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Research Article

Optimal Allocation of Water and Land Resources for Maximizing the Farm Income of Koga Irrigation Scheme

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ABSTRACT

The continuous increase of population accelerates the competition of scare water resource to address the food requirements. This study presented the formulation and application of linear programing model for the optimal allocation of land and water resources. The developed model was subjected to different constraint, which moderate water logging and deficit, while making optimal and equitable water resource allocation. The result indicated that application of the optimization approach for real-time irrigation water management can increase the benefit up to five folds over the observed treat. Taking in to consideration of the water and land resource, agricultural system, economics and social issues the optimal crop allocation of Koga irrigation scheme found to be 53% garlic, 21% onion, 9% potato, 11% maize, 5% wheat and 1% barley. So, Koga irrigation scheme can irrigate a designed 7000 ha irrigable land. The developed optimization approach is relatively easy to apply and thus, irrigation managers can use optimization approaches as an effective tool for irrigation planning and management.

Keywords: Linear programming; Optimization; Water balance; Koga dam

INTRODUCTION

Now a day water and land are a limited resource; moreover, degradation accelerates highs. Despite its limit and degradation crop production needs to be increase for the sustainable food supply for the growing global population, which is expected to be around 9.7 billion by 2050. This increase in global population requires about 60% more food to feed them in 2050. This goal can be achieved by either expanding agriculture in new areas or increasing production per uluvisol area [1].

Ethiopia is one of the top producers of agricultural crops in sub-Saharan Africa, while its productivity falling to more than 30 percent below the world average. It covers only 60 percent of its food demand. Indeed poor planning and management of irrigation schemes are critical that lead to social, economic and environmental crises. Low scheme performance of a region, which is less than 50%, is a good indicator for poor planning and management. Moreover, the climate change impacts, further limit the water availability. Therefore, it is imperative to optimize the limited resource to attain the desire goal.

The optimal allocation of water resources can be achieved by using an optimization model. These models evaluate various treats of water and land resources and select an optimal result based on sets of constraints. Application of optimization technique using water balance approach has been very popular because of its easy formulation and use and has been widely utilized across the world. For example H.R. Moradi utilizes a multi-objective optimal allocation model for irrigation water resources under multiple uncertainties. Qian Tan, et al. utilizes a multi-objective fuzzy-robust programming method for optimal use of agricultural water and land resources through reconfiguring crop planting structure under socioeconomic and ecological objectives. In recent times, H.R. Moradi, et al. use LP to optimization of land and irrigation water allocation based on water balance approach using linear programming [2].

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MATERIALS AND METHODS

Study area and data

Koga irrigation scheme is located in Mecha district, 41 kilometers from Bahir Dar on the way to Addis Ababa *via* Debre Markos road on 37°7'29.72" easting and 11°20'57.85" northing and at an altitude of 1953 m.a.s.l. The average annual rainfall of the area is about 1118 mm. The mean maximum and minimum temperature is 26.8°C and 9.7°C respectively. The soil type is generally light clay luvisol soil in its nature. The Field Capacity (FC) and permanent wilting point of the study area was 32 (%w/w) and 18 (% w/w) respectively [3]. The soil chemical properties of Koga were 4.6 pH, 0.92-2.88 exchangeable Al^{3+}, 0.62-2.35 H^{+}, 0.18-0.24 total N(%), 3.54-8.69 available P (ppm), 1.01 ECe (mmhos/cm) and 2.34-4.44 organic matter (%).

Koga irrigation scheme is a semi homogenous earth fill dam in the upper Blue Nile basin, Ethiopia. This dam has a maximum storage capacity of 83.1 Mm^3 and designed with 80 percent probability of 72.44 Mm^3 to irrigate 7000 ha. It consists of 22000 ha catchment area, 19.7 km long main canal and 12 individual irrigation command areas serviced by 12 Secondary Canals (SC), 95 territory canals and 11 Night Storage Reservoirs (NSR) supplied by the MC. The dam consists of 2000 m original ground level, 2006.1 m dead storage levels, 2015.25 m spill way crest level and 2020 crest level of dam [4].

Model formulation

The model was formulated to optimal allocation of available water and land resources in order to maximize net farm revenue and keeping equity among users. The model consists of objective function and set of constraint. Meanwhile, the developed mathematical model for irrigation planning was solved using excel optimization solver. The model describes as follows [5].

Sensitivity analysis

Sensitivity analysis of the model was performed to test its effectiveness in maximizing the net annual return. The selected input parameters chosen for sensitivity analysis were: Irrigation release, storage volume, cost of production and market price of crops. The market price and cost of production were increased by 10%, 20% and 30% from the existing values, while irrigation releases and stored water were reduced by 10%, 20%, 30% and 40% of the existing values [6].

Model inputs determination

The model inputs consisted of irrigation requirement of crops, water flow, cost of production and variable cost (excluding land and water cost). Description of different input parameters is as follows.

Irrigation requirement: Water requirement of the crop was estimated using crop wat 8.0, which was verified by Adet agricultural research center. The net water requirements of various crops are presented in Table 1. The Gross Irrigation Requirement (GIR) of each crop is calculated as net irrigation requirement of the crop over project efficiency. Project efficiency is estimated by multiplying field channel efficiency and application efficiency. The field measurement result showed that the overall irrigation efficiency of the scheme was 0.45, which was 0.6 application efficiency and 0.75 conveyance efficiency [7].

Table 1: The crop water requirements of the scheme in mm.

	Jan	Feb	Mar	Nov	Dec
Precipitation deficit					
Garlic	136.2	150.9	161.2	2.8	91.2
Onion	136.2	150.9	161.2	2.8	91.2
Potato	171.4	144.4	0	21.6	94.9
Maize	173.2	167.3	10.1	13	69
Wheat	152.3	166.5	58.9	13	48.8
Barley	173.3	157.1	53.4	13	97.1
Net scheme irr.req.					
In mm/day	4.7	5.5	4	0.2	2.8
In mm/month	144.6	153	123.9	6.2	87
In l/s/h	0.54	0.63	0.46	0.02	0.32
Irrigated area (% of total area)	100	100	91	100	100
Irr.req. for actual area (l/s/h)	0.54	0.63	0.51	0.02	0.32

Production cost: The total cost of production and farm get prices of each crop were collected from Koga irrigation project office and stakeholders in 2017/18 G.C. The production costs are the summation of all costs such as seeds, fertilizers, pesticides, labor, harvesting, etc [8]. The farm get prices were based on average price of the area. The net benefit of individual crops was determined by the developed production functions and prices of grain. It is presented in Table 2.

Table 2: Farm get prices of grain yield, straw and the variable cost of productions.

Market price (birr/ha)			
Crop	Grain	Straw	Variable cost (birr/ha)
Garlic	270000		17640
Onion	101750		73440
Potato	104000		17840
Green cob maize	29000	3000	8830
Wheat	21900	3500	9460
Barley	13900	5950	4730

Data on irrigation water release and irrigable land

The data on water level, volume of storage, crop allocation and irrigable land were acquired from Koga irrigation scheme management office. Irrigation was applied mainly by furrow method. The distribution of the available canal water was regulated by water user association. The operation and maintenance of the canal network was being monitored by Abay basin authority. The discharges through the canal were measured through stage measurements [9]. The average daily discharges through main canal were recorded between 300 and 6500 l/s and it runs around 5 to 6 months in each cropping season. Crop allocation, water flow, water level and irrigable land data describe in Table 3.

Table 3: Monthly water flow from dam to main canal.

Month	Oct-18	Nov-18	Dec-18	Feb-19	Mar-19	Apr-19	Total
Flow (m^3)	584766	5569740	34540320	14985562.8	11458080	3805560	70944029

RESULT AND DISCUSSION

Model application

The formulated linear programing model was applied to allocate water and land resource to maximize the net benefit and maintain equity. Excel solver was used to solve the optimization model. A total of 11 crops, existing cropping pattern, were considered for the model. The model gave minimum benefit with 11 crops at the inception and maximum benefit with sole crops at the last. Since the model didn't impose any constraint, the model gives maxima at a sole crop, while the cropping practice doesn't encourage. Felix dictates optimizing water use at farm level requires careful consideration of the implications of decisions made during both development and management, taking into account technical, economic and environmental issues. Then the model imposed maximum and minimum constraint to balance agricultural system. Take in to consideration of land and water resource, agricultural system, economics and social issues the model gives five crops (53% garlic, 21% onion, 9% potato, 11% maize, 5% wheat and 1% barley) to be produce in Koga irrigation scheme [10].

Optimal crop and land allocation

The comparison of area coverage for optimal, design and observed is present in Figure 1. Despite the design the observed irrigable land increase wheat area significantly followed by potato, onion and cabbage, etc. The maximum net benefit was achieved by increasing of garlic and decrease of wheat and maize. Even though garlic was not proposed during planning phases it ranks first in the optimization process, the suitability and water requirement of garlic is in line with the onion. Despite the least benefit wheat and barley was considered for social interest.

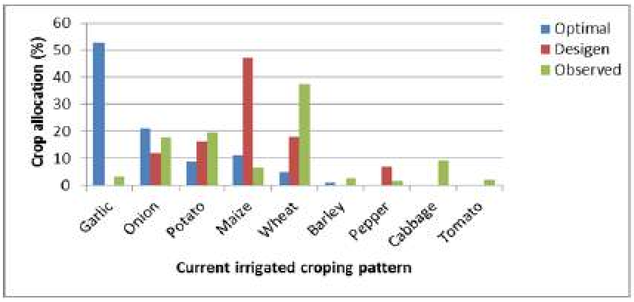

Figure 1: Comparison of observed, designed and optimization approach of crop allocation.

Optimal water allocation

The water allocation was done using backward recursion system and the water allocation from main canal to secondary canal and then to the tertiary canal is presented in Tables 4 and 5.

As shown in Table 4, the total water requires irrigating the crop was below the storage level of the dam. This implies the stored water was sufficient enough to irrigate the design command area for a given crop. The result is in line with the finding of dictates that the reservoir water is sufficient enough to meet 100% irrigation demand for design command areas of 7,000 ha. Moreover during hydrological drought the total water required to irrigate the crop was below the record level of the dam during hydrological drought period as well as below 80 percent probability of storage capacity [11].

As shown in Table 4 above there is a chance of occurring hydrological drought, so water productivity is very important to cope up the problem. Alternative furrow irrigation method is a first to increase water productivity with a minimum yield loss and also have a merit of expanding irrigable land by saving water. The method saves up to 40% to 50% of irrigation water by reduction of 15% yield.

Table 4: Maximize optimal water allocation from main canal to secondary canal.

Optimal water allocation for maximum benefit (Mm^3)							
	Irrigable land (ha)	Jan	Feb	Mar	Nov	Dec	Total
Kudmi	373	1.2	1.27	0.93	0.05	0.72	4.17
Chona	617	1.98	2.1	1.55	0.09	1.19	6.9
Ambo	812	2.61	2.76	2.03	0.11	1.57	9.09
Adbera	803	2.58	2.73	2.01	0.11	1.55	8.99
Tagele	616	1.98	2.09	1.54	0.08	1.19	6.89
Inguti	393	1.26	1.34	0.98	0.05	0.76	4.4
Laci	484	1.56	1.65	1.21	0.07	0.94	5.42
Bered	468	1.5	1.59	1.17	0.06	0.9	5.24
Andenet	497	1.6	1.69	1.25	0.07	0.96	5.56
Amarit	290	0.93	0.99	0.73	0.04	0.56	3.25
Tsleta	787	2.53	2.68	1.97	0.11	1.52	8.81
Tekledeb	864	2.78	2.94	2.16	0.12	1.67	9.67
Total	7004	22.51	23.81	17.55	0.96	13.54	78.37
Dam storage at 80% probability							72.44
Dam full capacity							83.1

Table 5: Equity optimal water allocation from main canal to secondary canal.

Water allocation for maintain equity up to 40% deficit (m^3)							
	Irrigable land (ha)	Jan	Feb	Mar	Nov	Dec	Total
Kudmi	373	0.72	0.76	0.56	0.03	0.43	2.5

Chona	617	1.19	1.26	0.93	0.05	0.72	4.14
Ambo	812	1.57	1.66	1.22	0.07	0.94	5.45
Adbera	803	1.55	1.64	1.21	0.07	0.93	5.39
Tagele	616	1.19	1.26	0.93	0.05	0.71	4.14
Inguti	393	0.76	0.8	0.59	0.03	0.46	2.64
Laci	484	0.93	0.99	0.73	0.04	0.56	3.25
Bered	468	0.9	0.95	0.7	0.04	0.54	3.14
Andenet	497	0.96	1.01	0.75	0.04	0.58	3.34
Amarit	290	0.56	0.59	0.44	0.02	0.34	1.95
Tsleta	787	1.52	1.61	1.18	0.07	0.91	5.28
Tekledeb	864	1.67	1.76	1.3	0.07	1	5.8
Total	7004	13.5	14.29	10.53	0.58	8.12	47.02
Dam storage at 80% probability							72.44
Dam full capacity							83.1

Sensitivity analysis

The results of the sensitivity analyses revealed that the variation in the market price of crops had a great influence on the net annual return, followed by irrigation release, stored water and cost of cultivation. The result is in line with Singh.

Net annual benefit

As shown in Figure 2 the net annual benefit from command area had increase in to ETB 1.05 billion through optimization. It increases by five folds than both observed and design [12]. The farmer and investors should concentrate to produce marketable crops to achieve the desired benefit. Despite the availability of adequate water resource, the observed irrigable land was much less than the design.

Moreover the cropping pattern grown in the command area was less preferable, low irrigation water requirement and minimum management than marketable crops; which implied poor support and advisory service of Koga irrigation scheme. Despite the reduction of 40%irrigation water the net benefit was quite 4 fold than design and observed treats. In conclusion, the irrigated land in 2017/18 was below the optimal value and the irrigation water was mismanaged. Therefore, with optimal crop planning and water management, the design command area of 7000 ha could be irrigated [13].

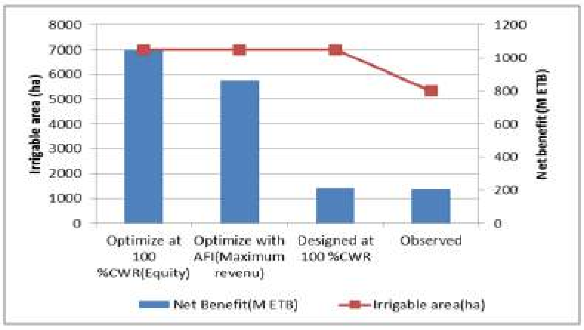

Figure 2: Comparison of treats against optimization approach.

CONCLUSION

The developed linear programing model is applied to allocate water and land resource and imposes different constraints. Despite the presence of adequate water resource in the dam, the observed irrigated land area and cropping pattern is none of the desired goal. Taking in to consideration of the agricultural system, economics and social issues the optimal crop allocation of Koga irrigation scheme find to be 53% garlic, 21% onion, 9% potato, 11% maize, 5% wheat and 1% barley. The results indicate that application of the optimization approach for real-time irrigation water management can increase the benefit under a given crop production.

So Koga irrigation scheme can irrigate a designed 7000 ha irrigable land for a given crop allocation as far as the water resource and the manager is there. The developed optimization approach is relatively easy to apply and thus, decision makers and water authorities can use optimization approaches as an effective tool for irrigation planning and management. On the basis of new data and future cropping pattern, the optimization will be examined and modified.

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REFERENCES

1. Birhanu KT, Alamirew T, Olumana MD, Ayalew S, Aklog D. Optimizing cropping pattern using chance constraint linear programming for Koga irrigation dam, Ethiopia. Irrigat Drainage Sys Eng. 2015;4(134):2.
2. Cosgrove WJ, Loucks DP. Water management: Current and future challenges and research directions. Water Resour Res. 2015;51(6): 4823-4839.
3. Gerten D, Heinke J, Hoff H, Biemans H, Fader M, Waha K. Global water availability and requirements for future food production. J Hydrometeorol. 2011;12(5):885-899.
4. Enchalew B, Gebre SL, Rabo M, Hindaye B, Kedir M, Musa Y, et al. Effect of deficit irrigation on water productivity of onion (*Allium cepa* L.) under drip irrigation. Irrigat Drainage Sys Eng. 2016;5(172):2.
5. Reinders FB. Irrigation methods for efficient water application: 40 years of South African research excellence. Water SA. 2011;37(12): 765-770.
6. Guo P, Chen X, Li M, Li J. Fuzzy chance-constrained linear fractional programming approach for optimal water allocation. Stoch Env Res Risk A. 2014;28:1601-1612.
7. Moradi HR, Jalili K, Bozorg Hadad O. Optimization of land and irrigation water allocation based on water balance approach using linear programming. Water Soil. 2017;31(2):372-385.
8. Li M, Guo P. A multi-objective optimal allocation model for irrigation water resources under multiple uncertainties. Appl Math Model. 2014;38(19-20):4897-4911.
9. Tan Q, Zhang S, Li R. Optimal use of agricultural water and land resources through reconfiguring crop planting structure under socioeconomic and ecological objectives. Water. 2017;9(7):488.
10. Singh A. Optimizing the use of land and water resources for maximizing farm income by mitigating the hydrological imbalances. J Hydrol Eng. 2014;19(7):1447-1451.
11. Singh A. Computer-based models for managing the water-resource problems of irrigated agriculture. Hydrogeol J. 2015;23(6):1217.
12. Singh A, Panda SN, Saxena CK, Verma CL, Uzokwe VN. Optimization modeling for conjunctive use planning of surface water and groundwater for irrigation. J Irrig Drain Eng. 2016;142(3):04015060.
13. Xie YL, Xia DH, Huang GH, Li W, Xu Y. A multistage stochastic robust optimization model with fuzzy probability distribution for water supply management under uncertainty. Stoch Env Res Risk A. 2017;31:125-143.