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Optimizing cropped area for creek irrigated ecosystem in coastal Odisha

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ABSTRACT

Coastal areas are very sensitive for exploitation of surface and groundwater resources as very limited options are available due to direct link with sea. Creek irrigated eco system is very common in most of the coastal areas of Odisha. But main problem in these areas are saline water intrusion through creeks during post monsoon and summer season. Hence cropped area is limited due to non availability of suitable water for irrigation purposes. In this paper, crop planning was proposed for 3900 ha area located within 15 km away from the coast line in Mahakalpada block of Kendrapara district, Odisha, India. Area receives 1000 mm of rainfall with 59 rainy days during monsoon season against potential evapotranspiration (PET) demand of 690 mm. Soil quality is favourable for growing crops, still 80% of cropped land remained fallow during post monsoon and summer season due to non availability of required amount of suitable water for fulfilling demand of the crops. Spatio-temporal variation in water quality from both surface (creek) and subsurface (hand operated bore wells) sources showed that creeks get salinized (EC of 6 to 27dS m^{-1}) from March onwards upto monsoon season. Ingression of saline water through creeks and drainage of excess water is checked by construction of sluice gate in the mouth of creek. The hydraulic design of creeks was proposed to carry the discharge of 25 m^3 sec^{-1} of water. Due to availability of water in creeks and water bodies, there was 27 and 37% increase in *rabi* and summer cropped area respectively. It also resulted in enhancement of crop productivity by 36% and 26% in *rabi* and summer season, respectively. Accordingly crop planning was proposed based on water availability through an optimization model for the entire area.

Keywords: Coastal area, Sluice gate, Creek, Saline water intrusion

INTRODUCTION

Nearly 40% of the world's population lives in coastal areas lying within 100 kilometers of coast. This imposes pressure on natural resources in coastal areas due to high population density and has lead to loss of biodiversity, siltation of water bodies and water pollution. Saline water intrusion is one of the major issues in coastal areas worldwide. East coast of India stretches 480 km along the Bay of Bengal. Odisha has geographical area of 155.7 lakh hectares of which total cultivated land is about 61.8 lakh hectares consisting around 39.7% of the area of the State (Govt. of Odisha, 2017-18). The net area sown is about 54.24 lakh hectares constituting 34.8% of the geographical area of the State. Small and marginal farmers constitute more than 90% of the farming community. There is challenge to increase the land and water productivity in these areas due to limited land and water resources, poor socio economic conditions of farming community. Todd (1974) presented various methods of preventing salt water from contaminating groundwater resources including; reduction of pumping rates, relocation of pumping wells, use of subsurface barriers, natural recharge, artificial recharge, abstraction of saline water and combination techniques. Hussain *et al.* (2019) presented a comprehensive review of the common methods that are being used to control and mitigate salt water intrusion in coastal aquifers. One of the approaches like abstraction, desalination, and recharge was proposed by Abd-Elhamid and Javadi (2011) and Javadi *et al.* (2012) to control salt water intrusion. In order to accelerate agricultural growth, there is need to integrate technology related to salt water intrusion along with crop planning based on soil condition and crop sensitive to salt water. This will help in management of water resources as per the field condition in coastal eco system. Rejani *et al.* (2009) developed two optimization models for the efficient utilization of water resources in Balasore coastal groundwater basin of Odisha in eastern India during non-monsoon periods. A non-linear hydraulic management model was developed and it is used for optimal pumping to ensure sustainable groundwater utilization in the basin. In this paper a study was conducted to develop a plan for managing water resources of creek irrigated eco system where salt-water ingression through creeks during summer season is the major constraint in crop production. Due to lack/poor irrigation infrastructure in these areas, maximum fresh water flows to the sea and causes flooding situation near the coast line. Hence, adequate attention has been given to develop and refine appropriate technological options to facilitate more fresh water availability throughout the year in order to increase the cropped area.

MATERIALS AND METHODS

Study area

The study was conducted in Mahakalapada block of Kendrapara district of Odisha, India. The area is situated at latitude & longitude ranging from 20.40° to 20.50° N and 86.45° to 86.75°E, respectively (Fig.1). The land area is 0-3m above mean sea level, along the coast line. Mahakalapada is the most populous and largest of all blocks in Kendrapara district of Odisha, with a geographical area of 490.57 sq. km. Mean annual rainfall (1994-2013) is 1409.58mm, out of which, 1236.8 (87.7%) is received during monsoon season (June-October). The maximum and minimum temperature varies upto 38.6°C in May and 11.2°C in January, respectively. Groundwater table depth varies from 1.2m to 3.5 m during February to May, where as water level remains 0.5 to 1m above the ground surface during monsoon and post monsoon season. Out of total geographical area of 3900 ha area, 1320 ha was cropped area (Sethi *et al.*, 2014). Creek is a narrow area of water that flows into the land and fall in the sea and it is considered as the main source of irrigation in the study area. Creek system forms the boundary of the study area and major crops are irrigated from the creeks apart from monsoon rainfall. Even though water is available throughout the year, but due to salt water intrusion through the creeks, *rabi* cropped area was limited to only 565 ha out of 1320 ha cropped area. During summer season

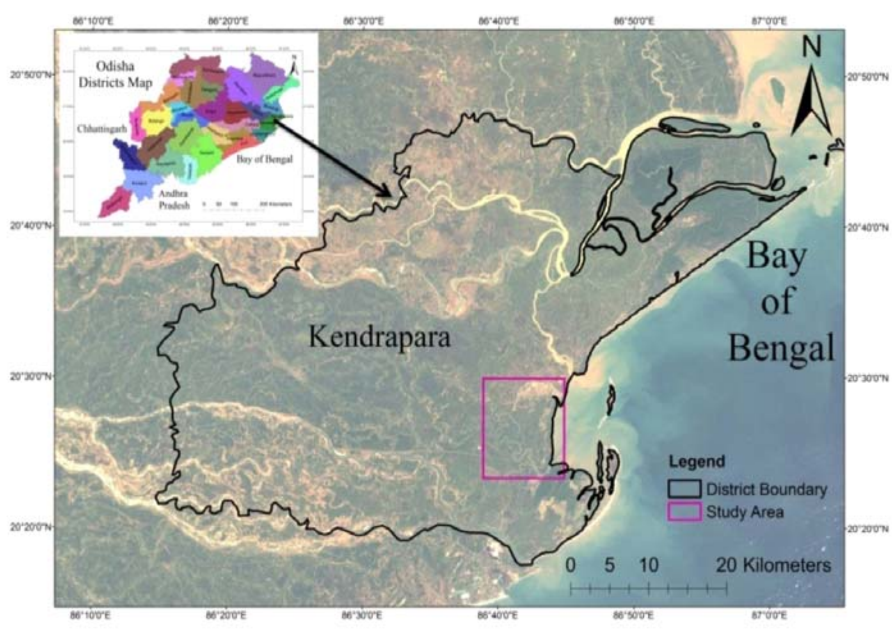

Figure 1. Location of study area

most of the land remains fallow due to poor water quality.

Methodology

In order to improve the study area in terms of optimal crop planning, hydrological studies via rainfall and runoff analysis, change detection analysis through remote sensing image classification analysis and periodic monitoring of soil and water quality was carried out. A total of 20 water samples (10 from surface creek and 10 from bore wells) were collected from the study area during the month of October 2013 (post monsoon) and March 2014 (Pre monsoon). Soil samples collected from different locations were analyzed within the study area (Fig. 2). Velocity of water was measured from different segments of Sunity creek and sub creek during November 2014, 2015 (post monsoon) and January 2015, 2016 (winter) using current meter.

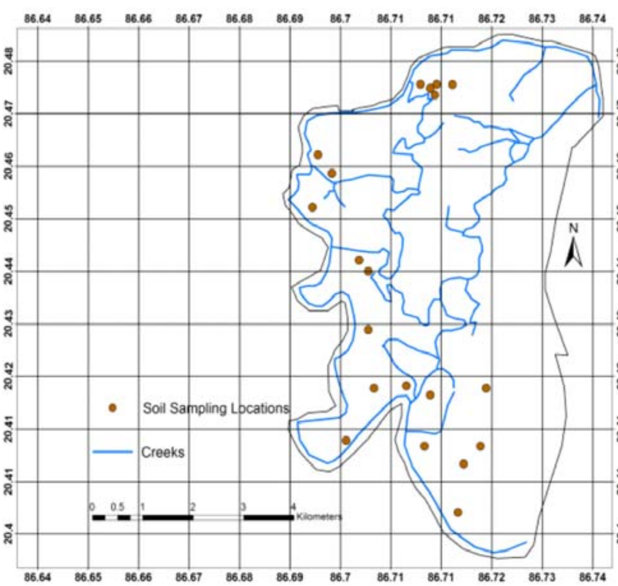

Figure 2. Soil sampling locations and creek sections in the study area

An optimization model for suitable crop planning was proposed. Based on the crop water requirement, redesign of water harvesting structures and creeks were proposed for maximizing crop production from the study area. Socio-economic analysis was carried out to know the changes from pre intervention to post intervention period. Questioner survey was conducted in the study area covering 5 villages in Sunity Gram Panchayat. Nearly 196 farmers were interviewed regarding their age, caste, land holding, annual income and number of water harvesting structures.

Optimization model (Simplex method) for crop planning

Use of Linear Programming by application of optimization techniques in agriculture is generally being used for maximization of profit. It usually gives an opportunity for planning and better allocation of resources in agriculture. In the paper, optimization is solved through simplex method considering various parameters like different crops, yield rates.

Objective function

$$R = P_r x + P_p y + P_v z \qquad (1)$$

Where, R is the total production from the area in tons, *x, y & z* are the areas under rice, pulses and vegetables respectively which is to be determined. P_x, P_y & P_z are the productivity (yield rate) of these crops, respectively. In the above case the objective is to optimize the production where the coefficients of the unknown quantities are the productivity (yield rate) in tons/ha which are assumed as fixed values.

Water requirement constraints

Water requirement of different crops play an important role for irrigation planning so that volume of water required during different crop growth period is quantified. Here water requirement of rice, pulses, and vegetable crops has been considered in the simplex method.

$$W_r x + W_p y + W_v z \leq W \qquad (2)$$

Where, W_r, W_p, W_v are the water requirement for rice, pulses and vegetables in m, respectively and W is the total available in terms of volume(m^3)

Here the crop water requirement is assumed as crop evapotranspiration ET_c.

Crop water requirement, $ET_c = K_C \times ET_0$ (3)

ET_0 is calculated by the equation proposed by Hargreaves and Samani (1985), which required lesser number of climatic parameters and found out one of the suitable method to estimate ET.

$$ET_0 = 0.0023\left(\frac{T_{max} + T_{min}}{2} + 17.8\right).\sqrt{T_{max} - T_{min}}.R_a \qquad (4)$$

Where, T_{max} and T_{min} are maximum and minimum daily air temperature, °C, R_a= extraterrestrial radiation, mm.day $^{-1}$

Area constraint

Study area is highly populated; the agricultural operations cannot cover more than 50% of the total area available. Thus, the total cultivable area is limited to half of the total area.

$$x + y + z = 0.5\,A \quad (5)$$

Irrigation constraints

Irrigation is provided to crops based on water requirement of crops. Depth of irrigation is specified for different crops.

$$D_r x + D_p y + D_y z \leq D \quad (6)$$

Where D_r, D_p, D_y are the depth of irrigation to be applied during the total crop period. And D is the total maximum irrigation depth of water available that can be applied to the crops.

Depth of irrigation (D_x) = Frequency of irrigation during crop period (f) × Depth of irrigation per unit irrigation (d)

$$D_x = \sum_{i=1}^{n} f_i d_i = f_1 d_1 + f_2 d_2 + f_3 d_3 + \ldots + f_n d_n \quad (7)$$

Frequency of irrigation = total crop period/ days required to reach the moisture level of soil from field capacity of allowable soil moisture depletion level

$$f = T_c / t_d \quad (8)$$

Where, T_c= total crop period, t_d = time required to deplete the water level from field capacity to allowable soil moisture depletion level

Salinity constraints

As we are considering the coastal area so salinity is one of the most important parameters in deciding the crops and their area. The salinity of the area is purely dependent upon the water quality of the area that is to be irrigated and the depth of water to be irrigated. The crops which require more irrigation depth in the crop period will deposit more salt in the soil but this parameter has a maximum limit. As salinity of the soil can't exceed the salt tolerance limit of the crops to be cultivated so it is kept as the limit of salinity that is developed by the irrigation.

$$S_r x + S_p y + S_y z \leq S \quad (9)$$

Where, S_r, S_p, S_v are the salt deposited in mg by rice, pulses & vegetables due to irrigation respectively. S is the maximum salt that can be allowed to be deposited in the total area of crops in mg.

$$S_x = I \times D_x \times 10000 \times 1000 \text{ mg/ha} \quad (10)$$

$$S_x = ID_x \times 107 \text{ mg/ha} \quad (11)$$

Where, I = salinity of soil in mg/L, D_x= depth of irrigation in m

Fertilizer application constraints

Production is important; but simultaneously we have to consider a factor of toxicity as we are applying fertilizers to the crops. That is why fertilizer requirement is another factor of consideration. Some crops require high amount of fertilizers and some require less. So the optimization will take care of the balancing of fertilizer application with the area of cultivation. The limit of fertilizer application should be the level tolerance of the soil or in other words the toxicity level of the soil.

$$F_r x + F_p y + F_y z \leq F \quad (12)$$

Where, F_r, F_p, F_v are the fertilizer application (in kg) to rice, pulses and vegetables, respectively. F is the maximum amount of fertilizer that can be applied considering a factor of toxicity.

Labour constraints

Agricultural operations are labour intensive works. Starting from primary tillage to harvesting of the crops labours play a major role. The cost of production for a crop in agriculture is also dependent upon the labour requirement. So it will be inappropriate if labour requirement factor isn't considered as a constraint. The labour requirement here is taken as the no of man hours required per ha per crop. The labour requirement is limited to maximum man hour available.

$$L_r x + L_p y + L_y z \leq L \quad (13)$$

Where, L_r, L_p, L_v are the man hours required for rice, pulses & vegetables, respectively. L is the available man hours for the total area that is to be cultivated.

Non negativity constraints

$$x, y, z \geq 0 \quad (14)$$

RESULTS AND DISCUSSION

Rainfall data of 21 years (1994 to 2014) showed that average annual rainfall and runoff of Kendrapara is 1507mm and 510mm respectively with 59 numbers of rainy days. The highest annual rainfall of 2832 mm occurred during the year 2003 with highest runoff of 1239mm. The lowest rainfall of 582 mm occurred during the year 2000 with lowest runoff of 78 mm. It showed the positive correlation between the rainfall and runoff (Fig. 3). Similarly highest monthly average rainfall was recorded during the month July, August, September and October with 300mm, 411mm, 237mm and 238mm, respectively. The highest runoff was also recorded for same months with 101mm, 152mm, 66mm and 93mm, respectively. On an average 72.7% of the annual rainfall is received during monsoon season. Pre and post monsoon rainfall contributed only 7.2% and 19.0% of the total annual rainfall in the study area. Rest 0.9% rainfall occurred during winter season. The average rainfall and evapo-transpiration trend in Kendrapada district is presented in Fig. 4. Water availability through rainfall is more than the evapo-transpiration rate during the monsoon season only. In all other months the water demand is high, hence there is need to increase the water availability through other sources.

Spatial analysis of water quality

Variation in water quality in terms of pH for borewell is comparatively higher than the surface water (Creek). But in case of electrical conductivity (EC), it is quite high in surface irrigation sources may be due to its linkage with the sea and same external factors. Spatial variation depicted the continuous increase in pH and EC content in water samples from inland towards the sea coast due to influence of sea. The variation of pH and EC for the creeks from the study area was found to be 0.185

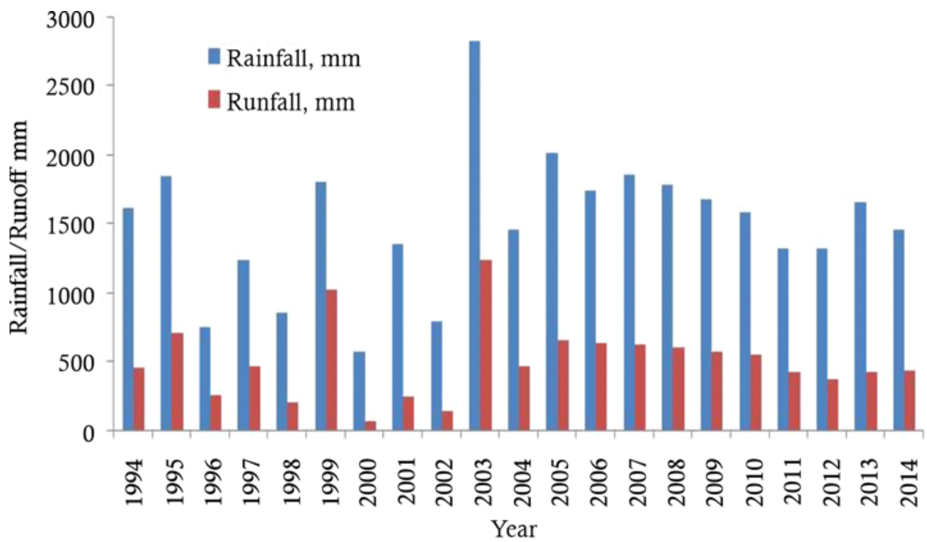

Figure 3. Annual rainfall, runoff of Kendrapara

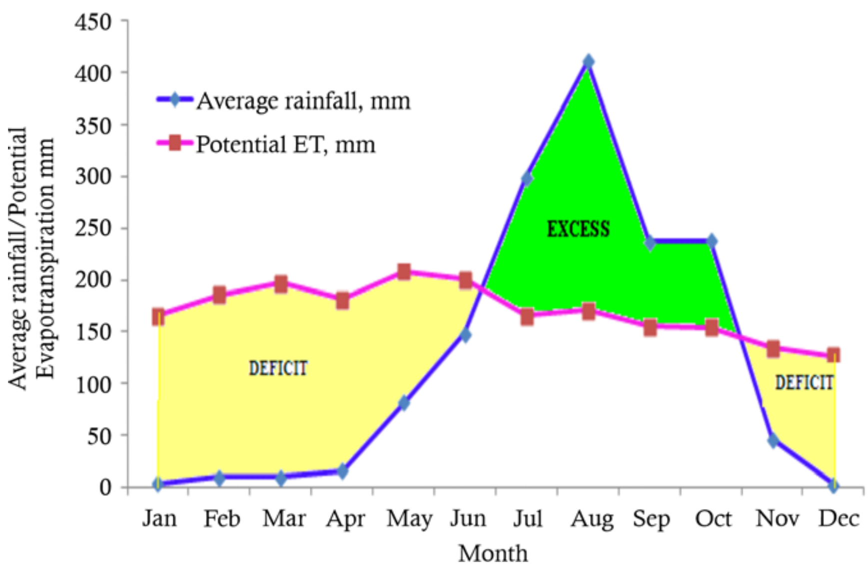

Figure 4. Rainfall and evapotranspiration trend in Kendrapara district

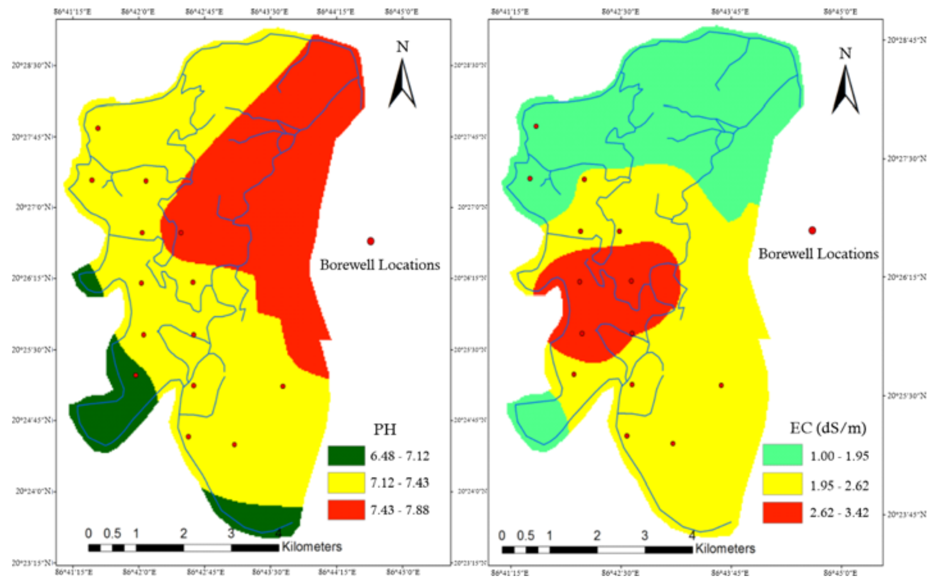

Figure 5. Spatial variation in groundwater quality of bore wells during June 2014

and 1.745 per kilometre, respectively and that for the borewells were 0.069 and 0.778 mS cm^{-1} per kilometre respectively. In case of post monsoon (October 2013) water samples, pH varied between 7.14 to 8.42 and 7.29 to 8.46 in creek and borewells respectively. But in terms of electrical conductivity in creek did not follow any trend which varied within 1 to 10.3 mS/cm reason could be due to its location and joining of many small creeks with different salinity content. In case of bore well, there was decrease in salinity towards inland. Further, it was also observed that the variation of pH as well as EC in surface water is comparatively larger than that of tube wells, which taps water from the deeper aquifer. For both the sources (surface/sub surface) saline water intrusion is the major concern for coastal areas.

Spatio-temporal variation in water quality from both surface (creek) and subsurface (hand operated bore wells) showed that creeks get salinized (EC of 6 to 27 dS/m) from March onwards upto monsoon season. The pH for tubewell water (hand pump operated) was comparatively higher than the surface water (Creek) throughout the year. EC of shallow groundwater wells (20-40m) was higher than the deeper wells with more than 100m depth (Fig. 5). It was also observed that pH of groundwater samples were slightly alkaline (7.43 to 7.88) along the coast line, whereas it ranged within 6.48 to 7.12 in other areas of Sunity during pre monsoon season. Electrical conductivity (EC) varied between 1 to 3.42 dS m^{-1} and EC ranged within 2.62 to 3.42 dS m^{-1} in areas where creek density (number of creeks per unit area) was higher. From survey, it was observed that the depth of bore wells ranged between 20-40m in these areas. But in other areas, depth of bore was more than 100m depth.

Crop water requirement

Crop water requirement was calculated based on the existing cropping pattern. Major crop in *kharif* season is paddy (1200 ha) and vegetables (122 ha) followed by pulses (green gram and black gram) in *rabi*, which covers around 500 ha and vegetable area for 65 ha. During summer season, only 50 ha area is under summer paddy and 150 ha area under vegetable crops leaving most of the areas under fallow. Details of cropped area with crop water requirement in different season was estimated at 1090.96, 205.5and 175 ha m during *kharif*, *rabi* and summer season respectively (Table 1). During *kharif* season, 80% of crop water demand is fulfilled from rainfall, whereas in *rabi* and summer, water availability in creeks and water bodies is sufficient to meet the irrigation demand. But due to ingression of saline water during high and low tides, available water in the creeks are saline, which is not used for growing crops in these region. Hence almost 57% of the cropped area and 85% of the cropped area remains under fallow during *rabi* and summer season respectively. In order to bring more area under crops and to optimize the land allocation in these areas, a Liner programming model was developed with

Table 1. Existing Cropped area within the study area

Sl. No.	Crop	Area (ha)	Irrigation water requirement (m)	Water requirement (ha m)
Kharif				
1	Paddy	1200	0.84	1008
2	Bitter guard	50	0.68	34
3	Lady finger	22	0.68	14.96
4	Tomoto	25	0.68	17
5	Ridge guard	25	0.68	17
	Total	1322		1090.96
Rabi				
6	Pulses	500	0.30	150
7	Tomato	5	0.90	4.5
8	Pointed guard	5	0.90	4.5
9	Bittergourd	5	0.90	4.5
10	Lady finger	10	0.80	8
11	Pumpkin	20	0.80	16
12	Cabbage	10	0.90	9
13	Cauliflower	10	0.90	9
	Total	565		205.5
Summer				
14	Paddy	50	1.10	55
15	Pointed guard	50	0.80	40
16	Bitter gourd	50	0.80	40
17	Lady finger	50	0.80	40
	Total	200		175

simplex algorithm for optimum land allocation to 3 existing major crops i.e. paddy, pulses and vegetables. Crop planning was proposed based on the irrigation water availability in natural creeks and water bodies. LP model with simplex algorithm was used for optimum land allocation to 3 existing major crops i.e. paddy (497 ha), pulses (289 ha) and vegetables (238 ha) for maximum production from the area. Table 2 showed the proposed cropped area with estimated water demand during *rabi.* In order to meet the crop water demand, existing water harvesting structures were standardized for average capacity up to 7000 cubic meter with depth constraint within 2.5 to 2.8 m below ground surface.

Table 2. Proposed cropped area with estimated water demand during *rabi* season

Sl. No.	Crop	Proposed area (ha)	Water demand (ha m)
1	Pulses	288	86.4
2	Tomato	40	36
3	Pointed guard	40	36
4	Bitter gourd	40	36
5	Lady finger	30	24
6	Pumpkin	20	16
7	Cabbage	30	27
8	Cauliflower	38	34.2
9	Paddy	497	596.4
	Total		892

Socio-economic analysis

Out of total, 138 farmers are classified under marginal (< 1 ha), 50 under small (1-2 ha), 6 under semi medium (2-4 ha) and 2 under medium (4-10 ha) land holding category. Before intervention i.e. construction of sluice structure at mouth of Sunity creek, *kharif* (Paddy+vegetables); rabi (pulses+ vegetables) and summer (paddy +vegetables) area were 167, 89.9 ha and 19 ha respectively. After operation of sluice structure i.e 2015-2016 there was 27 and 37% increased in *rabi* and summer cropped area (Fig. 6). The agriculture land, production and cost has been estimated for both pre and post interventions. It was found that during first year after the technological intervention, there was 20% increase land productivity in terms of cost of production from the sample survey area over.

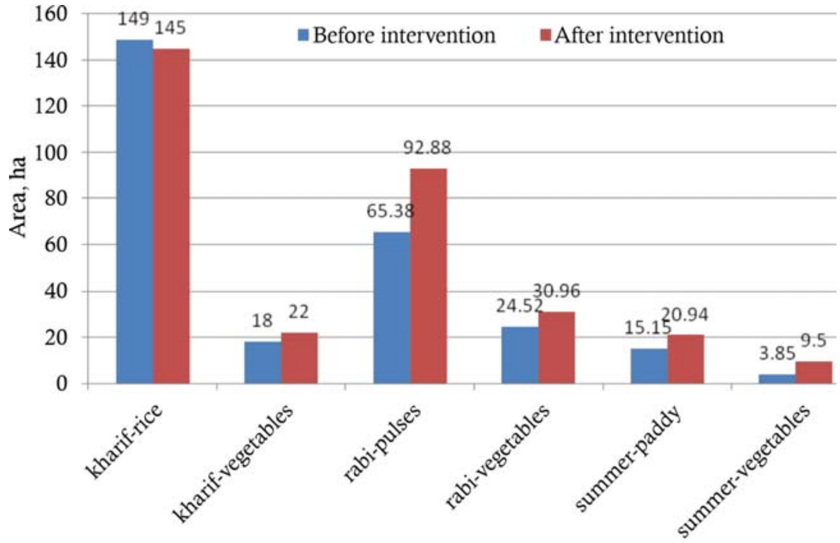

Figure 6. Cropped areas after construction of sluice structure

CONCLUSION

Crop planning was proposed for 3900 ha area, which is located within 15 kilometer away from the coast line in Sunity village of Mahakalapada block in Kendrapara district of Odisha, surrounded by natural creeks all along its boundary. In order to bring more area under crops during *rabi* and summer season, and to check the ingression of saline water through creeks, a sluice gate structure was constructed in the mouth of Sunity creek in collaboration with Department of Water Resources, Govt of Odisha. Spatio-temporal variation in water quality from both surface (creek) and subsurface (hand operated borewells) were monitored before and after construction of sluice gate structure. Then Liner Programming Model with simplex algorithm was used for optimum land allocation to three existing major crops i.e. paddy, pulses and vegetables for maximum production from the area. In order to meet the crop water demand, redesign of existing water harvesting structures and creek hydraulic structures were proposed. Sample survey result showed that after operation of sluice structure there was 27 and 37% increased in *rabi* and summer cropped area. Analysis on agriculture land, production and cost during pre and post interventions showed that during first year there was 20% increase in cost of production from the sample survey area.

REFERENCES

Abd-Elhamid, H. and Javadi, A. (2011). A cost-effective method to control seawater intrusion in coastal aquifers. *Water Resour. Manag.*, 25, 2755–2780.

Cheng, A., Halhal, D., Naji, A. and Ouazar, D. (2000). Pumping optimization in saltwater-intruded coastal aquifers. *Water Resour. Res.,* 36, 2155–2165.

Govt of Odisha, Activity report (2017-18). Department of agriculture and farmers empowerment, Government of Odisha.

Hussain, Mohammed S., Abd-Elhamid Hany F., Akbar A. Javadi, and Mohsen M. Sherif (2019). Management of seawater intrusion in coastal aquifers: A review. *Water*, 11, 2467.

Javadi, A.A., Abd-Elhamid, H.F. and Farmani, R. (2012). A simulation-optimization model to control seawater intrusion in coastal aquifers using abstraction/recharge wells. *Int. J. Numer. Anal. Methods Geomech.*, 36, 1757–1779.

Rejani, R., Jha, M.K., Panda, S.N. (2009). Simulation-optimization modelling for sustainable groundwater management in a Coastal Basin of Orissa, India. *Water Resour. Manag.*, 23(2), 235–263.

Ru, Y., Jinno, K., Hosokawa, T., Nakagawa, K. (2001) Study on effect of subsurface dam in coastal seawater intrusion. In: 1st Int Conf on saltwater intrusion and coastal aquifers, monitoring, modelling, and management, Morocco.

Sethi, R.R., Sahu A.S., Srivastava, R.C., Das, M., Kumar, A. and Tripathy, J.K. (2014). Monitoring land cover changes in coastal tract of Odisha using Landsat ETM+ Imagery. *Current World Environment,* 9(2), 430-436.

Todd, D.K. (1974). Salt-water intrusion and its control. *J. Am Water Works Assoc.,* 66, 180–187.