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Research Article

OPTIMIZATION OF AVAILABLE WATER RESOURCES FOR SUSTAINABLE AGRICULTURE IN ANANTAPUR DISTRICT

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Abstract: Assessment of the irrigation potential based on soil and water resources can only be done by simultaneously assessing the irrigation water requirements, which in turn depend on the cropping pattern and climate. The model CROPWAT 8.0 was used to calculate the effective rainfall which is an important parameter for calculating crop irrigation requirement. LINGO 11 software was used for optimization of available water resources with crop water demands. The current scenarios of irrigation vs cultivated areas based on available water resources, shows highest net benefits *i.e.*, Rs. 22363 crores for the year 2017 followed by Rs. 20610 crores for the year 2014 due to higher available surface and groundwater resources compared to other years 2004, 2009, 2011. For future scenarios, the net benefits for the minimum cultivation area for highest crop water demand crops like. paddy and sunflower reduced by 75, 50 and 25 per cent were observed to be Rs. 23841 crores, 23249 and 22856 crores respectively. The available water from surface and groundwater resources is insufficient, thus crops can be chosen to put the entire region under cultivation based on available water. It was proved that these procedures aid policymakers and water resource planners in future planning and water conservation in order to optimize the utilization of available water.

Keywords: *Sustainable agriculture, CWR, Crop water demand, Water resources and Optimization*

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Introduction

Anantapur district is one of the four districts of Rayalaseema region and the largest in area among the 13 districts of Andhra Pradesh. District is economically lagging and affected by chronic drought. Anantapur district lies between 13°40' N to 15°15' N latitude and 76°50' E to 78°30' E longitude with cultivable command area, irrigation potential created and irrigation potential utilized areas of extending in 167173, 214787 and 12455 ha respectively.

For the optimum planning, the information related to irrigation water requirement of different crops, availability of groundwater and surface water, annual consumption of crop product per the need of the people of command area was required. In Anantapur district, an attempt is made to assess the water resources and research the conjunctive usage for optimal allocation of surface and groundwater resources for sustainability and maximization of net returns.

Optimization models using linear programming were formulated to get optimal cropping and water resources allocation for different agriculture, season, and crop types. There is a strong need to have more scientific studies on linear programming model to optimize water resources and to formulate cropping pattern for maximum production in many canal commands.

Material and Methods

Meteorological data of Anantapur region for 35 years were collected from Chief Planning Officer, Anantapur. The estimation of crop water requirement for different crops in Anantapur region by using CROPWAT 8.0 software. Management of irrigation water begins by knowing the quantity of water available in Anantapur district. Therefore, the basic data required to accomplish the job was the collection and analysis of data on the water supply and demand. An important aspect of conjunctive water use planning is to find the optimal area under different crops depending on canal and groundwater availability and optimal allocation of the canal and groundwater resources to keep the water table within permissible limits. As per latest review on research works conducted in many parts of the word Lingo optimization model is so much versatile in solving the linear, integer and non-linear optimization models with higher degree of accuracy.

LINGO is a simple tool for utilizing the power of linear and nonlinear optimization to formulate large problems concisely, solve them, and analyze the solution. Optimization helps you find the answer that yields the best result.

The developed model is a linear optimization model using Linear Interactive Discrete Optimizer (LINGO 11). Therefore, the objective function is a linear in parameter function that is subject to several linear constraint equations. The outcome/Objective Function of the study is determination of optimum cropping pattern for available water utilized in the area to achieve maximum net benefits.

The objective function is the maximize the net profits

$MAX= \sum NB_i * Ai$

Where,

NB_i is Net benefit of production of i^{th} crop.

Ai is area of i^{th} crop

i=1,2,3,4.....n

Constraints of the problem

Available water resources

$\sum CWD_i * A_i <=$ Water Supply;

Where,

A_i- cultivated area of each crop, ha

CWD_i – Crop water demand of each crop, mm

Water supply is Ha-m

Table-1 Crop water demand of major crops in Anantapur district

Year	Crop	*Kharif*			*Rabi*			Total cultivated area (*Kharif* + *Rabi*)	Crop Water Demand (MCM)
		Area (Ha)	CWR (mm)	Crop Water Demand (MCM)	Area (Ha)	CWR (mm)	Crop Water Demand (MCM)		
2004	Groundnut	857823	405.3	3476.8	14500	640.1	92.8	872323	3569.6
	Sunflower	56819	403.2	229.1	27228	819.9	223.2	84047	452.3
	Paddy	24335	1052.3	256.1	9240	1306.9	120.8	33575	376.8
	Jowar	4300	325.0	14.0	11871	533.5	63.3	16171	77.3
	Maize	3495	422.6	14.8	3572	786.5	28.1	7067	42.9
	Total	946772		3990.7	66411		528.2	1013183	4518.9
2009	Groundnut	510874	347.9	1777.3	19507	612.2	119.4	530381	1896.8
	Sunflower	55286	328.6	181.7				55286	181.7
	Paddy	32226	914.7	294.8	19428	1170.6	227.4	51654	522.2
	Jowar	41409	326.2	135.1	17721	512.7	90.9	59130	225.9
	Maize	8852	414.6	36.7	4615	753.1	34.8	13467	71.5
	Total	648647		2425.5	61271.0		472.5	709918	2898.0
2011	Groundnut	733960	375.1	2753.1	19876	557.8	110.9	753836	2864.0
	Sunflower	13277	364.4	48.4				13277	48.4
	Paddy	37720	961.2	362.6	10948	1174.3	128.6	48668	491.1
	Jowar	7190	260.0	18.7	7907	454.9	36.0	15097	54.7
	Maize	25447	374.4	95.3	6208	454.9	28.2	31655	123.5
	Total	817594		3278.0	44939.0		303.6	862533	3581.6
2013	Groundnut	711145	308.7	2195.3	17303	633.3	109.6	728448	2304.9
	Sunflower	8109	303.5	24.6	5911	806.9	47.7	14020	72.3
	Paddy	28114	934.1	262.6	12283	1283.0	157.6	40397	420.2
	Jowar	14486	306.1	44.3	6605	528.9	34.9	21091	79.3
	Maize	27087	448.7	121.5	7777	775.8	60.3	34864	181.9
	Total	788941		2648.4	49879.0		410.1	838820	3058.5
2017	Groundnut	402435	311.3	1252.8	20689	613.8	127.0	423124	1379.8
	Sunflower	1444	299.6	4.3	507	783.5	4.0	1951	8.3
	Paddy	12293	936.9	115.2	18621	1234.8	229.9	30914	345.1
	Jowar	18362	240.7	44.2	4549	356.5	16.2	22911	60.4
	Maize	19044	319.1	60.8	4222	752.9	31.8	23266	92.6
	Total	453578		1477.2		3741.5	408.9	453578	1886.1

Table-2 Availability of water resources and crop water demand of major crops in Anantapur district

SN	Year	Groundwater available for irrigation (MCM)	Canal water (MCM)		Total available water resources (MCM)	Total crop water demand (MCM)	Remarks
			MPR	PABR			
1	2004	1047.72	306.39	8.04	1362.15	4518.9	-3156.75 (69.9%)*
2	2009	1037.03	349.71	167.38	1554.12	2898.0	-1343.88 (46.4)*
3	2011	1007.39	256.55	193.4	1457.34	3581.6	-2124.26 (59.3%)*
4	2013	1296.42	292.23	228.6	1817.25	3058.5	-1241.25 (40.6%)*
5	2017	1429.54	265.89	263.4	1958.83	1886.1	72.73 (3.9%)**
Mean		1163.62	294.15	172.16	1629.94	3188.62	

Table-3 The cost of cultivation of the major crops in Anantapur district

Major crops	Operational cost (Rs./ha)	Fixed cost (Rs./ha)	Total cost of cultivation (Rs./ha)	Maximum crop yield (kg/ha)	Minimum support price for the year 2021 (Rs./ Kg)	Gross returns (Rs./ha)	Net benefits (Rs./ha)
Groundnut (A)	51331	19603	70934	2070	52.75	109193	38258
Sunflower (B)	20537	7998	28536	830	58.85	48846	20310
Paddy (C)	56331	34914	91245	5410	18.68	101059	9814
Jowar (D)	40634	17429	58063	2830	26.20	74146	16083
Maize (E)	47492	29792	77284	9120	18.50	168720	91436

Table-4 Current scenarios of irrigation vs cultivated areas based on available water resources in Anantapur district

Crop	Items	Year				
		2004	2009	2011	2013	2017
	Available surface and groundwater resources (ha-m)	136215	155412	145734	181725	195883
Ground nut (A)	Cultivation area (ha)	353343	415470	384149	500625	546444
Sunflower (B)		5042	5042	5042	5042	5042
Paddy (C)		16723	16723	16723	16723	16723
Jowar (D)		12530	12530	12530	12530	12530
Maize (E)		10824	10824	10824	10824	10824
	Net benefits (Rs.)	14975 crores	17352 crores	16154 crores	20610 crores	22363 crores

Table-5 Potential scenarios of irrigation vs cultivated areas based on available water resources in Anantapur district

Crop	Items	Scenarios						
	Average available surface and groundwater resources (ha-m)	100% (Scenario 1) *i.e*, 162994 ha-m	90% (Scenario 2) *i.e*, 146697 ha-m	80% (Scenario 3) *i.e*, 130395 ha-m	70% (Scenario 4) *i.e*, 114095ha-m	60% (Scenario 5) *i.e*, 97796 ha-m	50% (Scenario 6) *i.e*, 81497ha-m	40% (Scenario 7) *i.e*, 65198ha-m
Groundnut (A)	Area (ha)	440007	387266	334509	281758	229010	176263	123514.9
Sunflower (B)		5042	5042	5042	5042	5042	5042	5042.000
Paddy (C)		16723	16723	16723	16723	16723	16723	16723.00
Jowar (D)		12530	12530	12530	12530	12530	12530	12530.00
Maize (E)		10824	10824	10824	10824	10824	10824	10824.00
	Net benefits (Rs.)	18, 291 crores	16,273 crores	14, 255 crores	12,237 crores	10,219 crores	8,201 crores	6, 183 crores

Table-6 Future scenarios of irrigation vs cultivated areas based on available water resources for the year 2017

Crop	Future scenarios based on reduced cultivated area for highest crop water demand crops like., paddy and sunflower			
	Available surface and groundwater resources (195883 ha-m)	Minimum cultivation area reduced by 25%, for highest crop water demand crops *i.e*., Paddy (12542.25 ha) and Sunflower (3781.5 ha)	Minimum cultivation area reduced by 50% for highest crop water demand crops *i.e*., Paddy (8361.5 ha) and Sunflower (2521 ha)	Minimum cultivation area reduced by 75% for highest crop water demand crops *i.e*., Paddy (4180.75 ha) and Sunflower (1260.5 ha)
Groundnut (A)	Area (ha)	561066	575689	590311
Sunflower(B)		3782	2521	1261
Paddy (C)		12542	8362	4181
Jowar (D)		12530	12530	12530
Maize (E)		10824	10824	10824
	Net benefits (Rs.)	22, 856 crores	23,349 crores	23, 841 crores

Total available cultivable area:

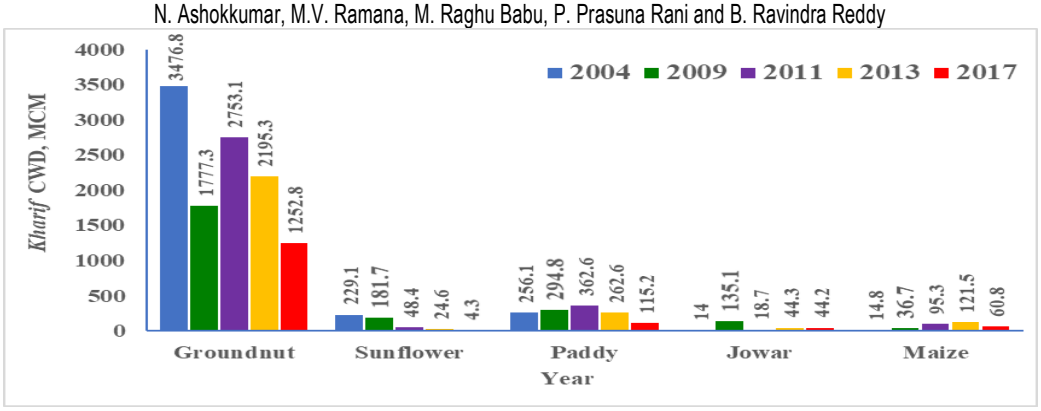
$\sum A_i <= A_{max}$;

Where, A_i- cultivated area of each crop, ha

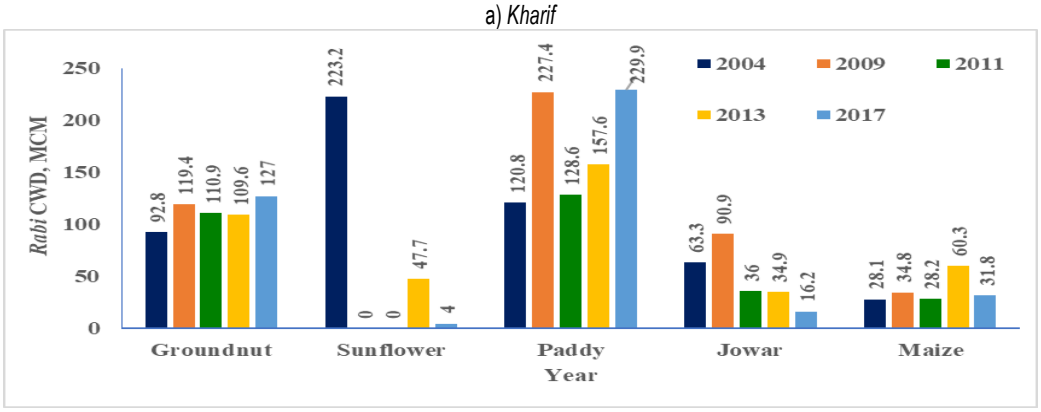
A_{max}- Maximum available cultivable area

The limits of crop cultivated area

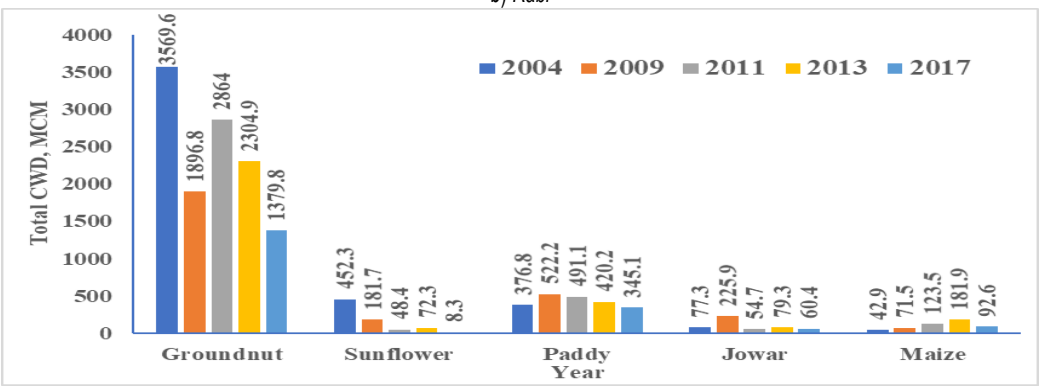
The range of the minimum and maximum cultivatable area of each crop in both *kharif* and *rabi* seasons. The current and potential scenarios of crop water demand for major crops grown in Anantapur district based on net returns of major



a) *Kharif*



b) *Rabi*



c) *Kharif+ Rabi*

Fig-1 *Crop water demand in kharif (a), rabi (b) and total kharif+ rabi (c) during 2004, 2009, 2011, 2013, 2017*

crops are calculated. For the prediction of future scenarios in the year 2018 based on autoregressive models, it is assumed to be available ground and surface water resources for the previous year 2017 *i.e.*, 195883 ha-m may be present in the future and considering the minimum cultivation area for highest crop water demand crops like, paddy and sunflower reduced by 75, 50 and 25 per cent.

Results and Discussion

The data on climate, rainfall, crop, cropping pattern and soil were provided as input in CROPWAT 8.0 model and estimations of crop water demand were presented in [Table-1]. Groundnut, sunflower, paddy, jowar, and maize had gross irrigation water requirements of 311.3, 299.6, 936.9, 240.7, 319.1 mm in the *kharif* season and 613.8, 783.5, 1234.8, 356.5, 752.9 mm in the *rabi* season in 2017. The findings support those of Roja *et al.* (2020) [1], Sreenivasa *et al.* (2020) [2], Khine (2019), Shreya *et al.* (2019)[3], Mehanuddin *et al.* (2018) [4], Ranjan and Kyle (2017) [5], Jawaharlal *et al.* (2017) [6], Laxman *et al.* (2017) [7], Ganesh *et al.* (2014) [8] who found that crop water requirements for major crops are similar.

Cultivated area of major crops for *kharif* and *rabi* seasons in Anantapur district in the year 2004, 2009, 2011, 2013 and 2017 are shown in [Fig]. The cultivation area of major crops like., groundnut, sunflower, paddy, jowar and maize in Anantapur district for *kharif* and *rabi* seasons *viz.*, 643247.4, 26987, 26937.6, 17149.4 and 16785 ha and 18375, 6729.2, 14104, 9730.6 and 5278.8 ha respectively for five years. The total cultivated area (five years) of major crops for the both *kharif* and *rabi* seasons like., groundnut, sunflower, paddy, jowar and maize in Anantapur district *viz.*, 1013183, 709918, 862533, 838820 and 453578 ha respectively. The highest and lowest cultivated area in *kharif* and *rabi* seasons for groundnut crop *viz.*, 857823, 20689 and 402435, 14500 ha respectively. Groundwater available for irrigation were taken from groundwater assessment reports for the five years 2004, 2009, 2011, 2013 and 2017. Crop water demand in *kharif*, *rabi* and total *kharif+ rabi* during 2004, 2009, 2011, 2013, 2017 are shown in [Fig-1].

The analysis for the years 2004, 2009, 2011, 2013 and 2017 were based on the groundwater assessment reports of Anantapur district [9-14]. From the [Table-2] and [Fig-2], the cumulative crop water requirement for five major crops of black soils in the Anantapur district for the years 2004, 2009, 2011, 2013 and 2017 were 4805, 3476, 3982, 3712 and 2491 respectively.

The available surface and groundwater resources in the Anantapur district for the years 2004, 2009, 2011, 2013 and 2017 were 1362.15, 1554.12, 1457.34, 1817.25 and 1958.83 MCM respectively and average available surface and groundwater resources in the Anantapur district was 1629.94 MCM. Further results indicate that the deficiency in water demand for four years *viz.*, 2004, 2007, 2011, 2013 respectively due to more cultivation area with lesser available water resources whereas surplus water demand *i.e.*, 72.73 MCM available in the year 2017 due to lesser cultivated area (*i.e.*, 453578 ha) with drought situation compared to other years. There is a need to optimize the available water resources for getting the maximum profits.

The results are consistent with those of Osama *et al*. (2017) [15], Shreedhar (2015) [16] and Banihabib *et al*. (2015) [17] for the optimization of water resources using a linear programming model and crop water productivity is also influenced by water resources availability.

The cost of cultivation of the five major crops *viz*., groundnut, sunflower, paddy, jowar and maize were represented in [Table-3].

The highest and lowest cost of cultivation *viz*., paddy (Rs.91245/ha) and sunflower (Rs.28536/ha) respectively whereas highest and lowest net benefits *viz*., maize (Rs. 91436/ha) and paddy (Rs. 9814/ha) respectively. The current and potential scenarios of irrigation potential for crops based on the average available surface and groundwater resources *i.e*., 162994 ha-m. To get the net benefits of the crops based on optimize average available water resources like., 100% (Scenario 1), 90% (Scenario 2), 80% (Scenario 3), 70% (Scenario 4), 60% (Scenario 5), 50% (Scenario 6) and 40% (Scenario 7) for the crop production [Table-4].

The linear programming model applied for the solution. Lindo 11 output files was shown in Appendix-I.

The objective function is the maximize the net profits

MAX = 38258*A + 20310*B + 9814*C + 16083*D + 91436*E;

Where,

A-Area of the groundnut crop
B-Area of the Sunflower crop
C-Area of the Paddy crop
D-Area of the Jowar crop
E-Area of the Maize crop

Constraints of the problem:

Available water resources:

0.309*A + 0.437*B + 0.949*C +0.334*D +0.441*E <= 162994;

Total available cultivable area: A + B + C + D + E <= 896166;

The limits of crop cultivated area:

A >= 20556; A <= 747837;
B >= 5042; B <= 34086;
C >= 16723; C <= 30604;
D >= 12530; D <= 13983;
E >= 3620; E <= 10824;

The current scenarios of irrigation vs cultivated areas based on available water resources, shows highest net benefits *i.e*., Rs. 22363 crores for the year 2017 followed by Rs. 20610 crores for the year 2014 due to higher available surface and groundwater resources compared to other years 2004, 2009, 2011 [Table-4]. For higher available surface and groundwater resources may be grown highest net benefits crops. The potential scenarios of irrigation vs cultivated areas based on available water resources, highest net benefits *i.e*., Rs.18,291 crores got Scenario 1 as compared to other 6 Scenarios [Table-5].

From the prediction of future scenarios, the net benefits for the minimum cultivation area for highest crop water demand crops like. paddy and sunflower reduced by 75, 50 and 25 per cent were observed to be Rs. 23841 crores, 23249 and 22856 crores respectively. Based on highest net benefits, the optimum values of irrigation potential areas for the major crops like., groundnut, sunflower, paddy, jowar and wheat crops were 590311.4, 1260.5, 4180.75, 12530 and 10824 ha respectively [Table-6]. According to the findings, reducing the cultivated area of the highest crop water demand crops may provide the highest net benefits. Policymakers and water resource planners will benefit from these studies.

Conclusion

The current scenarios of irrigation vs cultivated areas based on available water resources, shows highest net benefits *i.e*., Rs. 22363 crores for the year 2017 followed by Rs. 20610 crores for the year 2014 due to higher available surface and groundwater resources compared to other years 2004, 2009, 2011. For future scenarios, the net benefits for the minimum cultivation area for highest crop water demand crops like. paddy and sunflower reduced by 75, 50 and 25 per cent were observed to be Rs. 23841 crores, 23249 and 22856 crores respectively

The available water from surface and groundwater resources is insufficient, thus crops can be chosen to put the entire region under cultivation based on available water. It was proved that these procedures aid policymakers and water resource planners in future planning and water conservation in order to optimize the utilization of available water.

Application of research: Assessment of Irrigation potential and optimization of water resources in Anantapur district

Research Category: Crop water requirement

Abbreviations: CWD-Crop Water Demand, MCM-Million Cubic Metre
CROPWAT-Crop Water and Irrigation Requirements Programme

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University: Acharya N. G. Ranga Agricultural University, Lam, 522034, India
Research project name or number: Research station study

Author Contributions: All authors equally contributed

Author statement: All authors read, reviewed, agreed and approved the final manuscript. Note-All authors agreed that- Written informed consent was obtained from all participants prior to publish / enrolment

Study area / Sample Collection: Anantapur

Cultivar / Variety / Breed name: Nil

Conflict of Interest: None declared

Ethical approval: This article does not contain any studies with human participants or animals performed by any of the authors.
Ethical Committee Approval Number: Nil

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