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Impact of Groundwater Depletion on Irrigation Cost of Paddy and Maize Cropping System in the Anantapur District of Andhra Pradesh, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The study was conducted to estimate the cost of groundwater irrigation and the impact of groundwater over-exploitation on the irrigation cost of paddy and maize in the Anantapur district of Andhra Pradesh. Based on the stage of groundwater extraction, the Central Groundwater Board divided the study area into safe and exploited areas. Primary data was collected from both these safe and exploited areas. The study found that the annual irrigation cost of groundwater in over-exploited areas for both paddy (₹4033.38/acre) and maize (₹3570.26/acre) were observed to be higher as against paddy (₹2697.01/acre) and maize (₹2524.76/acre) in safe areas. The added cost of groundwater irrigation in over-exploited areas for paddy (₹988.08/acre) and maize (₹838.34/acre) were preponderantly greater than paddy (₹216.60/acre) and maize (₹187.82/acre) in safe areas. This revealed that groundwater over-exploitation had a more significant impact on over-exploited

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regions. Marginal and small farmers are the primary victims of groundwater over-exploitation in terms of cost and groundwater resources. Free/subsidized electricity for irrigation and water-intensive crops, paddy and maize, are one of the reasons for depleting groundwater in the study area. There is a solid requirement for controlling groundwater over-exploitation in the study area.

Keywords: Groundwater irrigation; irrigation cost; groundwater over-exploitation; added cost.

1. INTRODUCTION

For the survival of any civilization, water plays a crucial role. It is a prime natural resource of basic human needs. The critical functions of water are associated with production, consumption, and ecology, and they act as a resource for livelihood security and food supply. Of the total water available, only three per cent is fresh water, which the life on the earth can use. Polar ice and groundwater are the major sources of freshwater. Another source of freshwater is surface water in rivers, canals, etc. "Groundwater is the underground water in the cracks and spaces in soil, sand and rock". Groundwater is playing a remarkable role in India's economic growth. India is the largest groundwater user in the world, with an estimated use of 230 Km³ of groundwater per year (a quarter of the global total). In India, nearly 62 per cent of the irrigation water supply for agriculture, 85 per cent in rural areas, and 50 per cent in urban areas depend on groundwater. Groundwater is a critical source of irrigation, facing the problem of depletion in many parts of the world.

Groundwater depletion means long-term water-level declines caused by sustained groundwater pumping. This is strongly true in India, where 60 per cent of irrigation is carried out through groundwater [1,2]. On average, the water level has dropped by 8 m since the 1980s [3,4,5]. Poor water supply from public water distribution systems, advanced pumping technologies, government irrigation subsidies (for example, electricity subsidies) and the green revolution are some of the key factors responsible for the uncontrolled expansion of groundwater usage in India [6]. The green process, the introduction of groundwater pumps being the leading cause, and the lack of clear policy on the supply of electricity subsidies for groundwater use increased unchecked wasteful groundwater exploitation [7,8]. The greed for maximum economic returns also plays the way for poor water resources, leading to groundwater depletion and ending in an alarming situation. If the current trend of groundwater use continues,

after 20 years, 60 per cent of all Indian aquifers will be in danger [9].

States like Haryana, Rajasthan, Punjab, Dadra & Nagar Haveli and Daman & Diu have a high stage of groundwater extraction (more than 100 per cent) with annual consumption more than the annual extractable level and states like Karnataka, Uttar Pradesh, Delhi, Tamil Nadu and UTs of Chandigarh, Puducherry and Lakshadweep between 60-100 per cent and rest of states below 60 per cent. With the rapid increase of tube wells, the north-western parts like Punjab, Delhi, Haryana and Western Uttar Pradesh of India with abundant replenishable groundwater and southern peninsular parts of India like Andhra Pradesh, Karnataka, Tamil Nadu and Telangana and Western parts like Gujarat and Rajasthan are witnessing serious problem of overexploitation of aquifers [10].

1.1 Need for the Study

Rice and maize are two major crops grown in Andhra Pradesh, using large quantities of water. The study was conducted in the Anantapur district of Andhra Pradesh during 2021-22, where groundwater was the dominating source of irrigation. Even though the district had large and medium irrigation projects, groundwater acted as the major source of irrigation, accounting for 90.37 per cent of the total gross irrigated area [11]. Groundnut, cotton, paddy and maize are important crops grown in the district. Water-intensive crops like paddy lead to groundwater exploitation. The availability of free electricity subsidies may also be one of the causes of the overuse of groundwater. Andhra Pradesh government provides free power of 9 hours/day to agricultural consumers for Rs.9896.90 crore (18% higher than last year) [12]. Climate change also impacts groundwater systems, including the hydrological cycle, soil infiltration, deeper percolation, increased evaporative demand, and groundwater recharge. Groundwater over-exploitation and climatic conditions are causing depletion in the water table. Farmers are digging new bore wells/wells and deepening the old wells for groundwater. Deepening old wells and

digging new wells add extra costs to use the groundwater resources. The economically weaker section, mainly marginal and small farmers, cannot bear the additional investment. Water is one of the major inputs influencing the yield; it must be saved for the next generations. The present study entitled, "Impact of groundwater depletion on irrigation cost of paddy and maize cropping system in Anantapur district of Andhra Pradesh", was conducted to determine the farm situation of groundwater extraction and its impacts on the irrigation cost and make the concerned department aware of appropriate measures to reduce groundwater overuse. In this study, the cost of groundwater irrigation, the cost of irrigation across the farm size, and the impact of groundwater over-exploitation on irrigation costs across different sizes of farms are computed to assess the actual situation in the study area.

2. MATERIALS AND METHODS

2.1 Data Collection

The research study was confined to the Anantapur district of Andhra Pradesh, where there was more groundwater exploitation (semi-critical, critical and over-exploited). According to Ground Water Resources Assessment, [13] (GWRA-2022), the district was divided into safe, semi-critical, critical and over-exploited. But for the study, the district was divided as safe and exploited (semi-critical, critical and over-

exploited). Four mandals were selected from the district, two safe and two exploited. From each mandal, eight villages growing paddy and maize were selected randomly, and a list of all the farmers growing paddy and maize were prepared, and from that list, 40 farmers were selected randomly. Thus, a total of 160 sample farmers were selected for the study. Through pre-tested schedules, primary data was collected for the study, the rabi season, and the agricultural year 2021-22. Data related to the irrigation cost of the well at the year of digging and groundwater extraction details before subsidy were also collected from the respondents. The secondary data were collected from different sources like the Central Groundwater Board (CGB), Groundwater departments of Andhra Pradesh, etc., on various aspects.

2.2 Analytical Procedures

2.2.1 Pumping cost/irrigation cost and added cost

Added cost (cost towards some modifications/alterations made in the irrigation system due to groundwater depletion) was found to ascertain the impact on pumping cost. The cost of irrigation at the year of digging the well (present value) and the cost of irrigation in the current year were worked out by using the following formulae.

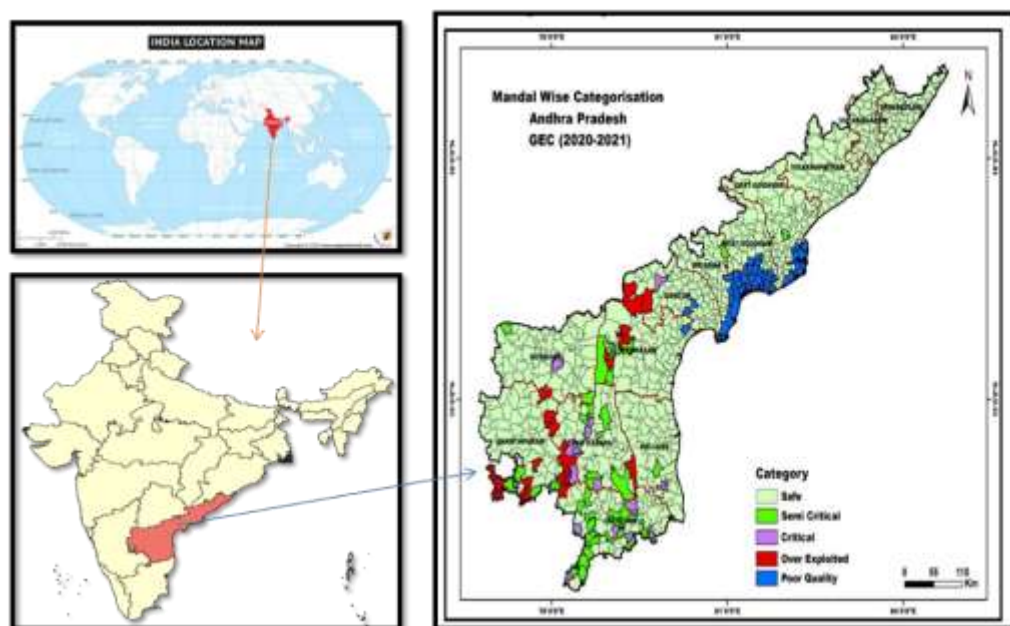


Fig. 1. Location map with status of groundwater exploitation in Andhra Pradesh

2.2.2 Annual irrigation cost

Annual irrigation cost = (sum of amortized and maintenance costs of pumping sets, well and annual electricity cost) /gross irrigated area [14,15].

$$i. \quad \text{Average life of well} = \frac{\sum_{i=1}^n (f_i x_i)}{\sum_{i=1}^n f_i}$$

f= frequency of well yielding irrigation in each age, x= well age in years (i=1,2,3....)

$$ii. \quad \text{Amortized drilling cost} = \frac{[BW_{cost} * (1+i)^{AL} * i]}{(1+i)^{AL}-1}$$

BWcost = investment on bore-well at current year price, AL = average life of bore-well, i=interest rate

$$iii. \quad \text{Amortized cost of pump sets} = \frac{[WL_{cost} * (1+i)^{AL} * i]}{(1+i)^{AL}-1}$$

WLCost = investment on pumping sets at current prices, and AL = Average life of pump sets.

2.2.3 Discount rate

Choosing a discount rate was a puzzle for evaluating public policies & programmes. According to Lind, 1997, discount rates range between 5 per cent to 10 per cent or 0 per cent to 3 per cent. Chandrakanth and Diwakara based on the debate among Weitzman, 1998, Gollier, 2002 and Pearce et al., 2003 on social discounting, gave an inverse relationship with time. They also said the growth rate for nominal investment made for irrigation wells in Karnataka was 2 per cent (i= 2 per cent) when considering the old wells. For the present study, by using sample data related to the investment made for the earliest well (IEW) and investment made for the latest well (ILW), the rate of interest was estimated by using the formula (IEW (1+i) n = ILW). By solving the rate of interest, it was found 2.8 per cent. This interest rate of 2.8 per cent was used for compounding & amortizing the cost [16].

3. RESULTS AND DISCUSSION

3.1 Cost of Groundwater Irrigation

The annual groundwater irrigation cost and volume of groundwater extracted per acre in safe and over-exploited areas for paddy

and maize were calculated and presented in Table 1. The annual irrigation cost of groundwater in over-exploited areas for both paddy (Rs.4033.38/acre) and maize (Rs.3570.26/acre) were found to be higher as against paddy (Rs.2697.01/acre) and maize (Rs. 2524.76/acre) in safe areas. The above clearly illustrated that the annual cost of groundwater irrigation was higher in over-exploited areas compared to safe areas (similar results were observed in Palanisami, Vidhyavathib and Ranganathan [17], Reddy [18], Ravinder and Binu, (2021). But the groundwater extracted per acre per annum in safe areas for both paddy (4295.11m³/acre) and maize (1350.89 m³/acre) were higher when compared to paddy (2858.33 m³/acre) and maize (1063.78 m³/acre) in over-exploited areas. The depth of the bore-well/well and pump sets/ motor & accessories were the important factors influencing groundwater irrigation's cost. From the table, it was observed that the depth of BW/TW/OW in over-exploited areas for paddy (57.23 m) and maize (93.23 m) were more as compared to paddy (45.01 m) and maize (68.20 m) in safe areas due to a fall in groundwater table that resulted in high drilling and casing cost of BW/TW/OW in over-exploited areas for paddy (₹1511.36/acre) and maize (₹1156.23/acre) in contrast to paddy (₹634.25/acre) and maize (₹882.10/acre) in safe areas. The increase in depth of BW/TW/OW also escalated the energy required (highcapacity motors) to draw groundwater for irrigation, resulting in high pump sets/ motor & accessories cost in over-exploited areas for paddy (₹1180.43/acre) and maize (₹1117.96/acre) in contrast to paddy (₹863.08/acre) and maize (₹785.81/ acre) in safe areas. Hence, there was a considerable difference in the cost of groundwater irrigation between safe and over-exploited areas. The unit cost for extracting groundwater for paddy (₹1.41/m³) and maize (₹ 3.36/m³) was found to be comparatively higher in over-exploited areas than paddy (₹ 0.63/m³) and maize (₹1.87/m³) in safe areas (similar result were found in Sharifa and Ashok [14]. The lower well yield (due to exploitation and an increase in well depth) increases the unit cost of extraction. Lower well yield coupled with higher annual cost of irrigation increased the unit cost of extraction in over-exploited areas.

3.2 Cost of Groundwater Irrigation Across the Farm Size (₹/acre)

An analysis of groundwater irrigation cost per acre incurred for paddy and maize in both safe

and over-exploited areas among different farm sizes is presented in Table 2. The annual irrigation cost per acre for paddy and maize in safe areas was marginal (₹4493.29 and ₹6212.36), small farmers (₹3370.28 and ₹2961.19), semi-medium (₹2917.47 and ₹2606.41) & medium (₹1147.39 and ₹948.74) and in over-exploited areas, it was marginal (₹9873.25 and ₹6606.72), small farmers (₹5305.27 and ₹4252.90), semi-medium (₹3273.79 and ₹3277.76) and medium (₹2046.15 and ₹2103.65). The above discussion indicated that for crops, paddy and maize in safe and over-exploited areas, the annual groundwater irrigation cost per acre decreased with an increase in farm size (similar results were found in Sharifa and Ashok [14], Pavneet, 2014, Anantha [19] and Reddy [18]. The unit cost for extraction of groundwater in safe and over-exploited areas for both paddy and maize was inversely related to farm size (Table 2) (similar findings are seen in Srivastava et al. [20], Palanisami, Vidhyavathib & Ranganathan, [17]. The annual groundwater irrigation cost for both paddy and maize were particularly higher in over-exploited areas; for paddy, it was marginal farm (₹9873.25/acre), followed by small farm (₹5305.27/acre), semi-medium (₹3273.79/acre) and medium (₹2046.15/acre) and for maize, it was marginal farm (₹6606.72), followed small farm (₹4252.90), semi-medium (₹3277.76) and medium (₹2103.65)). The overall average annual cost of groundwater irrigation in safe and over-exploited areas for paddy was estimated (₹2697.01/acre and ₹4033.38/acre) which were higher than that of maize (₹2524.76/acre and ₹3570.26/acre).

This variability in annual groundwater irrigation cost across different farm sizes and among the crops, paddy and maize, was predominantly due to low gross irrigable land area in both safe areas and over-exploited areas with high levels of investment. Marginal and small farmers, due to the financial crisis, purchase low-quality motors that burn frequently due to irregular electricity supply, resulting in high repairs and maintenance costs. The per BW/TW/OW cost may be higher on medium farms depending on high drilling cost due to well depth and higher capacity motor with higher cost, but the advantage of large irrigable land area with an increase in farm size enjoy the economies of scale with less per acre groundwater irrigation cost. For medium farmers, the advantage of choosing the best diving point

with high water yield to drill BW/TW/OW with lower cost will certainly positively impact lowering the cost to some extent. The lack of a groundwater market in the study area reduces the scope for effective groundwater use by marginal and small farmers, which may help reduce the pumping cost. The inequality in overall average groundwater irrigation cost between safe and over-exploited areas under both paddy and maize was due to a fall in groundwater table dominantly more in over-exploited areas, which have a positive impact on high drilling & casing cost of BW/TW/OW and increase in requirements of high capacity motors with higher cost.

3.3 Impact of Groundwater Over-Exploitation on Irrigation Cost

The added cost of groundwater irrigation to paddy and maize in the safe and over-exploited area was worked out and presented in Table 3. The impact of groundwater over-exploitation on pumping cost may be estimated by the difference in the cost of groundwater irrigation at the year of digging BW/TW/OW and the cost of groundwater irrigation in the present year. The difference is the added cost of irrigation. The greater the added cost of irrigation, the greater the impact of groundwater over-exploitation on pumping costs. The added cost of groundwater irrigation in over-exploited areas for paddy (₹988.08/acre) and maize (₹838.34/acre) were preponderantly greater than paddy (₹216.60/acre) and maize (₹187.82/acre) in safe areas. This indicates that groundwater over-exploitation had a greater impact on over-exploited areas when compared with safe areas (similar results were found by Reddy [18], Sharifa & Ashok [14], Palanisami, Vidhyavathib & Ranganathan [17].

3.4 Added Cost of Groundwater Irrigation in Safe Areas

The percentage increase in added cost in safe areas for paddy and maize was 8.73 per cent and 8.04 per cent (Table 3.). This increase in added cost was not due to the exploitation of groundwater but due to changes in motors due to the expiration of motors, an increase in repairs on account of motors reaching expiration, and the adoption of new technology like drip irrigation.

Table1. Annual groundwater irrigation cost (₹ /acre) in Anantapur district of Andhra Pradesh

S. No	Particulars	Paddy		Maize	
		Safe	Over-exploited	Safe	Over-exploited
1	Amortized drilling & casing cost of BW/TW/OW(₹)	634.25	1511.36	882.10	1156.23
2	Amortized cost on P & A(₹)	863.08	1180.43	785.81	1117.96
3	Amortized cost on CS(₹)	803.75	718.68	508.64	722.74
4	Amortized cost on drip irrigation(₹)	-	-	59.88	80.47
5	Repairs, electricity charges and maintenance costs in current price(₹)	395.93	622.91	288.33	492.86
6	Annual irrigation cost (₹/acre)	2697.01	4033.38	2524.76	3570.26
7	Annual irrigation cost/ BW/TW/OW(₹/well)	21153.28	31175.66	23892.51	32673.20
8	Groundwater extracted (m ³ /acre)	4295.11	2858.33	1350.89	1063.78
9	Cost of groundwater extraction(₹/m ³)	0.63	1.41	1.87	3.36
10	Total gross irrigated area(acre)	290.20	174.80	463.70	553.30
11	Gross irrigated area/farm(acre)	7.84	5.64	9.46	9.38

Source: Survey data

Note: BW-Bore well, TW-Tube well, OW-Open well, P-Pump, A-Accessories, CS-Conveyance structure

Table 2. Annual cost of groundwater irrigation across different sizes of farm (₹/acre) in Anantpur district of Andhra Pradesh

S. No	Particulars	Safe areas						Over-exploited areas													
		Paddy Marginal	Small	Semi-medium	Medium	Overall	Maize Marginal	Small	Semi-medium	Medium	Overall	Paddy Marginal	Small	Semi-medium	Medium	Overall	Maize Marginal	Small	Semi-medium	Medium	Overall
1	Amortized drilling & casing cost of BW or TW(₹)	1037.13	733.84	834.66	225.99	634.25	2107.26	895.16	1089.26	288.59	882.10	3443.87	1685.54	1226.56	963.49	1511.36	1757.28	1228.85	1176.36	788.02	1156.23
2	Amortized cost on P & A(₹)	1492.48	1107.93	760.52	441.74	863.08	1746.17	1080.38	648.14	402.48	785.81	2476.44	1808.34	1100.10	582.03	1180.43	1906.08	1387.02	1029.23	667.22	1117.96
3	Amortized cost on CS(₹)	986.46	1047.11	959.06	384.98	803.75	1324.47	510.51	567.27	179.08	508.64	1832.83	897.76	571.84	349.57	718.68	1251.84	888.83	707.00	355.50	722.74
4	Amortized cost on drip irrigation(₹)	-	-	-	-	-	57.68	71.50	98.79	23.99	59.88	-	-	-	-	-	281.12	70.18	-	150.59	80.47
5	Repairs, electricity charges and maintenance cost in current price(₹)	977.22	481.40	363.24	94.68	395.93	976.78	403.64	202.94	54.60	288.33	2120.11	913.64	375.28	151.06	622.91	1410.39	678.03	365.18	142.31	492.86
6	Annual cost of irrigation/acre(₹)	4493.29	3370.28	2917.47	1147.39	2697.01	6212.36	2961.19	2606.41	948.74	2524.76	9873.25	5305.27	3273.79	2046.15	4033.38	6606.72	4252.90	3277.76	2103.65	3570.26
7	Cost of groundwater extraction (₹/m ³)	0.95	0.70	0.82	0.33	0.63	4.30	2.10	2.04	0.74	1.87	2.90	1.73	1.47	0.73	1.41	5.82	3.86	3.16	2.05	3.36
8	Annual irrigation cost/ BW/TW/OW(₹)	14790.4	21353.1	24798.5	35951.4	21153.3	20811.4	19755.4	29539.3	33016.0	23892.5	27189.4	25936.9	36420.9	48084.5	31175.7	26332.5	28069.2	38595.7	54694.9	32673.2
9	Gross irrigated area(acre)	39.50	88.70	68.00	94.00	290.20	60.30	93.40	136.00	174.00	463.70	35.80	44.00	89.00	94	174.80	55.80	132.00	235.50	130.00	553.30
10	Gross irrigated area/farm(acre)	3.29	6.34	8.50	31.33	7.84	3.35	6.67	11.33	34.80	9.46	2.75	4.89	11.13	23.50	5.64	3.99	6.60	11.78	26.00	9.38

Source: Survey data

Note: BW-Bore well, TW-Tube well, OW-Open well, P-Pump, A-Accessories, CS-Conveyance structure

Table 3. Estimation of added cost of groundwater irrigation (₹/acre) of sample farmers in Anantpur district of Andhra Pradesh

S. No	Particulars	Paddy					Maize				
		At the year of digging	Present	Added cost	% to total added cost	% to total present cost	At the year of digging	Present	Added cost	% to total added cost	% to total present cost
Safe area											
1	Amortized drilling & casing cost of BW/TW/OW(₹/acre)	634.25	634.25	0.00 (0.00)	0.00	0.00	882.10	882.10	0.00 (0.00)	0.00	0.00
2	Amortized cost on P & A(₹/acre)	798.80	863.08	64.27 (8.05)	29.67	2.38	702.01	785.81	83.80 (11.94)	44.62	3.32
3	Amortized cost on CS(₹/acre)	758.98	803.75	44.77 (5.90)	20.67	1.66	496.46	508.64	12.18 (2.45)	6.48	0.48
4	Amortized cost on drip irrigation(₹/acre)	-	-	-	-	-	-	59.88	59.88 (-)	31.88	2.37
5	Repairs, electricity charges and maintenance cost in current price(₹/acre)	288.38	395.93	107.56 (37.30)	49.66	3.99	256.37	288.33	31.96 (12.47)	17.01	1.26
6	Total cost(₹/acre)	2480.41	2697.01	216.60 (8.73)	100.0	8.03	2336.94	2524.76	187.82 (8.04)	100.0	7.44
Over exploited areas											
1	Amortized drilling & casing cost of BW/TW/OW(₹/acre)	1176.95	1511.36	334.42 (28.41)	33.85	3.29	989.82	1156.23	166.41 (16.81)	19.85	4.66
2	Amortized cost on P & A(₹/acre)	853.86	1180.43	326.57 (38.25)	33.05	8.10	755.60	1117.96	362.36 (47.96)	43.22	10.15
3	Amortized cost on CS(₹/acre)	667.56	718.68	51.12 (7.66)	5.17	1.27	669.75	722.74	52.99 (7.91)	6.32	1.48
4	Amortized cost on drip irrigation(₹/acre)	-	-	-	-	-	-	80.47	80.47 (-)	9.60	2.25
5	Repairs, electricity charges and maintenance cost in current price(₹/acre)	346.94	622.91	275.96 (79.54)	27.93	6.84	316.75	492.86	176.11 (55.60)	21.01	4.93
6	Total cost(₹/acre)	3045.30	4033.38	988.08 (32.45)	100.0	24.50	2731.92	3570.26	838.34 (30.69)	100.0	23.48

Source: Survey data

Note: Figures within the parentheses indicate the % increase in the year of digging and the current year.

BW-Bore well, TW-Tube well, OW-Open well, P-Pump, A-Accessories, CS-Conveyance structure.

Table 4. Estimation of the added cost of groundwater irrigation across the different sizes of farm (₹/acre) in Anantpur district of Andhra Pradesh

S. No	Particulars	Safe area										Over-exploited area									
		Paddy					Maize					Paddy					Maize				
		Marginal	Small	Semi-medium	Medium	Overall	Marginal	Small	Semi-medium	Medium	Overall	Marginal	Small	Semi-medium	Medium	Overall	Marginal	Small	Semi-medium	Medium	Overall
1	Amortized drilling & casing cost of BW or TW(₹/acre)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	401.35 (48.64)	554.94 (135.85)	334.42 (28.41)	0.00 (0.00)	0.00 (0.00)	196.23 (20.02)	352.78 (81.05)	166.41 (16.81)
2	Amortized cost on P & A(₹/acre)	61.96 (4.33)	195.80 (21.47)	0.00 (0.00)	80.71 (22.36)	64.27 (8.05)	285.67 (19.56)	98.75 (10.06)	29.73 (4.81)	48.07 (13.56)	83.80 (11.94)	430.05 (21.02)	660.78 (57.58)	366.48 (49.96)	205.99 (54.78)	326.57 (38.25)	524.57 (37.97)	383.85 (38.26)	365.50 (55.07)	265.23 (65.98)	362.36 (47.96)
3	Amortized cost on CS(₹/acre)	102.23 (11.56)	53.11 (5.34)	0.00 (0.00)	45.14 (13.28)	44.77 (5.90)	23.67 (1.82)	16.51 (3.34)	14.07 (2.54)	4.40 (2.52)	12.18 (2.45)	66.82 (3.78)	9.40 (1.06)	82.66 (16.90)	34.82 (11.06)	51.12 (7.66)	91.73 (7.91)	60.92 (7.36)	54.71 (8.39)	25.18 (7.62)	52.99 (7.91)
4	Amortized cost on drip irrigation (₹/acre)	-	-	-	-	-	57.68 (-)	71.50 (-)	98.79 (-)	23.99 (-)	59.88 (-)	-	-	-	-	-	281.12 (-)	70.18 (-)	0.00 (-)	150.59 (-)	80.47 (-)
5	Repairs, electricity charges and maintenance cost in current price(₹/acre)	276.44 (39.45)	126.09 (35.49)	101.25 (38.65)	23.66 (33.32)	107.56 (37.30)	194.64 (24.89)	20.47 (5.34)	5.89 (2.99)	2.13 (4.05)	31.96 (12.47)	1128.33 (113.77)	370.85 (68.32)	139.64 (59.26)	49.13 (48.20)	275.96 (79.54)	638.50 (82.72)	223.40 (49.14)	118.63 (48.12)	33.76 (31.11)	176.11 (55.60)
6	Total cost (₹/acre)	440.63 (10.87)	375.00 (12.52)	101.25 (3.60)	149.51 (14.98)	216.60 (8.73)	561.66 (9.94)	207.24 (7.53)	148.48 (6.04)	78.59 (9.03)	187.82 (8.04)	1625.21 (19.70)	1041.03 (24.41)	990.13 (43.36)	844.88 (70.33)	988.08 (32.45)	1535.92 (30.29)	738.34 (21.01)	735.07 (28.91)	827.53 (64.85)	838.34 (30.69)
7	Gross irrigated area(acre)	39.50	88.70	68.00	94.00	290.20	60.30	93.40	136.00	174.00	463.70	35.80	44.00	89.00	6.00	174.80	55.80	132.00	235.50	130.00	553.30
8	Gross irrigated area/farm (acre)	3.29	6.34	8.50	31.33	7.84	3.35	6.67	11.33	34.80	9.46	2.75	4.89	11.13	6.00	5.64	3.99	6.60	11.78	26.00	9.38

Note: Figures within the parentheses indicate the % increase in cost at the year of digging and the current year
 BW-Bore well, TW-Tube well, OW-Open well, P-Pump, A-Accessories, CS-Conveyance structure

3.5 Added Cost of Groundwater Irrigation in Over-Exploited Areas

The estimated added cost of groundwater irrigation for paddy and maize on drilling & casing was found (₹334.42/acre and ₹166.41/acre), on pump/motor was (₹326.57/acre and ₹362.36/acre), and on repairs, electricity charges and maintenance was (₹275.96/acre and ₹176.11/acre). The overall average added cost of groundwater irrigation for paddy and maize was recorded at ₹988.08/acre and ₹838.34/acre. There was a more than 30 per cent increase in the added cost of groundwater irrigation for both paddy (32.45 per cent) and maize (30.69 per cent). In over-exploited areas, for both paddy and maize, there was a greater percentage increase in added cost of groundwater irrigation in the form of repairs, electricity charges and maintenance costs (79.54 per cent and 55.60 per cent), followed by pump/motor costs (38.25 per cent and 47.96 per cent), drilling & casing cost of BW/TW/OW (28.41 per cent and 16.81 per cent) and cost on conveyance structure (7.66 per cent and 7.91 per cent). But, the higher percentage contribution to the added cost of irrigation for paddy was the drilling & casing cost of BW/TW/OW (33.85 per cent), followed by pump/motors costs (33.05 per cent), repairs, electricity charges and maintenance cost (27.93 per cent) and the cost on conveyance structure (5.17 per cent). In the case of maize, a larger percentage contribution to the added cost of groundwater irrigation was pump/motors costs (43.22 per cent), drilling & casing cost of BW/TW/OW (19.85 per cent), repairs, electricity charges and maintenance cost (21.01 per cent), cost on drip (9.60 per cent) and the cost on conveyance structure (6.32 per cent). In over-exploited areas, the added cost alone contributed more than 20 per cent (in paddy, it was 24.50 per cent and in maize, it was 23.48 per cent) to the present groundwater irrigation cost [21]. The rise in the groundwater over-exploitation caused a fall in the groundwater table, ultimately leading to the drying up of BW/TW/OW. Thus, it may be pointed out that many of the farmers in over-exploited areas are forced to modification of BW/TW/OW (purchasing high capacity motors due to an increase in depth of motors due to a fall in the water table, digging new bore wells due to drying up of old bore well, repairing and reusing motors, damage of motors due to shortage of water and electricity fluctuation)

leading to increase in groundwater pumping cost.

3.6 Impact of Groundwater Over-Exploitation on Irrigation Cost Across Farm Size

The added cost of groundwater irrigation of paddy and maize in safe and over-exploited areas across farm sizes was analyzed and presented in Table 4.

3.7 Added Cost (Modification Cost) of Groundwater Irrigation Across the Farm Sizes in Safe Areas

In safe areas, the added cost of groundwater irrigation for paddy was higher for marginal farms (₹440.63/acre), followed by small farms (₹375.00/acre), medium farms (₹149.51/acre) and semi-medium farms (₹101.25/acre) and for maize, it was higher for marginal farms (₹561.66/acre), followed by small farms (₹207.24/acre), semi-medium farms (₹148.48/acre) and medium farms (₹78.59/acre) (Table 4). But the percentage increase in added cost of groundwater irrigation for paddy was comparatively high for medium farms (14.98 per cent), followed by small farms (12.52 per cent), marginal farms (10.87 per cent) and semi-mediums (3.60 per cent) and for maize, it was observed higher for marginal farms (9.94 per cent), followed by medium farms (9.03 per cent), small farms (7.53 per cent) and semi-medium (6.04 per cent).

As the gross irrigated acreage for irrigation for both paddy and maize was low for marginal and small farms, the added cost of groundwater irrigation per acre was comparatively higher than for semi-medium and medium farms. The percentage increase in the added cost of groundwater irrigation was larger on medium farms, followed by small farms in paddy crops, indicating the economic strength of medium and small farms in purchasing new motors compared to marginal farms. The lower percentage increase in the added cost of groundwater irrigation in maize crops for semi-medium farms compared to marginal, medium, and small farms indicated that the semi-medium farmers were using best-quality motors compared to marginal, medium, and small farmers. In safe areas, this added cost of groundwater irrigation for both paddy and maize was assessed not due to the impact of

groundwater over-exploitation, but it was due to changes in motors (motors reaching expiry), increase in repairs due to motors reaching expiry and adoption of new technology like drip irrigation.

3.8 Added Cost (Modification Cost) of Groundwater Irrigation Across the Farm Size in Over-Exploited Areas

In over-exploited areas, the added cost of groundwater irrigation for paddy was comparatively high for the marginal farms (₹1625.21/acre), followed by the small farms (₹1041.03/acre), semi-medium farms (₹990.13/acre) and medium farms (₹844.88/acre) and on the other hand, for maize, it was larger for the marginal farms (₹1535.92/acre), followed by medium farms (₹827.53/acre), small farms (₹738.34/acre) and semi-medium farm (₹735.07/acre) (Table 4). This portrays that the burden of over-exploitation on per acre irrigation cost was observed more on marginal and small farmers [18]. The percentage increase in the added cost of groundwater irrigation for paddy was higher for the medium farms (70.33 per cent), followed by semi-mediums (43.36 per cent), small farms (24.41 per cent) and marginal farms (19.70 per cent) and for maize, it was higher for medium farm (64.85 per cent) followed by marginal farms (30.29 per cent), semi-medium farms (28.91 per cent) and small farms (21.01 per cent).

The inverse relationship between the added cost of groundwater irrigation and farm sizes in the case of paddy was probably because of the high gross groundwater irrigation acreage holding of medium farms in comparison to marginal farms. In the case of maize, except for medium farms, an inverse relationship was registered between the added cost of groundwater irrigation and farm size. Finally, the added cost of groundwater irrigation for medium farms was higher in maize crops than for small and semi-medium farms. This was because of the dominating digging cost of the new bore well and cost on P & A (high economic stability), which could not make groundwater utilization effective. From the point of individual costs, the percentage increase in both (the amortized added drilling & casing cost of BW/TW) and (the amortized added cost on P & A) for both paddy and maize could increase with an increase in the farm size and further, the added cost of repairs, electricity charges and maintenance decreased with increase in the farm

size. The analysis further indicated that the medium farmers and semi-medium farmers, economically potential, are stronger in making additional investments in drilling new BW /TW and purchasing new pump/motors due to over-exploitation as compared to marginal and small farmers unable to afford are making more investments in repairing and reusing the pump/motor.

4. CONCLUSION

The study has shown that the added cost of groundwater irrigation for both paddy and maize was greater in over-exploited areas than in safe areas. This reveals groundwater over-exploitation had a greater impact on the irrigation cost of paddy and maize in over-exploited areas. Among the crops, the impact of groundwater over-exploitation was more in paddy. The marginal and small farmers are the main victims of groundwater over-exploitation, as it raises their groundwater irrigation costs. The annual cost of groundwater irrigation was higher in over-exploited areas for both paddy and maize and decreased with an increase in farm size. Paddy had more annual groundwater irrigation cost per acre, while per unit extraction cost of groundwater was higher in the case of maize. More subsidies should be provided to farmers for adopting efficient modern irrigation technologies like sprinklers, drip, etc., to ensure their livelihood security. Farmers should participate in constructing rain water harvesting structures to bridge the gap between groundwater recharge and groundwater extraction. Free/subsidized power supply is one of the key factors for groundwater over-exploitation. Government officials, agencies and planners should come forward and ensure the rational use of electricity and groundwater through a proper planning framework to restrict groundwater exploitation, safeguard groundwater for future generations, and maintain the ecological balance.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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