly due to a very low quantum of groundwater use and partly due to unavailability of complete datasets.

Table 1. Data Used in the Study with Sources

Param2eters	Data Sources
Value of Crop Output	Directorate of Economics and Statistics, Ministry of Agriculture (2010)
Energy Use in Groundwater Irrigation	Fifth Minor Irrigation Census (2013)
Fertilizer Consumption (NPK)	Fertilizer Statistics (FAI 2011)
Agricultural Workers	Population Census (2011)
Irrigated Area	Agricultural Census (2010)
Gross Cropped Area	Agricultural Census (2010)
Groundwater Use in Irrigation	Dynamic Groundwater Resources of India, Central Groundwater Board (2013)

Districts of the hilly and mountainous states of India were not included because of its unique agro-ecosystem, which is mostly dependent on rainfall, springs and local water bodies. For the econometric analysis, 468 districts have been classified to regional dummies (D1, D2, D3, D4, and D5) based on Minor Irrigation (MI) Census to take into consideration the variability of agro-climatic and groundwater use variations across the districts (see Figure 1).

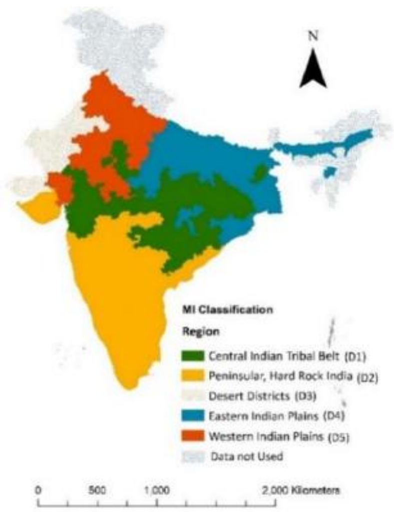

Figure 1. Regional Classification of India

2.2 Energy Use Estimation

The study estimates the energy use from groundwater pumping using the latest Fifth Minor Irrigation Census dataset. Annual energy consumption for each electric-powered pump and the diesel-operated pump is estimated separately, and then aggregated for 20.5 million groundwater wells to estimate the national-level energy consumption (see eq. 1).

Energy Use (in kWh) = $[\sum (Pe*He) * 0.746]/ (\eta*T) + [\sum(Pd*Hd) *0.746]/ \eta$………(eq. 1)
Where, Pe= Electric-pump size in HP, He= Hours of operation of electric pumps, Pd = Diesel-pump size in HP, Hd = Hours of operation of diesel pumps, η = Pump Efficiency, T= Transmission loss. Conversion factor of 0.746 was used to convert Horse power (HP) into kilowatt.

Energy use from groundwater pumping is sensitive to pump efficiency. Nelson et al. (2009) reported that energy consumption can be reduced by 30-50% by increasing pump efficiency from 0.2 to 0.3. The estimated value of pump efficiency in India varies between 30-40% across the studies (Patle et al. 2016, Shah 2009, Nelson et al. 2009, Rajan & Verma 2017) reported that the on-farm energy consumption by electric pumps was closest to the electricity supplied to agriculture at 40% pump efficiency. For this study, we have computed energy use and emissions at an efficiency of 40% for electric pumps. For diesel pumps, the computations have been done at an efficiency of 30% (Shah 2009). We have assumed the transmission and distribution losses (T&D) to be 20% in case of electric pumps based on a recent T&D estimation done by the Government of India (CSO 2017).

Energy productivity is defined as the agricultural output produced using per unit of energy (Upadhyaya and Sikka 2016). Energy productivity is expressed in terms of Rs. per kWh in the study.

2.3 Value of Crop Output Estimation

Value of Crop output (VoP)is the aggregate value of all crops in the year 2010-11 (in Indian Rupees at constant prices of 2004-05) at district-level. To estimate the energy productivity, the study only accounts for VoP coming from groundwater irrigated areas. Public datasets don't provide such information. In order to estimate the VoP from groundwater, we apportioned the VoP among groundwater irrigated area, surface water irrigated area and rainfed area using productivity weights. The weights of productivity were surmised to be 1.6:1.2:1 between groundwater irrigated area, surface water irrigated area and rain-fed area, and sourced from Goswami et al. 2017. Goswami et al. 2017 estimate that crop-output of 1 ha of groundwater irrigated area and 1 ha of surface water irrigated area are 1.6 and 1.2 times of 1 ha of rainfed area. Overall, VoP of groundwater irrigated area is estimated to be Rs. 4.2 trillion-around 48% of the total value of crop output.

3. RESULTS AND DISCUSSION

3.1 Energy Use in Groundwater Irrigation in India

Energy consumption in agriculture has rapidly surged since the ushering of the Green Revolution. According to CEA, electricity supply to agriculture, around 90% of it being used for groundwater pumping, has increased 54 times in between 1970-2016 - from 3,857 GWh to 1,87,493 GWh (Dharmadhikary et al. 2018). Use of diesel-oil increased from 1 million tonnes in 1980 to around 8 million tonnes in 2006 in the agriculture sector (Jha et al. 2012). Roughly 25-30% of total diesel consumption in agriculture is used for pumping groundwater. Our estimations from the latest Fifth MI Census showsaround

220 GWh of energy was consumed by groundwater irrigation in 2013. Of 221 GWh, electric pumps accounted for roughly 179 million kWh; diesel pumps accounted for 41.2 million kWh; and other sources like solar, wind, etc. did marginal contribution of 0.8 million kWh. 82% of India's total energy use in agriculture is sourced from electricity. Figure 2a shows the divide in energy use in groundwater irrigation. Incidence of very high energy use (>1500 kWh/ha) can be observed in the districts of Punjab, Haryana, western Uttar Pradesh, Rajasthan, Telangana, and Tamil Nadu. Groundwater stressed western and southern India -from Punjab in the north to southernmost state of Tamil Nadu- has relatively high energy use when compared to the groundwater-rich, eastern India (CGWB 2013). Cost of pumping varies from US $ 0-5 per MWh in the western and southern India because of supply of free or highly subsidized electricity; whereas the cost of pumping in diesel-dominated eastern India is US $ 350 MWh (Shah et al. 2018). Pricing of energy is one of the key drivers in determining the energy use in the country.

On equating the energy consumption figures with annual groundwater draft for irrigation in 2013 (i.e. 228 bcm) (CGWB 2013), it comes out that, on an average, 1 kWh of energy is used to draft 1 m3 of groundwater in the country. Figure 2b maps the district-wise energy used to draft 1 m3 of in the country. Energy use per m3 is relatively very high in the western and southern states of India when compared to the eastern states. Possible reasons behind the high energy use in the region can be partly due to inefficient pumping practices because of free or subsidized power and partly in response to depleted aquifers. High energy use for pumping has high economic and environmental costs associated with it.

However, majority of the farmers don't bear the actual energy cost of groundwater extraction but there is a huge public investment being done for groundwater access. It will be interesting to understand how efficiently energy is being utilized in agricultural production.

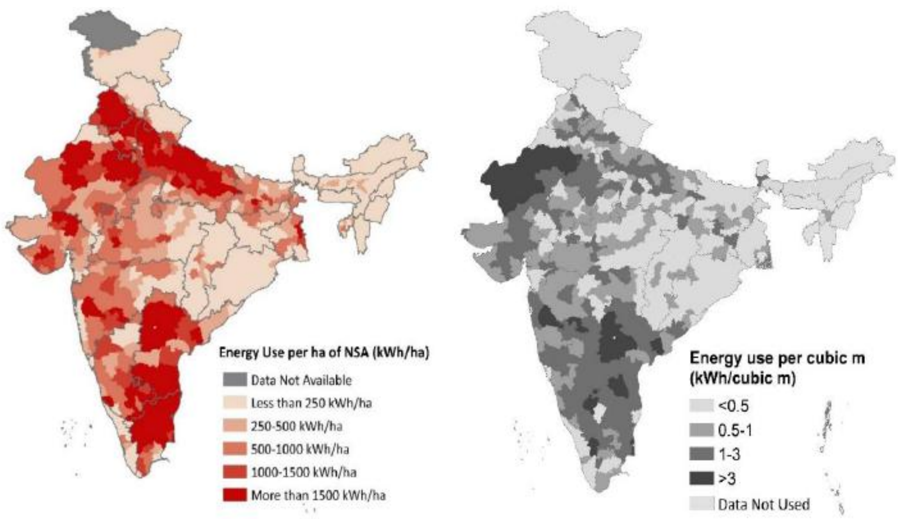

Figure 2a. Energy Use in India; Figure 2b: Energy Used per cubic m of groundwater

3.2 Energy Productivity of India's Groundwater Irrigated Agriculture

Figure 3 shows the energy productivity of districts in the country. It appears that Indo Ganga basin -from Punjab in the west to West Bengal in the east- coastal Andhra Pradesh, Tamil Nadu, Kerala and pockets in Gujarat generate more agricultural output

from every unit of energy. Whereas the majority of the districts located in western and southern India, where energy use is high (see Figure 2a), generates the lowest output from the energy used.

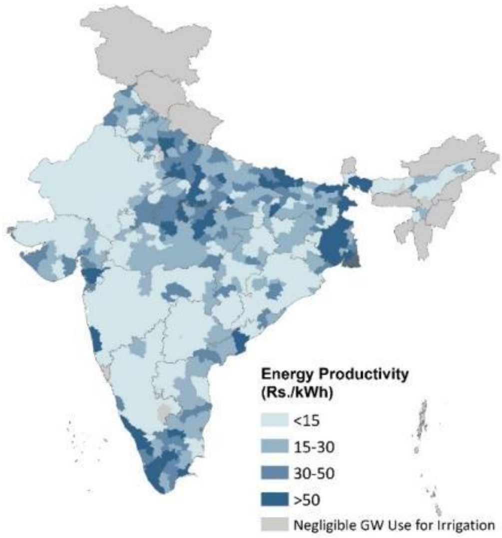

Figure 3. Energy Productivity of India

States of Maharashtra, Karnataka, Rajasthan, Telangana and Andhra Pradesh emerged as the most inefficient in terms of energy use (Figure 4). These states consume the maximum energy to yield a unit of groundwater and generates the least value of output using the energy consumed. Together these states consume around 44% of the total energy used for pumping in the country and account for only 18% of the total crop output. Inefficient pumping practices

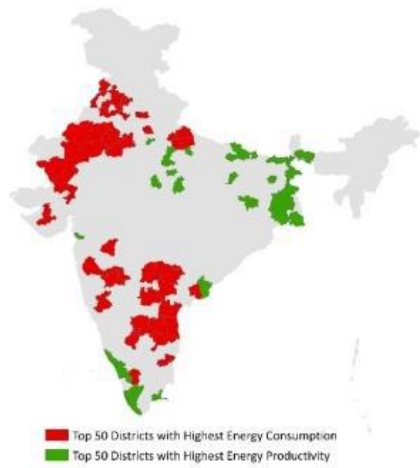

Figure 4. State-wise Energy Productivity and Energy Used per m^3

Kerala and West Bengal (WB) have the highest energy productivity among all the states. Two broad reasons for their better performance: [a] energy requirement to extract a unit of groundwater i.e. 0.25-0.35 $kWh/m^3$is low in both the states; and [ii]

water extracted is used for cultivation for high-value crops. High-value crops[3] account for 90%, and 62% of the value of crop-output in Kerala and WB respectively. With its high energy productivity, West Bengal (WB) stands apart from its adjacent states of Bihar and Assam, which have similar hydrogeology and agro-climatic conditions

Figure 4 shows that energy used to yield one unit of water is almost similar in WB, Bihar, and Assam. Groundwater pumping is dominated by cost-intensive diesel pumps in all the three states - more than 70% of total pumps are diesel-powered. Despite these similarities, WB has high-productivity because of large-scale cultivation of high-value crops like potato. Potato alone accounts for around 45% of WB's crop output comes. On the contrary, agriculture in Bihar and Assam are still paddy-wheat centric, which consumes more water. High-value crops roughly contribute to 27% and 23% of the value of crop-output in Bihar and Assam respectively. WB makes the most out of its costly diesel-based irrigation by cultivating potato- which requires less water and generates more value in comparison of paddy and wheat.

3.3 Are Top Energy-Guzzling Districts Generating High Agricultural Value?

This section investigates the performance of top energy consuming districts of India and assesses how efficiently they utilize their energy resources. India's 50 districts with the highest energy consumption belong to the western and southern states majorly (Figure 5). These 50 districts account for 25% of total groundwater wells, and draft 27% of total groundwater used for irrigation in the country. However, these districts disproportionately use 46% of the country's total energy used in groundwater pumping to abstract this volume of water. None of the 50 highest energy consuming districts overlaps with the highest energy productive districts (see Figure 5).

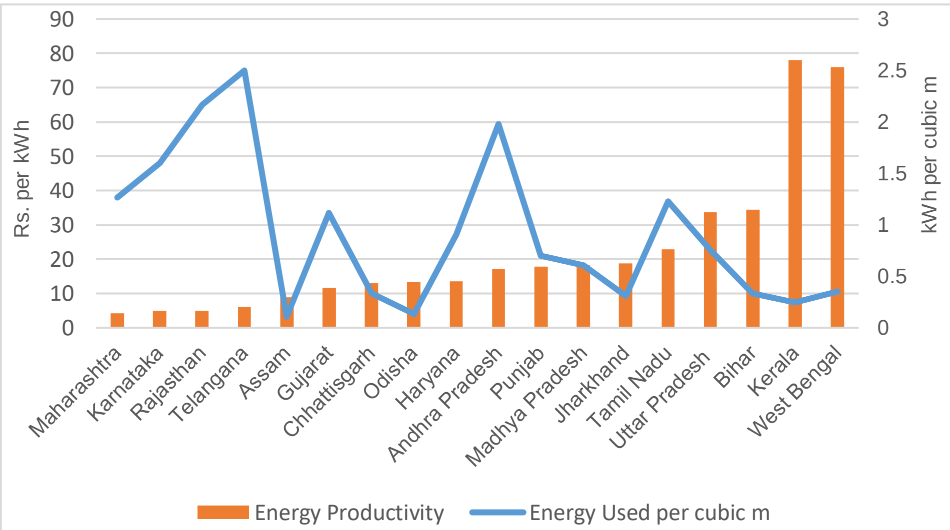

Figure 5. Top 50 Energy Consuming Districts and Top 50 Energy Productive Districts

This section investigates the performance of top energy consuming districts of India and assesses how efficiently they utilize their energy resources. India's 50 districts with the highest energy consumption belong to the western and southern states majorly. These 50 districts account for 25% of total groundwater wells, and draft 27% of total groundwater used for irrigation in the country. However, these districts disproportionately use 46% of the country's total energy used in groundwater pumping to

3 High-value crops are oilseeds, fruits, vegetables, spices, sugarcane, fiber crops, and tobacco.

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Table 2 compares the fifty highest energy consuming districts with fifty highest energy productive districts (see Figure 5). Both energy productivity and water productivity of this 50 energy-guzzling are worryingly low. What troubles more is that energy and water applied in these districts are mostly used for subsistence, low-value agriculture.

Table 2: Top 50 Energy Consuming Districts vs. Top 50 Energy Productive Districts

	50 districts with the highest Energy consumption	**50 districts with highest energy-productivity**
Average Energy Productivity (Rs./kWh)	10	103
Average Energy Use per m3 (kWh/m3)	1.76	0.35
Average Water Productivity (Rs./m3)	17	35
Share of High-Value Crops (%)	38	61

The energy requirement to draw one cubic meter of water is 75% more than the national average of 1 kWh per m3in the 50 highest energy consuming districts (see Table 2). High energy requirement indicates the precarious groundwater scenario in these districts. Of the 50 districts, 21 are in the over-exploited stage of groundwater development; and 15 others are in semi-critical and critical stage (CGWB 2013). Due to depleted aquifers, farmers in these districts use deeper wells to extract groundwater. According to Fifth MI Census, of 2.5 million Deep Tube wells (DTWs) -which operate at >70 meters of depth-, around 1-1.2 million DTWs are concentrated in these 50 districts.

Drawing water using DTWs from greater depths requires more energy to extract every cubic meter of water (). What troubles more is the poor application groundwater in these districts. Districts of Punjab and Maharashtra use the cost-intensive and scarce groundwater resource to cultivate thirsty crops like paddy and sugarcane.

3.4 Role of Energy as a Modern Input: An Econometric Analysis

This section discusses the relationship between energy use and crop output at the district level. An attempt has been done to assess the impact of energy as an input on the crop output using econometric analysis. For the present analysis, the following form of Cobb-Douglas function has been estimated on the input-output data of 460 districts.

Log_n(Output)	=	$\beta_0 + \beta_1$ Log (Energy)+ β_2 Log (Fertilizer)+ β_3 Log (Land)+ β_4 Log (Irrigation)+ β_5 Log (Labour)+ β_6 Log (Rainfall) $+\sum_{i=1}^{5} \alpha Z + \upsilon$
Output	=	Value of crop output of all major crops in Rupees
Energy Use	=	Total energy used for groundwater irrigation in kWh
Land	=	Gross Cropped Area in hectares in the district
Fertilizer	=	Chemical Fertilizers (Nitrogen [N], Phosphorus [P] and Potassium [K] in kg) consumed in the district
Irrigation	=	Percentage of the net sown area under irrigation in the districts
Rainfall	=	Annual Rainfall in (in mm) in the district

Labor = Number of Agricultural Workers in the district
Z = Regional Classification based on Minor Irrigation Census
u = Stochastic Error term

The choice of independent variables i.e. input factors has been done partly by their importance as contributors to the agricultural output and partly by the availability of reliable data at the district level. The underlying hypothesis in this production relationship is that the district-level production is an increasing function of energy, land, labor, irrigation, fertilizers, and rainfall. Consequently, we include 5 dummy variables in our model to control for agro-climatic and groundwater use variations across the districts in India.

Table 3. Results of Cobb-Douglas Input-Output Regression Function

Variables	Estimates of Regression Coefficients
Energy	0.057** (0.026)
Fertilizer	0.134* (0.038)
Land	0.478* (0.055)
Irrigation	0.123* (0.029)
Labour	0.119** (0.052)
Rainfall	0.202* (0.059)
Constant term	10.7 (0.721)
D2 (Hard Rock Peninsular Region)	0.455* (0.088)
D3 (Desert Region)	0.006 (0.202)
D4 (Eastern Plains)	0.260* (0.073)
D5 (Western Plains)	0.342* (0.097)
R-square	0.71
Number of Observations	468

Notes: Figures in parentheses is standard errors of the coefficients. * and** indicate coefficients significant at 1 percent and 5 percent level of significance respectively for the two-tailed t-test.

The results of the regression are reported in Table 3 shows that the impact of various factors on the agricultural output is positive, statistically significant and on the expected lines. The magnitude of the coefficients of the inputs determines their respective importance on agricultural output. Impact of inputs can be interpreted as elasticities where the magnitude of energy elasticity is the lowest of all the inputs. This indicates the lower importance of energy used in agricultural production vis-à-vis other inputs. The results can be interpreted as for every 1% increase in energy used, crop output increases by 0.05%. Doubling the current energy use in the country will increase the crop output by only 5%. It seems that the large public investments on power subsidies have a mild impact on the crop output of the country.

4. CONCLUSION

Energy is an important aspect of groundwater irrigation. Availability and pricing of energy play an important role in India's groundwater development and agricultural output. This energy productivity estimation conducted in this study shows that energy productivity varies from Rs. 2-3 kWh per m^3 in districts of Maharashtra to Rs. 90-100 kWh per m^3 in some districts of West Bengal. Unmetered and free access to energy for pumping has created asymmetries in the groundwater availability and its utilization in the western and Southern India. This region uses more energy to abstract groundwater because of depleted aquifers, and when extracted, water is inefficiently utilized for cultivation of crops like paddy in some pockets. The study also identified the 50 districts, which are the hotspots of the inefficient energy utilization for cultivation in the country. These districts account for half of India's total energy consumption for pumping to yield a quarter of the total crop output from groundwater irrigation. The high population of deep tube wells, operating on subsidized electricity, has led to the distortions in water-energy-food equilibrium in these districts. The results from the econometric analysis show that energy has a significant and positive impact on crop output, but its impact is quite low when compared to other modern inputs. In summary, the massive energy subsidies passed to the farmers for easy access to groundwater irrigation is poorly utilized for subsistence level cultivation in the country. Policy interventions are required to curtail the energy consumption and diversify the cropping pattern to improve the energy productivity of the country.

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