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Optimal water resources allocation and crop planning for Mandla district of Madhya Pradesh

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ABSTRACT

In India, it is essential to improve the net profit by optimized agriculture. The continuous decline on water resources indicates to adopt the sustainable utilization of resources in tribal area of Mandla district, Madhya Pradesh. To arrive at the optimal crop planning, linear programming (LP) optimization techniques were used to formulate an efficient cropping pattern for maximizing net profit for the Mandla district of Madhya Pradesh. The allocation of water to the agriculture is heavily influenced by cropped area that guarantees food requirement, therefore, land constraint is required. The optimized results shows that the area of major crops like rice, wheat, gram, vegetables, mustard and soybean crop increases against the reduction in area of crops like maize, black gram, moong, and arhar. Existing cropping intensity of the district is 110%. The net income is expected to increase by ₹ 5.92 Cr, when compared to existing income. In Mandla district, it is observed that, Nainpur blocks has highest net seasonal return for both the season followed by Bichhiya block. To achieve the maximum profit per unit of land, cropping intensity should be more than 180% for the district, therefore an extensive measures were taken to fix out the water demand supply gap for agriculture. In this analysis a user-friendly Linear programing software, TORA 2.0 was used for optimal allocation of water and land resources under multi-crop condition for Mandla district. The net annual profit is increased by 5.1% under optimal allocation conditions, which is also reflected into cropping intensity *i.e.* 195%. The sensitivity analysis of model parameter shows that the better price of crop is the most sensitive parameter followed by the crop area. The optimized model can be applied as a reliable decision tool for adopting the farm and regional level decisions of optimal land and water resources allocation. The outcome of the study can assist the policy-makers in taking decisions to develop a sustainable plan of land and water resources for the available area.

1. INTRODUCTION

As a developing country, India is experiencing rapid population growth, urbanization, agricultural and industrial development (Trivedi *et al.,* 2021). The declining trend of water table is due to insignificant groundwater recharge from rain and base flow contributions from seasonal rivers / surface drains, which requires a groundwater balance study for determining the annual safe yield (Sethi *et al.,* 2006). Increasing water demand and its consistency have created a gap between water availability and demand. As a result, optimal and sustainable management and utilization of available water resources are important to mitigating a water problem (Khare *et al.,* 2007 ; Joodavi *et al.,* 2015). Moreover, the yield produced from agriculture farms has high demand and supply is less, that difference influence the market prices significantly. Hydro-economic models are frequently used to evaluate land and water resource management options, with the aim of understanding, how to do crop planning and maximize water and land use value (Hatamkhani and Muridi, 2021; Gautam *et al.,* 2021; Trivedi and Gautam, 2022, Rajput *et al.,* 2022). A study shows that the water demand towards domestic use and for livestock is much less than the water required towards crops. About 80% of utilizable water is consumed by the agriculture sectors (Gautam and Awasthi, 2020; Gautam *et al.,* 2022; Nath *et al*., 2022, Ramkrushna *et al.,* 2022). Generally farmers follow a traditional method for a cropping pattern or allocation of land and water to various crops varies depending on the available resources (Dasa *et al.,* 2015). The existing cropping pattern has been the same for many years and may not utilize resources at maximum economic efficiency (Singh *et al.,* 2001; Singh, 2017). Diversification of cropping pattern could maximize the net return per unit quantity of land and water availability from different sources. Linear programming models (LPM) can handle a large number of constraints and thus, are an effective tool to add in optimization process (Singh, 2014a; Singh, 2014b). There is a strong need to have more scientific studies on LPM to optimize water resources and to formulate cropping pattern for maximum production (Gautam *et al*., 2020; Meena *et al.,* 2022; and Nazarifar *et al.,* 2017). The aim of the present study is to formulate feasible and acceptable cropping pattern in the Mandla district for maximizing the optimal profits at different water availability levels.

A linear programming (LP) is an optimization technique, which is widely used to allocate the limited resources because of the proportionate characteristic of the allocation problem (Matanga and Marino, 1979). Rath *et al.* (2016) studied the cropping pattern in a part of Hirakund command area using crop simulation and compared the result with LINGO. The result showed that CS technique provides a very promising result as compared to LINGO. Kumar *et al.* (2022) investigates the prevailing cropping pattern, adopted by the farmers of the study area. It aims to improve the net benefits from the farming activities with present irrigation water allocation. To arrive at the optimal cropping pattern, various swarm intelligence techniques, such as genetic algorithm (GA), cuckoo search (CS) and particle swarm optimization (PSO) techniques are used to formulate an efficient cropping pattern for maximizing net return for the part of Hirakud command area, India. Chetty *et al.* (2013) considered the Taung Irrigation Scheme situated in the Taung district, in the north-west province of south Africa for annual crop planning using the swarm intelligence techniques. Banik *et al.* (2014) derived a comparative crop water assessment tool using CROPWAT. They investigated the potential of CROPWAT to model the water assessment of using field data. Singh (2014) developed LP model to optimize the use of land and water resources for maximizing the farm income of Rohatak district of Haryana, India. Rao and Trivedi, 2012 conducted the study for managing the irrigation canal system with optimum scheduling in Nothern Gujrat, India. CROPWAT model has been used for the analysis of the data. This study conclude that the performances of this system depend on preparation of realistic canal operation plan and its implementation.

Gautam *et al.* (2020) developed the a LP-model for finding an optimal crop planning, for the maximum net profit at tribal areas of Jabalpur district in Madhya Pardesh, India. The results of the analysis recommends different crops for *rabi* and *kharif* season crop for obtaining the maximum economical profit (increased 10%) at the full water availability, the cropping pattern should be changed to an optimal combination of wheat, mustard, gram, potatoes and rice. Moreover, rice, vegetable and oil crops were suggested the most consistent profit in the district.

The main objectives involved in this study are: (a) formulation of maximization function for crop planning and maximization of net profit in the Mandla district. The optimization model have been applied to find the optimal cropping pattern with the objective of maximizing the benefits for the farmers of the Mandla district. The present study has fulfilled its objective as it provides an insight into the whole water and land resources allocation.

2. MATERIAL AND METHODS

Study Area

The Mandla district is situated at the latitudes $22^{0}05'$ and $23^{0}15'$N and meridian of longitudes of $79^{0}40'$ and $81^{0}10'$E at an altitude of 425.72 (Fig. 1). It covers an area of 5805 km^2. The district has 9 blocks *viz.,* Bichhiya Bijadandi, Ghughri, Mandla, Mawai, Mohgaon, Nainpur, Narayanganj, Niwas. Mandla is surrounded by river Narmada on three sides and Narmada river passing through north-west side of

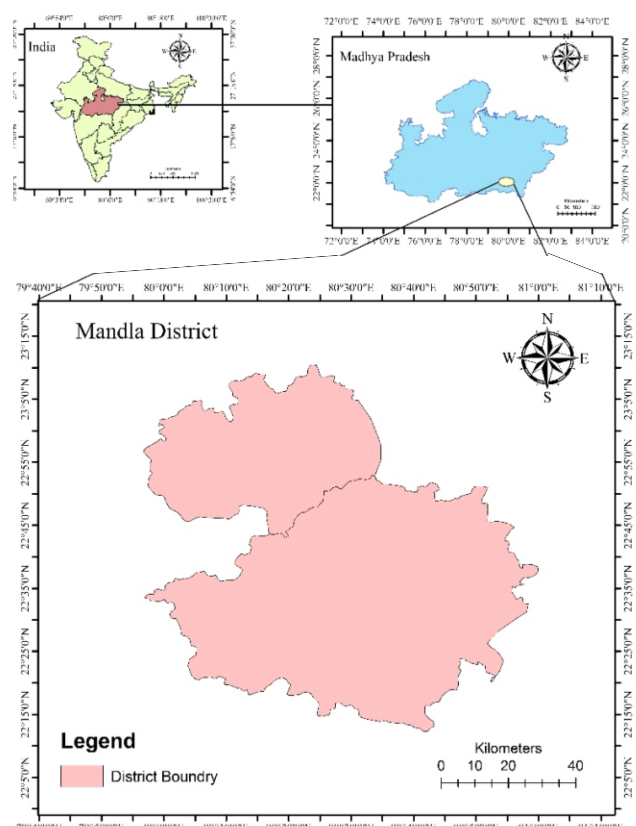

Fig. 1. Location of study area

Mandla (Gautam *et al.,* 2020). The most fertile part of the District falls in the valley of Banjar river which is a feeder river of Narmada, this fertile part of district is called 'Haveli' Awasthi *et al.,* 2018. The study area features tropical regional condition with an average annual rainfall of 1428 mm (India-WRIS, 2014).

Physiography and Soil Type

Mandla district is hilly and forested (Satpura hill range) and highly undulating with narrow strip of cultivated plains in the valley portion of river and nala. The plateau is in the northern part formed by basalt and east west trending hill in the southern part. The soils in the area are generally of clayey loam types with sandy loam soil in some areas. In the northern and central parts of the district, the undulating plateau with mounds are covered with slightly deep soil, well drained, fine to fine loamy soils on gentle slopes marked by moderate erosion (Anonymous, 2017; Anonymous, 2022).

Data Acquisition

For the study area, the following input data such as crops suitable for cultivation in this area, crop sowing / planting pattern, harvesting time, water requirement of crops, water and land resource availability for agriculture, labor availability, human and animal population, production cost and selling price of different crops, district statistical data were collected. All the above mentioned data were collected from Department of Agriculture, Mandla and District Collector office, Mandla. At district the weekly mean ET_0 varied between 22.5 mm week^{-1} to 73.1 mm week^{-1} (Anonymous, 2012, 2017, 2022). The mean monthly ET_0 exceeds the corresponding rainfall value for all the months except July, August and September, due to high rainfall, as shown in Fig. 2. The normal maximum temperature observed during December is 10°C. The normal annual mean maximum and minimum temperature of district is 32.5°C and 18.5°C.

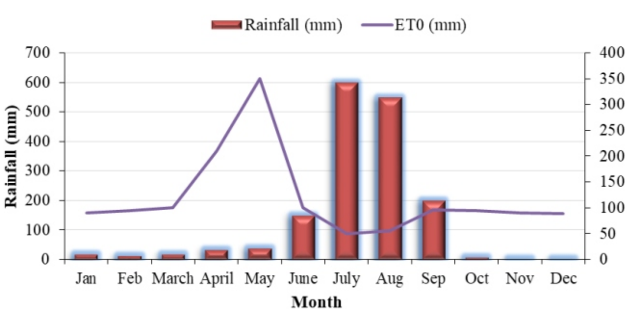

Fig. 2. Distribution of mean monthly rainfall and evaporation

Availability of Water Resources

The total utilizable water for agriculture purpose is the addition of utilizable surface and ground water. The total groundwater resources for water table aquifers are taken as annual ground water recharge plus potential recharge in shallow water table zone (CGWB, 1997, 2013). The total groundwater resource, thus computed would be available for utilization for irrigation, domestic and industrial uses. About 80% of total utilizable groundwater is used for only irrigation purpose (India Water Resource Information System, 2015). The total water resources available for utilization was estimated based on national commission on Agriculture Guidelines, 2002 (Anonymous, 2002). As per estimation total utilizable water resources availability (including surface and groundwater) was 3355 MCM. Block wise available surface and groundwater resources are presented in the Fig. 3.

Irrigation Water Requirement of Crop

Crop grown in the district during. For calculating crop water requirement, potential evapotranspiration is calculated from pan evaporation by formula of James (1988).

$$ET_0 = K_p \times E_p \quad ...(1)$$

Where, ET_0 is potential evapotranspiration (mm day^{-1}), E_p = Pan evaporation (mm day^{-1}), K_p = pan coefficient (dimensionless).

Crop evapotranspiration can be calculated by using formula:

$$ET_c = K_c \times ET_0 \quad ...(2)$$

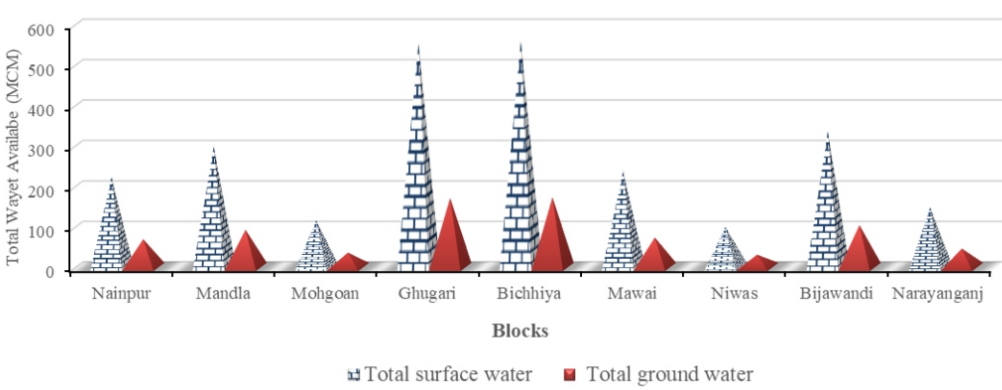

Fig. 3. Total water available for utilization at different blocks of district

Table: 1
Water requirement (WR) of different crops at Mandla district (Awasthi *et al.*, 2017)

Kharif Crop	WR (mm)	*Rabi* crop	WR (mm)
Rice	810	Wheat	650
Maize	580	Gram	550
Other Pulse	645	Lentil	518
Black gram	518	Pea	510
Moong	520	Sugarcane	1500
Soybean	440	Other pulse	530
Sesame	545		
Rice	810		
Maize	580		

Source: ET_o Tables for districts of Madhya Pradesh, 2017

Where, ET_c is crop evaporatranpiration (mm day^{-1}) and K_c is crop coefficient. Water requirement of different crops are maintained in the Table 1.

Cropping Pattern

The climate of district is enough good for proper cultivation of all types of crops like, cereals, pulses, oilseeds and horticultural crops. About 31% of total area comes under irrigated area. Gram, pea, mustard and wheat is the major crop *rabi* season and covers around 75% of total CCA. In *kharif* and *rabi* seasons, paddy, maize, lentil and pigeon pea crops are cultivated in a small manner. Existing seasonal cropping pattern and crop area in Mandla district is presented below in Table 2.

Optimization Model Formulation

A model consist of objective function and set of constraints. The development of optimization models for better water management expanded rapidly in the last decade. In a present days the concept of allocating water and land resources based on a market appliance that is dealing with water as any other commodity allocated according to its demand and supply a mathematical model was formulated to allocate water among different crops to get the maximum revenue out of each unit of it (Zare and Koch, 2014; Xue *et al.,* 2015).

Objective Function

The objective function determines the optimal combination of crop production that shows the maximization of net annual return above total costs. It denotes the net profit out of a given cost of crops to be planted, *i.e.* their cost of production subtracted from their final selling price at the market. In this method use in both condition existing and after proposed resources.

$$Maximize\ Z = \sum_{i=1}^{n} P_i A_i \qquad ...(3)$$

For $i = 1, 2, 3 \ldots\ldots N$

Where, Z = Net profit from obtained from crops

Table: 2
Existing seasonal cropping pattern and crop area in Mandla district (Anonymous, 2017)

Kharif crop	Area (ha)	*Rabi* crop	Area (ha)
Rice	132383	Wheat	47987
Maize	18075	Gram	9323
Other Cereals	28044	Other Pulse	47588
Arhar	5880	Sugarcane	2796
Black gram	2136	Other Vegetables	2690
Soybean	435	Rapeseed/Mustard	21720
Sesame	1409		

Source: District Statistical Report - 2017

(₹); N = Number of crops; P_i = Net profit from i^{th} (₹) and A_i = Crop area under i^{th} (ha).

Model Constraints Crop

In this study land and water resources were deliberated as a model constraints.

Land Area Constraints

Land area is a first constraints for model. Land distributed for different crops must not be greater than the total available cultivable land for *kharif* and *rabi* season. Expression for land constraints is given below:

For *kharif* season

$$\sum_{i=1}^{n} A_i \leq Total\ area\ available \qquad ...(4)$$

For *rabi* season

$$\sum_{i=2}^{n} A_i \leq Total\ area\ available \qquad ...(5)$$

Area non negativity constraint

$$A_i \geq 0 \qquad ...(6)$$

Where, A_i = the crop area under i^{th} crop (ha)

Water Availability Constraints

Water availability constraints should not be greater than the total available water (surface and ground) resources for both seasons.

For *kharif* season

$$\sum_{i=1}^{n} W_i A_i \leq Maximum\ available\ water\ (surface\ and\ groundwater) \qquad ...(7)$$

W_i = Water requirement of crop in *kharif* season

For *rabi* season

$$\sum_{i=2}^{n} W_i A_i \leq Maximum\ available\ water\ (surface\ and\ groundwater) \qquad ...(8)$$

W_i = Water requirement of crop in *rabi* season

Allowable Area Constraints

To fulfill the food requirement under certain crops to meet the local demand in the district, minimum and maximum land acreage must be restrict.

i. Lower limit

$$Ai \leq \mu_{ij} A_C \qquad \ldots(9)$$

ii. Upper limit

$$Ai \geq \mu_{ij} A_C \qquad \ldots(10)$$

Where, μ_{ij} = function of cultivable area that can be allotted to i^{th} crop in j^{th} season.

Non-Negativity Constraints

$$A_i \geq 0;\ W_w \geq 0 \text{ for all } i \text{ and } j \qquad \ldots(11)$$

Where, A_i = Crop area under i^{th} (ha); W_w = Total water resources availability (surface and ground), ha m; i = Total 1 to 12 crops.

Total 12 crops (*kharif* and *rabi*) have taken for study *viz.,* rice, maize, arhar, black gram, soybean, sesame, wheat, sugarcane, pea, black gram, mustard and vegetables.

In this study the optimal cropping pattern and cultivated area allocation in order to availability of water resources (surface and groundwater) were obtained for both *kharif* and *rabi* seasons by developing an optimization model. The model implemented is a LPM with a linear objective function, subjected to a set of linear constraints. TORA 2.0 Software was used to solve the model. The model was run to obtain the optimal allocation of cultivated land area of the selected crops. The operation of TORA 2.0 software was presented in the diagram (Fig. 4).

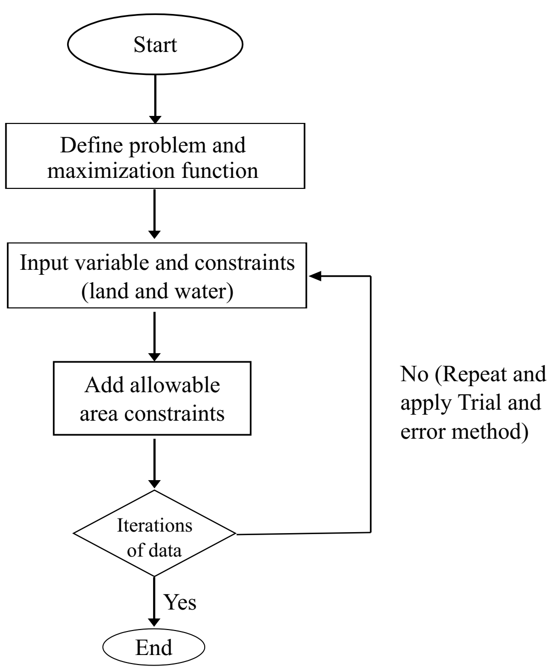

Fig. 4. Process flowchart of optimization of TORA 2.0 software

3. RESULTS AND DISCUSSION

Model Development

The development of optimization models for improved water management expanded rapidly in the last decade. LP is used for multiple crop models and dynamic programming for a single crop model. In irrigated agriculture, where various crops are competing for a limited quantity of land and water resources, LP is one of the best tools for optimal allocation of land and water resources. The objective of the model is to maximize the net annual return from the study area considering the returns from crop but excluding the irrigation cost.

Water budget is a necessary tool to estimate the gap between demand and availability of water resources from different sources. The estimated block wise water budget of the 9 blocks of Mandla district were presented in the Fig. 5.

Optimum Resources Allocation

The results are presented in the form of Fig's 6 and 7) shows the optimum allocated area plotted together with existing cultivated area for *kharif* and *rabi* season crop. It can be seen that under optimal condition rice, sesame and soybean area has increased against decrease in maize, other cereals and black gram for *kharif* crop season. While for *rabi* season wheat, gram, mustard and vegetable area has increased against decrease in other pulses, butarea of sugarcane remain unchanged. The maximum area during *kharif* and *rabi* season is increased for rice, Wheat, gram and sesame, meanwhile area is decreased for arhar, black gram and other pulses. It is also observed that utilization of water resources has increased under optimized condition. Fig's 6 and 7 shows the existing area and optimally allocate area.

The new optimal area allocation graph is plotted together with existing cropping pattern in Fig's. 6 and 7. In *kharif* season rice, sesame and soybean cultivation area is increased by 4%, 29.35% and 16.50%, respectively, while in *rabi* season wheat, gram, mustard and vegetables cultivated area is increased by 2%, 3%, 2%, and 15%, respectively. Minor changes was seen in cereals crop cultivation area. Under the optimization process maize, black gram, arhar and other pulses area are reduced by 3%, 41%, 32%, and 3%, respectively. There is no change was observed in sugarcane cultivation area.

Net Annual Income

The net profit of seasonal crops depends on the crop yield, cost of cultivation and current market price. All these things varies from place to place, which directly influence the net return. The net return from cultivation of crops was calculated considering a prospective yield. The net income is expected to increase by ₹ 5.92 Cr, when compared to existing income. Fig's 8 and 9 indicates the total profit generated by optimal cropping pattern. In Mandla district,

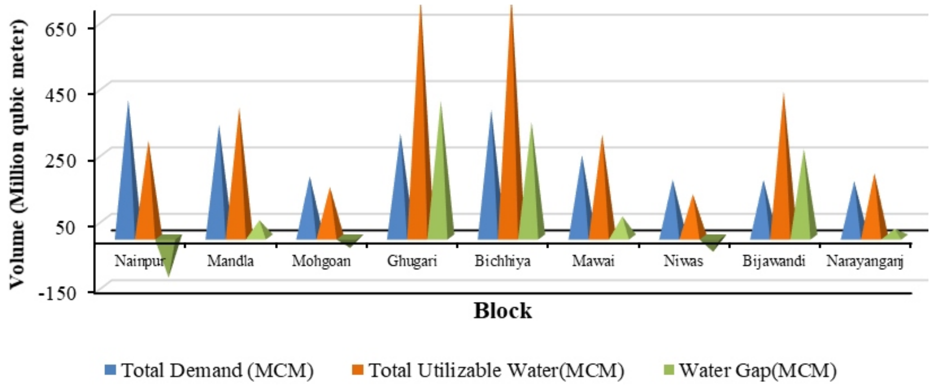

Fig. 5. Water budget of Mandla district

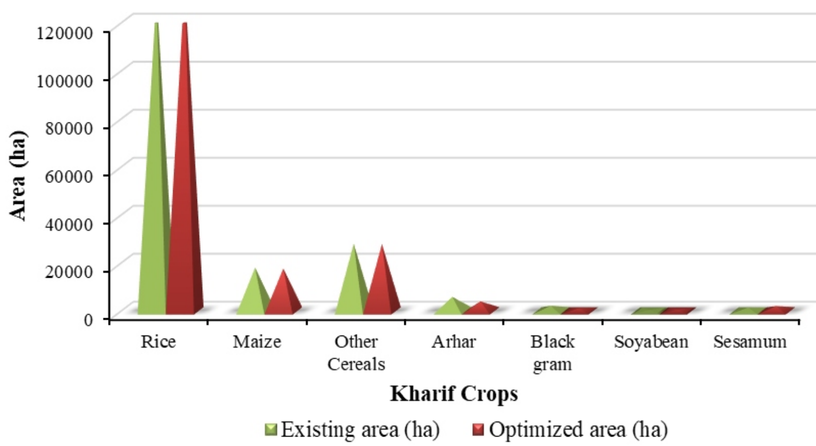

Fig. 6. Comparison of existing and optimal allocated area for *kharif* season crop

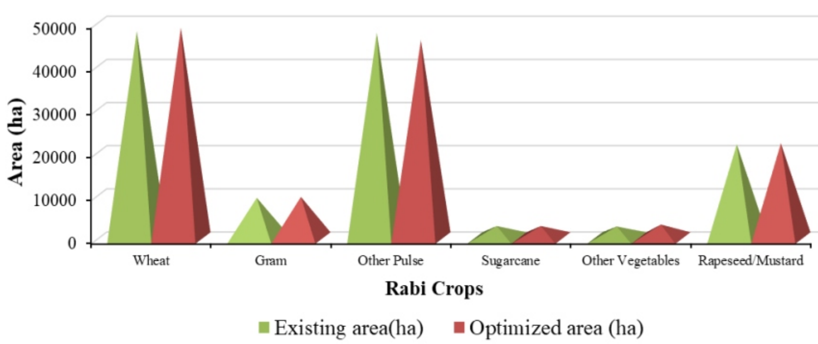

Fig. 7. Comparison of existing and optimal allocated area for *rabi* season crop

the net profit generated after optimization was 2.0 to 5.1% more than the existing return.

4. CONCLUSIONS

In this study, optimal land and water resources are allocated, considering the availability and economic factors. As per estimation total utilizable water resources availability (both surface and groundwater) was 3355 MCM. This study presents the formulation of model for seasonal land and water resource optimization for crop planning and maximizing the net profit. The optimized land area obtained from the model shows a slightly variation in net annual profit from the current cropping area by optimally utilization of available water (surface and ground) resources. The optimized results shows that increase in major crops area like rice, wheat, blackgram, vegetables, mustard and soybean crop against the reduction in area of maize, black gram, moong, and arhar. The net income is expected to increase by ₹ 5.92 Cr, when compared to existing income. The net profit was increased by 5.1%. In

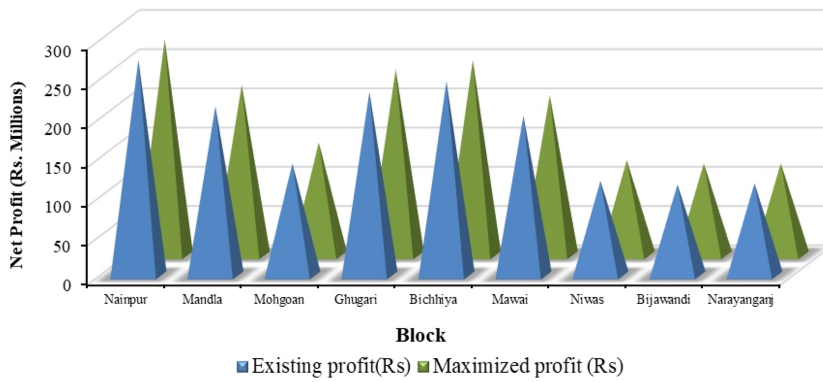

Fig. 8. Comparison of net seasonal return for *kharif* crop

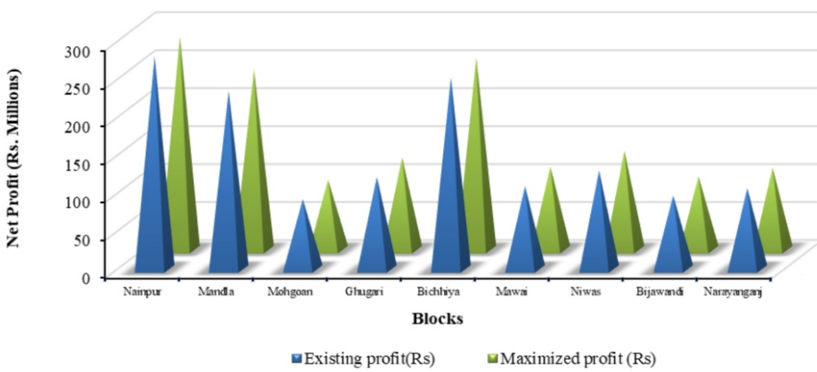

Fig. 9. Comparison of net seasonal return for *rabi* crop

Mandla district, it is observed that, Nainpur blocks has highest net seasonal return for both the season followed by Bichhiya block. The escalation in a land area was noticed due to allocate more area for higher yield and valued crop, which is a tool to boost the farm net profit but these are site specific application, sometimes not acceptable in the field level. The optimization technique adopted here is very practical and may be applied anywhere in the world for crop planning as well as maximization of net farm revenue. However, based on the surface / groundwater quality / quantity conditions, the model's limitations may vary under different agro-hydro-geologic situations.

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