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A Linear Programming Approach to Sustain Groundwater by Optimization of Cropping Plan

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ABSTRACT

Groundwater is the predominant source of irrigation in several places where there are less surface water sources like river, streams, dams etc., Groundwater is available at the ease of disposal, which paves way for its continuous pumping. This continuous pumping of groundwater in some places exceeds annual quantity of groundwater recharge and the region is termed as over exploited region. Coimbatore district is one among them, where groundwater is extracted beyond its recharge and the district has 26 over-exploited firkas among the total 38 firkas. Hence Coimbatore district in the Western Agro-climatic zone of Tamil Nadu is purposively selected for this study. The objective of the study is to calculate the quantity of water available from different sources for irrigation, to compute the water requirements of different crops and to optimise cropping area for sustaining groundwater with increased profits. The study was based on secondary data with the application of CROPWAT software to compute crop water requirements and Linear programming for sustainable groundwater use in the study area. Total water available for irrigation from different sources and potential irrigable area by the sources were calculated. As area to be irrigated by dams and tanks reduces, there arises the need for excess groundwater causing overexploited regions. Hence optimised cropping area to sustain groundwater was computed. The results were to reduce the area under paddy and sugarcane and to increase the areas of less water consuming crops like pulses, millets, groundnut, maize, etc. The study concludes that the gap between potential irrigable area by dams and tanks and actual area irrigated by them to be reduced, bridged and optimized cropping plan may be followed to sustain groundwater.

Key words: *Groundwater, Optimisation, Cropping area, Sustainability, Irrigation.*

Introduction

Water is one of the most essential, important natural resources for humans, plants, animals, etc. According to Peter. H. Gleick out of 1,338,000,000 km^3 of water available on earth, only 35,029,000 km^3 (2.53 of the total water available) is fresh. In this 10,530,000 km^3 volume of water is found below the earth surface as groundwater, the second largest fresh water source which is 30.01 percent of the total fresh water available whereas 68.7 per cent is locked in the form of snow, icecaps and glaciers. Hence groundwater is the top most fresh water source for use. Even though such importance is laid on groundwater, it is only 0.76 per cent of the total water availability.

Groundwater is the predominant source of irriga-

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tion in several places where there are less surface water sources like river, streams, dams etc,. 40 per cent of the world's irrigation is met by groundwater and in India it is about 50 per cent (Dhawan, 2017). Agriculture alone consumes 80 per cent of the worlds water resource (Kumari *et al.,* 2017a) and in India, agriculture is the topmost exploiter of Groundwater with 92 per cent followed by industrial and domestic sector.

Groundwater irrigation has gained momentum from 1965 in India, after the introduction of tube well technology which increased the area irrigated by groundwater from 29 % in 1951 to 63 % in the year 2014 (Jain *et al*., 2019). Groundwater is available at the ease of disposal, which paves way for its continuous pumping. This continuous pumping of groundwater in some places exceeds annual quantity of groundwater recharge by various sources and it is termed as over exploited region. This continuous pumping may not be uniform in all the places causes unstable groundwater level in certain places.

In Tamil Nadu, out of 1166 firkas, 462 firkas is categorised under over-exploited region which is 40 per cent to the total number of firkas. Since agriculture is the predominant user of groundwater, optimising the cropping area is essential to make groundwater sustainable. With this background, this study was done with following objectives:

- To estimate the water availability in the study area
- To estimate the total water requirement for cropping in the study area
- To optimise cropping area in the study area to maximise profits

Methodology

Area selection

Coimbatore district in the Western Agroclimatic Zone of Tamil Nadu is purposively selected for the study. In this district, based on the groundwater resources assessment, out of 38 firkas, 26 firkas come under overexploited category which is 68 per cent to the total and is greater than the state's percentage of over-exploited firkas; five firkas under critical and six firkas under semi critical category. Annual extractable groundwater is 43907.51 ha.m. But, in actual 44737.0 ha. m water is extracted for irrigation alone, whereas for industrial and domestic consumption, it is about 483.01 ha.m and 4415.54 ha.m respectively. Hence total annual extraction is 49635.60 ha.m and it is about 113.05 per cent of the total annual groundwater recharge. As of above, the district selected is suitable to this study.

Data collection

Required secondary data like crop area, yield, production and groundwater data were collected from different sources like Coimbatore District G- returns, Statistical Handbook of Coimbatore District, report on Dynamic Ground Water Resources Assessment of Tamil Nadu – 2020. In addition, Crop coefficient data from FAO website, data on Cost of cultivation of different crops, Minimum Support Prices and Farm Harvest Prices of major crops from Commission on Agricultural Costs and Prices were also used for this study.

Tools of analysis

Water availability

Data of groundwater availability for agriculture in the study area were taken from the report on Dynamic Ground Water Resources Assessment of Tamilnadu – 2020. Surface water availability calculated from Irrigation profile of Coimbatore district. It is the sum of total capacity of dams and tanks used for irrigation. Data on surface water available for agriculture is calculated as the balance water available after deducting the data on demands of households and industry. Transmission loss and other losses of water in canal was also taken into account as 20 percent (Mohammadi, 2019; Clemente, 2013). Annual extractable groundwater is taken as total groundwater available. Water use for industry and house hold are detected from the total and 10 percent may be left for sustaining future use. Quantity of water left after meeting those demands are meant for irrigation purpose.

CROPWAT

Crop water requirement for each crop in the study area were calculated by CROPWAT 8.0 software developed by FAO by which the total water demand in the study area can be calculated. The FAO CROPWAT program includes reference evapotranspiration and crop water requirement calculations under various soil, crop and climatic characteristics.

Reference evapotranspiraton (ET_0), was calculated by using Penman–Monteith method by using latitude, longitude, altitude, maximum and minimum temperature, relative humidity, windspeed, sunshine hour of the available meteorological station in the required area. Crop evapotranspiration (ET_C) of a particular crop was calculated by the formula

$ET_C = K_C * ET_0$

where K_C is the crop coefficient of that particular crop. K_C values for initial, mid and late growth stages of annual and seasonal crops are used and for perennial crops, same K_C is used for the whole year (Surendran *et al.,* 2015). It also includes soil characteristics, effective rainfall and crop details for calculation of crop evapotranspiration. Thus, crop water requirement (mm) is calculated by subtracting crop evapotranspiration from effective rainfall.

Thus, water requirement (ha.mm) of a particular crop is calculated by multiplying crop water requirement (calculated by CROPWAT) with total cultivated area (ha) of that crop in the study area. In this way water requirement is calculated for different crops cultivated in the study area. By summing, the water requirement of all the crops in the study area we get the total water requirement (ha.m) of the study area for agriculture.

Linear Programming

Linear programming is a method of determining a profit maximizing combination of farm enterprises that is feasible with respect to a set of fixed farm constraints. In this study Linear Programming is used for sustaining groundwater use.

Objective function - Maximization of Profit

Maximize $Z = \sum_{i=1}^{n} P_i * A_i$, (i = 1,2,….. n)

where P is the profit from i^{th} crop (in Rs./ha), A is the Area of the i^{th} crop (in ha) and n is the number of crops. (Kumari *et al.*, 2017b; Gautam *et al.*, 2020)

Model constraints

i) Land area constraint

Land area constraint is one of the important constraints. The sum of land optimized under all the crops should not be greater than the total cultivable area. It is given as follows

$$\sum_{i=1}^{n} A_i \leq TA$$

Where A is the area of individual crops from 1 to n and TA is the total cultivable area (ha)

ii) Water availability constraints

Total quantity of water required for irrigation of all the crops in the study area should be less than or equal to total available water (surface and ground water) after meeting all the demands except agriculture including households, industry, transmission losses and others in the study area. It is given as

$$\sum_{i=1}^{n} W_i * A_i \leq TWA$$

Where $W_i * A_i$ is the water required for ith crop and TWA is the total water availability (in ha.m) in the study area.

iii) Crop Area constraint

To meet the local requirements and to prevent the prevailing cropping practices in the study area, upper and lower limits was fixed by considering the area of all cultivated crops for the past ten years in the study area

$A_i^{min} \leq A_i^{opt} \leq A_i^{max}$

where, A_i^{min} and A_i^{max} is the minimal and maximal area that the ith crop can be cultivated to that extent and A_i^{opt} is the optimized area.

iv) Non negativity constraint

$A_i \geq 0$; $W_i \geq 0$

Area and water requirement of ith crop will not be negative and should be greater than 0 (Singh *et al.,* 2020; Singh, 2016).

Results and Discussions

Table 1 shows the quantity of water available from different sources. The total surface water availability for all sectors viz., agriculture, industry and households are found to be almost double in volume as that of groundwater availability. Of the total water availability for irrigation, surface water availability is almost 60 percent, groundwater availability is 40 percent. Water available for irrigation is calculated by reducing the water demand for households, industry and losses that occurs during transmission in canals from the total water availability. 20 per cent of water is taken as losses during transmission through canals in case of tanks and dams.

The Table 2 shows the area irrigated from different sources. It could be seen that groundwater is the predominant source for irrigation in Coimbatore district i.e., wells. It irrigates 85.66 percent of the total irrigated area whereas dams and reservoirs irrigate only 14.16 percent. Though the area that can be

Table 1. Source wise Water Availability in Coimbatore district, 2020 -2021

Source	No	Total water available (ha.m)	Water available for irrigation (ha.m)
Dams and reservoirs	27	80870	47127.2 (53.77)
Ponds/ Tanks	48	6770	5416 (6.18)
Tubewell/ Borewell	20540	43907.51	35108.06 (40.05)
Open well	48880		
	Total		87651.26 (100.00)

Note: Calculated and compiled by author based on the data available in Irrigation profile and G-returns of Coimbatore district, 2020 – 2021.

Table 2. Source wise Area irrigated in Coimbatore district, 2020 -2021

Source	Potential irrigable area (ha)	Actual area irrigated (ha)	% of actual area irrigated to potential area
Dams and reservoirs	44080	16873.76 (14.16)	38.28
Ponds/ Tanks	5276	202.79 (0.17)	3.84
Tubewell/ Borewell	NA	34343.1 (28.83)	-
Open well		67722.58 (56.84)	-
	Total	119142.23 (100.00)	-

Note: Calculated and compiled by author based on the data available in Irrigation profile and G-returns of Coimbatore district, 2020 – 2021.
NA – Not available

irrigated by dams, reservoirs is more, the actual area irrigated is low. The same is the case for tank irrigation also. Table 2 shows that the area that can be irrigated by dams and tanks are 44080 ha and 5276 ha respectively but the actual area irrigated was 16873.76 ha and 202.79 ha respectively, which was only 38.28 per cent to the total area that can be irrigated by dams and only 3.84 per cent in case of tanks. This may be due to urbanization, several encroachments on the banks of channels that causes reduced water supply. High availability of wells at the farm level makes groundwater at the ease of disposal. Also, it was found that no demand was made from farmers in the study area to release surface water through channels. Farmers started to use their own wells at the farm level for irrigation to their own desired level. This causes increased use of groundwater and excess depletion of groundwater. The study found that this might be the reason for increase in the numbers of overexploited and critical firkas in Coimbatore region. As more than 80 percent area under irrigation is by groundwater, crop area optimisation is essential which is done in this study after estimation of crop water requirement, for accuracy.

Table 3. Crop Water requirements in Coimbatore district (in mm)

Crops	Water requirement
Paddy	636.5
Maize	251.1
Millets	213.3
Pulses	204.1
Cotton	347.8
Sugarcane	1388.6
Groundnut	166.1
Coconut	801.33
Banana	914
Citrus	764.4
Mango	1007.3
Grapes	405.9
Melons	437.39
Vegetables	259.7
Arecanut	701.3
Cocoa	796.3
Fodder crops	199.4

Table 3 shows the water requirements of different crops in Coimbatore district calculated using FAO CROPWAT 8.0 software. The results revealed that Sugarcane alone requires more than 1300 mm of water and is the major water consuming crop in the study area. It is followed by Mango, Banana, Coconut, Cocoa and Arecanut. Since sugarcane and Banana life cycle ranges from 10 – 12 months, it requires water for the entire year and the remaining few crops also requires water for the whole year as they are perennial in nature. Annual or seasonal crops like paddy requires 636.5 mm of water. Pulses, Maize, millets and groundnut requires around 150 to 250 mm of water.

The results of the Table 4, show the area of different crops in the existing plan and optimized plan. Optimised cropping plan will reduce groundwater use by 9628. 94 ha. m and increase profit by 6.82 %. Since more than 80 percent of the cropping followed in the study area is perennial crops, which cannot be replaced and hence that area not considered for optimisation. Even in the 20 per cent, the nonperennial crop area considered, as surface water supply for irrigation is very poor (as discussed in Table 2), and as crops like paddy, sugarcane is supplied with more groundwater and therefore that area may be reduced. On the other hand, as crops like millets, pulses, maize, cotton consumes less water and that area is to be increased.

Conclusion

The study reveals that there exists mismatch between the potential irrigable area through dams, tanks and the actual area irrigated through dams and tanks. This might be due to urbanization and ease availability of wells at the farm level. This mismatch causes excess exploitation of groundwater resources and hence optimization of cropping plan arises inorder to reduce groundwater usage. Thus, optimised cropping plan will reduce groundwater use by 9628. 94 ha. m and increase profit by 6.82 %. Crops like paddy, sugarcane consumes much water and that area is to be reduced. On the other hand, crops like millets, pulses, maize, cotton consumes less water and that area is to be increased. The study concludes by recommending the following policy suggestions:

On comparing Table 1 and 2, it is found that dams and tanks are the source of major water supply but the area irrigated by dams and tanks was very low, the gap has to be bridged by proper irrigation through channels, so that potential irrigable area through dams and tanks equals actual area that can be irrigated through dams and tanks.

Since major area of the cropping in the study are perennial in nature, water is required throughout the year. This made farmers to have wells of their own because canal water availability is seasonal. Groundwater is at ease of disposal and also there arises no request to release water through channels from dams and tanks. Hence, Groundwater irrigation has to be limited in areas where channels are

Table 4. Comparison of Optimised crop area plan with existing crop area plan

Crop	Existing area (in ha)	Optimised area (in ha)
Rice	998.43	267
Maize	2380.66	3013
Green gram	9.1	47
Black gram	2.53	32
Red gram	2.42	44
Cotton	160.035	146.32
Sugarcane	392.588	143
Groundnut	159.54	403
Millets	598.275	712
Coconut	88467.14	88467.14
Perennial fruit trees	8683.116	8683.116
Arecanut	2280.933	2280.933
Cocoa	746.745	746.745
Vegetables	10782.82	10782.82
Fodder crops	1034.923	1034.923
Others	2442.98	2339.238
Total	119142.23	119142.23
Quantity of groundwater use reduced (ha. m)	**9628.94**	
Increased profit percentage	**6.82**	

available for irrigation and conjunctive use of groundwater and surface water can be followed to reduce groundwater usage.

In order to improve groundwater level, optimal cropping plan and proper irrigation by each source should be followed. This will help in reducing the use of groundwater from 44737.0 ha.m to 35108.06 ha.m for agriculture and thus sustainability in groundwater resources can be achieved in future, hence reduction in number of over exploited firkas.

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