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

Abstract

India is the largest groundwater user in the world,using 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. The green revolution, the introduction of groundwater pumps, and the lack of clear policy on the supply of electricity subsidies for groundwater use increased the unchecked wasteful groundwater exploitation. Rice and maize are the major crops grown inthe Anantapur district of Andhra Pradesh, using large quantities of water.Considering the above, a study was made in the Anantapur district of Andhra Pradeshto look at the cost of groundwater irrigation, the cost of irrigation across farm sizes, the impact of groundwater over-exploitation on irrigation cost and how groundwater over-exploitation impactsthe cost of irrigation across different sizes of farm.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 observedto 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. Thisrevealed that groundwater over-exploitation had a more significant impact on over-exploited regions when compared to safe areas in the study area. Marginal and small farmers are the primary victims of groundwater over-exploitationfor irrigation cost and effect. There is a solid requirement for controlling groundwater over-exploitation in the study area.

Keywords: Groundwater irrigation, irrigation cost, groundwater over-exploitation, added cost

Introduction

"**Water, the resource for life**",is a prime natural resource which is a basic human need. The key functions of water are associated with production, consumption, and ecology, and they act as a resource forlivelihood security and food supply.Of the total water available, only three per cent is freshwater, which the life on the earth can use.Polar ice and groundwater are the major sources of freshwater. Groundwater is considered the key 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 Km^3 of groundwater per year (a quarter of the global total). In India, nearly 62 percent of the irrigation water supply foragriculture, 85 per cent in rural areas, and 50 per cent in urban areas depend on groundwater(Anonymous, 2022).In India, groundwater is a key resource for rural areas(Anonymous). 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 (Sibert *et al.,* 2010; Saha *et al.,* 2018). On average, the water level has dropped by 8 m since the 1980s (Rodell *et al.,* 2009;Aeschbach-Hertig and Gleeson, 2012; Sekhri,2012).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 uncontrolledexpansion of groundwater usage in India (Pahuja *et al.,* 2010).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. 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 percent of all Indian aquifers will be in danger (Anonymous,2022).

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 (Anonymous,2022)

Need for the study

Rice and maize are two of the major crops grown in Andhra Pradesh,using large quantities of water.The study was conducted in the Anantapur district of Andhra Pradesh during 2022-23, 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 (Anonymous 2021).Groundnut, cotton, paddy and maize are important crops grown in the district. Water-intensive crops like paddy will lead to groundwater exploitation.The availability of free electricity subsidies may also be one of the causesof 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)(Anonymous 2021).Climate change also impacts groundwater systems, including the hydrological cycle, soil infiltration, deeper percolation, increased evaporative demand, and groundwater recharge.Declining groundwater tables coupled with digging new bore wells/wells and deepening the old wells exploit groundwater andaffect the livelihood of the marginal and small farmers who cannot bear the additional investment due to over-exploitation.(Rewrite the sentence)Water is one of the major inputsinfluencing the yield; it must be saved for the next generations. This study may help to determine the farm situation of groundwater extraction and how it impacts the irrigation cost.The study wouldhelp the concerned department advise appropriate measures to reduce overuse and makeeconomical use of groundwater.Considering the above, a study was conducted,**"Impact of groundwater depletion on irrigation cost of paddy and maize cropping system in Anantapur district of Andhra Pradesh",**to find outthe cost of groundwater irrigation, cost of irrigation across the farm size, the impact of groundwater over-exploitation on irrigation cost and how groundwater over-exploitation impact cost of irrigation across different size of farm.

Materials and methods

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, 2022 (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 mandalas 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 year2021-22. 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.

Analytical procedures

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.

Annual irrigation cost

Annual irrigation cost = (sum of amortized and maintenance costs of pumping sets, well and annual electricity cost) /gross irrigated area (Sharifa and Ashok2011; Kumar, Patil and Chandrakanth 2016).

i. **Average life of well =** $\frac{\sum_1^n (f_i x_i)}{\sum_1^n f_i}$

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

ii. **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. **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.

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 found2.8 per cent. This

interest rate of 2.8 per cent was used for compounding & amortizing the cost. (Chandrakanth, Patil & Kumar,2019).

Results and discussion

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 wereobserved in Palanisami, Vidhyavathib and Ranganathan, 2008;Reddy, 2005; Ravinder and Binu,2021).But the groundwater extracted per acre per annum in safe areas for both paddy (4295.11m^3/acre) and maize (1350.89 m^3/acre) were higher when compared topaddy (2858.33 m^3/acre) and maize (1063.78 m^3/acre) inover-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 thatthe depth ofBW/TW/OW in over-exploited areas forpaddy (57.23 m) and maize (93.23 m) were more as compared to paddy(45.01m) and maize(68.20 m) in safe areas due to a fall in groundwater table thatresulted in high drilling and casing cost of BW/TW/OW in over-exploited areas forpaddy (₹ 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 (high capacity motors) to draw groundwater for irrigation, resulting in high pump sets/ motor & accessories cost in over-exploited areas forpaddy (₹ 1180.43/acre) and maize(₹ 1117.96/acre) in contrast topaddy(₹ 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/m^3) and maize (₹ 3.36/m^3) wasfoundto be comparatively higher in over-exploited areas than paddy(₹ 0.63/m^3) and maize (₹ 1.87/m^3) in safe areas(similar result were found in Sharifa and Ashok 2011). The lower well yield (due to exploitation and an increase in welldepth) 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.

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

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

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 sizesis 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 (₹ 9873.25and ₹ 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, 2011; Pavneet, 2014; Anantha, 2013; and Reddy, 2005). 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.*2017; Palanisami, Vidhyavathib& Ranganathan,2008).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, purchaselow-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 choosingthe 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 dominatingly 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.

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 diggingBW/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 foundby Reddy 2005; Sharifa & Ashok 2011; Palanisami, Vidhyavathib& Ranganathan,2008).

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					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(₹)	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

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

Added cost of groundwater irrigation in safe areas

The percentage increase in added cost in safe areas for paddy and maize was8.73 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.

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 recordedat ₹ 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,forboth 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 (21.01per 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(the result follows Narayanamoorthy, 2014)). The rise in the groundwater over-exploitation causeda 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.

Table3. Estimation of added cost of groundwater irrigation (₹ /acre) of sample farmers in Anantpur district of Andhra Pradesh

S. No	Particulars	Paddy					Maize				
		Atthe 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**

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

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 wasanalyzed and presented in Table 4.

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 formaize,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 cropsfor semi-medium farmscompared 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 wasassessed 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.

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 maze, 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(results follow Reddy, 2005). The percentage increase in the added cost of groundwater

irrigation forpaddy was higher for the medium farms (70.33 per cent), followed by semi-mediums (43.36 per cent), small farms (24.41per 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 betweenthe added cost of groundwater irrigation and farm sizes inthe case of paddy was probably because of the high gross groundwater irrigation acreage holding of medium farms in comparison to marginal farms. Inthe case of maize,exceptfor medium farms, an inverse relationship was registeredbetween 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 investmentsin repairing and reusing the pump/motor.

Conclusion

The annual cost of groundwater irrigation was higher in over-exploited areas as compared to safe areas The annual irrigation cost of groundwater in over-exploited areas for paddy (₹ 4033.38/acre) and maize (₹ 3570.26/acre),whereas in safe areas, it was only for paddy (₹ 2697.01/acre) and maize (₹ 2524.76/acre).The cost of groundwater irrigation 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 inthe case of maize. It was observed that the added cost of groundwater irrigation for paddy and maize in over-exploited areas was preponderantly greater than that of paddy and maize in safe areas. This infers thatgroundwater over-exploitation is used to createa greater impact on over-exploited areas. The marginal and small farmers are the main victims,mainly because groundwater over-exploitation raises groundwater irrigation costs. They cannot effectively utilize the irrigation source due to less gross irrigable land. Government officials, agencies and planners should come forward and ensure the rational use of groundwater through a proper planning framework to restrict groundwater exploitation, safeguard future generations and maintain the ecological balance.

(Improve the conclusion, it should meet your title)

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

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