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Proper water management is becoming a must since shortage started to cause serious problems in Koga Dam, which is a large-scale irrigation scheme in the upper Blue Nile. Finding optimal solutions under high demand and limited irrigation is complex and requires the use of optimization models. Therefore, the application of efficient water management and resource allocation technique is pertinent. This study aims to maximize the net revenue of the Koga irrigation scheme under alternative deficit irrigation techniques. Linear programming model was applied to allocate land and water resource thereby maximizing net return in the Koga irrigation scheme using five different scenarios i.e., Full irrigation, Regulated Deficit Irrigation (10 %, 20 %, and 30 %), and Alternative Furrow Irrigation (AFI). The study was subjected to available water, total area, and non-negative constraints. Microsoft excel solver function was used for optimization technique and CROPWAT 8.0 model was used for estimation of crop and irrigation water requirement. The study revealed that the maximum net benefit of $ 23.12 million was obtained using Scenario V (Alternative Furrow Irrigation). It improved the farm revenue by 81 % from existing practice, 37 % from full irrigation and 36% from 20 % regulated deficit irrigation. Moreover, this technique creates a chance to irrigate additional land of 2,159 ha over the existing practice, 2,882 ha over full irrigation, and 1,517 ha over 20 % regulated deficit irrigation concerning regional limitations and water availability. Therefore, using Alternative Furrow Irrigation and using appropriate cropping patterns enables irrigating 8341 ha with maximum net benefit.

Alternative furrow irrigation, Koga, Linear programming, and Deficit irrigation

Access to water provides a basis for livelihoods, culture, and progress otherwise it creates social instability and potentially violent conflicts (Smit and Wandel 2006). The increasing world population and expansion of irrigated agriculture are the major factor for global water stress (Vorosmarty et al 2000; Ercin et al 2014). Moreover, the water resource is highly variable both spatial and temporal (Ayalew 2018). Besides, most irrigation schemes adopt flood irrigation systems, which is poor in water use efficiency. Realizing the importance of irrigation agriculture, the Ethiopian governments start to invest in irrigation infrastructure development (Abate 1994).

Koga large dam and irrigation project is one of the infrastructures located in the Blue Nile Basin, Ethiopia. The irrigable potential of the Koga irrigation scheme is 7583 ha (Mac Donald 2006, unpublished). However, the actual irrigable area for the last five years (2014 to 2019) ranges from 3620 ha to 6182 ha of land with more than twelve cultivated crops (Koga irrigation management office report 2020, unpublished). This reveals that the released water from the reservoir was either not sufficient, poor cropping patterns, or mismanaged water to cultivate the irrigable land. Improved agricultural water management practices and techniques are essential for the improvement of farm profitability and water productivity in the period of limited water supplies (Ali 2010). Effective water resource allocation saves water and increases the farm gate revenue. To optimize irrigated agriculture and crop productivity, optimization is pertinent in a water-limiting environment (Faisal 2009; Chartzoulakis and Bertaki 2015). Therefore, under such conditions more efficient water management (deficit irrigation) methods and optimization techniques must adapt.

Deficit irrigation is a strategy to increase water use efficiency (Fereres and Soriano 2007). In principle, there are two deficit irrigation techniques, regulated deficit irrigation (RDI) where a reduced amount of water is applied uniformly to the root zone, and alternative furrow irrigation (AFI), where water is applied on a reduced area of the root zone. The feasibility of deficit irrigation was studied extensively in different crops and found a remarkable result of water-saving with insignificant yield reduction (Bogale et al 2016; Hassene and Seid 2017; Eba 2018). Though drip and sprinkler irrigation have higher water-saving potential compared to furrow irrigation, AFI is inexpensive, easy to implement, and avoids the cost associated with investment and management (Casa and Rouphael 2014).

Linear programming technique (LP) has a wider application for optimum allocation of natural resources in irrigated areas due to its simplicity in usage (Reddy et al 2002). Dires (2019); Tewabe and Dessie (2020) apply the LP model to enhance water productivity with nine crops under different levels of regulated deficit irrigation. Birhanu et al (2015) also apply the LP model to develop a rule curve with five crops under different inflow probability expedience. However, the contribution of those studies is limited because the study did not consider the scheme already design under deficit irrigation and the system already implemented in the scheme. In the main time, the investigators did not catch there was a problem in irrigation duration. Moreover, the dynamics of the market, cropping pattern, and climate uncertainty need up-to-date modification of the existing practice with an introduction of high-value crops to the farmer. Therefore, this study aims to maximize the net revenue of the Koga irrigation scheme under alternative deficit irrigation concerning regional limitations and water availability using linear programming.

Koga irrigation scheme is located in the Mecha district. It is 41 km far from Bahir Dar on the way to Addis Ababa which is the capital city of Ethiopia (Figure 1). The Koga catchment lies between 37° 02' 29.72" to 37° 11' 19.12" Easting and 11° 20' 57.85" to 11° 32' 17.81" Northing. The average annual rainfall of the area is about 1,431 mm. The mean maximum and minimum temperatures is 26.8 ^{0}C and 9.7 ^{0}C respectively. The soil type is generally light clay luvisols. The average field capacity and permanent wilting point of the study area were 32 to 45.4 and 18 to 30.6 (%) respectively (AARC laboratory report,unpublished). Koga irrigation scheme is a semi-homogenous earth-fill dam to irrigate 7,000 ha of land that has a maximum storage capacity of 83.1 million m^3 and designed with an 80 % probability of inflow storage capacity of 72.44 million m^3 (Mac Donald 2008, unpublished). It consists of a 22,000 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 main canal (MC) (MacDonal 2008, unpublished). The dam was constructed on 2,000 m original ground level, 2006.1 m dead storage levels; 2015.25 m spillway crest level, and 2020 crest level of the dam (Mac Donald 2006; Mac Donald 2008).

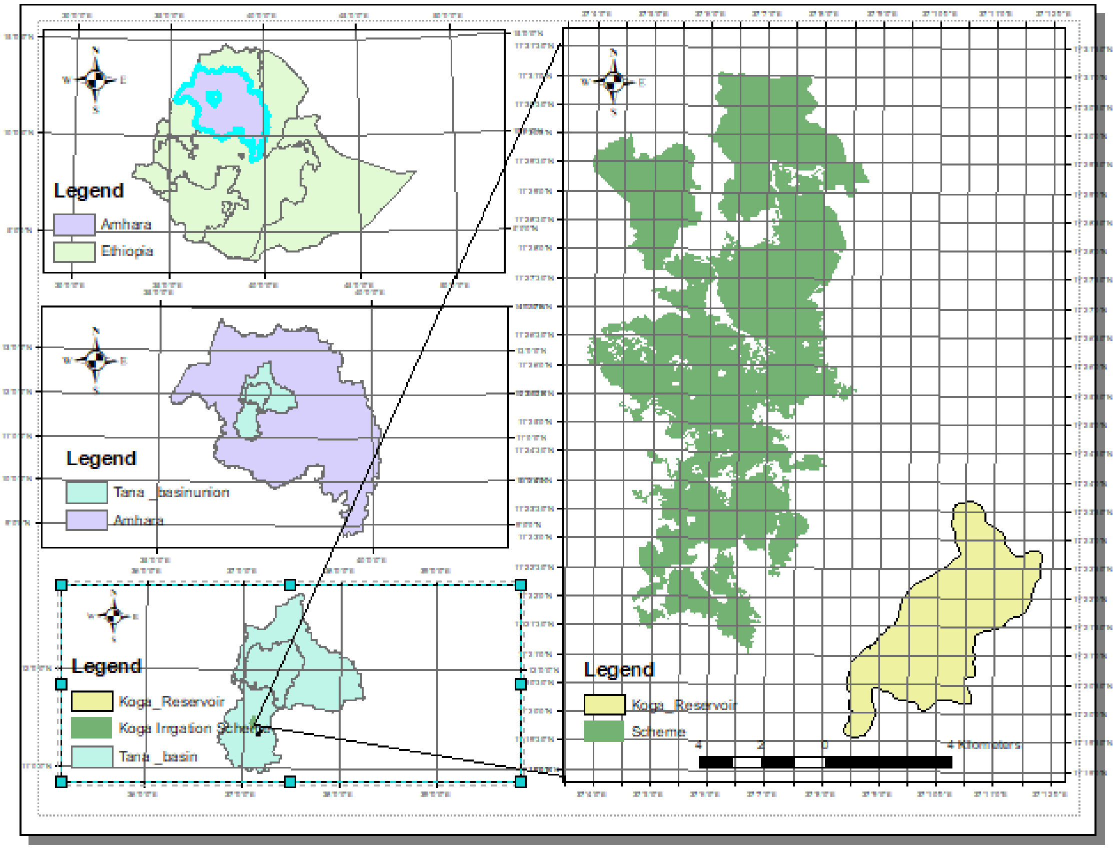

Figure 1. Location of the study area

Primary data such as conveyance efficiency was measured using a current meter and measuring tape. Besides, application efficiency was also measured using RBC flume. Secondary data such as irrigation water release, area of irrigated, cropping pattern, agricultural input, length of the growing period, and farm gate price were collected from the Koga irrigation and water management office and direct interviews with clients (Table 1). Both primary and secondary data helps to determine scheme efficiency, set new water allocation, and cropping pattern trend. Besides, it helps as a benchmark to maximize the scheme revenue.

The study area has only temperature and rainfall data records. Hence temperature and rainfall data were taken from the site while the remained from Bahir Dar, Adet, and Dangla metrological station using the Thiessen polygon method (Table 2).

Table 1: Maximum yield, Production cost, Farmgate price, and cultivated area for 2019/2020

Crop	Maximum yield (t or cob no ha^{-1})	Production cost (\$ha^{-1})	Farm gate price (\$t^{-1})	Cultivated Area (ha)
Wheat	3	287	221	3,216
Barley	3	143	201	166
Green Maize	5,453	268	0	524
Pulses	3	287	303	7

Potato	25	541	158	1,114
Cabbage	38	395	73	201
Tomato	37	407	86	79
Melon	44	268	303	17
Garlic	8	2,225	667	76
Onion	24	480	303	488
Pepper	8	287	222	280
Avocado	15	909	303	13
Total				6,182

Table 2: Munthly average climate data of the study area

Month	Min Temp °C	Max Temp °C	Humidity %	Wind m/s	Sun hours	Rad MJ/m²/day	ETo mm/day	RF mm
January	7.5	27.4	51	0.7	9.8	21.3	3.69	1.5
February	9.2	29.3	45	0.8	9.8	22.8	4.25	1.8
March	12.0	29.5	42	0.9	9.1	23.1	4.62	13.9
April	13.3	29.8	43	1.0	8.8	23.1	4.85	26.8
May	14.4	28.9	53	0.8	8.6	22.4	4.57	72.8
June	14.0	26.6	67	0.8	6.7	19.2	3.91	191.3
July	13.7	24.0	76	0.7	4.4	15.9	3.17	438.7
August	13.6	24.0	77	0.5	4.3	15.9	3.11	397.3
September	12.9	25.1	72	0.7	5.9	18.2	3.51	193.2
October	12.5	26.2	63	0.5	9.0	21.9	3.93	81.7
November	10.4	26.3	57	0.6	9.5	21.2	3.71	9.9
December	7.9	26.2	54	0.5	10.0	21.0	3.44	4.5

The model was formulated for the optimal allocation of available water and land resources to maximize net farm revenue. The model consists of an objective function and a set of constraints. Meanwhile, the developed model was solved using a Microsoft Excel Solver function. The study considered that land and water were the only limitations for optimal allocation. The input and output cost of crop productions (including fertilizer, labor, and pesticide) were considered during the formulation of the model. "Besides, this study considers the reduction of yield that comes due to water stress does not affect the market price of the crops".

The response of yield to the water supply for regulated deficit irrigation is quantified through the yield response factor (ky) which relates relative yield decrease to relative evapotranspiration deficit. It is assumed that the relationship between the relative yield and the relative evapotranspiration is linear and valEMlaor wat31(It) f4(iraf)-4(t)-6toesps(availa)950hat %d

(Doorenbos and Kassam 1979). On the other hand, the response of yield to the water supply for alternative furrow irrigation quantified on average as 10 % yield reductions with 35 % of water-saving, which were generated from local field experimental results of wheat, maize, potato, tomato, and onion (Bogale et al 2016; Hassene and Seid 2017; Eba 2018).

Crop and irrigation water requirement was estimated using CROPWAT 8.0 software model. Due to a lack of locally validated values, data of crop coefficient (Kc) for estimation of crop water requirement, the yield response factors (Ky) for each growth stage, and length of the growing period were adopted from (Doorenbos and Kassam 1979; Allen et al 1998) The model has developed using five different agricultural water management including scenario I (Full irrigation), scenario II (90 % crop water requirement), Scenario III (80 % crop water requirement), Scenario IV (70 % crop water requirement) and Scenario V (Alternative furrow irrigation method with 60 % crop water requirement).

The objective function was to maximize the total net benefits and is given by equation (1)

$$R = Max\sum_{i=1}^{n}(PnYa - Cn)An ---------------------------1$$

Where, R is the objective function (maximized revenue), P_n is the price of the crop in Ethiopian Birr (ETB), Y_a is actual yield under crop n (t ha^{-1}), n is the number of crops, A_n cultivated area under crop n (ha) and C_n production cost under crop n (ha).

The model subjected to the following constraints

Water availability constraint

The gross water required for all irrigated crops should not exceed the total water available for irrigation. From field measurement, the overall project efficiency of the scheme was 0.42 and the water availability constraint was determined using equation 2 below. The average water released from the reservoir during the study period was 72.4 million meters cubic for the last five years. The operation of the reservoir water mostly started in November and was released through irrigation off-takes.

$$\sum_{i=1}^{n}(GIRi * Ai) \leq \ Rwr ---------------------------2$$

Where, GIR is the gross irrigation requirement for crop i, Ai is the area for crop i, Rwr is the average released water from the reservoir.

The crop area restrictions are considered based on the general cropping pattern in the region; which is 60 % of vegetables, 25 % of cereals or food crops, 10 % of oil and fiber crops, and 5 % of fruit crops (MOA 2018). The selection of these crops is based on their productivity in the area and the farmer’s preference for the crops. Therefore, the area allocated to each crop should be less than or equal to the maximum allowed land in the cropping pattern and mathematically expressed as;

$$Ai \leq Amax ------------------------------ 3$$

Where, *Amax* is the maximum allowed area of crop.

All parameters should be greater than or equal to zero.

$$Ai, GIR, Rwr \geq 0 ------------------------------ 4$$

As shown in Table 3, the irrigable land increase is proportional to the increment of scenarios. Scenario III, Scenario IV, and Scenario V have 643 ha, 1571 ha, and 2159 ha area advantage while Scenario I and II have (-722 ha) and (-122 ha) disadvantages as compared to the existing practice respectively. This is attributed to the high water requirement of the two scenarios. As shown in the table the available water was not sufficient to irrigate the potential area of the scheme. Birhanu et al(2014), reported that the reservoir water is not sufficient to meet 100 % irrigation demand for entire command areas and a need to introduce deficit irrigation.

Consequently, applying deficit irrigation techniques in the scheme shows improvement on the total irrigable land as well as the crop area. The finding is in line with Dires (2019); Dires and Mekete (2020), reported that deficit irrigation has the potential to irrigate more land with a better net benefit and water productivity.

The area of Fruit, vegetable, and pulse increase with the increment of the scenarios while not wheat, barley, and green maize as shown in Table 3. This might be due to the enterprise choice and the water productivity of the crop. The finding is in line with Dires and Mekete (2020), who reported that adopting high yielder and cash crop cultivars has the potential to increase water productivity with a better net benefit.

Table 3: Area allocation under different crops for different scenarios

Crop	Actual irrigated land	scenario I	scenario II	scenario III	scenario IV	scenario V
Wheat	3216	1124	1247	1405	1596	1717
Barley	166	58	64	73	82	89
Green Maize	524	183	203	229	260	280
Pulses	7	546	606	682	775	834
Potato	1114	1623	1802	2029	2305	2480
Cabbage	201	293	325	366	415	447
Tomato	79	115	128	144	164	176
Melon	17	25	28	32	36	39
Garlic	76	110	123	138	157	169

Onion	488	701	778	876	995	1070
Pepper	280	409	454	511	580	624
Avocado	13	273	303	341	388	417
Total area (ha)	6182	5460	6060	6825	7753	8341

As shown in Table 4, all scenarios show positive net benefit as compared to existing practice. Scenario I, II, III, IV, and V give a net benefit increment of 31.6 %, 31.9 %, 32.5 %, 32.4 %, and 80.9 % as compared to the existing practice. This remarkable result (80.9 % increment) indicated that Scenario V is the prior option in water-saving with minimum yield reduction as compared to other scenarios. Bogale et al (2016); Hassene and Seid (2017); Eba (2018) state a similar report, alternative furrow irrigation improves water productivity as compared to the regulated deficit and full irrigation technique. Despite the positive net benefit of scenario IV, the incremental increase turns down. This decrement is due to the reason that as the deficit level is increased the yield loss significantly increased. The result is in line with Dires and Mekete (2020), who reported that deficit irrigation gives a better net benefit and water productivity. Unlike the area of irrigable land size, Scenario I and II show a better net benefit as compared to existing practice. This is due to the choice of the cropping pattern. Nimah et al (2003) state a similar report, available irrigation water increases the cropping pattern tends to have few field crops, more vegetable and high-water consuming trees.

Based on the area of the land and maximum net benefit a given cropping pattern for the monthly scheme supplies of Koga irrigation scheme is present in (Table 5). The variation of the released volume of water is due to the variation of irrigation water requirements at the different growth stages and the amount of water harvested in the reservoir. The new water allocation presented below (Table 5) can use for the water release schedule for the Koga irrigation scheme for maximum net benefits using alternative furrow irrigation.

Table 4: Net benefit for different scenarios

crop	Existing practice	scenario I	scenario II	scenario III	scenario IV	scenario V
Wheat	2.11	0.74	0.72	0.71	0.68	1.01
Barley	0.09	0.03	0.03	0.03	0.03	0.04
Green Maize	0.86	0.3	0.29	0.28	0.27	0.41
Pulses	0.01	0.52	0.54	0.55	0.56	0.72
Potato	4.28	6.24	6.37	6.55	6.72	8.57
Cabbage	0.55	0.80	0.8	0.81	0.81	1.10
Tomato	0.25	0.36	0.36	0.36	0.35	0.50
Melon	0.23	0.34	0.33	0.33	0.33	0.46
Garlic	0.37	0.54	0.54	0.53	0.51	0.75
Onion	3.49	5.01	4.95	4.88	4.76	6.89

Pepper	0.48	0.70	0.69	0.68	0.67	0.97
Avocado	0.06	1.23	1.23	1.23	1.22	1.69
Total benefit (M $)	12.78	16.82	16.86	16.94	16.92	23.12

Table 5: Water allocation using alternative furrow irrigation

Crop		Jan	Feb	Mar	Apr	Jun	Oct	Nov	Dec
Wheat		74	102	96	11	0	0	1	39
Barley		103	102	65	0	0	0	1	63
Green Maize		92	108	90	4	0	0	1	48
Pulses		93	101	44	0	0	0	2	60
Potato		88	101	109	22	0	0	2	67
Cabbage		65	79	108	107	0	0	3	90
Tomato		64	95	120	103	0	0	0	55
Melon		63	91	106	22	0	0	0	46
Garlic		83	92	98	0	0	0	3	91
Onion		73	91	108	26	0	0	0	64
Pepper		63	90	110	59	0	0	0	55
Avocado		72	79	105	110	14	31	35	56
Net scheme IWR	mm day^{-1}	4.2	5.7	5.2	1.6	0.0	0.1	0.1	2.0
	L s^{-1} h^{-1}	0.5	0.7	0.6	0.2	0.0	0.0	0.0	0.2
Irrigated area (%)		100	100	100	87	5	5	77	100
Water release (Mm3)		15.8	19.3	19.5	5.1	0.01	0.02	0.4	12.1

The available water in the Koga reservoir is not sufficient to irrigate the entire command area. Therefore, the adoption of efficient water management and resource allocation techniques is very important for the optimal allocation of water and land. The result revealed that Scenario V (Alternative furrow irrigation) maximizes the net benefit of Koga irrigation scheme as compared to the regulated deficit and full irrigation technique. Alternatively, scenario III, 20 % deficit irrigation gives a better net benefit and water productivity next to Scenario V. Moreover, the choice of the cropping pattern and farm gate price improve the net benefit against the area of irrigable land size with poor cropping pattern and farm gate price. The principle of deficit irrigation technique is to improve water productivity and use the saved water to irrigate additional land and thereby increase benefit. Scenario II to IV, 10 to 30 % regulated deficit irrigation, increases the irrigable land size in the range of 11 to 43 % as compared to Scenario I (Full irrigation). Similarly, Scenario V (Alternative furrow irrigation) increases the irrigable land by 53 %. Linear programming is relatively easy to apply and thus decision-makers and scheme managers could adopt these agricultural water management options during the planning and real-time management.

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