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Impact of electricity subsidies on groundwater exploitation in rice and maize cultivation in Anantapur District, Andhra Pradesh

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Abstract

Rice and maize are crucial for food security and livelihoods in Andhra Pradesh, where electricity subsidies heavily influence groundwater extraction. This study explored the effect of these subsidies on groundwater use for paddy and maize in Anantapur district, sampling 160 farmers across selected blocks. Primary data related to groundwater extraction before and after irrigation subsidy (agricultural year, 2021-22) were collected for the study. Results showed a significant rise in groundwater use following subsidy implementation, particularly in over-exploited areas. Maize saw a 22.82% increase in groundwater extraction, while paddy rose by 16.83% in over-exploited areas. The impact varied across farm categories, with marginal and small farms extracting more groundwater than medium and semi-medium farms. The subsidy led farmers to invest in electric pumps and extend pumping hours, intensifying groundwater depletion. These findings highlight the need for policy changes to adjust electricity subsidies based on crop water requirements, aiming to reduce excessive groundwater use.

Keywords: Electricity subsidies, groundwater exploitation, safe areas and over-exploited areas

Introduction

Groundwater is an essential resource that plays a significant role in agriculture, economic development, and the sustenance of life globally. It provides about 40% of the world's irrigation needs, which has allowed regions with scarce surface water resources to maintain and expand agricultural production. Groundwater is especially crucial in arid and semi-arid regions where it serves as a buffer against rainfall variability and droughts (Shah, 2009) ^[17]. Furthermore, groundwater is a vital component in ensuring food security, economic stability, and rural livelihoods, particularly in developing countries. As such, sustainable groundwater resource management is critical for human well-being and national development. India is the largest consumer of groundwater globally, extracting approximately 230 billion cubic meters annually, with over 90% of this used for irrigation (Shah *et al.*, 2009) ^[17]. The Green Revolution of the 1960s significantly increased the reliance on groundwater to support high-yielding crop varieties and fertilizers, leading to enhanced food production. However, this growth has come at a cost, with regions like Punjab, Haryana, and parts of Uttar Pradesh experiencing acute groundwater depletion due to over-extraction (Rodell *et al.*, 2009) ^[15]. In Andhra Pradesh, groundwater is a critical resource for agriculture, especially in districts like Anantapur, where groundwater supports over 23% of the irrigated area, making it vital for the production of water-intensive crops such as paddy and maize (Season and Crop Report, Andhra Pradesh, 2021-22). Globally, electricity subsidies have been instrumental in

enabling farmers to access groundwater for irrigation at reduced costs. In countries like India, Mexico, and China, government-provided subsidies have lowered the cost of pumping groundwater, increasing agricultural productivity (Badiani & Jessoe, 2013) ^[1]. However, these subsidies often result in unintended consequences, such as over-irrigation and groundwater over-exploitation. In India, electricity subsidies have incentivized the widespread installation of tube wells, leading to unsustainable groundwater extraction rates, especially in water-scarce regions (Fishman *et al.*, 2015) ^[8]. The same trend is observed in Andhra Pradesh, where heavily subsidized electricity allows farmers to extract groundwater cheaply, leading to over-extraction in areas like Anantapur. In Andhra Pradesh, ₹ 4384.8 crores were given for electricity subsidy during 2022-23. The state government provides 9 hours of free electricity during the daytime for approximately 18.5 lakhs of agricultural farmers (borewells) (Socio-Economic Survey, 2022-23, Planning Department, Government of AP). Studies show that in states where electricity is provided at highly subsidized rates or even free, farmers tend to over-extract groundwater, often irrigating more water-intensive crops than what is sustainable for the local aquifers (Badiani & Jessoe, 2013; Shah, 2009) ^[1, 17]. This over-reliance on groundwater is unsustainable in the long run, especially in regions like Anantapur, where groundwater levels are declining. To address these challenges, it is necessary to reform the existing electricity subsidy policies. Evidence suggests that adjusting subsidies, improving irrigation efficiency, and promoting the adoption of water-saving technologies can

help mitigate groundwater depletion (Mukherji *et al.*, 2009)^[13]. In Andhra Pradesh, modifying the structure of electricity subsidies, combined with incentives for farmers to adopt water-efficient practices, could help to achieve a balance between agricultural productivity and groundwater sustainability. Moreover, promoting crop diversification towards less water-intensive crops could further reduce the pressure on groundwater resources. This study investigates the impact of irrigation subsidies on groundwater exploitation in Anantapur district, Andhra Pradesh, focusing on the cultivation of paddy and maize crops. By examining the relationship between current electricity subsidy policies and groundwater depletion, this research aims to provide insights that can guide future policy reforms to promote more sustainable groundwater management practices while maintaining agricultural productivity.

Methodology

The research study was done in the Anantapur district of Andhra Pradesh, having a greater number of groundwater exploitation blocks (semi-critical, critical, and over-exploited blocks) in the state. As per Ground Water Resources Assessment, 2022 (GWRA-2022), Anantapur district was categorized into safe blocks, semi-critical blocks, critical blocks, and over-exploited blocks. But, for the study, the district was categorized as safe blocks and exploited blocks (semi-critical blocks, critical blocks & over-exploited). Four blocks (two safe blocks and two exploited blocks) were selected from the district. From each selected block, eight villages growing paddy and maize were chosen randomly, and a list of all the farmers growing paddy and maize was prepared, from that list, 40 farmers were selected randomly. Thus, a total of 160 sample farmers were selected for the study. Primary data was collected for the study through pre-tested interviews for the agricultural year 2021-22. Groundwater extraction details before subsidy were also collected from the respondents.

Analytical procedures

The effect of irrigation subsidies (electricity subsidies) on groundwater exploitation was estimated by using the difference between the volume of groundwater extracted before and after irrigation subsidies (electricity subsidies).

The volume of groundwater extraction

Groundwater extraction is the process of withdrawing water from underground water sources for freshwater or irrigation, either temporarily or permanently. Groundwater extraction is generally measured in litres or cubic meters per unit of time. In many areas, groundwater is pumped through wells,

borewells, and tubewells. This process of abstraction may lead to lowering the groundwater table. Over-extraction of groundwater occurs when the rate of groundwater extraction surpasses the rate of its recharge. When this occurs, wells, borewells, and tubewells yields decrease, and start to dry up. It may become necessary to drill wells, borewells, and tubewells deeper into the aquifer, which further lowers the water table. This leads to groundwater depletion, threatening and potentially reducing water supplies. Thus, the difference in depth of well/borewell/tubewell, the engine power of the pump (in HP) required to extract groundwater, the diameter of the suction pipe, and the duration of extraction will differentiate the amount of groundwater extracted. This will further raise the cost structure.

The volume of groundwater extraction (in litres) was estimated by using a pre-tested estimation model given by Eyhorn *et al.*, 2005^[7] followed by Srivastava *et al.*, 2009^[23], Watto and Mugeru 2015^[24], and Khair *et al.*, 2021^[11] given below and converted into cubic meters for further analysis.

$$Q = \frac{t * 129574.1 * BHP}{d + \frac{255.5998 * BHP^2}{d^2 * D^4}}$$

Where

Q = Quantity of groundwater extracted (in litres)

t = Total duration of irrigation (in hours)

BHP = Engine power of pump (in HP)

d = Average depth of the well (in metres)

D = Diameter of the suction pipe (in inches)

Results and Discussion

Impact of irrigation subsidies (IS) on groundwater exploitation (GWE)

In Andhra Pradesh, irrigation subsidies particularly in the form of electricity subsidies, have facilitated agricultural users (farmers) to get electricity at reduced rates (below the marginal cost of supply). This effectively lowered the costs associated with groundwater irrigation and extraction, which were critical components of agricultural production. The irrigation subsidy (electricity subsidy), which is primarily responsible for the over-extraction of groundwater, is consumed disproportionately across various sources used for pumping groundwater, such as electric pumps and diesel pumps. This consumption also varies based on the capacity of the pump or motor and the type of crop being cultivated. A paired sample t-test was conducted to test the hypothesis and the results were presented in Table 1.

Table 1: Paired samples t-test

Particulars	Paired Differences					t-value	df	p-value
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Safe areas								
Paddy	307.44	190.17	31.26	244.03	370.85	9.834	36	0.000***
Maize	87.68	90.34	12.90	61.73	113.63	6.794	48	0.000***
Over-exploited area								
Paddy	412.00	359.94	61.72	286.41	537.59	6.674	33	0.000***
Maize	197.68	106.33	13.84	169.97	225.39	14.279	58	0.000***

Note: Data is a pair of volumes of extracted water (After subsidy - Before subsidy) Significant: ** $p < 0.05$

Impact of irrigation subsidies on groundwater exploitation in Anantapur district of Andhra Pradesh

Data on the volume of groundwater extracted for irrigation (m^3/acre) in safe and over-exploited areas for paddy and maize, before and after subsidy was calculated and presented in Table 2. Additionally, it shows the percentage change in groundwater irrigation, total duration of irrigation (hours/acre), engine power of pump (in HP), and average depth of the borewell/tubewell/pump (in metres) following the electricity subsidy implementation. From the table, before the electricity subsidy, the groundwater used for paddy in safe areas was $3987.69 \text{ m}^3/\text{acre}$, while in over-exploited areas, it was $2446.64 \text{ m}^3/\text{acre}$. After the electricity subsidy, these values increased to $4295.11 \text{ m}^3/\text{acre}$ and $2858.33 \text{ m}^3/\text{acre}$, respectively. For maize, the groundwater usage before the electricity subsidy was $1263.24 \text{ m}^3/\text{acre}$ in safe areas and $866.11 \text{ m}^3/\text{acre}$ in over-exploited areas. Following the electricity subsidy, the groundwater usage rose to $1350.89 \text{ m}^3/\text{acre}$ in safe areas and $1063.78 \text{ m}^3/\text{acre}$ in over-exploited areas. The data reveals that after the electricity subsidy, the volume of groundwater used for both paddy and maize increased in both safe and over-exploited areas (Amandeep Gahlawat, 2022) ^[26]. In safe areas, the increase was $307.42 \text{ m}^3/\text{acre}$ for paddy and $87.65 \text{ m}^3/\text{acre}$ for maize. In over-exploited areas, the increase was $411.69 \text{ m}^3/\text{acre}$ for paddy and $197.67 \text{ m}^3/\text{acre}$ for maize. In relative terms, the volume of groundwater used increased by 7.71 per cent for paddy and 6.94 per cent for maize in safe areas,

and by 16.83 per cent for paddy and 22.82 per cent for maize in over-exploited areas (These results were similar to findings as envisaged by *Srivastava et al.* 2017) ^[22]. These findings demonstrate that irrigation subsidy/electricity subsidy substantially increases groundwater exploitation. Free electricity subsidy/ irrigation subsidy led to an increase in the adoption of new tube wells, excess use of electricity, and use of higher horsepower electric pumps. These were the key causes for over-exploitation of groundwater. Due to free electricity/ irrigation subsidies, the cost of electricity per unit of groundwater extraction and the overall cost of groundwater irrigation could decrease. This led to longer pumping hours and contributed to the over-exploitation of groundwater resources (these results were in like manner with Zhu, Ringler & Cai 2007; Singh 2012; Kumar, Scott & Singh 2013; Pfeiffer and Lin 2014; Baweja, Aggarwal & Brar 2017; Sidhu, Kandlikar & Raman Kutty 2020, Zarandi & Fakhr 2022) ^[20, 14, 4, 25, 27]. Free electricity subsidy/ irrigation subsidy also enhanced the adoption of new tube wells by sample farmers and thus increased groundwater extraction (these findings by and large matched with the findings of Singh, 2012; Badiani & Jessoe, 2018) ^[3, 20]. Excess use of electricity led to groundwater over-exploitation (these results were in like manner with Kannan, 2013) ^[10]. Increasing the horsepower load increased the quantity of groundwater withdrawn (a similar result was seen in Gupta, 2023) ^[9].

Table 2: Impact of irrigation subsidies on groundwater exploitation in Anantapur district (Andhra Pradesh)

S. No	Particulars	Safe areas			Groundwater over-exploited areas		
		Before irrigation subsidy	After irrigation subsidy	Percentage change	Before irrigation subsidy	After irrigation subsidy	Percentage change
Paddy							
1	t = Total duration of irrigation (in hours/acre)	182.38	196.49	14.11 (7.74)	124.56	156.47	31.91 (25.62)
2	BHP = Engine power of pump (in HP)	7.64	7.64	0.00	7.56	8.09	0.53 (7.01)
3	d = Average depth of the well/Motor (in metres)	45.01	45.01	0.00	49.70	57.23	7.53 (15.15)
4	D = Diameter of the suction pipe (in inches)	2.36	2.34	-0.03 (-1.14)	2.46	2.46	0.00
5	Volume of groundwater extracted (m³/acre)	3987.69	4295.11	307.42 (7.71)	2446.64	2858.33	411.69 (16.83)
Maize							
1	t = Total duration of irrigation (in hours/acre)	83.88	90.67	6.79 (8.09)	64.53	86.18	21.65 (33.55)
2	BHP = Engine power of pump (in HP)	7.94	7.94	0.00	8.55	8.89	0.34 (3.98)
3	d = Average depth of the well/Motor (in metres)	68.20	68.95	0.75 (1.09)	82.34	93.23	10.89 (13.23)
4	D = Diameter of the suction pipe (in inches)	2.24	2.24	0.00	2.24	2.24	0.00
5	Volume of groundwater extracted (m³/acre)	1263.24	1350.89	87.65 (6.94)	866.11	1063.78	197.67 (22.82)

Note: Figures within the parentheses indicate % change after irrigation subsidy

Comparing the impact of electricity subsidy on groundwater exploitation between safe and over-exploited areas in Anantapur district (Andhra Pradesh)

From Figure 1, after irrigation subsidy, for both paddy and maize, compared to safe areas, over-exploited areas showed more per cent increase in the volume of groundwater applied per acre. In safe areas, before the subsidy, due to

the availability of more groundwater resources at shallow depths, the farmers used to apply maximum water and because of this reason, there was less percent increase in the volume of groundwater applied after the subsidy. Before the subsidy, in over-exploited areas, due to low availability and deeper depth of groundwater, the farmers went on applying less amount of groundwater for irrigation and after

the subsidy, irrigation subsidies helped them to draw groundwater for deeper depth by using higher HP motors for a longer period that induced them applying more percent of groundwater (Table 2) (results were on the similar line with Badiani & Jessoe 2011)^[2]. Fluctuations in the power supply

also made the farmers switch on the motor repeatedly which made them draw more groundwater water leading to more groundwater exploitation (a similar result was seen in Kannan, 2013)^[10].

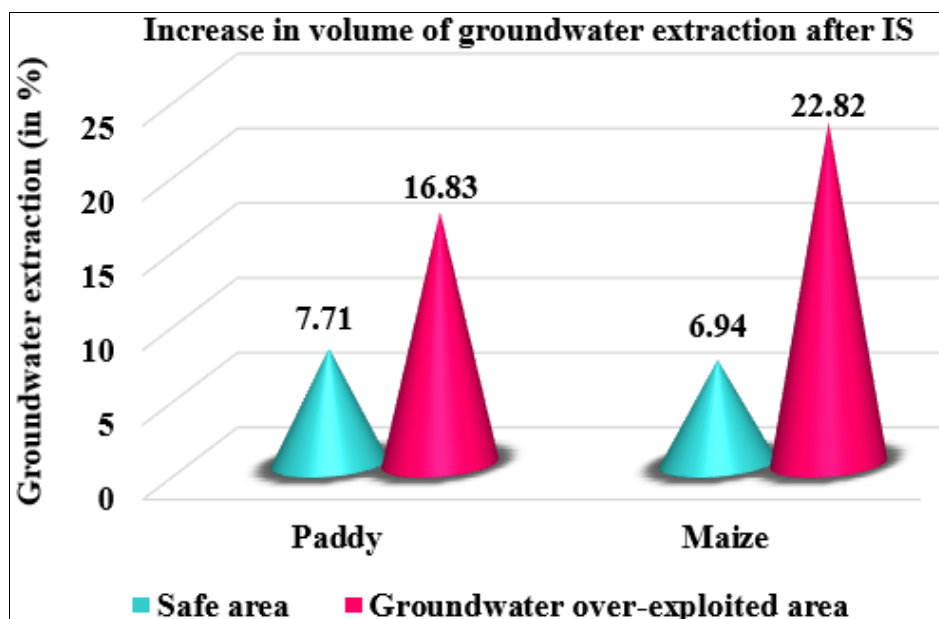


Fig 1: Comparing the impact of electricity(irrigation) subsidy on groundwater exploitation in safe and over-exploited areas in Anantapur district (AP)

Comparing the impact of irrigation subsidy on groundwater exploitation between paddy and maize in Anantapur district (Andhra Pradesh)

From Figure 2, after the irrigation subsidy, maize experienced a greater percentage increase in the volume of groundwater applied per acre compared to paddy, in over-exploited areas (a similar result was seen in Srivastava *et al.* 2017)^[22]. In safe areas, there was almost an equal percentage increase in paddy and maize. As paddy is a water-loving crop, before subsidy, both in safe and over-

exploited areas, farmers tried to apply the maximum water required and, in the maize, the required quantity of water was not been fulfilled especially in over-exploited areas. But, after subsidy, the irrigation subsidy helped them to draw groundwater from deeper depths and for longer periods, especially in over-exploited areas which facilitated the farmers to apply more percent of groundwater in maize as compared to paddy.

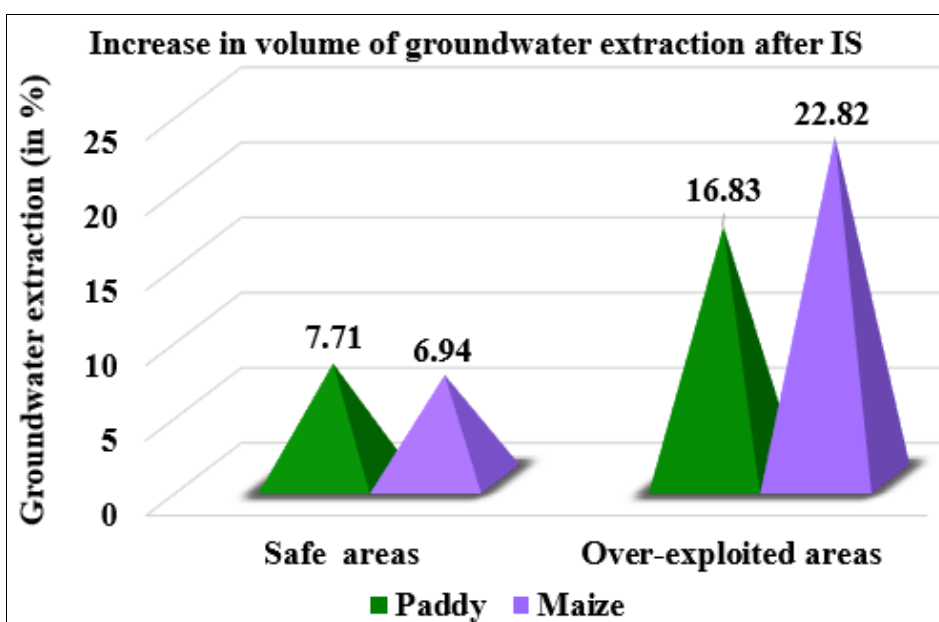


Fig 2: Comparing the impact of electricity/irrigation subsidy on groundwater exploitation between paddy and maize in Anantapur district (AP)

Impact of irrigation (Electricity) subsidy on groundwater exploitation in different categories of farms in Anantapur district (Andhra Pradesh)

The percentage increase in the volume of groundwater extracted after irrigation subsidy on different farm categories was worked and presented in Table 3. The table also showed the percentage increase in total duration of irrigation (hours/acre), engine power of pump (in HP), and average depth of the well/motor (in metres) after the electricity (irrigation) subsidy implementation. In safe areas, the percentage increase in groundwater extracted for irrigation after the introduction of an irrigation subsidy was as follows: for paddy and maize, marginal farms enhanced by 8.59% and 8.38%, small farms by 10.82% and 6.46%, semi-medium farms by 3.06% and 5.98%, and medium farms by 7.31% and 6.97%. In over-exploited areas, the percentage increase in groundwater extracted for irrigation after the subsidy was notably higher. Marginal farms raised by 19.21% and 28.85% for paddy and maize, respectively; small farms increased by 18.29% and 20.40%; semi-medium farms by 17.98% and 24.19%; and medium farms increased by 15.18% and 15.14%. Further, from Figure 3, in

safe areas, the highest percentage increase in groundwater extraction for paddy was observed on small farms (10.82%), while for maize, marginal farms showed the largest increase (8.38%). From Figure 4, in over-exploited areas, the greatest increase for paddy was on marginal farms (19.21%), and for maize, it was also on marginal farms (28.85%), with medium farms showing the smallest increases for both crops. The data explained that marginal and small farms registered more sensitive to subsidies, showing higher percentage increases in groundwater extraction. In contrast, semi-medium and medium farms had lower percentage increases, likely due to better-existing infrastructure and less dependency on additional financial incentives for irrigation expansion. Marginal and small farmers, along with irrigation subsidies, small land holding, own bore wells, fluctuation in power supply and lack of groundwater market tried to use maximum groundwater to the available land holding. However, semi-medium and medium farmers due to large land holding and fluctuation in power supply used to extract and distribute lesser groundwater to available land holding. Thus, there was an almost negative trend of the impact of subsidy with an increase in farm size.

Table 3: Impact of irrigation subsidies on groundwater exploitation of different farm categories in Anantapur district (AP)

S. No	Particulars	(in cubic meters per acre)									
		Safe areas					Groundwater over-exploited areas				
		Marginal farms	Small farms	Semi-medium farms	Medium farms	Overall	Marginal farms	Small farms	Semi-medium farms	Medium farms	Overall
A. Paddy											
1	t = Total duration of irrigation (in hours/acre)	14.83 (8.80)	18.14 (10.87)	7.50 (3.06)	10.00 (6.98)	14.11 (7.74)	30.77 (27.78)	14.00 (20.19)	36.25 (20.14)	67.25 (36.80)	31.91 (25.62)
2	BHP = Engine power of pump (in HP)	0.00	0.00	0.00	0.00	0.00	0.38 (5.41)	0.28 (4.31)	1.31 (15.0)	0.00	0.53 (7.01)
3	d = Average depth of the tubewell/Motor (in metres)	0.00	0.00	0.00	0.00	0.00	4.69 (13.22)	1.35 (6.24)	14.48 (17.12)	16.76 (18.80)	7.53 (15.15)
4	D = Diameter of the suction pipe (in inches)	-0.13 (-5.08)	-0.04 (-1.45)	0.00	0.33 (16.67)	-0.03 (-1.14)	0.00	0.00	0.00	0.00	0.00
5	Volume of groundwater extracted (m³/acre)	374.89 (8.59)	470.47 (10.82)	105.43 (3.06)	234.12 (7.31)	307.42 (7.71)	548.06 (19.21)	475.23 (18.29)	433.57 (17.98)	367.70 (15.18)	411.69 (16.83)
B. Maize											
1	t = Total duration of irrigation (in hours/acre)	7.39 (8.38)	4.21 (6.46)	5.83 (5.98)	14.20 (16.17)	6.79 (8.09)	22.50 (45.99)	19.40 (29.13)	24.85 (33.40)	17.20 (29.25)	21.65 (33.55)
2	BHP = Engine power of pump (in HP)	0.00	0.00	0.00	0.00	0.00	0.18 (2.43)	0.40 (5.25)	0.45 (4.85)	0.00	0.34 (3.98)
3	d = Average depth of the tubewell/Motor (in metres)	0.00	0.00	0.00	7.32 (8.63)	0.75 (1.09)	8.53 (16.18)	9.27 (12.92)	13.53 (12.65)	13.41 (12.29)	10.89 (13.23)
4	D = Diameter of the suction pipe (in inches)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	Volume of groundwater extracted (m³/acre)	111.59 (8.38)	85.49 (6.46)	71.97 (5.98)	83.17 (6.97)	87.65 (6.94)	254.24 (28.85)	186.86 (20.40)	202.00 (24.19)	135.19 (15.14)	197.67 (22.82)

Note: Figures within the parentheses indicate % change after irrigation subsidy.

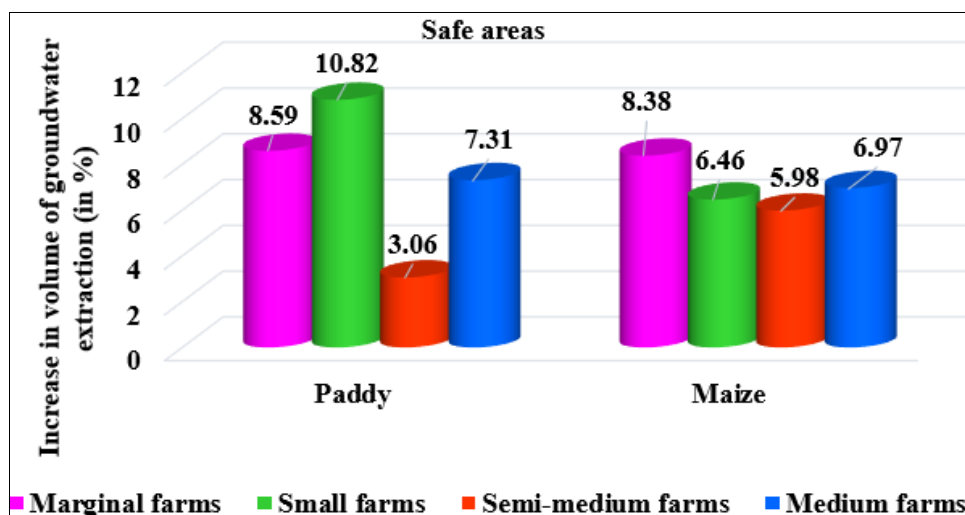


Fig 3: Impact of electricity(irrigation) subsidy on groundwater exploitation of different farm categories in safe areas in Anantapur district (AP)

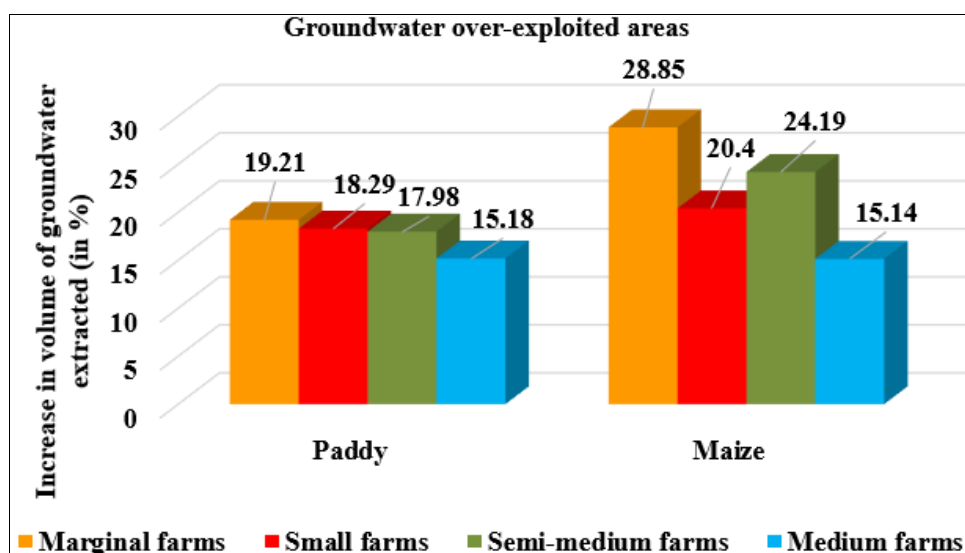


Fig 4: Impact of electricity (irrigation) subsidy on groundwater exploitation of different farm categories in over-exploited areas in Anantapur district (AP)

Conclusion

The study made in the safe and over-exploited areas in the Anantapur district of Andhra Pradesh exhibited that, the increase in the volume of groundwater withdrawal for irrigation for paddy and maize, in safe areas was 7.71 per cent & 6.94 per cent and in over-exploited areas was 16.83 per cent & 22.82 per cent. As compared to safe areas, over-exploited areas had a greater per cent increase in the volume of groundwater applied per acre. In over-exploited areas, maize farms with 22.82 per cent are exploiting more percentage of the volume of groundwater as compared to paddy farms (16.83 per cent). The impact varied across farm categories, with marginal and small farms extracting more groundwater than medium and semi-medium farms. The subsidy encouraged farmers to adopt electric pumps, and increased pumping hours, contributing to groundwater over-extraction. Policy reforms for sustainable groundwater management like ration electricity subsidies for minimizing severe groundwater exploitation and as per crop water needs. Incentivize rainwater harvesting to recharge aquifers and adopt water-efficient irrigation technologies. Enhance

irrigation literacy and encourage optimal fertilizer use for efficient resource management. Real-time monitoring and smart meters for electricity subsidies and groundwater usage caps based on farm category.

References

1. Badiani R, Jessoe K. Electricity subsidies for agriculture: Evaluating the impact and persistence of these subsidies in India. *J Agric Econ*. 2013;64(2):327-54.
2. Badiani R, Jessoe KK. Electricity subsidies for agriculture: Evaluating the impact and persistence of these subsidies in India. DRAFT; c2011.
3. Badiani-Magnusson R, Jessoe K. Electricity prices, groundwater, and agriculture: the environmental and agricultural impacts of electricity subsidies in India. In: *Agricultural productivity and producer behaviour*. Chicago: University of Chicago Press; c2018. p. 157-83.
4. Baweja S, Aggarwal R, Brar M, Lal R. Groundwater depletion in Punjab, India. In: *Encyclopedia of Soil*

- Science. 2017;3(3):1-5.
5. Central Ground Water Board (CGWB). Groundwater Yearbook: Ministry of Jal Shakti, Government of India. 2020.
 6. Central Ground Water Board (CGWB). Dynamic groundwater resources of India; c2022. Available from: <https://www.cgwb.gov.in>
 7. Eyhorn F, Mader P, Ramakrishnan M. The impact of organic cotton farming on the livelihoods of smallholders: Evidence from the Maikaal BioRe project in central India. Frick, Switzerland: Research Institute of Organic Agriculture (FiBL); c2005.
 8. Fishman R, Jain M, Kishore A. Groundwater depletion, adaptation, and migration: Evidence from India. *J Dev Stud.* 2015;51(6):802-24.
 9. Gupta D. Free power, irrigation, and groundwater depletion: Impact of farm electricity policy of Punjab, India. *Agric Econ.* 2023;54(4):515-54.
 10. Kannan E. Do farmers need free electricity? Implications for groundwater use in South India. *J Soc Econ Dev.* 2013;15(2):16-28.
 11. Khair S, Rasheed A, Culas R. Socio-Economic Analysis of Groundwater Resource Management for Balochistan, Pakistan. Albury, NSW 2640, Australia: Institute for Land, Water and Society, Charles Sturt University; c2021.
 12. Kumar MD, Scott CA, Singh OP. Can India raise agricultural productivity while reducing groundwater and energy use? *Int J Water Resour Dev.* 2013;29(4):557-73.
 13. Mukherji A, Facon T, Burke J. Revitalizing Asia's Irrigation: To Sustainably Meet Tomorrow's Food Needs. Colombo, Sri Lanka: International Water Management Institute; c2009.
 14. Pfeiffer L, Lin CYC. The effects of energy prices on agricultural groundwater extraction from the High Plains Aquifer. *Am J Agric Econ.* 2014;96(5):1349-62.
 15. Rodell M, Velicogna I, Famiglietti JS. Satellite-based estimates of groundwater depletion in India. *Nature.* 2009;460(7258):999-1002.
 16. Season and Crop Report, Andhra Pradesh; c2021-22. Available from: <https://des.ap.gov.in>
 17. Shah T, Bhatt S, Shah RK, Talati J. Groundwater governance through electricity supply management: Assessing an innovative intervention in Gujarat, western India. *Agric Water Manag.* 2009;95(11):1233-42.
 18. Shah T. Taming the Anarchy: Groundwater Governance in South Asia. Washington, DC: RFF Press; c2009.
 19. Sidhu BS, Kandlikar M, Ramankutty N. Power tariffs for groundwater irrigation in India: A comparative analysis of the environmental, equity, and economic tradeoffs. *World Dev.* 2020;128:104836.
 20. Singh K. Electricity subsidy in Punjab agriculture: Extent and impact. *Indian J Agric Econ.* 2012, 67(4).
 21. Socio-Economic Survey, Planning Department, Government of Andhra Pradesh. 2022-23. Available from: <http://www.apsdps.ap.gov.in>
 22. Srivastava SK, Chand R, Singh J, Kaur AP, Jain R, Kingsly I, *et al.* Revisiting groundwater depletion and its implications on farm economics in Punjab, India. *Curr Sci.* 2017;113(3):422-29.
 23. Srivastava SK, Kumar R, Singh RP. Extent of groundwater extraction and irrigation efficiency on farms under different water-market regimes in Central Uttar Pradesh. *Agric Econ Res Rev.* 2009;22(1):87-98.
 24. Watto MA, Mugera AW. Econometric estimation of groundwater irrigation efficiency of cotton cultivation farms in Pakistan. *J Hydrol Reg Stud.* 2015;4:193-211.
 25. Zarandi MT, Fakhr FH. Comparison of groundwater costs calculated with different methods and the effect of electricity subsidy liberalization. *Groundwater Sustain Dev.* 2022;18:100804.
 26. Gahlawat A. A Study of groundwater depletion and its impact on agriculture in Eastern Haryana. *Int J Geogr Geol Environ* 2022;4(1):141-144. DOI: 10.22271/27067483.2022.v4.i1b.99
 27. Zhu T, Ringler C, Cai X. Energy price and groundwater extraction for agriculture: Exploring the energy-water-food nexus at the global and basin levels. In: International Conference of Linkages Between Energy and Water Management for Agriculture in Developing Countries, Hyderabad, India; c2007.