Int.J.Curr.Microbiol.App.Sci (2020) *9*(12): 446-455

International Journal of Current Microbiology and Applied Sciences
ISSN: 2319-7706 **Volume 9 Number 12 (2020)**
Journal homepage: http://www.ijcmas.com

Original Research Article https://doi.org/10.20546/ijcmas.2020.912.055

Optimization of Water Resources for Maximizing Crop Production in the Coastal Areas of Odisha

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A B S T R A C T

Keywords

Linear Programming, Maximization, Optimal cropping, Tora, Optimization

Article Info

Accepted:
07 November 2020
Available Online:
10 December 2020

The study area, Kendrapara district, is located between 20° 21’ N to 20° 47’ N latitude and 86° 14’E to87° 03’ E longitude. The length of Coastline of Kendrapara district is 48 kilometer from Dhamra Muhan to Batighar. The area of district is 2,644km^2.Kendrapara situated in the delta formed by Bramhani, Baitarini and branch rivers of Mahanadi. For the purpose of objective function to maximizing production paddy and jute is taken as major field crop in khraif season and paddy, wheat, groundnut, mustard, sesamum, castor blackgram, greengram, horsegram, sugarcane and potato was taken as major field crop in rabi season. The existing water resource of the study area were worked out for rabi and kharif season based on data collected from District Irrigation Division Kendrapara, CWC and CGWB Bhubaneswar. Total Surface water and Groundwater availability during rabi and kharif season 396 MCM and 1437.48 MCM respectively. An optimization model for maximizing the crop production under various formulated constraints was performed by Tora optimization system window version 2. Total water resources of the study area were 1833.49MCM. The study of optimization model shows that area of paddy was found 90,000 hectare and area of jute was found 44460 hectare that shows area of paddy get reduced up to 38,000 hectare and area of jute was increased up to 42,000 hectare. Optimal cropping pattern shows net benefit of Rs. 243.52 Crore. Similarly in rabi season area of ground nut increased up to 1580.12 hectare and area of sesamum, horse gram and sugarcane was reduced up to zero. Optimal cropping pattern in rabi season gives return of Rs. 201.58 Crore The eliminated crops by the model may be obtained as per demand by formulating new constraints.

Introduction

As the demand of water is increasing continuously in India due to growth of population and industrialization, to fulfill those requirement we have to plan a better management and utilization of water resources to secure our future because the availability of good quality of water resources is varying and limited. Mainly two types of water resources are present in nature surface water and ground water in between ground water is important one. Groundwater is a unique source of freshwater as it is free from bacteria and virus which causes infections and harmful diseases. It is also free from suspended contaminants, so that groundwater has most important preferred source of water for domestic and agriculture uses. In coastal areas of Odisha paddy cultivation in large scale and shortage of sufficient canal running days causes significantly changes in quality and quantity of groundwater. Excessive and continuous tapping of groundwater for paddy cultivation results the lowering of groundwater table and thus sea water intrusion take place into the coastal aquifer. So we have to short out the problems of land and water management plan and formulate suitable constraints for optimal cropping pattern. To ensure maximization of production and to get more benefit a farmer needs to follow optimal cropping pattern and efficient land and water management techniques before each irrigation requirement of seasonal crop. As population and economy of India is growing fast, the demand of water is also increasing continuously. Water is the primary source of all activities and to ensure our better future demand and supply of water should be fulfilled. To satisfy food and fodder requirement over country it is important to optimize the available land and water resources to achieving maximum production as well as returns. Linear programming is an effective tool in optimization operation thus it may be used as new technique by formulating objective function followed by constraints.

Mtanga and Marino concluded that the information provided by the inter-seasonal model is used in an area allocation model that allocates acreage available for planting among the crops for unlimited and limited water supplies[1]. Frizzone *et al.,* developed a separable linear programming model, considering a set of technical factors which may influence the profit of irrigation project. The model presents objective functions that maximize the net income and specifies the range of water availability [2]. Haouari and Aziaiez proposed mathematical programming model for optimal cropping patterns under water deficit in dry regions[3]. Sethi *et al.,* for effective planning and groundwater management two models have been developed, groundwater balance model and optimal cropping and ground water management model to determine optimum cropping and groundwater allocation [4]. Sen and Ambast studied a soil water balance model for rainfed rice cultivation in humid, deltaic lowlands. A simple linear programming model was used to propose an optimal land allocation for dry season (winter and summer)[5]. Rao *et al.,* developed a regional conjunctive model for a near-real deltaic acquifer ystem, irrigated from a diversion system, with some reference to hydrogeo-climatic conditions prevalent in the east coastal deltas of India. The combined simulation-optimization model proposed in this study is solved as a nonlinear, non-convex combinatorial problem using a simulated annealing algorithm and an existing sharp interface model[6]. Vedula *et al.*, proposed the aquifer response in modelled through the use of a finite element groundwater model[7]. Sethi *et al.*, Concluded that intensive rice cultivation results extensive pumping of groundwater by a network of shallow, mini-deep, and deep tube wells. DLP model and CCLP model were developed to allocate land and water resources optimally [8]. Sheng and Xiuling concluded that in autumn and winter river water is diverted to and stored in deep ditches and canals to recharge groundwater and to promote the freshening of saline groundwater. In this way, thorough the conjunctive use of surface and groundwater, the balance between exploitation and supplementing of water resources has been maintained[9]. Sethi and Panda developed decision support system for optimum cropping and water resources management. A knowledge based DSS helps to decide cropping pattern and water resources allocation of a coastal river basin of India [10].

Materials and Methods

In this part of research total available water resource (surface water and groundwater) was calculated after that total water demand (seasonal crop water, livestock and domestic) was calculated. Formulation of objective function was formulated in terms of net return. Various land and water constraints were formulated. Location map of study area is shown in figure 1.

Seasonal water requirement of crops

Hargreaves and Samani (1985) method of estimating reference evapotranspiration (ET_0) was adopted in this study. Since Blaney-Criddle method is not suitable for monthly estimates, only Hargreaves method is selected in this study. Since solar radiation data are not frequently available, Hergreaves and Samani temperature based method was found to be suitable. This method estimate ET_0 from extra terrestrial radiation and mean monthly maximum and minimum temperatures as follows (Table 3):

$$ET_0 = 0.0023 R_a \sqrt{T_{max} - T_{min}} \left(T_{avg} + 17.8\right) \quad \dots 1.$$

Where,

ET_0 = Daily reference evapotranspiration (mm/day)

T_{max} = Maximum temperature (°C)
T_{min} = Minimum temperature (°C)
T_{avg} = Average temperature (°C)
R_a= Extra terrestrial radiation (MJ/m^2/day)

The total requirement of water for the study area may be calculated by multiplying seasonal crop water need of crops to total area in which crops are grown. The value of crop coefficients for different crops may be calculated using Food and Agriculture paper no.56 under similar climatic condition at initial, crop development, mid season and late season stages. Thus crop evapotranspiration is calculated by using relationship between Reference crop evapotranspiration and crop coefficient as follows

$$K_c = \frac{ET_C}{ET_0} \quad \dots 2.$$

Where,

K_C = Crop coefficient
ET_C= Crop evapotranspiration (mm/day)
ET_0=Reference-evapotranspiration (mm/day)

Domestic water demand

From the population Figurers of 2011 census the present population and projected population for 2020 was estimated considering the prevailing growth rate of 12.5%.

The domestic water demand was estimated considering 80 liters in rural and 120 liters of consumption per person per day in urban area basis.

Livestock water demand

As no specific water availability facility is available for livestock population the total demand was taken as the potential to be created for meeting out of the water needs of the livestock.

Water budget

Water budget is a necessary tool to estimate the gap between demand and availability of water resources from different sources. As already mentioned the water availability in the district is sufficient to meet the demand but due to many factors like water logging, salinity ingression the total cropped area is low especially during *rabi* and *summer* season.

Existing land use pattern of study area

The study area comes under Kendrapara Irrigation Division. The geographical area of the district is 2, 64,000 ha out of which 1, 52, 000 ha comes under cultivated area. The net sown area is 1, 35,000 ha and gross cropped area is 2, 36, 000 ha. 10% (25, 000 ha) area of district was covered by forest. The area put to non-agriculture use as settlement and many other uses is 49, 000 hectare which is 19 % of the total area.

Optimization of water resources

Water resources optimization models are multiple crop model in which functions was formulated in linear programming. The method used for solving linear programming problems is simplex method.

In optimization we deals with limited quantity of land and water resources and to get optimal allocation of land water resources linear programming is the best tool. In this study our objective function is to maximize the net profit of crops annually. Irrigation cost is not considered in this study.

The present study deals with optimal cropping pattern in which seasonal cropping pattern are decided in both *rabi* and *kharif* season according to available land and water resources. Formulated maximization function was achieved looking to their formulated linear constraint like available surface water, groundwater, area available for cultivation and various non-negative constraints.

Objective function

Under the study, to optimize the resources firstly the data about the net return of different crops and available land and water resources in different seasons are collected. The objective function is to maximize the net returns. Land used pattern data was collected from the Kendrapara district agriculture statistics published by district Headquarter, State Water Resources Department, Kendrapara. It is evident from the collected data as given in Table 7 paddy and green gram are the main crop of the study area.

Area covered by paddy is 98% of cultivable in *kharif* season where as green gram and black gram covers 82% of cultivable land in *rabi* season.

Formulation of model is to maximize net returns with respect to allocation of allocation of available area between crops in *rabi* and *kharif* season. Formulation of model is given below.

Objective function

$$\text{Max } Z = \sum_{i=1}^{n} P_i A_i \qquad i = 1,2,3,4 \ldots \ldots n$$

Where,

Z = Total production from all the crops (quintal)

n = Number of crops.
P_i = Profit from i^{th} crop (Rs./ha)
A_i = Crop area under i^{th}crop (ha)

Objective function is formulated based on linear and non negative constraint. Various linear constraints are as follows:

Constraints on available water

$$\sum_{i=1}^{n} W_i A_i \leq W_T \qquad i = 1,2,3 \ldots \ldots n$$

Where,

W_i= Crop water requirement of i^{th} crop(cm)
W_T= Total available water (ha-cm)

Constraints on seasonal available land area

$$\sum_{i=1}^{n} A_i \leq A_K \qquad i = 1,2,3 \ldots\ldots\ldots n$$

Where,

A_K = Cultivable area within the season (ha)
i=1-13 for paddy, jute, *rabi* paddy, mustard, groundnut, wheat, sesamum, green gram, black gram, sugarcane, castor, potato, horsegram

Constraints on food requirement

$$\sum_{i=1}^{n} Y_i A_i \leq F_J \quad i = 1,2,3 \ldots \ldots n$$

Where,

Y_i = Yield of i^{th} crop in (quintal/ha)
F_J= Food requirement of i^{th} crop (quintal)
i=4, J=4, and i=2, J=2 for wheat and rice crop.

Constraints on crop area

$E_i \leq X_i \leq M_i$ i = 1,2,3…..n

Where,

E_i= Existing area under i^{th} crop (ha)
M_i= Maximum area which may be kept under cultivation of i^{th} crop (ha)

X_i=Actual area of crop that should be cultivated.
i = 13 for paddy, jute, *rabi* paddy, mustard, groundnut, wheat, sesamum, green gram, black gram, sugarcane, castor, potato, horsegram.

Non-negativity constraints

$A_i \geq 0$ i = 1, 2, 3……n

Where,

A_i = Area of crop under i^{th}crop (ha)
i=1–13 for paddy, jute, *rabi* paddy, mustard, groundnut, wheat, sesamum, green gram, black gram, sugarcane, castor, potato, horse gram.

Results and Discussion

Seasonal crop water requirement is calculated for each crop for the study area and total seasonal water requirement is calculated (Table 7). During *khrif* season, seasonal water requirement is 136.27MCM and during *Rabi* season, seasonal water requirement is 48.12MCM. Hence total water requirement over a year is 184.39MCM (Table 4). Present requirement are worked out to be 7.927561MCM. On finding the demand and availability, the gap in the district for the present level is worked out. The present demand for the district is estimated 237.48 MCM (Table 4) respectively indicating a gap of 1596.71 for the present. Hence surplus water is available. Total surface water available in both *rabi* and *kharif* season is calculated based on collected data. The district has available surface water 1727.399 MCM. For measuring available groundwater potential total number of open well, deep tube well and shallow tube well and their potential under Kendrapara was estimated in both *rabi* and *kharif* seasons. Total available ground water potential during study period was calculated as 110MCM.The present demand for the district was found to be 237.48MCM respectively, indicating surplus of 1596.71 MCM of water for the present situation.

An optimization model for maximize the crop production under various formulated constraints was performed by Tora optimization system window version 2. Total water resources of the study area were 1833.49MCM (Table 1 and Table 2).

Table1. Availability of surface water

S.No.	Sources	Area(ha)				Available water (BCM)		
		Kharif	Rabi	Summer	Total	Kharif	Rabi	Total
1.	Canal (major and medium irrigation)	46727	0	0	46727	0.75	0.00	0.75
2.	Minor irrigation tanks	9657	9657	0	19314	0.15	0.10	0.26
3.	Lift irrigation system	25252	19672	0	44924	0.40	0.21	0.61
4.	Rain water harvesting/ Community tanks	34	34	0	68	0.00	0.00	0.00
5.	Treated effluent from STP	0	0	0	0	0.00	0.00	0.00
6.	Untreated effluent	0	0	0	0	0.00	0.00	0.00
7.	Creek irrigation system	4177	4177	0	8354	0.07	0.04	0.11
	Total	85847	33540	0	119387	1.37	0.35	1.73

Source: District irrigation division, Kendrapara

Table.2 Availability of groundwater

S.No.	Sources	Area (ha)				Available water (BCM)		
		Kharif	Rabi	Summer	Total	Kharif	Rabi	Total
1.	Open well	0	0	0	0.00	0.00	0.00	0.00
2.	Deep tube well	933	933	0	1866.00	0.01	0.01	0.02
3.	Medium tube well	0	0	0	0.00	0.00	0.00	0.00
4.	Shallow tube well	3063	3063	0	6126.00	0.05	0.03	0.08
	Total	3996	3996	0	7992.00	0.06	0.04	0.11

Source: District irrigation division, Kendrapara

Table.3 Monthly evapotranspiration of the study area

Month	Temperature(°C)				Ra (MJ/m²/day)	ET_0 (mm/day)	ET_0 (mm/month)
	T_{max}	T_{min}	T_{max}-T_{min}	T_{avg}			
Jan	29.4	11.2	18.2	20.3	15.876	5.94	2.07
Feb	32.3	18.2	14.1	25.25	18.432	6.85	2.87
March	33	18.4	14.6	25.7	20.304	7.76	3.45
April	37.7	24.8	12.9	31.25	22.212	9.00	4.63
May	36.6	23.5	13.1	30.05	21.456	8.55	4.23
June	35	23.3	11.7	29.15	15.804	5.84	2.44
July	27.3	24.6	2.7	25.95	14.112	2.33	0.87
Aug	33.8	24.1	9.7	28.95	14.112	4.73	1.87
Sept	33.4	24.4	9	28.9	14.58	4.70	1.88
Oct	34.6	23.7	10.9	29.15	15.84	5.65	2.36
Nov	32.6	17.8	14.8	25.2	15.408	5.86	2.25
Dec	30.6	13.6	17	22.1	15.372	5.82	2.09

Table.4 Water budget for the blocks of the study area

Name of the Blocks	Available water (BCM)		Total available water (BCM)	Total water demand (BCM)	Water Gap(BCM)
	Surface water	Groundwater			
Kendrapara	0.307	0.009	0.315	0.116	-0.199
Derabisi	0.207	0.038	0.245	0.102	-0.143
Marsaghai	0.146	0.002	0.148	0.079	-0.069
Mohakalpara	0.033	0.001	0.035	0.171	0.137
Garadpur	0.03	0.014	0.044	0.066	0.021
Pattamundai	0.028	0.001	0.029	0.096	0.067
Aul	0.061	0.002	0.063	0.084	0.021
Rajkanika	0.054	0.001	0.055	0.141	0.086
Rajnagar	0.054	0.001	0.055	0.142	0.086
Total	0.921	0.069	0.99	0.997	0.007

Table.5 Land Allocation of different crops and maximum benefit in *kharif* season

Crops	Existing land allocation(ha)	Optimal land allocation(ha)	Maximum Benefit (Crore Rs.)
Paddy	132000	90000	243.52
Jute	2460	44460	

Table.6 Land Allocation of different crops and maximum benefit in *rabi* season

Crops	Existing land allocation(ha)	Optimal land allocation(ha)	Maximum benefit (Crore Rs.)
Paddy	2800	2800	201.57
Musturd	1880	1800	
Groundnut	10170	1580.12	
Wheat	320	320	
Sesamum	260	0	
Green gram	35930	35930	
Black gram	38700	38700	
Sugarcane	470	0	
Castor	20	20	
Potato	470	470	
Horse gram	1900	0	

Table.7 Total seasonal water requirement of different crops

Season	Total (Day)	ET_c (mm)	CWR (mm)	Area '000hac.	Vol. of water (MCM)
kharif					
Paddy	120	815	1018.75	132	134.47
Jute	150	587	733.75	2.46	1.80
Rabi					
Paddy	130	796	995	2.8	2.79
Musturd	90	422	527.5	1.88	0.99
Groundnut	125	496	620	10.17	6.31
Wheat	120	645	806.25	0.32	0.26
Seasmum	100	374	467.5	0.26	0.12
Greengram	75	258	322.5	35.93	11.59
Horsegram	110	495	618.75	1.9	1.17
Blackgram	75	469	586.25	38.7	22.69
Sugarcane	330	1960	2450	0.47	1.15
Castor	180	905	1131.25	.02	0.23
Potato	125	564	705	1.17	0.82
			Total	228.26	184.39

Fig.1 Location of study area

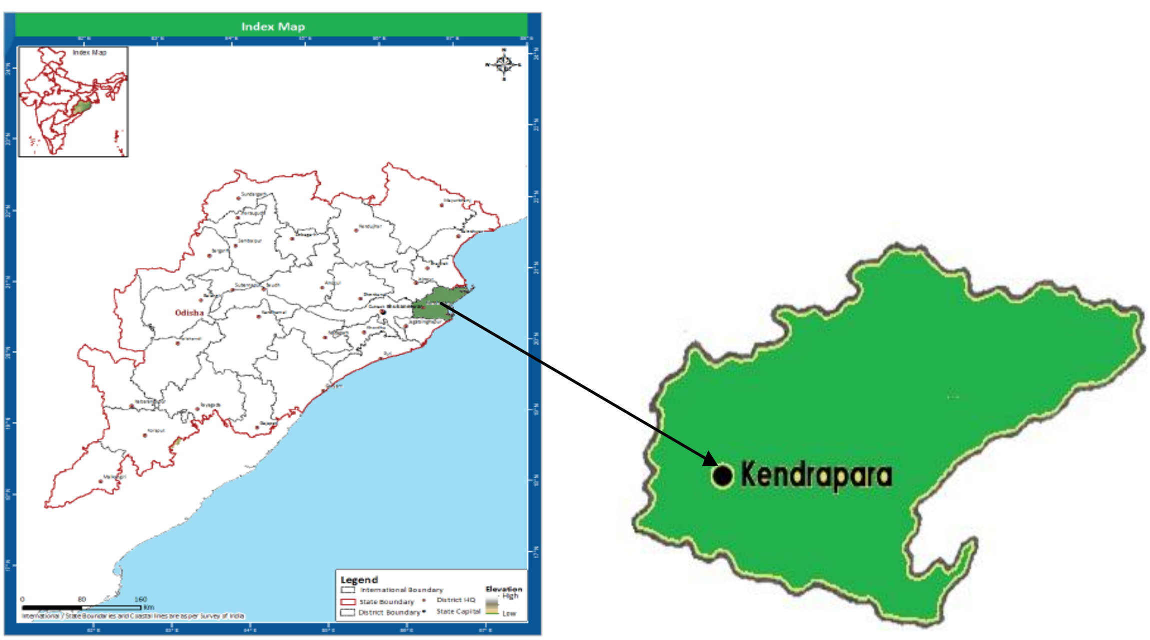
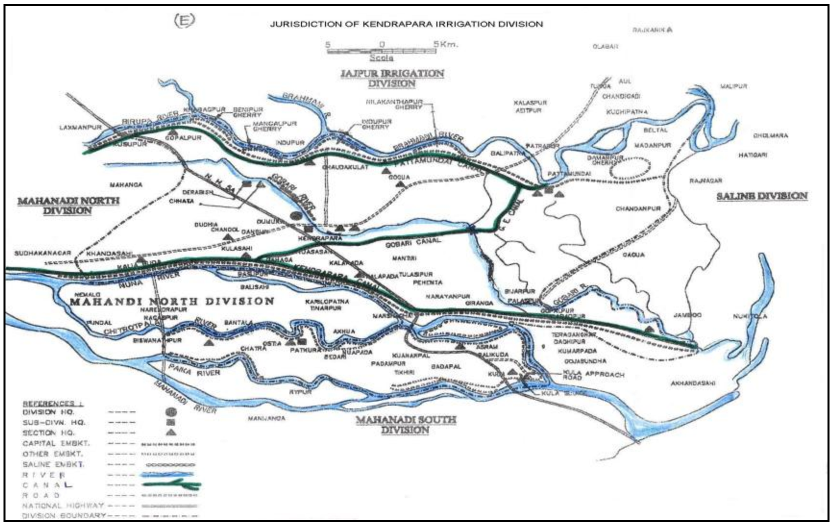


Fig.2 River network of Kendrapara irrigation division



The study indicates that farmer should cultivate paddy in less area as compared to jute in *kharif* season and paddy, groundnut, wheat, greengram, blackgram, sugarcane and castor in *rabi* season. It was found that profit of Rs 201.58 Crore (Table 5) by suggested optimal cropping pattern of *kharif* season and Rs.243.52 Crore (Table 6) in *rabi*season production.

In conclusion the present study linear programming model was developed for the production maximization and solved in TORA software tool. The area allocated for paddy and jute crop in *kharif* season was found to be 90,000 ha whereas 44,460 ha. In *rabi* season area allocated for paddy, mustard, groundnut, wheat, sesamum, green gram, black gram, sugarcane, castor, potato, horsegram was found 2800, 1800, 1580.12, 320, 0, 35930, 0, 20, 40 and 0 ha respectively. Maximum benefit of 243.52 and Rs. 201.57 crore was found by the suggested cropping pattern.

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How to cite this article:

Surjeet Singh Adile, Rahul Dev Kurre, M. P. Tripathi and Sethi, R. R. 2020. Optimization of Water Resources for Maximizing Crop Production in the Coastal Areas of Odisha. *Int.J.Curr.Microbiol.App.Sci.* 9(12): 446-455. doi: https://doi.org/10.20546/ijcmas.2020.912.055