INEXACT SECTOR-WISE PLANNING OF LAND AND WATER RESOURCES IN A LARGE CANAL COMMAND IN THE SUB-HUMID REGION OF EASTERN INDIA

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Abstract

A stepwise linear programming (SLP) is utilized for solving the land and water resources management problem. The formulated model considers integrated planning of surface water and ground water resources. The developed model is applied to Hirakud command area of western Odisha. The western part of Odisha faces acute shortage of drinking water almost every year. The study area is bounded by Mahanadi river in the west. Model is applied for the major crops in the canal command area. The model is evaluated for different inexact bounds on available natural resources (land and water). The model results are useful in evolving crop specific land utilization levels and quantities of surface and ground water resources for deriving maximum benefit. The model also provides season specific crop scheduling information. The performance evaluation study shows potential applicability of the developed methodology.

Keywords: Integrated Water Resources Management, Groundwater, Surface Water, Inexact Number, Inexact Optimization

1. Introduction

Land and water resources management are the essential factors for sustainable agricultural development. Fresh natural resources are under threat due to increasing trend of the population. To ensure the availability of land and water resources integrated land and water management framework is needed. In land and water management, both system parameters and decision variables are susceptible to deviation. An inexact framework based integrated land and water management model incorporating possible variation(s) in parameter and decision variable is developed for command area systems.

Different irrigation water management studies have incorporated components that can identify the optimal cropping patterns (Jiracheewee et al., 1996; Singh et al., 2001; Panda et al., 2003; Khare et al., 2007; Rajani et al., 2009), determine the quantity of water to be delivered from different sources (Jiracheewee et al., 1996; Khare et al., 2007), maximize the net return from the agricultural production (Paul et al., 2000; Singh et al., 2001; Khare et al., 2007). Only a few studies have incorporated imprecise information (both parameter and decision variable) based formulation in irrigation planning, e.g., Lu et al. (2009), Zhang and Huang (2011).

Therefore, parameters and control variables can be represented as inexact numbers to consider imprecise information. The model considers the objective of maximizing net annual return subject to optimal allocation of land and water resources for given imprecise information on net return of crop, available land and water resources, and water demand in the cultivable command area (CCA). A Inexact Linear Programming (SLP) model has been proposed for solution of inexact integrated land and water management model. The proposed model has been applied to the Hirakud sub-command area for inter-seasonal integrated land and water management planning.

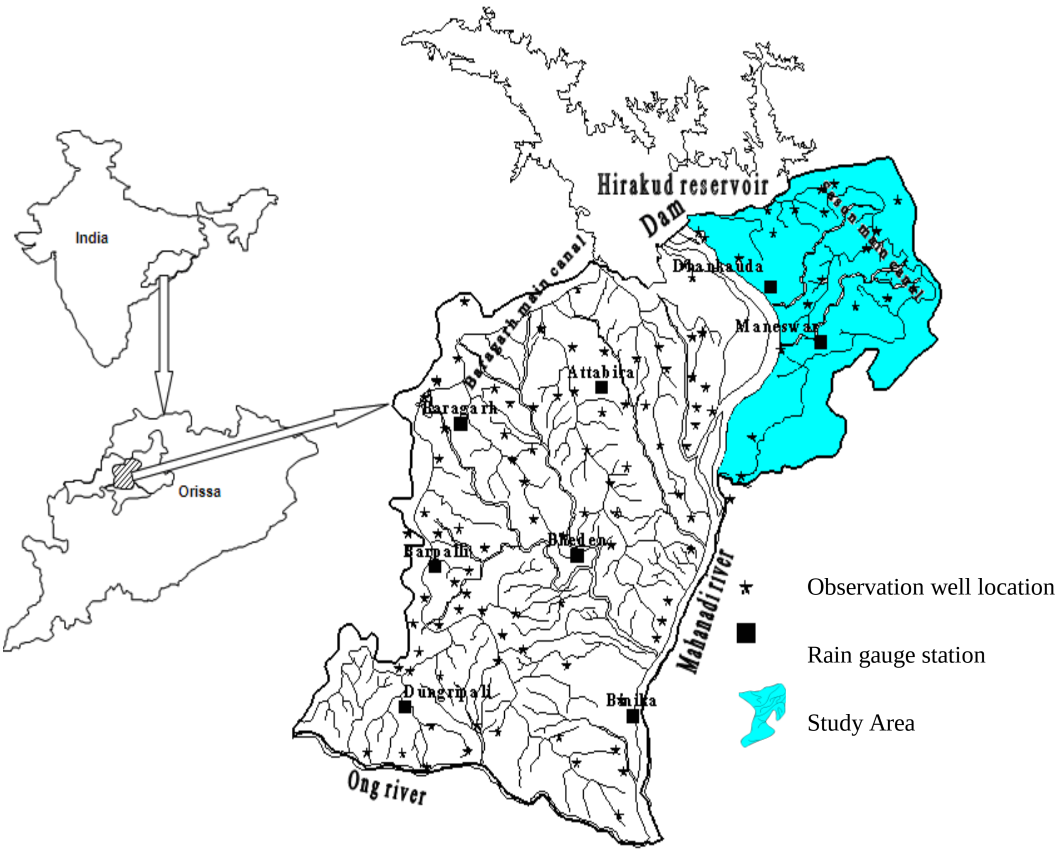

Figure 1: Study area (Sub-canal command area of Hirakud canal command)

2. Study area

Hirakud sub-command area, situated in the western part of Odisha (India) is chosen as the study area. The study area (Figure 1) is bounded by north latitudes 200 15' 53" to 210 35' 10" and east longitudes 830 52' 0.6" to 840 10' 21" and falls in two UTM zones, 44Q and 45Q. Topography of the study area varies from plain to undulating. The whole area is bounded by river, canal, distributory and Hirakud reservoir viz. Mahanadi River, Sason main canal and its distributaries: Huma tail as boundary of the eastern and southern part of the study area. The Mahanadi River is perennial while the tributaries (Harad and Multi Jhor) are ephemeral. Year wise variation of rainfall of the study area is shown in Figure 2. The average annual rainfall (Figure 2) of this area has been found to be 1495.23 mm. Temperature varies in between 8 0C (in January) - 47.5 0C (in May) with an average value of 28 0C. Major part of this area is underlain by granite, granite gneisses, quartzites. These rocks are generally very hard, compact and lack of primary porosity. Groundwater occurs under phreatic condition in the weathered residuum and under semi-confined to confined conditions in the fractures zone.

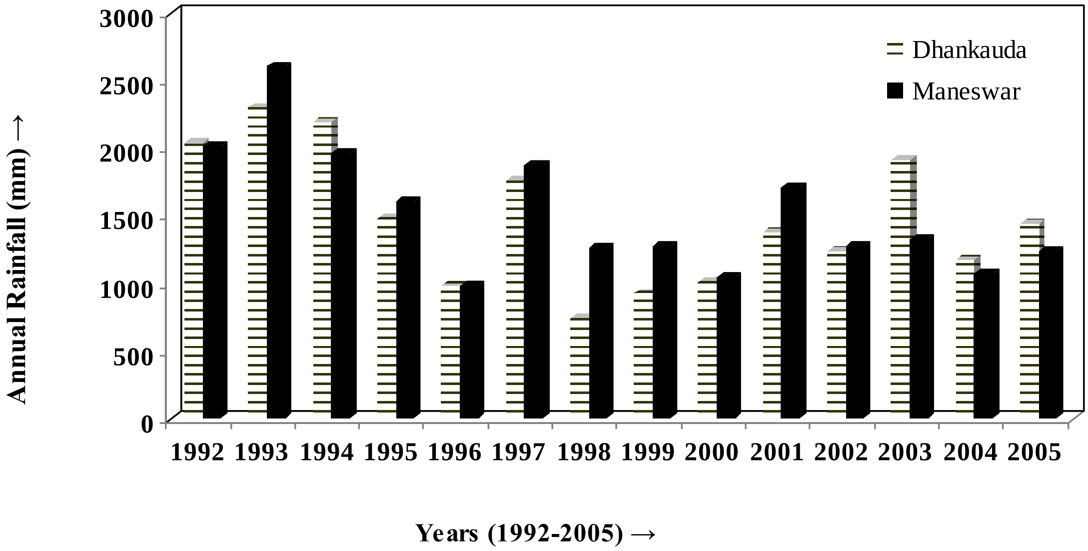

Figure 2: Annual rainfall of the study area (Source: IMD, Pune, India).

3. Land and water management model

A single objective optimization models is developed for land and water management in canal command systems.

3.1 Objective Function

Objective function is maximization of net benefit (net-return: net spending on water and cultivation cost). Mathematically the objective function can be expressed as:

$$Max\ f\left(A_{ijk}^{\pm}, SW_{ij}^{\pm}, GW_{ij}^{\pm}\right) = \sum_{i=1}^{n_{sect}} \sum_{j=1}^{n_{seas}} \sum_{k=1}^{n_{crop}} a_{ijk}^{\pm} A_{ijk}^{\pm} - \sum_{i=1}^{n_{sect}} \sum_{j=1}^{n_{seas}} \left(C_{ij}^{SW\pm} SW_{ij}^{\pm} + C_{ij}^{GW\pm} GW_{ij}^{\pm}\right) \qquad (1)$$

where, i, j, and k index for sector of command area, crop growing season, and crops respectively; j=1, for *Kharif* season and j = 2, for *Rabi* season; $a_{ijk}^{\pm}$ = net return for crop k in season j of sector i (₹ /ha); n_{sect} = no. of sectors; n_{seas} = no. of seasons; n_{crop} = no. of crops; $A_{ijk}^{\pm}$ = area allocated to crop k in season j of sector i (ha); $SW_{ij}^{\pm}$ = surface water allocated in season j for sector i, (ha-m); $GW_{ij}^{\pm}$ = groundwater allocated in season j for sector i, (ha-m); $C_{ij}^{GW\pm}$ = unit cost of groundwater for all i and j (₹ 3700/ha-m); $C_{ij}^{SW\pm}$ = unit cost of surface water for all i and j (₹ 2700/ha-m); $(\,)^{\pm}$ = grey number, i.e., value within the bounds [$()^{-}$, $()^{+}$].

3.2 Constraints

Relevant constraints are discussed below:

Water allocation constraints

Crop water requirement and net irrigation requirement calculation is an essential component for water allocation problem. Conjunctive use is an attractive option for surface and/groundwater shortage problem.

$$\sum_{i=1}^{n_{sect}} \sum_{k=1}^{n_{crop}} NIR_{ijk}^{\pm} A_{ijk}^{\pm} - \sum_{i=1}^{n_{sect}} \alpha_1^{\pm} \left(\beta_1^{\pm} SW_{ij}^{\pm} + GW_{ij}^{\pm} \right) \leq 0 \; ; \forall \; j. \tag{2}$$

where, $NIR_{ijk}^{\pm}$ = net irrigation requirement of crop *k* in season *j* of Sector *i* (m); $\alpha_1^{\pm}$ = field water application efficiency, 60 - 70 % = 0.60 – 0.70; $\beta_1^{\pm}$ = conveyance efficiency, 65-80 % = 0.65 - 0.80.

Land Area Constraint

Summation of individual crop area should be less than or equal to total cultivable command area for all seasons and sectors.

$$\sum_{k=1}^{n_{crop}} A_{ijk}^{\pm} \leq TCA_{ij}^{\pm} \; ; \forall \; i \; \& \; j. \tag{3}$$

where, $TCA_{ij}^{\pm}$ = total cultivable command area of sector *i* for all *j* (ha).

Water Availability Constraints

Sector and season wise surface water use should be less than or equal to total available surface water.

$$SW_{ij}^{\pm} \leq TSW_{ij}^{\pm} \; ; \forall \; i \; \& \; j. \tag{4}$$

Sector and season wise groundwater use should be less than or equal to total available groundwater.

$$GW_{ij}^{\pm} \leq TGW_{ij}^{\pm} \; ; \forall \; i \; \& \; j. \tag{5}$$

where, $TSW_{ij}^{\pm}$ = total available surface water in sector *i* and season *j* (ha-m), and $TGW_{ij}^{\pm}$ = total available groundwater in sector *i* and season *j* (ha-m).

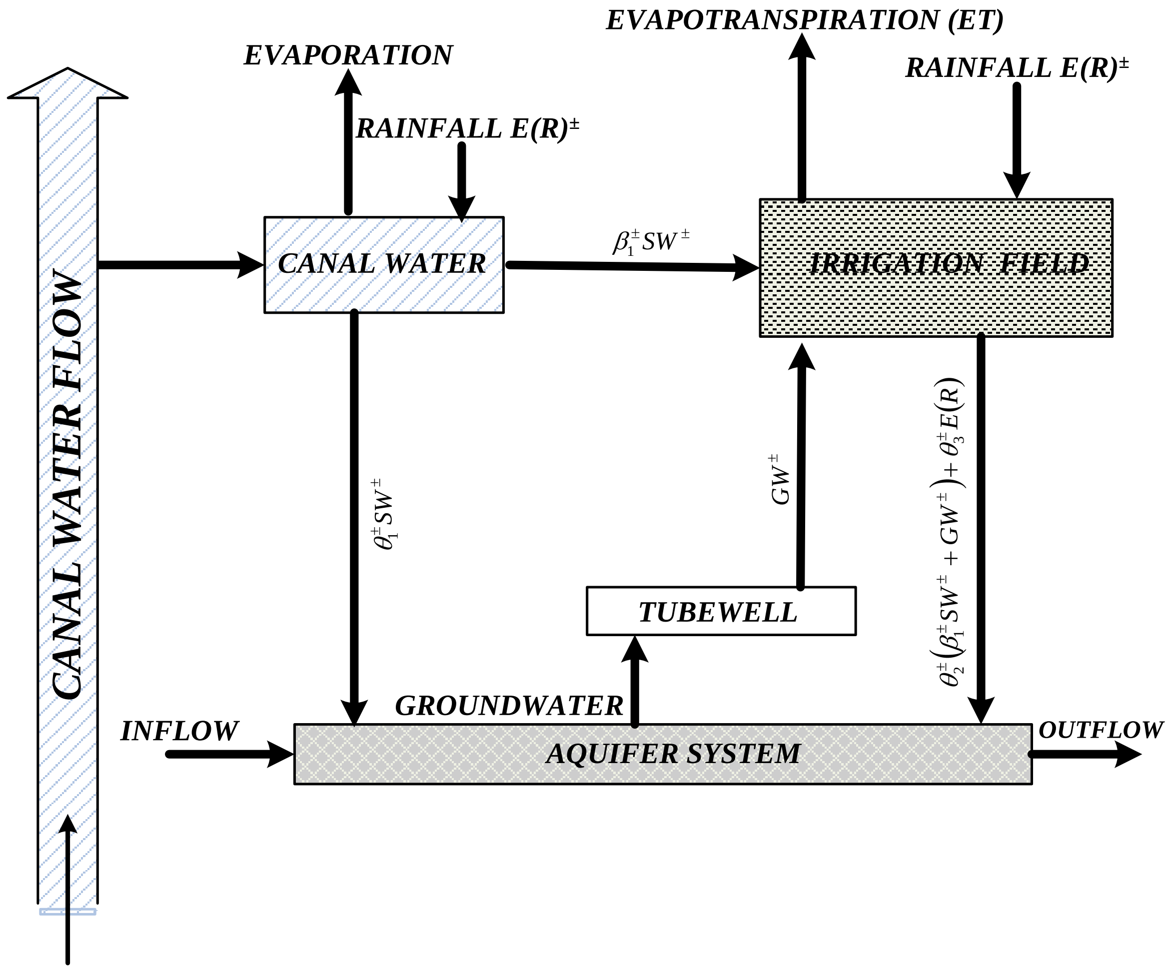

Figure 3: **Schematics diagram of surface water and groundwater balance for the study area.**

Hydrologic Balance of Aquifer

Conceptual line diagram in Figure 3 shows the hydrologic balance in the aquifer system of the canal command area. Inflow into the aquifer is equal to outflow from the aquifer system is assumed. Mathematically, the hydrologic water balance constraint can be expressed as:

$$\sum_{i=1}^{n_{sect}}\sum_{j=1}^{n_{seas}} \left[GW_{ij}^{\pm} - \left(\theta_1^{\pm} SW_{ij}^{\pm} + \theta_3^{\pm} E(R_{ij})^{\pm} A_i^{\pm} + \theta_2^{\pm} \left(\beta_1^{\pm} SW_{ij}^{\pm} + GW_{ij}^{\pm} \right) \right) \right] \le PMA^{\pm} \qquad (6)$$

where, $\theta_1^{\pm}$ = conveyance loss of surface water (fraction) = 0.20 - 0.35; $\theta_2^{\pm}$ = field water application loss 30%; $\theta_3^{\pm}$ = rainfall recharge (fraction) = 10 - 18% (Sharma et al., 1999; Nirala et al., 2005); $E(R_{ij})^{\pm}$ = expected rainfall of sector i and season j = 1077 - 1169 mm; $A_i^{\pm}$ = total available rechargeable area; $PMA^{\pm}$ = permissible annual mining allowance of the aquifer (ha-m).

Non-negativity

For grey linear programming all constraints must be greater or equal to zero.

$$A_{ijk}^{\pm} \geq 0;\ SW_{ij}^{\pm} \geq 0;\ GW_{ij}^{\pm} \geq 0.\ \forall\, i, j, \text{ and } k. \tag{7}$$

4. APPLICATION OF SLP MODEL

In order to evaluate the SLP formulation, a scenarios is considered. In this scenario, minimum and maximum available surface water values are taken as 70% and 95% of the design surface water (based on design discharge of Sason main canal) respectively. Moreover, season wise variation in the cost of surface and groundwater are considered. Cost of surface water is ` 2700/ha-m in Kharif and ` 4500/ha-m. in Rabi season, whereas the cost of groundwater varies between ` 3700 (Kharif) - 4000/ha.m (Rabi). Minimum value of the cultivable command area is taken as 95 % of the total command area. Rainfall value is considered to be varying in between the 50 percentile (1364 mm) and 90 percentile (1963 mm) value (calculated based on the available historical data). Minimum net return is taken as 80 % of the maximum net return (based on market analysis). Considering socio-economic aspect, lower limit of the cropping area is taken as 50% of the existing crop land (Rabi and Kharif programme, 2010).

Net return ranges in between ` 3.45×108 and ` 5.20×108. Table 1 shows that unlike other crops allocated area for rice cultivation significantly differs from maximum and minimum allocatable area. Rice needs more water. Moreover, rice cultivation fetches less profit compared to other crops. Thus the optimization model suggests reduction of existing cropping area for rice cultivation. However, allocated areas attain the respective maximum values for other crops due to availability of surface and groundwater in sufficient quantity.

Table 1: Optimal allocation of land resources for the study area using SLP model

	Blocks											
	Dhankauda				Maneswar				Jujumura			
	Kharif		*Rabi*		*Kharif*		*Rabi*		*Kharif*		*Rabi*	
Crops	A^-	A^+	A^-	A^+	A^-	A^+	A^-	A^+	A^-	A^+	A^-	A^+
H. Y. paddy	5230.85	5564.38	2169.56	2169.56	5838.38	6252.11	1912.24	1912.24	2553.09	2720.53	401.75	401.75
H. Y. Maize	0.00	0.00	7.80	7.80	0.00	0.00	8.41	8.42	0.00	0.00	2.84	2.84
Total Millet	11.70	11.71	-	-	16.83	16.83	-	-	22.69	22.69	-	-
Arhar	66.34	66.34	-	-	50.49	50.49	-	-	28.36	28.36	-	-
Mung	263.17	310.22	567.75	567.75	281.69	326.91	757.32	757.32	171.75	224.01	175.82	175.82
Biri	280.95	280.95	156.08	156.08	538.54	538.54	42.07	42.07	266.57	266.57	130.45	130.45
Horse Gram	124.87	124.87	265.34	265.34	67.32	67.32	180.92	180.92	56.72	56.72	83.18	83.19
Other Pulse	70.24	70.24	19.51	19.51	149.36	149.36	25.24	25.24	74.68	74.68	75.62	75.62
Groundnut	31.22	31.22	62.43	62.43	29.45	29.45	50.49	50.49	30.25	30.25	22.69	22.69
Til	316.07	316.07	624.33	624.33	378.66	378.66	302.93	302.93	199.46	199.46	287.36	287.37
mesta	0.00	0.00	-	-	0.00	0.00	-	-	0.00	0.00	-	-
Sweet Potato	3.90	3.90	19.51	19.51	6.31	6.31	25.24	25.24	17.96	17.96	9.45	9.45
Other Veg.	732.42	732.42	803.83	803.83	1214.66	1214.66	610.07	610.07	683.06	683.06	306.27	306.27
Chilli	54.63	54.63	124.87	124.87	56.80	56.80	130.43	130.43	36.87	36.87	64.28	64.28
Ginger	39.02	39.02	-	-	88.35	88.35	-	-	28.36	28.36	-	-
Turmeric	1.95	1.95	-	-	0.00	0.00	-	-	2.84	2.84	-	-
Sugarcane	3.90	3.90	3.90	3.90	3.37	3.37	3.37	3.37	1.89	1.89	1.89	1.89
Wheat	-	-	15.61	15.61	-	-	18.93	18.93	-	-	17.01	17.02
Gram	-	-	7.80	7.80	-	-	4.21	4.21	-	-	11.34	11.34
Field Pea	-	-	46.82	46.83	-	-	42.07	42.07	-	-	37.81	37.81
Cow Pea	-	-	42.92	42.92	-	-	37.87	37.87	-	-	28.36	28.36
Mustard	-	-	234.12	234.13	-	-	155.67	155.67	-	-	109.65	109.65
Sunflower	-	-	15.61	15.61	-	-	12.62	12.62	-	-	5.67	5.67
Potato	-	-	35.12	35.12	-	-	29.45	29.45	-	-	39.70	39.70
Onion	-	-	109.26	109.26	-	-	117.81	117.81	-	-	60.50	60.50
Garlic	-	-	28.10	28.10	-	-	12.62	12.62	-	-	15.13	15.13
Corriander	-	-	70.24	70.24	-	-	61.00	61.01	-	-	24.58	24.58

Table 2: Optimal water resources allocation for the study area using SLP model

	Seasons							
	Kharif				*Rabi*			
Blocks	**SW⁻**	**SW⁺**	**GW⁻**	**GW⁺**	**SW⁻**	**SW⁺**	**GW⁻**	**GW⁺**
Dhankauda	7268.24	8550.87	377.44	2126.23	2565.93	3684.34	1173.62	1508.93
Maneswar	7836.82	9219.78	387.88	2292.56	2627.19	3762.86	1265.43	1626.98
Jujumura	3521.48	4142.91	251.15	1088.94	1714.15	2434.24	601.07	772.80

6. CONCLUSIONS

A generic formulation is developed for optimal land and water resources allocation. The formulation is utilizing Grey Linear Programming for solving the management model. The integrated land and water management framework model solution gives the optimal allocation range of land area, surface and groundwater in different block and season wise. The developed methodology is applied to the Hirakud sub-command area.

In Scenario, surface water and groundwater use are maximum for Kharif and Rabi season respectively. Rice cultivation significantly differs from maximum and minimum allowable area compared to other crops. In Rabi season optimum land area allocation shows the maximum area allocated for maximum profit and values are deterministic in nature. Results show that there is scope for increasing the cropping intensity in Rabi season. Thus some encouragement to the farmers (may be in terms of water cost reduction) can help in improving the situation. This limited evaluation results shows the potential applicability of the developed methodology for command area systems. However, more rigorous (inclusion of detailed physics based description of the system in terms of complex equations) evaluations are needed for actual application to the field.

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