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Irrigation Efficiency Performance Assessment of Modern Spate Irrigation Scheme: In Case of Kobo Woreda, North Wollo, Ethiopia

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Abstract

Spate irrigation is form of water management that is unique to arid and semi- arid area where floods are diverted in to cultivated crops by constructing diversion weir across the river. The general objective of the study was Assessments of irrigation efficiency Gobu-I and Gobu-II modern spate irrigation schemes. To achieve the study primary data were collected which includes measurement of soil moisture contents before and after irrigation, measurement of field discharge. The parameters used to compare the efficiencies at the farm field levels were application, storage and distribution uniformity efficiency. The application efficiencies of Gobu-I was 62.75, 72.61 and 77.56% and for Gobu-II was 57.88, 66.12 and 70.14%. The storage efficiencies of Gobu-I schemes were 89.06, 88.71 and 87.8% and for Gobu-II schemes were 90.97, 89.81 and 88.1%. Distribution efficiency for Gobu-I scheme were 92.65, 87.67 and 96.38% and For Gobu-II schemes were 85.05, 89.95 and 95.03% in the head, middle and tail field respectively. Application efficiencies of both schemes were not good because of it's under limit but storage and distribution efficiencies were good. By strengthening the capacity of DA's and farmer's frequent evaluation and follow-up are critical to maintain sustainable performance of the modern spate irrigation schemes.

Keywords: Field Evaluation • Irrigation Performance Efficiency • Modern Spate Irrigation • Soil Moisture • Gobu-I and II

Introduction

General

Irrigation is the process of supplying water, in addition to natural precipitation, to field crops, orchards, vineyards, or other cultivated plants. Irrigation water is applied to ensure that water available in the soil is sufficient to meet crop water need.

Much of the eastern, southern and northern parts of the country very often receive insufficient and/or unpredictable rain. However, considering the current situation with growing population pressure in the highland areas and a rapidly declining natural resource base has necessitated irrigated agriculture and in line with this irrigation is given prime attention on the country's development agenda [1]. Spate irrigation is diversion of flood water by construction weir across in modern on the ephemeral river for irrigation purposes. Under the guise of 'modernization' extensive civil engineering investments have been made in the head works of spate irrigation systems in Yemen and to a lesser degree in Morocco, Pakistan, Eritrea and Ethiopia. Also in some systems a sedimentation pond was part of the head works, designed to avoid coarse sediments going into the command area. Because such modernized head works are costly, in many cases, a traditional system with multiple off-takes from the river was replaced by a single diversion structures supplying a newly-built long flood channel [2]. Poor management in modern spate irrigation water is one of the principal reasons for low water efficiency in irrigation systems. However due to water resource become scarce, more emphasis is given to efficiency use of irrigation water for maximum economic return and water resources sustainability. This requires measuring and evaluating how efficiently water is extracted from a water source to produce crop yield.

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Materials and Methods

General Description of the Study Area

The study was caring out at two modern spate irrigation schemes in the Amhara National Regional State (ANRS) specifically in North Wollo Administrative Zone (NWAZ) of Kobo Rural Woreda. The land use and the vegetation pattern of the study area are greatly influenced by its semi-arid to arid or dry Kolla (Dry hot) agro-climatic conditions. The rainfall in the area is uni-modal rainfall pattern; although bimodal-like rainfall but with very little and unreliable belg (spring) rainfall exist in the peak mountainous areas of the woreda. The main season; locally referred to as Kremt (summer), spreads from July to August and this are the period when much of the rainfall events occur. The minor season, the Belg (spring) happens from February to April. The mean annual rainfall that the project area received is 499.5mm. The dominant agriculture practiced in this area is rained agriculture, mainly supplemented by spate irrigation.

- **Gobu-I and II Modern spate irrigation scheme:** Gobu-I and II spate irrigation project is situated in North Wollo Zone Kobo woreda along the border of Tigray region specifically in Amaya Kebele, 12 km from kobo town along with main road Kobo to Alamata having dry weather road to the head work site. The geographical location of the Gobu-I is located at longitude: 1352399.8040 UTM m, latitude: 559561.1430 UTM m and 1589.47m Elevation and the headwork site of Gobu-II is located at Latitude: 561408.005 UTM m, Longitude: 1354474.0394 UTM m and Altitude: 1531.37m. Even though the two spate irrigation scheme is designed on no perennial river, the scheme is using both spate during Belg or spring time and supplementary irrigation in summer until the river flow ends after the main rainy season. Although the project area of this spate irrigation scheme is around kobo town the source of water is from upstream catchment flood flow (i.e., Gidan woreda peak highlands) which shown in (Figure 1).
- **Crop production: Gobu-I :** Different crops were grown on the command

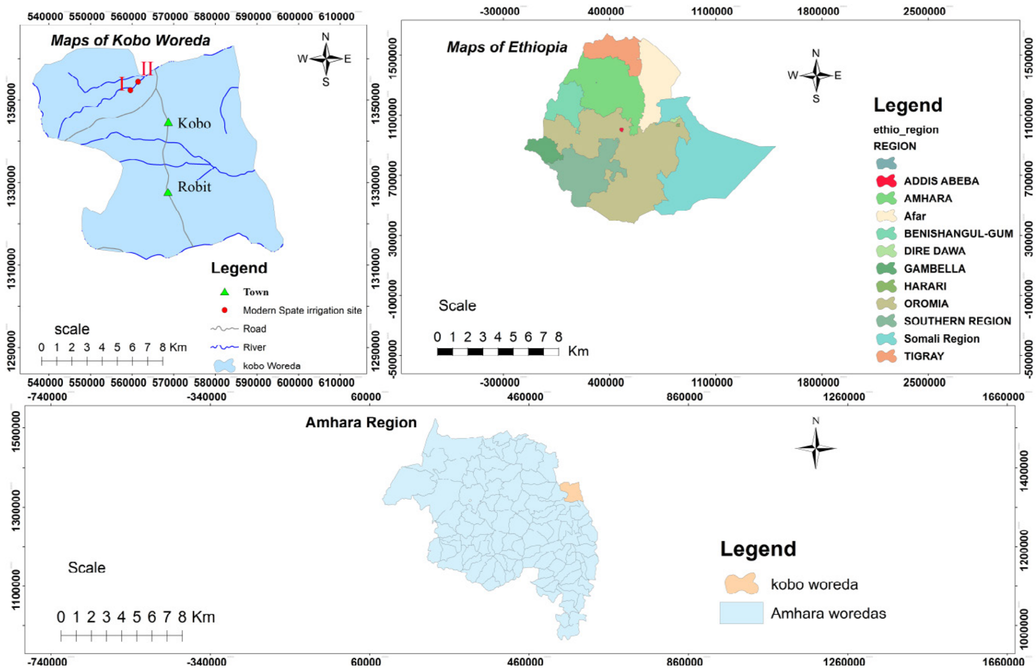

Figure 1. Location of Gobu-I and Gobu-II modern spate irrigation scheme.

area of the project where farmers depending on climate condition of the project area, soil condition of the study area, adaptation of crops to the growing conditions of the study area, socio-economic condition of the study area and yield potential ,market potentials of crops. Among, teff, Sorghum and Onion were crops grown on the command area during the study. Sorghum and teff are the major staple food crops grown in the area. Teff and onion are also used for market as cash incomes. In the project area is found, onion is the leading crop having a land share of 38.4% followed by sorghum (31.4%), and teff (30.2%). In this command area spate water extend from September at the rain stop up to half of October, so that shallow root crops like onion and teff were grown.The major crops grown in Gobu-II scheme is sorghum (100% grown) complete their entire growth period (September to November) based on the soil moisture stored during the flood season from 20 July to end of August.

- **Soil Types:** Based on field observation and based on the information extracted from 1:500,000 scale soils maps by GIS, two types of soils have been identified in the watershed (Gobu-I and Gobu-II) namely Eurtic cambisols and Litosols. According to soil sample laboratory result, the textural class of the command area is clay loam and the depth to which plant roots can effectively exploit (effective soil depth) was measured during the field working days. Hence, the command area has deep soils with 1.5 meter depth.

General Data Collection

Primary data collection:

- Three farmers' fields were selected from each spate irrigation projects based on their location at the head, middle and end of water users of each irrigation project
- Moisture contents of the soils of the selected irrigation fields were determined before and after irrigation by taking the soil samples at different depth of (0-30), (30-60), (60-120) based on crop root depth of soil profile by using gravimetric method. The moisture contents of the soils of the selected farmers' field at different depth were determined in Sirinka agricultural Research center(SARC)

Determination of the amount of water applied to the field: In order to determine the amount of water applied by the farmers to the irrigable fields, by installed rectangular weir at the entrance of each field and frequent readings were taken. During the determination of water applied to the field the depth of water passing on the weir crest to the field and width of weir crest are recorded. The discharges of water applied were taken and multiplied by the time to be irrigated the land. According to Bos, (1989) in some schemes along the field discharge measuring devices are installed. These are mainly rectangular weir structures attached to discharge box. In such cases, the measurements are easier to make and they are relatively accurate.

$Q = 2/3*L\sqrt{2g}\ H^{1.5}$

Where

L= full width (m) of full contracted weir

H= head (m) over the crest of a full contracted weir

Q= flow rate (m^3/se)

Moisture content determination: The soil moisture content measurements before and two days after irrigation were made by gravimetric method which involves collecting soil samples with auger and weighting the wet soil sample by sensitivity analysis, then removing the water content by drying in an oven to 105^{0}c for 24hrs and re-weighting the soil sample to determine the amount of water removed. For every nine plots, soil samples were taken by zigzag fashion before irrigation and after irrigation at different depth (0-30), (30-60), (60-120) cm per test pit. Soil moisture content in each sample was determined on weight basis using the equation [3].

$$\theta w = \frac{Ww - Wd}{Wd} * 100 \quad (1)$$

Where,

$\theta wd = soil\ moisture\ content\ on\ weight\ basis\ (\%)$

Ww= weight of the wet soil sample (g)

Wd= weight of soil sample after oven drying (g)

To convert soil moisture content of soil sample were converted to volumetric water content (θv) by multiplying with specific gravity (ρb)as

$$\theta v = \theta w * \rho b \quad (2)$$

Then the moisture contents of the soils collected from the selected fields at different depths based on the effective root zone were determined.

Data Analysis Techniques

Determination of application efficiency: Application efficiency related to the actual storage of water in the root zone to meet the crop water needs in relation to the water applied to the field. It includes any application losses to evaporation or seepage from surface water channel or furrows, evaporation droplets in the air, or runoff from the field [4]. Especially in spate irrigation runoff from the field was the common problems as application losses due to farmers' management problems.

After determine the depth of water actually applied in to the irrigated fields using rectangular weir method and the depth of water stored in the root zone of the soil based on soil samples were collected from different fields at different depths and the amount of water stored in the root zone determined by gravimetric method.

$$Ea = \frac{Ws}{Wf}x100 \quad (3)$$

Where Ea = water application efficiency (%)

Ws =irrigation water stored in the root zone of farm soil

Wf = irrigation water delivered to the farm (field channel)

Determination of storage efficiency: Storage efficiency is the percentage of water stored in the root zone to water required to fill the root zone to field capacity during the irrigation. By knowing the soil water storage capacity allows the irrigator to determine how much water to apply at one time and how long to be wait or turns between each irrigation.

Conceptually, the adequacy of irrigation depends on how much water is stored with in the crop root zone, losses percolating below the root zone, losses occurring as surface runoff or tail water the uniformity of the applied water, and the remaining deficit or under-irrigation within the soil profile following irrigation.

$$Es = \frac{Ws}{Wn}x100 \quad (4)$$

Es = water storage efficiency, %

Ws = water stored in the root zone of the plant

Wn = water needed in the root zone prior to irrigation

Determination of distribution efficiency: The water distribution efficiency represents the extent to which the water has penetrated to a uniform depth, throughout the field. When the water has penetrated uniformly throughout the field, the deviation from the mean depth is zero and distribution efficiency is 100% [5].

At each selected points of the field soil samples were taken at different depth and then the soil moisture content of the soil at the selected point were analyzed to determine the depth of water penetrated.

$$Du = \left(1 - \frac{d}{D}\right) \quad (5)$$

Where Du = distribution uniformity

D= mean depth of water stored during irrigation

d= average of the absolute value of deviations from the mean

Results and Discussions

Soil characterizationThe soil characteristics in the command areas (moisture content at field capacity (FC) and permanent welting point(PWP), moisture content before and after irrigation. Bulk density (BD)), were taken and analyzed for the purpose of understanding the general feature of the irrigated soil type. Based on the laboratory analysis majority of the command area has clay loam soil textured at all depths for both schemes and the selected farms at both schemes were homogeneous soil texture. From the laboratory result the clay loam soil at the command area has gravimetric water content at field capacity values ranging between 19.16% to 29.11% and 19.4% to 28.1% at Gobu-I and Gobu-II irrigation schemes respectively. Whilst the gravimetric water content at permanent welting point values ranging between 17.6% to 22.8% and 17.2% to 23.8% at Gobu-I and Gobu-II modern spate irrigation schemes respectively in table 3.1 and 3.2. Depends on the mineral made up and degree of compaction for the command area the bulk density values ranging from 1.08 to 1.48g/cm^3 at Gobu-I and 0.97 to 1.34 g/cm^3 at Gobu-II irrigation schemes. The selected soil characterized for both modern spate irrigation schemes are shown in (Tables 1 & 2) respectively.

Farmer's field evaluation at each irrigation projects

In this irrigation project water has been diverted from Gobu Ephemeral River and discharged in to the main canal through the intake in to the irrigable lands. Three farmers field were selected based on their location as shown (Table 3 & 4) (head, middle and tail) in order to determine the efficiency of the both irrigation scheme. The average areas of the selected fields were 0.5ha each and the texture of the soil at each farm were classified as clay loam soils. All the selected fields were covered with three dominant crops (onion, sorghum and teff) in Gobu-I irrigation schemes and dominantly sorghum for Gobu-II. Crops need water to meet water requirement in the growth period, in such case farmers were applying irrigation water traditionally (crops gives more yield if watered more) without taking in to account the crop water requirement (Tables 3 & 4).

Application efficiency: The main concepts of application efficiency is the percentages of water delivered to the field and ready for crop used. From the (Table 5), the application efficiencies from the three farms were in the range of 62.45% to 77.56% with an average 70.97%. The obtained average values of the selected fields (head, middle and tail) were 62.72%,72.61% and 77.56% for head, middle and tail(downstream) users field respectively at Gobu-I. The same selected field Gobu-II irrigation scheme the application efficiency varies from 57.88% to 70.24% with an average 64.75%. (Table 5)

At both irrigation schemes indicates that the irrigation efficiencies were inefficient due to applying excess water to their fields. Farmers expected more water applied to the irrigated crop means more production. In addition to this the whole coming water through the secondary canal is allocated to each farms at the head users, as a result farmers are unable to control or manage the excess flood water and allowing it to be flooded in the farm, consequently a large amount of water is lost as a run off at the farm field without reaching the root zone. According to the conclusion of [6] attainable application efficiency for basin irrigation ranges from 80% - 90% and [4] irrigation application efficiency ranges from 80%-95%. According the conclusion from Solomon (1988) and Howell (2003) the water application efficiency of the command area in both irrigation projects were below applicable. The reason for poor water application efficiency may be the absence of extension works and required

Table 1. Physical soil properties of selected fields of Gobu-I modern spate irrigation.

Farmers field	Soil depth(mm)	Bulk density(BD)	FC%	PWP%	soil texture class
Field I	0-30	1.29	28.3	21.1	Clay loam
	30-60	1.12	21.3	19.41	Clay loam
	60-120	1.29	19.5	18.2	Clay loam
Field II	0-30	1.08	29.11	21.3	Clay loam
	30-60	1.33	22.77	19.9	Clay loam
	60-120	1.37	21.07	18.93	Clay loam
Field III	0-30	1.11	28.56	22.8	Clay loam
	30-60	1.31	23.25	19.9	Clay loam
	60-120	1.48	19.16	17.6	Clay loam

Table 2. Physical soil properties of selected fields of Gobu-II modern spate irrigation.

Farmers field	Soil depth(mm)	Bulk density(BD)	FC%	PWP%	soil texture class
Field I	0-30	1.29	27.5	23.8	Clay loam
	30-60	1.33	25.2	20.62	Clay loam
	60-120	1.31	21.05	19.85	Clay loam
Field II	0-30	1.28	28.1	21.9	Clay loam
	30-60	1.01	22.1	19.6	Clay loam
	60-120	0.97	20.5	17.2	Clay loam
Field III	0-30	1.2	27.3	21.25	Clay loam
	30-60	1.32	23.03	19.8	Clay loam
	60-120	1.34	19.4	17.2	Clay loam

Table 3. Average soil moisture contents before and after two days irrigation at Gobu-I irrigation.

Farmer's field	Time of soil sampling		Soil moisture contents, % volume Soil depths, cm	
		0-30	30-60	60- 120
Field I	Before irrigation	30.22	30.44	32.12
	After irrigation	31.38	32.9	35.54
Field II	Before irrigation	32.5	33.41	31.96
	After irrigation	36.84	34.42	33.38
Field III	Before irrigation	26.6	28.37	27.12
	After irrigation	32.81	28.55	29.06

Table 4. Average soil moisture contents before and after two days irrigation at Gobu-II irrigation.

Farmer's field	Time of soil sampling		Soil moisture contents, % volume, Soil depths, cm	
		0-30	30-60	60- 120
Field I	Before irrigation	31.28	32.05	34.8
	After irrigation	33.81	34.64	36
Field II	Before irrigation	34.5	36.8	37.06
	After irrigation	36.27	38.37	38.28
Field III	Before irrigation	33.9	32.5	29.8
	After irrigation	34.51	33.73	31.03

Table 5. Calculated efficiency selected fields at Gobu-I and II modern spate irrigation.

	Gobu-I			Gobu-II		
Efficiency (%)	Field-I	Field-II	Field-III	Field-I	Field-II	Field-III
Application	62.75	72.61	77.56	57.88	66.12	70.14
Storage	89.06	88.71	87.8	90.97	89.81	88.1
Distribution	92.65	87.67	96.38	85.05	89.95	95.03

training, types of irrigation system used which is predominately wild flooding, farmer's absence of knowledge of irrigation time and time of schedule. Since every farmers is aware of the effects of poor application of irrigation water, they spend much time and effort to ensure proper application of water.

The application efficiency at the downstream user's field was slightly high at both irrigation schemes. This indicates that those irrigators, who are getting less access irrigation water, were able to efficiently utilized they have got. And also the topography of the command area of the irrigation schemes were slanted land configuration starting from the head up to the end of the site, so increases the inter flow of water to the tail end of the farm and the application efficiency at the tail end of the farm were increased. The application efficiency of Gobu-I modern spate irrigation scheme was slightly better than Gobu-II modern spate irrigation. This may be concerned with the institutional set up of Gobu-I irrigation scheme which is stronger than Gobu-II.

Storage efficiency: Storage or adequacy efficiency is the measure of how close the applied amount is to the perceived requirement (the right amount) over the entire subject region and defined as the ratio between the amounts actually stored in the subject region to the required amount. The main use of soil water storage efficiency is to manage surface irrigation systems where the objective is to minimize labor and number of irrigation events, and prevent over irrigation.

The evaluation of water storage efficiency for selected field tests at both irrigation schemes were based on the mean values of the three irrigation fields. The result shows in the table 3.5 below the storage efficiency for the scheme was 89.06%, 88.71% and 87.8% for head, middle and tail end user's field respectively at Gobu-I and the same selected field at Gobu-II the storage efficiency was 90.97%, 89.81% and 88.1% for head, middle and tail end user's field respectively. According to [7] the natural resource conservation service recommended irrigation adequacy for homogeneous soil condition is 87.5%. Therefore, from the result of the selected field at both schemes it is possible to say that the water applied would be achieved to meet the root zone moisture content at field capacity. Or simply say that the storage efficiency at both modern spate irrigation schemes was fulfilling the soil moisture that required for good productive of the crops.

Distribution Uniformity (DU): Distribution uniformity indicates the uniformity of infiltration throughout the field in the irrigation period. Distribution uniformity of the selected fields was evaluated by monitoring the depth of water infiltrated in to the root zone depth. The average results as shown table 3.5 the distribution uniformity at the selected fields was 92.65%, 87.67% and 96.38% at the head, middle and tail end users field respectively for Gobu-I modern spate irrigation and the same manner for Gobu-II spate irrigation scheme the distribution uniformity of the selected fields was 85.05%, 89.95% and 95.03% at the head, middle and tail end users field respectively. In both irrigation schemes the distribution uniformity was below 100% because of in all irrigation systems have distribution uniformity less than 100%. In the field observation and results of DU farmers applying too much water too soon (poor irrigation water management) causes the greatest overuse of water. From the results observed in table 4.5 bellow, there was a slightly difference of uniformity with in the selected user's field at both irrigation schemes. DU in this study fall within the acceptable limit, which is set by FAO, Merriam and Keller to be 80% [3] and [8] .

Comparison of schemes with efficiency: The application efficiency at the farm field based on their location in the head, middle and tail end water users were 62.75%,72.62% and 77.56 for Gobu-I irrigation schemes and 57.88%, 66.12% and 70.24% for Gobu-II irrigation schemes respectively. In the same way the storage efficiency of Gobu-I at the farm field were 89.06%, 88.71% and 87.8% and for Gobu-II storage efficiencies were 90.97%, 89.81% and 88.1% at the head, middle and tail end water users respectively. Although the distribution efficiency of Gobu-I irrigation scheme at the farm field based on their location in the head, middle and tail end water users were 92.65%, 87.38% and 96.38% and in the same way for Gobu-II schemes were 85.05%, 89.95% and 95.03% respectively. This shows that efficiencies were different based on their location but averagely Gobu-I was better application efficiency and distribution efficiency than Gobu-II irrigation schemes but Gobu-II irrigation scheme storage efficiency was greater than Gobu-I. In both irrigation schemes the application was under the limit due to farmer's poor water application in to the field without knowledge of crop water requirement.

Conclusions

In this study, an attempt was made to evaluate the performance of the two modern spate irrigation schemes at kobo woreda, North Wollo Up on evaluating the two modern spate irrigation schemes individually.

In both modern spate irrigation efficiencies were different based on their location but averagely Gobu-I was better application efficiency and distribution efficiency than Gobu-II irrigation schemes but Gobu-II irrigation scheme storage efficiency was greater than Gobu-I. In case of application efficiency in both irrigation schemes was under the limit due to farmer's poor water application in to the field without knowledge of crop water requirement

The selected farmers' field at each modern spate irrigation project has similar trends of water application efficiency as observed from the head of the water users to the tail end water users. But there was poor application efficiency. Low efficiency was achieved where due to applying excess water to their fields combined with poor knowledge about the crop water requirement.

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