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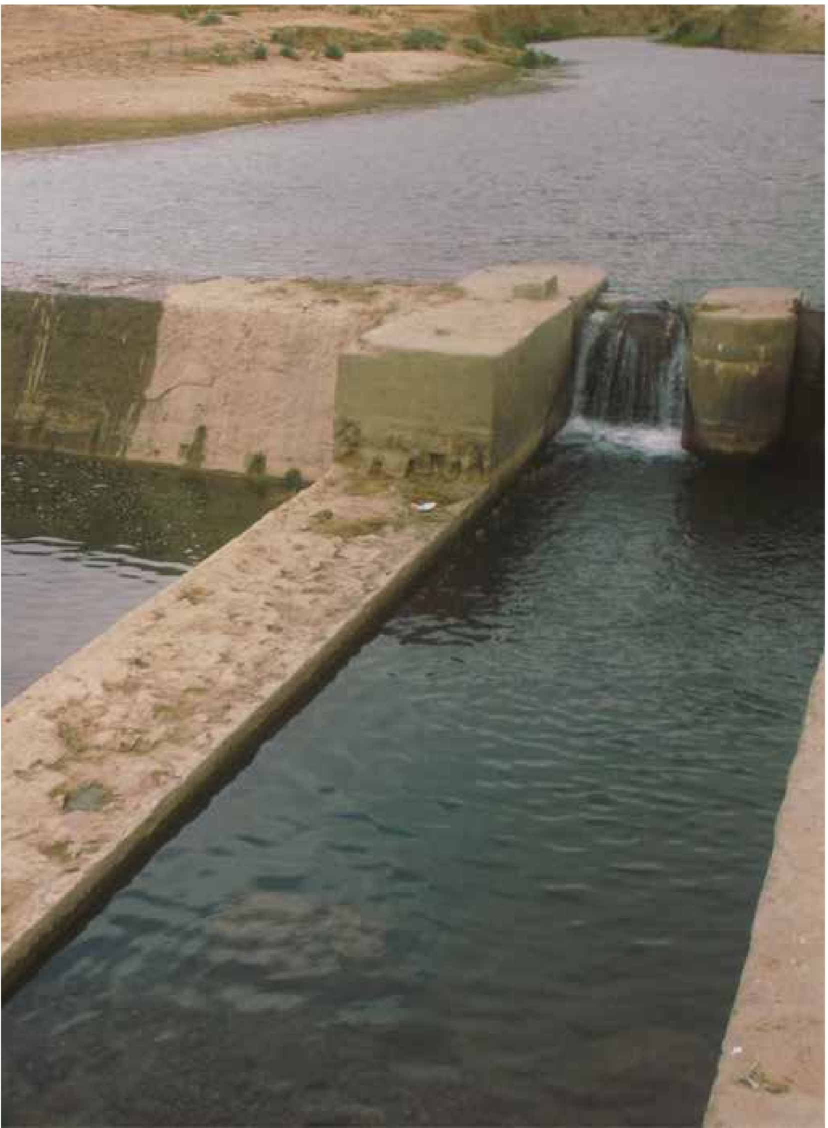

Analysis of water delivery performance of smallholder irrigation schemes in Ethiopia: Diversity and lessons across schemes, typologies and reaches

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Acronyms

ARIS	Average relative irrigation supply
CI	Cropping intensity
CV	Coefficient of variation
FGD	Focus group discussion
FLA	Farm level adequacy
FRD	Farm relative delivery
Ii	Irrigation intensity
IR	Irrigation ratio
IWD	Irrigation water demand
IWUA	Irrigation Water User Association
masl	Metres above sea level
RIS	Relative irrigation supply
RWS	Relative water supply
SIL	Sustainability of irrigated land
SNNPR	Southern Nations Nationalities and People's Region
WLE	Water, Land and Ecosystem

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Abstract

Irrigation systems consist of three interdependent components involving: the irrigation scheme, the on-farm management and the organizations. The irrigation scheme refers to the infrastructure for water acquisition and distribution (water delivery). This study focused on water delivery performance of 10 smallholders irrigation schemes in four regions of Ethiopia, representing diverse water sources, distribution systems, command areas (50–6000 ha) and number of beneficiary farmers (233–500 farm households) and across agro-ecologies as represented by elevation ranges (1500–2725 masl). Relative irrigation supply (RIS), irrigation intensity (Ii), cropping intensity (CI), farm level adequacy (FLA), sustainability of irrigated land (SIL), and equity and field application efficiency were employed as performance indicators. The study involved focus group discussions, household surveys and measurements of water flow across selected points of water delivery systems during 2014/2015 cropping season. More than 300 sample farmers were selected randomly from different reaches (*head, mid and tail*) of the schemes and before the analysis the 10 irrigation schemes were clustered into three typologies (*modern, semi-modern and traditional schemes*) using seven comprehensive and weighted indicators. The result showed that irrigation typology developed in this study enabled to identify three relatively homogeneous irrigation schemes typologies: *modern, semi-modern* and *traditional*. There was apparent diversity of the study schemes in terms of indicators used. At typology level, as illustrated by the RIS, the highest amount of water was diverted for semi-modern schemes (RIS of 3.84); while the highest water delivery at farm relative delivery (FRD) was recorded for the modern schemes (FRD 2.21). Traditional schemes consistently showed lower value for both RIS and FRD. Regardless of their typologies, all study schemes suffer from mismatch of water demand and supply. The lower the RIS and FRD values, the stronger was the water supply disparities between irrigation reaches. Assessment of farmers' perception on fairness of irrigation water delivery substantiate these arguments. Implicitly, it is important to track the fate of diverted excess water. Field observation and empirical evidences show divergent points of losses of excess water indicating focus areas of improved water conservation on smallholder irrigation schemes. For example the largest proportion of over supplied water (~100%) in the semi-modern schemes and in traditional schemes was lost in the conveyance and distribution systems. For modern schemes water losses in the processes of conveyance was low (26%), while the significant proportion of water (76%) was lost on farm. In view of this evidence, we concluded that irrigation schemes in Ethiopia, regardless of their typology, have low water delivery performance. As every scheme has shown its own strength and weakness, concluding sustainability in terms of typology is misleading and this suggests that policy directions should be based on composite sustainability indices.

Key words: irrigation performance, water delivery, water distribution, sustainability, equity, irrigated area, Ethiopia

1. Introduction

Irrigation systems are complex and consist of several interconnected elements. For instance Lemperiere et al. (2014), considered three constituents of irrigation systems: irrigation scheme, on-farm management, and organizations. According to these authors an irrigation scheme essentially refers to the physical infrastructure for water acquisition, control and delivery to irrigated lands. With increasing scarcity and competition for water, the irrigation scheme (also technical system) is indeed one of the most important and challenging part of the irrigation systems.

In terms of quality of their infrastructure, smallholder irrigation schemes in sub-Saharan Africa generally show variations. For ease of understanding, there are tendencies to cluster irrigation systems based on technology used for their construction, organizational structures and scheme size (Yami and Snyder 2012; Namara et al. 2010; Amede 2014). For example in Ethiopia, as suggested in Ethiopian Irrigation Water User Association (IWUA) proclamation (number 841/2014) by the Federal Democratic Republic of Ethiopia (FDRE) (2014), Yami and Snyder (2012) and Amede (2014), irrigation schemes are classified as modern or traditional, irrespective of size of irrigation systems and tenure (public or smallholders). Modern schemes are those equipped with permanent irrigation infrastructure such as water diversion (headworks) and flow control structures and conveyance and distribution systems (Dejen et al. 2012). Traditional schemes do not have permanent structures for water acquisition and flow control, and are made using local knowledge with local materials; including stones, soils, wooden logs, sand bags, etc. These are constructed by the efforts and own initiatives of the farmers and are reconstructed every year (Amede 2014). The question here is to understand if such classification has connotation in terms of water delivery performance.

Non-empirical evidence suggests that traditional schemes under smallholder irrigation schemes are generally built based on indigenous knowledge and take good advantage of emerging opportunities associated with interventions; at same time they suffer from inadequate maintenance of irrigation infrastructure (Awulachew et al. 2005; Awulachew et al. 2010; Dejen 2014; Ulsido and Demissie 2014). On the other hand, the 'modern schemes' under smallholders and also public schemes face challenges related to: i) Little community involvement during planning and implementation; ii) Lack of technical knowledge and skills of farmers for effective operation and maintenance; iii) Poorly maintained water conveyance and distribution systems; iv) Little flexibility of the systems to respond to farmers' needs and v) Damage of flow control structures by farmers in an attempt to deliver more water (Tadesse et al. 2007; Dadaser-celik et al. 2008). Although qualitative identification of strengths and weakness of typologies of smallholder irrigation has its own virtues, little attention has been given to the analysis of relative water delivery performances of modern and traditional irrigation (Dejene 2014) and underlying questions involving: i) Where the hotspots contributing to poor performance lay; ii) How the water delivery system performances across scheme, typologies and irrigation reaches differ and iii) What policy implication therefore could be drawn and how farmers perceive these. Irrespective of irrigation typology, we argue that the conflict between different water use groups across reaches within smallholder irrigation schemes is largely associated with failure of the water distribution and delivery systems (to ensure equitable and timely water delivery). Therefore, the major objectives of this paper were: i) To undertake a comparative evaluation of the performance of the distribution and water delivery system across scales (irrigation schemes, typology and reaches); ii) To propose a relatively homogenous irrigation typology and iii) To draw lessons on priority challenges and propose interventions to improve the water distribution and delivery system.

2. Materials and methods

2.1. Location and characterization of the study irrigation schemes

Figure 1 depicts the location of the study irrigation schemes. The study covers 10 irrigation schemes representing diverse water sourcing, distribution, command areas (50–6000ha), and number of farmers engaged (233–500 farm households) and agro-ecologies as indicated by elevation [ranges of 1500–2725 masl Table 1). The irrigation schemes were from four regional states of Ethiopia: Two from Tigray, three from Amhara, two from Oromia and three from Southern Nations Nationalities and People's Region (SNNPR).

Figure 1: Location map of the study irrigation schemes.

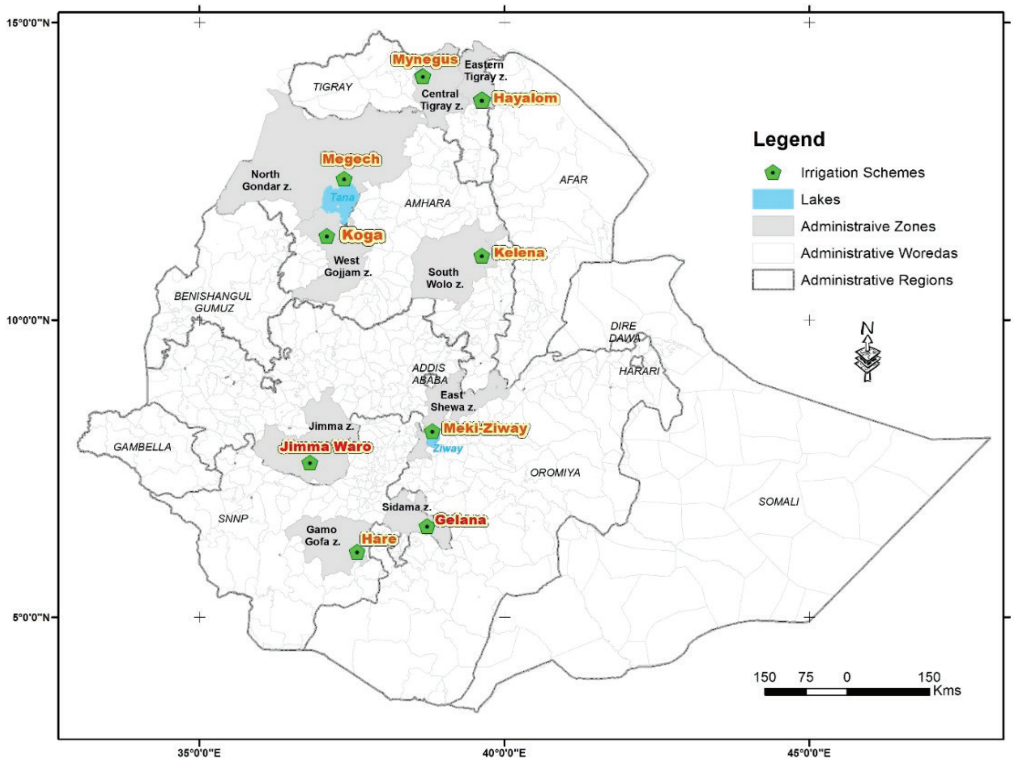


Table 1: Salient features of the selected irrigation schemes as related to the water supply and distribution system

Key features	Tigray region		Amhara region			Oromia region		South region	
	Irrigation schemes								
	Wukro	May-Nigus	Koga	Megech	Dessie-Zuria	Meki	Waro	Hare weir/ diversion*	Gelana
Administrative zone	Eastern Tigray	Middle Tigray	West Gojam	North Gondar		East Shoa	Jimma	Gamo Gofa	Sidama
Elevation metres above sea level (masl)	2725–1927	2016	1880 -2020	1810	2262	1650	1780	1500	2550
Year of commissioning	1993	1995	2010		1996	1986	1985	1972-1995	1994
Type of water acquisition/ headwork	Cascade diversion weirs	Embankment (Earth dam)	Embankment (Earth dam)	Private diesel pumps from river	Traditional diversion	Private diesel pump from main canal	Traditional diversion with soil bunds	Diversions weir/ traditional	Diversion weir
Type of water distribution system	Mainly earthen canals and small parts of main canals at the heads lined	Mainly earthen canals and small parts of main canals at the heads lined	Main, secondary and tertiary canals lined	Earthen canals	Earthen canals	Earthen canals	Earthen canals	For the weir small parts of main canals lined and the traditional is fully earthen canal	Mainly earthen canals and mall parts of main canals at the heads is lined
Schemes typology**	Modern	Modern	Modern	Modern	Traditional	Modern	Traditional	Modern / traditional	Modern
Initial designed area, ha	500	150	7,004	200	1287	3000	300	1500/1000	180
Relative competition for water from initial observations	High	Moderate	Low	High	High	Moderate	Low	Moderate	High
Sources of water	River	River	River	River	River	Lake	River	River	River
Irrigated area	330	70	6000	150	634	700	300	1300/800	50
General maintenance condition	Good	Fair	Good	Fair	Poor	Fair	Fair	Poor	Poor
Number of farmers active in irrigation practices	550	233	5000	188	909	350	300	1182/727	150

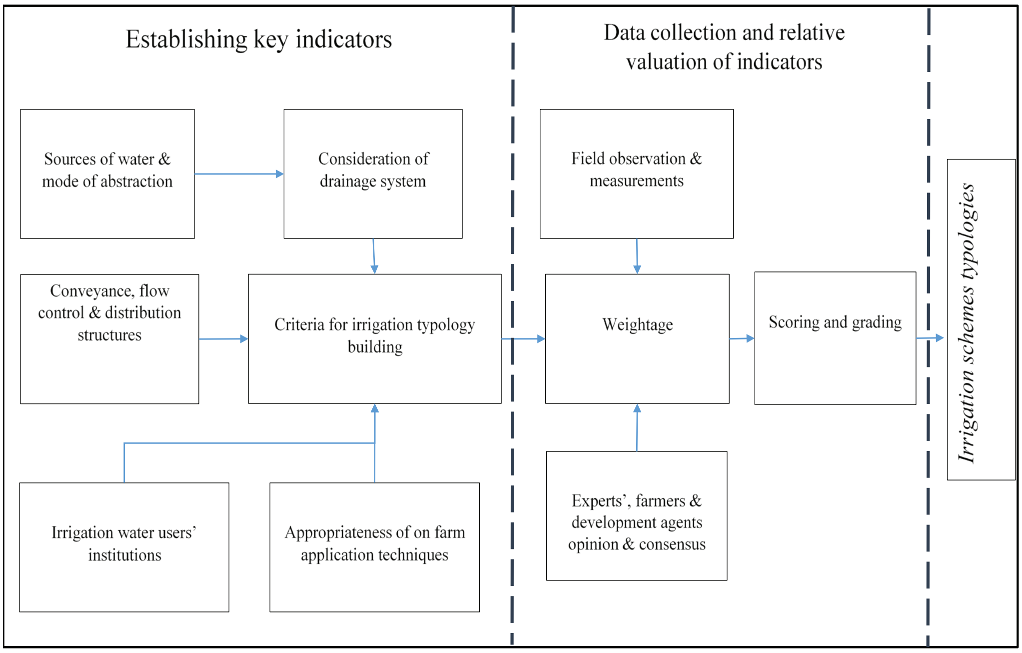
* Hare weir and Hare diversion have the same location and have the same source of water. One diversion is made from local material and the other one is from concrete diversion weir. The Hare diversion is located on the upstream and the weir diversion is on the downstream at about 500 m. ** Typologies as defined in EFDR (2014); Yami (2013); Amede (2014).

2.2. Framework for irrigation typology building

The customary way of classification of irrigation schemes (typology) in Ethiopia is based only on the method of water sourcing structures (headworks) and whether these structures are permanent or not (Yami and Snyder 2015; FDRE 2014). This approach does not critically consider the types and conditions of the conveyance and distribution systems, the presence and condition of control structures, method of water allocation and scheduling at scheme levels, on farm water management practices, equity in water allocation, institutional aspects for management and operation. Policymakers in Ethiopia often use this typology (FDRE 2014) for decision-making. Many conventional irrigation typologies being adopted in Ethiopia tried to embed these customary classifications. For example, Werfring et al. (2004) classified irrigation schemes in Ethiopia into four typologies: traditional small-scale irrigation schemes; modern small-scale irrigation schemes; modern private commercial irrigation schemes; and large- and medium-scale public irrigation schemes. In this classification, the scale, size of ownership and the water acquisition methods (headwork) of the schemes were the major criteria used. Most often irrigation schemes typology building efforts are not consistent and criteria are not well developed particularly in sub-Saharan Africa. Criteria for typology building can be different depending as to whether the typology is for schemes or the system. As discussed earlier scheme is dealing with the infrastructure and institution managing it, while the system has a livelihood components (e.g. holding size, productivity, cropping system etc.). Many of the typologies widely used across many sub-Saharan African countries failed to address these distinctive features and are thus misleading during national policy decision or diagnostic study using benchmarking approaches.

While a scheme is classified as modern based on water abstraction structures, it might fail to meet expectations due to poor water distribution, inequity, water depleting on farm application, etc. On the other hand, there can be cases where traditional schemes performed better than those classified as modern on mere consideration of headwork. Clustering of irrigation schemes into homogeneous water delivery characteristics will enable improved comparison of irrigation schemes performance (Renault and Godaliyadda. 1999). In this paper, we argue that while these classifications are extremely useful, considering more aspects related to the irrigation systems would make the classification more comprehensive and homogeneous and thus facilitate policy decisions and targeting of interventions. Hence, an inclusive and comprehensive approach for building the typology of irrigation schemes is important.

Figure 2: A simplified framework for irrigation schemes typology building (compare also Table 2 for detail).



The present study considered a multi-criteria approach, in which seven major criteria to determine the typology was applied (Table 2, Figure 2). Each of the seven criteria had sub-criteria which were used during the field observation and to justify the value of weightage given for the main criteria. For each of these seven criteria, a weightage was assigned (out of 10) based on its relative importance as noted by experts and based on participatory discussions with farmers and development agents (Table 2, Figure 2). Then each scheme was evaluated against these criteria and graded on a scale ranging from 0 to 10. The irrigation schemes were then scored against the seven attributes and overall weighted grade determined out of 100 (Table 3) after field visits. The next step is categorization and in this regards experiences of categorization of irrigation schemes based on empirical values is virtually absent. One possible option is then to use expert views and thus for categorization, weighted grades (at breaking points) were first decided by a group of experts. Weighted grades were fixed and the schemes were classified based on the fixed grades (Table 4). The fixed scales were: *modern* if grade is greater than or equals to 80%; *semi-modern* if grade is greater than or equals to 50% and less than 80%; and *traditional* if grade is less than 50%. The irrigation systems were then clustered into these three typologies (*modern, semi-modern* and *traditional systems*) as indicated in Table 4.

Table 2: Criteria for typology building and their weightage

Criteria	Weightage
Source of water	0.75
Reliability of the source	
Impacts on ecosystem	
Upstream/downstream relation	
Water quality	
Mode of abstraction	2.00
Presence of fixed structure/mechanism for abstraction	
Reliability/durability	
Independence of operation	
Ease of operation	
Water conveyance system	1.5
Types of conveyance systems	
Independent for operation	
Level of risk of water loss	
Canal capacity	
Canal crossing structures	
Flow control structures on conveyance and distribution	2.00
Presence of control structures at offtakes	
Appropriateness/types	
Operationally	
Simplicity of operation	
Measurement facility	
On-farm application (water management practices)	1.75
Regulation of application	
Appropriateness of water application method	
On-farm erosion	
Drainage system	0.75
Presence of flood control structures	
Adequacy of the drainage system	
Functionality	
Irrigation water users organizations	1.25
Presence of IWUA	
Written bylaws	
Enforcement of bylaws	
Total	10

Table 3: Multi-criteria ranking for irrigation system typology building (compare also figure 2)

Criteria	Water source	Mode of abstraction	Conveyance system	Flow control in conveyance and distribution	On-farm management	Drainage facilities	Irrigation organizations	Overall weighted grade	Rank
Weightage	0.75	2	1.5	2	1.75	0.75	1.25	10	
Scheme	Score out of 10								
	Weighted grade								
Koga	10	10	10	9	8	9	9	92.5	1
	7.5	20	15	18	14	6.75	11.25		
Meki	8	4	3	6	10	3	7	59	3
	6	8	4.5	12	17.5	2.25	8.75		
May-Nigus	7	8	7	5	4	3	9	62.25	2
	5.25	16	10.5	10	7	2.25	11.25		
Wukro	4	8	6	5	4	3	9	58.5	4
	3	16	9	10	7	2.25	11.25		
Hare weir	6	8	4	5	6	3	7	58	5
	4.5	16	6	10	10.5	2.25	8.75		
Gelana	10	6	7	5	2	4	3	50.25	6
	7.5	12	10.5	10	3.5	3	3.75		
Waro	10	0	7	0	8	4	6	42.5	8
	7.5	0	10.5	0	14	3	7.5		
Megech	3	5	7	5	5	1	0	42.25	9
	2.25	10	10.5	10	8.75	0.75	0		
Hare diversion	4	1	4	2	6	3	7	36.5	10
	3	2	6	4	10.5	2.25	8.75		
Dessie-Zuria	5	7	5	3	4	1	6	46.5	7
	3.75	14	7.5	6	7	0.75	7.5		

Table 4: Irrigation systems clustering into three typologies based on multi-criteria ranking

Scheme	Grade	Typology	Grade scales for classification
Koga	92.5	Modern	If grade > 80%
May-Nigus	62.25	Semi-modern	
Meki	59.00		
Wukro	58.50		50 < Grade < 80
Hare weir	58.00		
Gelana	50.25		
Dessie-Zuria (Kelena)	46.50	Traditional	
Jimma Waro	42.50		Grade < 50
Megech	42.25		
Hare diversion	36.5		

2.3. Performance assessment indicators

Pre-determined criteria are useful to evaluate irrigation performance across the irrigation schemes (Şener and Konukcu 2007). There are a number of criteria available to assess an irrigation scheme's water delivery, but careful selection of context specific and objectives oriented criteria is crucial (Şener and Konukcu 2007; Ulsido, and Alemu 2014). Performance indicators are generally expressed as numerical values of certain measurable parameters against which the schemes can be rated. Selection of indicators depends on the purpose of the assessment (Bos 1997). In the present study, we targeted both internal and external performances indicators to evaluate irrigation water deliver. Internal indicators such as equity, adequacy and reliability were taken into account (Dejen et al. 2012). In terms of external performance, RIS and Ii were considered. In the following part, we highlight details of these indicators.

Relative irrigation supply (RIS, m^3/m^3) is a useful indicator to assess the degree of irrigation water deficit or abundance in relation to demand (Dejen et al. 2012). It tells how well irrigation water supply and demand are matched. The RIS can be determined at different time scales: daily, monthly, seasonal or annual basin and at different levels of irrigation schemes including scheme, secondary, tertiary or field levels. In this study RIS at the intake level was calculated by determining the average values of diverted water and irrigation water demand over a period of two irrigation seasons (Season I: January to June and Season II: September to December). Appropriate irrigation efficiencies and duration of field irrigation (12 hours or 24 hours) were considered. RIS value over 1 would suggest over supply, while a value of less than 1 indicates shortage of irrigation water (Dejen et al. 2012).

RIS was first determined on monthly basis for each of the study scheme and then the average RIS was determined over two seasons using the cropping period as a guide (Table 5). RIS can be represented by equation 1 below; where IWS is irrigation water supply and IWD represents irrigation water demand.

$$RIS=IWS(m^3)/(IWD(m^3)) \quad (1)$$

The irrigation water demand (IWD) (flow rate) at the intake was determined on monthly basis using Cropwat 8 for the existing cropping pattern [Table 5, (Allen et al. 1998)]. In Ethiopia, values on irrigation water distribution efficiencies are more of qualitative and empirical evidences are generally lacking. Thus to determine demand, at the intake, conveyance and distribution efficiencies of 70% were assumed uniformly across all schemes. Flows at intake were measured using sluice gates and velocity-area methods. However, at scheme levels, irrigation diversions at the head were measured a few times (during field visits) in this study as there was little time to monitor irrigation diversions. So, in addition to measured flows, water diversions over the remaining months were estimated based on three approaches: i) From household survey data on the variability of irrigation flows; ii) For the storage schemes (Koga and May-Nigus), from the seasonal water release plan from the reservoirs and iii) From the characteristics of the water source to give an idea of the relative abundance or shortage of irrigation water.

Table 5: Major crops, % of area occupied and growing season at different schemes

Scheme	Major crops	% area cropped	Growing season
Koga	Wheat	60	December to January
	Maize	10	April to May
	Potato	15	October to November
	Onion	15	November to December
Meki	Cabbage	30	January to February
	Maize	30	April to May
	Onion	30	October and February
	Tomato	10	October
May-Nigus	Maize	40	January and May
	Onion	30	November and June
	Tomato	20	November
	Chick pea	10	January
Wukro	Maize	30	January and May
	Wheat	30	June to July
	Onion	30	October to November
	Pepper	10	October
Hare weir	Banana	65	Perennial
	Maize	25	October and May
	Mango	10	Perennial
Dessie-Zuria	Wheat	50	December to January
	Maize	40	May to June
	Potato	10	April
Gelana	Maize	20	January and June
	Coffee	30	January
	Enset	30	Perennial
	Tomato	20	November to December
Megech	Onion	50	November to December
	Maize	40	April to May
	Sorghum	10	April to May
Waro	Potato	40	November to December and April to May
	Cabbage	30	October
	Maize	20	April to May
	Pepper	10	November to December
Hare diversion	Banana	85	Perennial
	Maize	3	October and May
	Mango	12	Perennial

Relative water supply (RWS) (m^3/m^3) is related to ratio of water supply (irrigation plus rainfall) to crop water demand. It takes into account that the total crop water demand can partly be met from rainfall and partly from irrigation. This can be represented by equation 2 below; where IWS and RWS are water supply from irrigation and water supply from effective rain respectively and *CWR* is total crop water demand.

$$RWS=(IWS+RWS(\ m^3))/(CWR\ (m^3)) \quad (2)$$

Weather data required for input to the equation were derived from LocClim (FAO 2005) and also crop water requirement was estimated using Cowpat 8 (Allen et al. 1998).

Irrigation intensity (Ii (%)-: is related to the degree to which the nominal command area of the scheme is put under irrigation in a year. Its value is less than 100% if irrigated crops are grown on part of the command area only once in a year, and greater than 100% if irrigated crops are grown twice or more in a year on part or all of the command area (Boss et al. 1994). It is the ratio of annual irrigated area to nominal command area. Irrigation intensity is one of the indicators for the degree of availability of irrigation water (Boss et al. 1994). This can be represented by Equation 3; where Ii stands for irrigation intensity; AIH stands for annual irrigated harvested land area (ha) and NIL stands for nominal irrigable land area (ha)

$$Ii=(A\ IH\ (ha))/(NIL\ (ha)) \quad (3)$$

Cropping intensity (CI%) is an indicator for the degree of utilization of the available land using both irrigation and rainfall (Bos et al. 1994). It is the ratio of total annual harvested area to nominal command area. Cropping intensity depends on a number of factors; such as irrigation water availability, amount and temporal distribution of rainfall, types of crops grown, access to agricultural inputs, etc. In this study, Ii was determined considering only cropping under irrigation, while CI was determined based on cropping under both rainfall and irrigation. Cropping intensity (CI) is expressed by equation 4: where AHA and NCA stand for annual harvested area and nominal command area, respectively.

$$CI=(AHA\ (ha))/(NCA\ (ha)) \quad (4)$$

Irrigation ratio (IR ratio) is the ratio of currently irrigated area to the command area (Bos et al. 1994). It tells the degree of utilization of the available irrigable area at a particular time. While there are several factors contributing to the variation in IR, availability of irrigation water is the major one, but even under sufficient water supply low figures can be caused as a result of misuse. This can be represented by equation 5 below; where IR stands for irrigation ratio.

$$IR=(\text{Irrigated area (ha)})/(\text{Irrigable command area (ha)}) \quad (5)$$

Sustainability of irrigated land (SIL, ratio) is the relationship between the area under irrigation at a particular point in time and the initial irrigated area (Eq. 6). It is a useful indicator to evaluate whether irrigated area diminished or expanded in a scheme in time (Dejen et al. 2012). The causes for irrigated areas contraction in schemes are complex, but, limited water availability and poor reliability are the major ones (Bos et al. 1994; Lemperiere et al. 2014).

$$SIL=(\text{Irrigated area (ha)})/(\text{Initial irrigated area (ha)}) \quad (6)$$

Irrigation efficiency (%) is a popular term and is a major concern for agricultural water management, particularly in water scarce regions. It can be defined at different scales: i.e. at field level (application efficiency), tertiary canals level (distribution efficiency), and primary and secondary canal level (conveyance efficiency), or for the whole system (scheme efficiency). It is an inverse of RIS (Bos et al. 1994), although this description is relevant for canal irrigation, the fact that in many of the pump irrigation considered here the water is either pumped to a canal and then distributed or pumped from one distribution canal to farm, makes the indicator relevant. This can be represented by equation Eq. 7 whereby IWD is irrigation water demand/consumed and IWS stands for irrigation water supply.

$$IE=IWD(m^3)/IWS\ (m^3) \quad (7)$$

In addition, the following internal indicators for the water delivery and distribution were considered.

Farm level adequacy [farm relative delivery (ratio)] refers to the adequacy of water delivery at farm levels (farm inlet or offtake). While the RIS, used in this study, refers to the water diversion at the source, the relative delivery is useful to better understand the water delivery process (Dejene 2014). Together with the RIS, it is useful to track water losses in the system. Water delivered at the farm varies from farm to farm and between reaches. Hence, farm relative delivery, may, in many cases, be required as an aggregate for a number of farm offtakes. In this respect, Molden and Gates (1990) suggested that the farm level adequacy can be aggregated in an area R over time T. Adequacy for instance can be considered for head, middle and tail reaches of irrigation schemes. In this study, irrigation reaches (head, middle and tail) are well addressed because there occurs distinct features regarding water delivery process. The distinction between these three reaches depends mainly on the physical location within the scheme along the water distribution systems. Hence, the adequacy of the water delivery was considered within the head, middle and tail reaches. The farm relative delivery can be also expressed in terms of field application efficiency. Field irrigation efficiency is the ratio of field (farm) irrigation water demand by field (farm) irrigation supply. The field demand for the main irrigated crop was determined from climatic and crop parameters using Cropwat 8 software (Swennenhuis 2010; Allen et al. 1998). While the field delivery was estimated from data collected from sample farmers regarding their size of irrigated plots, number of irrigations, duration of irrigation and farm delivery flow rate. The farm relative delivery (*FRD*) for a single offtake is given by equation 8; where *FWDl* is farm water delivery and *FWDm* is farm water demand. Aggregate adequacy indicator for a number of offtakes is given by equation 9; where P_A is adequacy indicator aggregated over a region *R* and time *T*, p_A is a ratio of delivered to required flows at a point (farm inlet).

$$FRD=FWDl/FWDm \quad (8)$$

$$P_A=1/T\sum_T(1/R\sum_R p_A) \quad (9)$$

Spatial equity: Equity implies the fairness of water delivery to different parts of an irrigation system. In this study we calculated the coefficient of variation (CV) of the ratio of water delivered (Q_D) to water required (Q_R) over an area R and time T as proposed by Molden and Gates (1990) (Eq. 10):

$$P_E=1/T\sum T\ CV_R(Q_D/Q_R) \quad (10)$$

Where P_E is equity indicator, Q_D is delivered water (m^3) and Q_R is required delivery in (m^3), R is region of consideration and T is time period of consideration.

2.4. Defining irrigation reaches, data acquisition and scales of analysis

The water supply and delivery varies from one part of the scheme to the other depending on various factors related to the scheme infrastructure, such as maintenance conditions, functioning of flow control structures, operation and etc. It is generally true that water users at the head of the scheme are more favoured in terms of reliability of the water supply compared to the tail irrigator (Dejene 2014; Habtu et al. in press). The intensity distribution may vary seasonally and from scheme-to-scheme depending on the volume of water availed throughout the year. In order to capture spatial variations in the water supply and delivery service, each scheme was stratified into three: the head, the middle and the tail users based on the physical location of their plots within the schemes. The boundary between the reaches was defined arbitrarily after a transect walk to monitor distance from the main canal and in discussion with the development agent and water users on their perceived differences on water availability. As part of this, transect walk was made through each schemes to physically observe and define the boundaries. After the reaches were defined, sample farm distribution for the household survey and field and flow measurement were planned and executed accordingly.

Over all the data collection methods mainly involved transect walk, farm household interview, focus group discussions (FGDs), and measurements of discharges, plot sizes, irrigable service areas and field irrigation (furrow) run lengths (Bos et al. 1994). For the farm household survey, 10 households were randomly selected from the head, middle and tail reaches each (about 300 farms and over 600 plots for all 10 study schemes). FGDs were held with a group consisting of water users, development agents and Kebele[1] administrators. Three FGD groups were considered for each scheme (one group from each reach). Discharges were measured at different bifurcation and supply points in

1 Kebele is the lowest administrative unit in Ethiopia

the distribution system: intakes, main canals, secondary offtakes, tertiary offtakes, and at farm inlets as appropriate. Discharge measurements were made with the velocity-area method, whereby the flow velocities were measured using float method. Given the relatively small time available for field measurements in this study, flow measurements at particular locations were made over a maximum of two weeks. To minimize errors that could be introduced due to the irregular shape of the canals, recurrent measurements of canal depth, length and flow time elapsed were taken. In order to capture fluctuations in flows over time, data related to reservoir operation rules (for storage schemes), farmers perception of seasonal water source fluctuations, and information on water deliveries in time was collected.

Three interactive scales evaluations were made for this smallholders irrigation water delivery performance assessment: for individual scheme; scheme typology (modern, semi-modern and traditional); and reaches (head, middle and tail). Computation of empirical value involved some level of aggregation. Initially, data at farm level was aggregated to reaches and the reaches to specific scheme and then to typologies.

3. Results and discussion

3.1. Assessment of water delivery performance

Relative irrigation water supply at headwork diversions

Tables 6 and 7 depict actual area irrigated, intake required flows over different months and values of RIS respectively. Value of RIS exhibited apparent variability among study schemes. For example, while all the other schemes delivered excess water at their intakes, Hare weir, Hare diversion and Megech schemes had RIS less than 1.0 during both seasons, suggesting diversions less than demand at the headwork. At Hare weir and diversion, inadequate and inefficient water supply and distribution were major challenges. In these schemes, discussion with farmers reveled that water availability, even in the normal years, is inadequate. Similar studies on Hare schemes revealed RIS value close to 1 and suggests that there is injudicious management of water (Ayana and Awulachew 2009). At Megech, there are two key contributing factors: first, the availability water itself is not reliable: i.e. during low discharge, the flow is stopped by the upstream reaches with farmers and hence downstream farmers suffering serious shortages. Second, as farmers in Megech depend on private diesel pumps for water abstraction and farmers would not over irrigate; as more water means more pumping implicitly this makes irrigation an expensive venture.

The average relative irrigation supply (ARIS) was aggregated into two growing periods of the year as shown in Table 7. Season-I (January to May) is the main irrigation season for all the schemes and Season-II (June to December) is a season for supplementary irrigation (rarely practiced). It is interesting to note that the RIS for May-Nigus and Gelana schemes were exceptionally high during both seasons. Discussion with farmers revealed that in both schemes, the designed command areas of the schemes have contracted over time because of water shortages resulting from mismanagement and inequitable water destitution. However, the available and diverted water would have irrigated more land than it currently does. The RIS was in fact calculated for the actual area under irrigation, which resulted in large excesses, and it is within a range of RIS value (3.33 and 6.68) estimated between 1997 and 2002 by Behailu et al. (2004). Overall the IRS value revealed that all investigated schemes suffer either from over supply or under supply of water and the value of RIS is dependent on multiple of factors involving the means of water lifting (e.g. pump); over all water scarcity, poor management and lack of institutions ensuring equitable distribution (Ayana and Awulachew 2009; Behailu et al. 2004).

The annual RIS was also then aggregated by typology as shown in Figure 3. It is apparent that in semi-modern irrigation schemes more excess water is diverted compared with the modern and traditional schemes. This can be explained by the rigid headwork of semi-modern schemes which enable large amount of diversion and also lack appropriate water conveyance and distribution structures, and are inefficient in water use. Arguably, over diversion could be associated to compensations of water that would be lost as a result of inefficient conveyance. Traditional schemes, be they pump or diversion based, on the other hand diverted the least amount of excess water: i.e. slightly higher than needed at the headwork. This could be accounted for by the temporary water diversion (headwork) which are built from locally available material. Field observation suggests that seepage loss at the offtake is one of the major problems here. For pump-based traditional irrigation schemes, for example at Megech, the cost of fuel for pumping acts as a barrier to excessive pumping.

Table 6: Actual area irrigated (ha) and intake required flows (RFAI) over different months

Typology	Scheme		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Modern	Koga**	Area	5950	5950	4900	5250	4500	4500	5200	5200	700	1050	1750	5950
		RFAI	3.40	4.42	3.15	0.75	0.36	0.08	0.00	0.00	0.01	0.05	0.53	1.79
	Meki**	Area	700	700	490	700	700	700	600	600	630	630	490	490
		RFAI	0.29	0.20	0.19	0.29	0.44	0.29	0.01	0.00	0.04	0.20	0.29	0.29
Semi-modern	May-Nigus*	Area	70	98	70	70	98	120	70	70	50	34	42	42
		RFAI	0.07	0.08	0.10	0.09	0.05	0.02	0.00	0.00	0.00	0.00	0.04	0.05
	Wukro**	Area	231	330	198	198	330	132	132	132	132	132	231	132
		RFAI	0.11	0.10	0.15	0.14	0.08	0.02	0.00	0.00	0.03	0.06	0.07	0.08
	Hare weir**	Area	1,300	1,300	780	390	780	1,300	1,300	1,300	1,300	780	1,300	910
		RFAI	0.46	0.32	0.25	0.07	0.07	0.41	0.52	0.45	0.24	0.21	0.45	0.49
Traditional	Gelana**	Area	35	35	20	10	40	40	45	45	30	30	40	25
		RFAI	0.01	0.01	0.01	0.000	0.000	0.000	0.001	0.000	0.000	0.001	0.01	0.01
	Megech**	Area	1500	1500	1500	1500	1500	2700	0	0	1500	1500	1500	1500
		RFAI	0.73	0.36	0.73	1.03	0.79	0.23	0.00	0.00	0.02	0.49	1.01	1.05
	Waro**	Area	240	240	240	240	300	300	300	300	300	210	210	210
		RFAI	0.12	0.04	0.03	0.06	0.02	0.00	0.00	0.00	0.00	0.03	0.08	0.12
	Hare diversion**	Area	800	800	480	240	480	800	800	800	800	480	800	560
		RFAI	0.29	0.19	0.15	0.04	0.04	0.25	0.32	0.27	0.15	0.13	0.27	0.30
	Dessie-Zuria **	Area	1,280	1,280	1,280	1,280	640	0	0	0	640	640	640	640
		RFAI	0.59	0.99	1.10	0.55	0.04	0.00	0.00	0.00	0.01	0.14	0.19	0.02

*Is 12 hours flow, while ** is for 24 hours flow.

Table 7: Relative irrigation supply (RIS) at headwork diversions

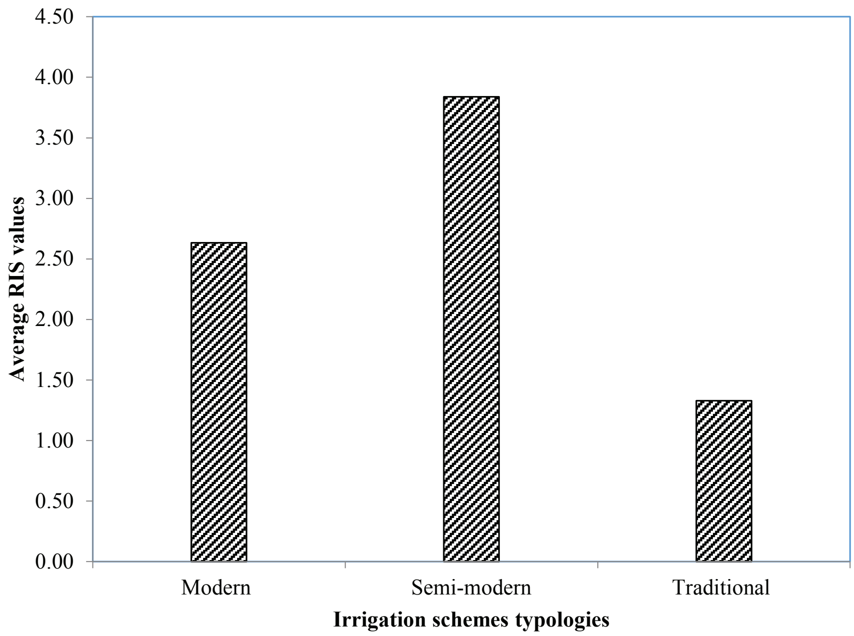
Scheme	Season I (January-May)					Season II (June-December)				
	Avg. demand, m3/s	Demand, m3	Supply, m3/s	Supply, m3	RIS	Avg. demand, m3/s	Demand, m3	Supply, m3/s	Supply, m3	RIS
Koga	2.93	30,378,240	5.50	57,024,000	1.9	0.59	6,117,120	2.00	20,736,000	3.4
Meki	0.24	2,511,648	0.70	7,257,600	2.9	0.20	2,112,480	0.70	7,257,600	3.4
May-Nigus	0.08	429,754	0.40	2,073,600	4.8	0.02	114,566	0.15	777,600	6.8
Wukro	0.13	1,308,701	0.34	3,545,856	2.7	0.06	620,747	0.25	2,592,000	4.2
Hare weir	0.27	2,830,464	0.21	2,177,280	0.8	0.35	3,610,286	0.28	2,903,040	0.8
Gelana	0.01	103,680	0.05	518,400	5.0	0.01	103,680	0.07	725,760	7.0
Megech	0.71	7,361,280	0.36	3,680,640	0.5	0.64	6,635,520	0.43	4,423,680	0.7
Waro	0.06	630,967	0.11	1,140,480	1.8	0.06	598,752	0.13	1,347,840	2.3
Hare diversion	0.17	1,741,824	0.15	1,555,200	0.9	0.21	2,221,714	0.20	2,073,600	0.9
Dessie-Zuria	0.67	6,946,560	0.72	7,464,960	1.07	0.12	1,244,160	0.3	3,110,400	2.50

There are arguments suggesting water pricing and cost recovery as one of the strategies to reduce over irrigation and thus save water and contribute to food security and ecosystem conservation (MoWR 1999). On top of the infrastructure-based argument shown above, discussion with development assistants, farmers and also field observation revealed that the traditional schemes have no detailed studies, thus lack matching between available water and irrigable land. Increasing irrigable areas in most cases can be an individual farmer's decision which leads to mismatch between the land and water. This contrasts with the modern irrigation schemes (Table 3), where better matching between available water and land is exercised at the design stage.

Field observations revealed that modern irrigation schemes have good water distribution and conveyance at larger canal levels (main, secondary and tertiary canals). Usually, in view of scheme manager, from Koga irrigation scheme, the farm offtake canals are manipulated by the field owners and thus creates 'artificial demand'. In fact as a result of such 'artificial demand' the total designed command areas could not be fully developed. Currently, only 6000 ha of the planned 7004 is irrigated.

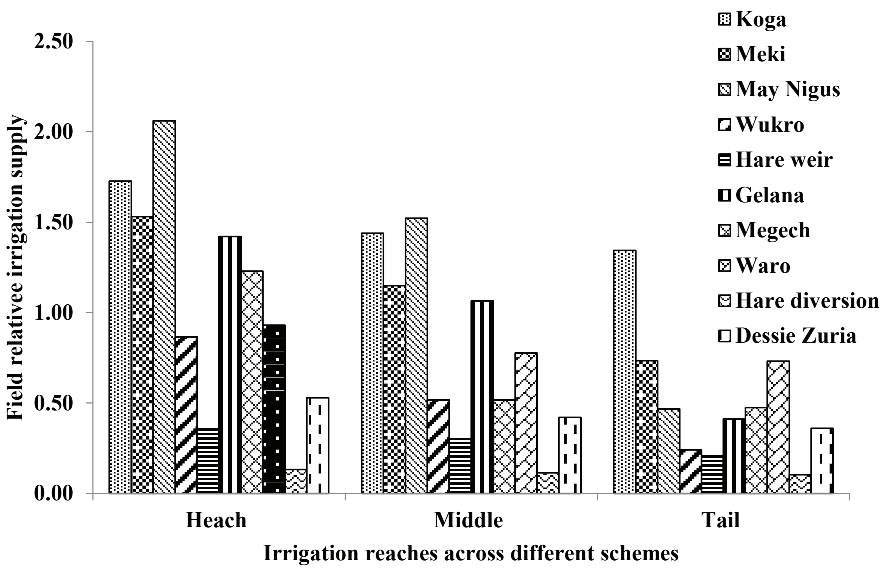
According to the Ethiopian Federal Government proclamation number 841/2014, one of the duties of IWUA is to monitor equitable water distribution among the beneficiaries (FDRE 2014). However, many irrigation schemes lack IWUA that performs this duty. While all typologies may suffer either from over supply or under supply of irrigation water, the root cause can be typical or shared among the different typologies. For example lack of institutions, which can enforce the proper uses of farm level off take gate, is the major causes for modern irrigation, while for semi-modern and traditional the major causes are related to quality of infrastructure (Ulsido and Alemu 2014).

Figure 3: Annual relative irrigation supply (ARIS) by typology.



A closer look at RIS at reach level illustrates the level of access to water by reaches and variation across schemes. Unlike FLA, RIS here was estimated from measured water flows at the inlets of sample farms. The shortcoming in these estimations is that the flow measurements were rapid. Figure 4 shows the result of this exercise. Accordingly, there was apparent discrepancies in RIS across the studied schemes. Overall, it tended decreases from the head to tail reach offtakes. This is something expected in surface irrigation systems with low quality water distribution infrastructure and water delivery schedules and where IWUA are weekly organized (Amede 2014). However, it is particularly interesting to note that field RIS values at Koga and Waro schemes do not show significant variations along the reaches. At Koga scheme, it is so because of the good water conveyance, distribution and control system. There is a well-developed irrigation schedule during each month and the irrigation system management does not allow significant variation in head-tail water delivery. Waro scheme is a traditional scheme; yet the water distribution and delivery system performs well. Irrigation schedules are well adhered to and water delivery equity is satisfactory. Also, the RIS was estimated at the head, middle and tail reaches across all schemes. Similar to Figure 4 it shows that the aggregated field RIS at field level decreases from head to tail reaches. On average, in the head reaches, offtakes are supplied with 14% more water on average across all schemes; while the tail reach offtakes of all schemes are supplied at their farm inlets with nearly 50% of their demand.

Figure 4: Field relative irrigation supply at head, middle and tail reach offtakes for each scheme.



There are arguments that suggest as far as the water in the return flow is used for irrigation by downstream farmers at scheme level the water is not lost. To highlight this, it is important to identify where the over supplied water has gone and next section will give details on this.

Tracking the fate of excess water: variation by irrigation schemes typology

Demeku et al. (2011), from their work on smallholder irrigation in Ethiopia, suggested that significant volume of water diverted from the source would be lost in the conveyance, distribution or on-farm. In the current study, there was an apparent variation in the proportion of water lost in the conveyance and distribution and on-farm for the different schemes and irrigation typologies. The water loss proportions in the distribution and on-farm for each scheme were estimated as the differences of flow value at the intakes and at farm inlets of sampled fields in the head, middle and tail reaches (Table 8). Then, based on information of average measured deliveries at the farm heads, the proportion of losses in the distribution and on-farm were estimated. The fields under the traditional schemes were on average under-supplied and part of the supplied water was lost in the conveyance and distribution systems. For the semi-modern irrigation schemes, where the relative excess diversion was the highest, a significant volume of the water was lost in the conveyance and distribution systems due to leaky and seeping canals, poor flow control structures and inadequate maintenance (Ayana and Awulachew 2009; Behailu et al. 2004, Amede 2014).

On the other hand, for the modern scheme, the major portion of the excess diverted water (74%) was lost on farm. The results of optimum water application study conducted in Koga irrigation scheme (Schmitter et al. 2015) suggest that farmers are over applying water by about 30% of the actual water demand and by about 50% of irrigation events and these explain the on farm water loss revealed in this study. The group discussion held at Koga revealed the excess on farm application has resulted in rising ground water and waterlogging in some irrigation blocks, which has affected crop productivity. Owing to the fact that almost all the conveyance and distribution systems in Koga scheme are lined and the main canals are wide, the significant proportion of the water lost in the canals would be by evaporation.

In view of this finding, it is important to focus on improving the on farm application of the modern irrigation schemes, while targeting efficient water conveyance and delivery for semi-modern and traditional schemes.

Table 8: Average proportion of over supplied water losses by points of losses and by typology

Scheme	Modern	Semi-modern	Traditional
RIS at diversion (source)	2.63	3.84	1.18
% loss in conveyance and distribution	26	100	100
% loss on-farm	74	-	-

Irrigation and cropping intensity

Information related to cropped area and cropping intensities is provided in Table 9. The cropping intensity is based on total annual harvested area and the irrigable command area of the schemes (may or may not be fully irrigated at present). On the other hand, irrigation intensity is based on the annual irrigated area and nominal currently irrigated area (Table 9). Overall, the cropping intensity is low (165) compared the expected result (~200%). There was an apparent variation among schemes (125 at Gelana and 205% at Koga scheme). Cropping intensity at Gelana is low mainly because it is dominated by perennial crops such as coffee (*Coffee arabica*) and enset (*Ensete ventricosum*). On the other hand, cropping intensity at Koga is about 200, indicating harvest from the whole land twice a year (irrigation and rainfed). Due to a relatively reliable water supply at this scheme, the major proportion of the scheme area is cropped mainly with wheat (*Triticum aestivum*) during irrigation season and maize (*Zea mays*) and finger millet (*Eleusine coracana*) during the rainfed season.

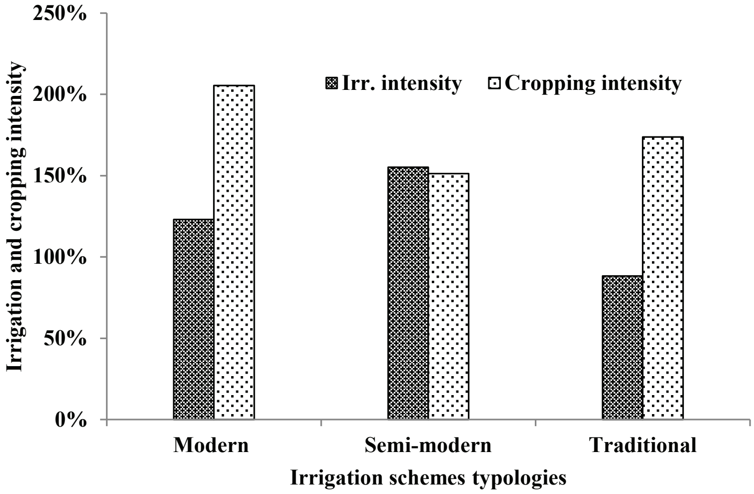
As for the cropping intensity, the study revealed also low irrigation intensity which varied between 81% for Hare traditional diversion scheme and 143% for May-Nigus. This can be accounted for by availability and reliability of irrigation water supply: the better the water supply, the stronger was the value of irrigation intensity. For example, there was a clear relation between the non-reliability and shortage of irrigation water at Hare diversion scheme and this was reflected in low irrigation intensity. On the other hand, there was practically no irrigation water shortage at May-Nigus at scheme level, which in turn resulted in a higher irrigation intensity.

To see the trend of irrigation and cropping intensities at the scale of typology, the results at scheme level were then aggregated to typologies of irrigation (Figure 5). It illustrates that irrigation intensity is less than 100% for 60% of the investigated schemes. The lowest value was computed for traditional schemes (88%). In fact, different picture emerges when the average annual irrigation intensity is aggregated across the reaches of all schemes. The value decrease from head to tail. It is observed that about 10% of the nominal irrigable area in the tail reaches of all schemes are not irrigated, even for one growing season in a year (irrigation intensity = 90%). García-Bolaños et al. (2012), also reported value as low as 66% of irrigation intensity for small-scale irrigation in West Africa.

Table 9: Relevant areas and irrigation and cropping intensity at schemes

Scheme	Irrigable command area, ha	Nominal currently irrigated area, ha	Annual harvested area, ha	Annual irrigated area, ha	Irrigation intensity, %	Cropping intensity, %
Koga	7000	6000	14,377	7000	85	205
Meki	3000	700	3980	980	140	133
May-Nigus	150	70	250	100	143	167
Wukro	500	330	778	278	84	156
Hare weir	1500	1300	2600	1100	85	173
Gelana	180	45	225	45	100	125
Megech	200	150	330	130	87	165
Waro	300	300	600	300	100	200
Hare diversion	1000	800	1650	650	81	165
Dessie-Zuria	827	634	1367	540	85	165

Figure 5: Irrigation and cropping intensity by typology.



The result for our study could be attributed to non-reliability of irrigation supplies and absence of permanent structures for flow control and distribution as illustrated earlier. Inequity resulting from poor flow control also contributes to low irrigation intensity. These schemes are particularly characterized by temporary water distribution structures [Figures 6, Figure 7 (Amede 2014)]. In these schemes, irrigation intensities were low mainly because water does not adequately reach part of the schemes down the water courses. This in turn forces some fields located at the schemes tail to be left unirrigated. Megech, Dessie-Zuria and Hare diversion schemes are good examples for serious inequity levels and high competition for water between the head and tail users.

Cropping intensity on the other hand is highest for the modern typology (Koga), while irrigation intensity was the second lowest. In fact, low irrigation intensity contrasts with the higher value of IRS which substantiate our argument of high on farm water losses. Relatively higher values of cropping intensities for traditional typology compared to its irrigation intensity implies that these schemes make significant use of rainfed crop production than other typologies as irrigation water supply is not reliable enough. Overall, such low irrigation intensity and contrastingly higher water wastage (on farm and in the conveyance) indicate the potential for improving food security. Amede (2014) suggests that the government of Ethiopia planned to increase irrigation infrastructure by three fold until end of 2015. Although identifying priority investment area (improved management of existing schemes or construction of new) is a policy decision, it is clear that improving irrigation intensity means enabling a higher number of harvests on same land unit per year and thus contributes to food security. The point here is also to see entry points to address these problems. In view of our earlier arguments related to over supply/undersupply of irrigation water, it is critical to ensure optimum and equitable water management and proper crop selection [short duration (Amede 2014)].

Figure 6: Traditional flow control with debris and stones at Waro scheme.

Figure 7: Traditional way of raising water levels in canals at Dessie-Zuria scheme.

Figure 8: Koga scheme dam outlet and off taking main canal.

Overall findings of this study suggest key areas and types of interventions. For the traditional schemes, where water is in short supply and major part of the water is lost in conveyance and distribution, interventions involving deficit irrigation need to be practiced. This is a protective type of irrigation where the available water is distributed all over the command area with acceptable yield reductions. This will enhance equity of water delivery, while increasing the overall scheme level productivity. However, in the absence of proper water distribution structures, the implementation of such a measure is challenging. Awareness creation with farmers, institutionalizing water management and building their capacities would help for better water management in these schemes (Ulsido and Alemu 2014). For the modern scheme (Koga), major intervention should be to match demand with release from the reservoir and to reduce excess on farm applications. For the semi-modern schemes, improving conveyance and distribution systems to reduce excess seepage and operational losses and enhancing head-middle-tail equity should be the focus of interventions (Ulsido and Alemu 2014).

Sustainability of irrigated land

Though sustainability is a complex issue, under scarce data, Bos et al. (1994) suggested that a ratio of current irrigated area to initial total irrigated area is a good indicator of irrigation scheme sustainability. In fact, the degree to which the initially planned (irrigated) area of schemes is sustained years after the implementation of a scheme is an important issue for the success of an irrigation scheme. It is related to losing or gaining of irrigated land in the command area over seasons (Sener et al. 2007). In principle, neither extension nor shrinkage is desired, particularly where schemes are well planned and command areas were defined based on land suitability and water availability. The major factors that can contribute to shrinkage of irrigated land would be: water shortage (unreliability), lack of proper maintenance of infrastructure for water conveyance and distribution, lack of interest in irrigation when it is not paying back (for example poor access to marketing system), etc.

Table 10 depicts the result of SIL estimation. Accordingly, SIL was lowest at Meki scheme (SIL=0.23) and Gelana scheme [SIL= 0.25 (Table 10)]. Meki scheme, when it was developed in 1987, it was for an irrigable land of 3000 ha. There were nine pumps installed with a discharge capacity of 764 litres/ second each. These were adequate enough to irrigate 3000 ha of land by then, although the distribution canals and structures were not completed well at that time. However, only one pump was running regularly during this study. Moreover, the main conveyance canal runs for only about 5 km, after which it is totally filled up by sediment. Distribution canals do not exist in the tail reaches. So water does not reach tail users which caused significant shrinkage of irrigated area. Currently, only a total of about 700 ha was put under irrigation. Hence the problem is both water shortage and problem of water distribution and control at Meki scheme. Few flow control structures, existing in the distribution system, are out of order. At Gelana scheme, the major challenge for reduction of irrigated area is a fictitious water shortage plus high inequity resulting from poor conveyance and distribution system. While there is enough water at the source (river), the headwork (intake) does not have sufficient capacity to divert adequate supplies. Moreover, the conveyance system at the main canal has serious construction and operational problems, including poor grading, high seepage losses, poor maintenance, absence of flow control structures, etc. Significant volume of the diverted water was lost in the head reach. Overall, the irrigated fields are hilly (~ >10%) and canals are leaky and as the result, in the head fields, the amount of water infiltrating into the soil is low. Hence, farmers in the head reach apply more water than needed, as part of it runs quickly down the hilly fields to the valley and river course. The canal water fails to reach downstream users of the scheme leaving those areas unirrigated.

Aggregated values of SIL for irrigation typologies are shown in Table 10. Traditional schemes had SIL of 0.76 which is slightly lower than that for modern (SIL=0.85). In contrast to their irrigation intensity, the traditional schemes showed stronger value of SIL than the semi modern typologies. Dejen et al. (2012) also made a comparative performance evaluation of two irrigation schemes in the Awash Basin and found a higher SIL for the community-managed scheme.

Table 10: Sustainability of irrigated land for individual schemes and by scheme typology

Scheme	Typology	Current irrigated area, ha	Initially irrigated area, ha	SIL	Aggregate SIL by topology
Koga	Modern	6000	7004	0.86	0.86
Meki	Semi-modern	700	3000	0.23	
May-Nigus		70	150	0.47	
Wukro		330	500	0.66	0.50
Hare weir		1300	1500	0.87	
Gelana		45	180	0.25	
Megech	Traditional	150	200	0.75	
Waro		300	300	1.00	0.76
Hare diversion		800	1000	0.80	
Dessie-Zuria		634	1287	0.49	

This implies that although the water supply is less reliable at traditional, farmers here do not totally give up irrigation. The most probable reason for this is the fact that these schemes are entirely community-managed and farmers have their own agreed upon values and rules for water distribution, which do not totally deny tail users' access to water. The other reason could be the fact that at the traditional schemes, food self-sufficiency is one of the major concerns compared to semi-modern and modern schemes. Hence, farmers prefer going for deficit irrigation than abandoning irrigation practices on their farm or plot. There are cases where pulses such as chickpea (*Cicer arietinum*) were planted as coping mechanism. According to Table 8 the semi-modern schemes experienced significant shrinkage in their irrigated lands, operating on average at 50% of their initial irrigated land. Implicitly, it is apparent that semi-modern irrigation is making less productive use of its land and water resources and irrigation infrastructure than the traditional schemes.

The modern irrigation scheme Koga, with the relatively highest SIL value, is operating for the last five years and because of imprudent use, a significant proportion of water is lost on farms (Table 8) and it is not enough to cover the total irrigable areas. If the current scenario continues, it is likely that ground water will rise and the irrigation system sustainability will be threatened.

Farm level adequacy—FRD

The water delivery adequacy at farm levels is very important from the farmers' point of view; as farmers are generally interested in the amount of water delivered at the head of their fields. Due to the different types of crops grown by the individual farmers, it was not easy to determine the actual water deliveries for each of the crops at field levels. Hence, the water deliveries at farm levels for the major crops at each scheme were determined for the sample farmers in the head, middle and tail reaches. Field irrigation data on major irrigated crops at each scheme including area under the main crop, length of the growing season, number of irrigations per season, duration of each irrigation, the field discharge (main d'eau), were collected from the farmers and with measurements whenever possible.

Table 11 depicts farm level adequacy or farm relative delivery for the selected major irrigated crops and indictors aggregated at scheme level. There was apparent variability on the value of farm relative delivery across the study schemes. Values ranging between 0.13 and 2.21 were observed. Generally, the value of farm relative delivery tended to decreased from modern to semi-modern and traditional (Table 12).

The farm relative delivery is maximum for the modern scheme (Koga) with a value of 2.21. This simply means that the water applied at the farm levels of Koga scheme is on average 2.21 times higher than the actual field demand. It can also be explained in terms of field application efficiency (Table 12). The application efficiency for the main crop at Koga scheme is 1/2.21, which is about 45%. This efficiency is by far low, and can be regarded as a low level of sustainability. Over irrigation at Koga is indeed well observed and farmers themselves admitted the ill-effects (sign of waterlogging) they were experiencing as a results of excess application in the past. May-Nigus (semi-modern) comes second in terms of excess on farm application. The diversion at the headwork (reservoir) at May-Nigus scheme was five and seven times the crop demand for season I and II respectively. However, the farm relative delivery is 1.66, meaning the on farm application is 66% higher than the actual field demand. This illustrates that the largest proportion of excess water diverted at May-Nigus scheme is lost in the conveyance, distribution and field channels as seepage and leakage as presented earlier (compare also Behailu et al. 2004).

Though traditional schemes are relatively more sustainable in their irrigated areas (compared to semi modern) their average farm relative delivery was only 0.59. This suggests that farmers at these schemes tend to practice deficit irrigation unlike their peers in semi-modern and modern schemes. This is generally related to crop selection and also the purpose of irrigation (e.g. cash or food security).

Stronger values of farm relative delivery mean lower efficiency and vice versa as shown in Table 12. In relation to this, Kalue et al. (1995) suggest that irrigation water distribution equity and application efficiencies are inversely related. Our results (Table 12) substantiate this argument and when the field irrigation supply is less than the field demand, the maximum efficiency will be 100% as in the case of the traditional typology.

Table 11: Major crops with field level water delivery and demand across study schemes

Scheme	Major crop	Average area cultivated per farm (ha)	Length of growing period, days	Avg. no. of irrigations per season	Avg. duration of irrigation, hours	Field discharge q, litre/sec.	Vol. applied in single irrigation, m^3	Farm water delivery per season (FWD), m^3	Farm water demand (FWD), m^3	Farm relative delivery (FWD/FWD)
Koga	Wheat	1.52	150	14.0	12	25	1080	15,120	6850	2.21
Meki	Onion	2.33	120	16.4	24	5	432	7084.8	6580	1.08
May-Nigus	Onion	0.33	120	14.1	12	3	129.6	1828.8	1103.3	1.66
Wukro	Maize	0.51	150	6.6	12	5	216	1429.3	1971.5	0.72
Hare weir	Banana	0.75	365	6.0	6.0	5	108	648	1862.6	0.35
Gelana	Coffee	1.33	240	13.8	3	5	54	742.5	599.6	1.24
Megech	Onion	1.31	120	5.9	15.6	15	841	4969	5463	0.91
Waro	Potato	0.25	135	10.4	4.0	4	57.6	600.7	837.5	0.72
Hare div	Banana	0.75	365	2.8	6	4	86.4	241.92	1862.6	0.13
Dessie-Zuria	Wheat	0.60	150	8.2	12	3	136	1111	1920	0.58

Table 12: Farm relative delivery and irrigation efficiency by typology

Typology	Farm relative delivery	Field application efficiency (%)
Modern	2.21	45
Semi-modern	1.01	99
Traditional	0.59	100

Water delivery equity

The spatial coefficient of variation (CV) of the ratio of water delivered at the field inlet to on farm water demand is a good indicator of water delivery equity (Bos 1997). In the present study this was computed from the data on farm water delivery and demand; however, in this case both demand and delivery of the individual farmers were considered instead of the average values for the schemes indicated. A spatial coefficient of variation of 0.10 is considered adequate for a good water delivery. CV between 0.11 and 0.25 is considered fair, while if it is greater than 0.25 it is termed poor according to Molden and Gates (1990). The CV of individual schemes across the three reaches (head, middle, tail) and the aggregated values of the spatial CV (adequacy indicator, PE) are shown in Table 13. The water delivery equity at modern (Koga) scheme is fair according to the classification. The inequity levels are extremely poor for the semi-modern typology, while it featured better than the semi-modern for the traditional schemes. Hussain et al. (2003), in a similar study in South Asia, suggested that inequity is one of the major issues in irrigation schemes and variation is stronger within a distribution and increases along the distribution canals as it goes from head to tail. A number of scholars (Rogers 2002) suggest water pricing and volumetric water charging as one of the options to reduce wastage of water by head irrigators, but farmers' willingness and capacity to pay are points of argument in the Sub-Saharan Africa context. Even if farmers were willing to pay, governments would still have important roles to play in providing stable and appropriate institutions for the successful operation.

Table 13: Equity indicator for schemes and by typology

Scheme	Scheme equity indicator, PE	Typology	Equity indicator by typology	Performance level by typology
Koga	0.13	Modern	0.13	Fair
Meki	0.35	Semi-modern	0.46	Poor
May-Nigus	0.60			
Wukro	0.58			
Hare weir	0.30			
Gelana	0.54			
Waro	0.13	Traditional	0.27	Poor
Megech	0.57			
Hare diversion	0.12			
Dessie-Zuria	0.28			

Water delivery equity

Table 14 shows equity of the water delivery at head, middle and tail reaches aggregated for all schemes. Accordingly, although there was apparent variability in terms of PE, the performance level of all clusters is poor. This suggests that the water delivery at the head, middle and tail reaches when the aggregate for all schemes is inequitable and which are depicted by high values of the spatial CV, defined as equity indicator P_E. These aggregated equity indicators across different schemes for specific reaches depict that the water delivery service is highly variable inadequacy even in the same reaches across schemes. In this regard, Kalu et al. (1995) suggested that under conditions of poor equity productivity declines and thus to increase the role of irrigation on food security, it is important to improve equity across reaches. The key issue here is also to understand farmer perception and mechanisms they adopt to mitigate the impact.

Table 14: Reach based water delivery equity across all schemes

Reach	Equity indicator, P_E	Performance level
Head	0.67	Poor
Middle	0.69	Poor
Tail	0.77	Poor

3.2. Water delivery service quality as perceived by farmers

In addition to computed water supply, qualitatively farmers' view irrigation water delivery service is a valuable indicator for suitability of the water delivery (Ulsido and Alemeu 2014). Farmers are the end users of the irrigation system and their views on the quality of the services is hence important. Accordingly, farmers' views on four aspects (elements) which qualitatively characterize the nature and quality of irrigation water delivery service (good, medium or bad) were collected from the head, middle and tail reaches farmers in each scheme (Ulsido and Alemeu 2014). Service indicators evaluated using this approach involved: flow rate, duration of water delivery, water delivery as per prior arrangement, and fairness of water delivery.

Accordingly, farmers' perception for many of the investigated services indicators substantiate the empirical findings presented earlier. For example, the percentage of farmers responding 'good' on the flow rate of water delivery decreased from the head to tail reaches (Figure 9). Similarly, the responses 'good' for duration of water delivery decreased from head to tail reaches. Figure 10 depicts fairness of water delivery and illustrates that almost all the farmers at the head, middle and tail reaches are concerned about the fairness of the water delivery. Figure 10 also shows reliability of water supply and the response 'good' is highest for the middle reach; however, it is the lowest for the tail reach. Only 2 or 3% of the total respondents in each reach considered the water delivery to be 'fair', and about 25 and 31% of them from the head and tail reaches consider the water delivery to be 'unfair. In fact, the highest number of responses for 'unfair' water delivery occurred at the tail ends, which is in line with the fact that tail users are the most marginalized ones.

In some cases, there was disparity between the trends from empirical findings and qualitative farmers' perception analysis. Arguably, this can be explained for by farmers interpretation of what is good and what is bad, presumably a relative term. For example the 'bad' for the head reach farmers who are more favoured by the water delivery could be 'good' or 'medium' for the tail reaches. This is of course the most likely reason that 65% of farmers at the tail reaches responded 'medium'.

Figure 9: Responses on flow rate and duration of water delivery across reaches of all schemes.

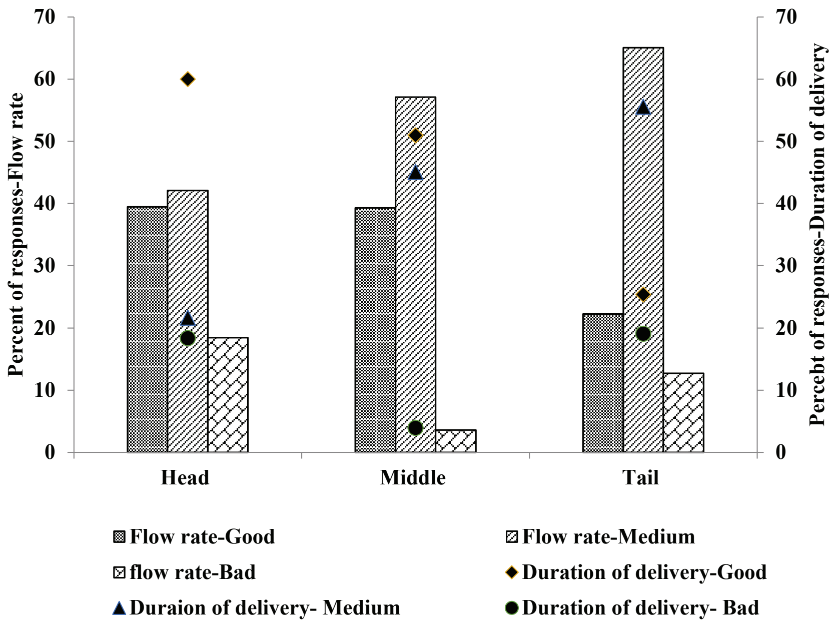
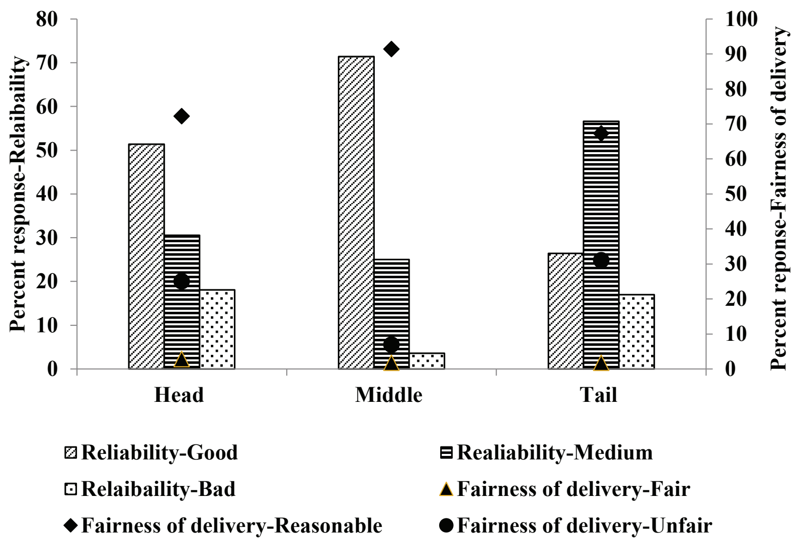


Figure 10: Responses on reliability and fairness of water delivery across reaches of all schemes.



3.3. Synthesis of key challenges and entry points to addresses problems of water delivery in the study irrigation schemes

The previous sections presented empirical values and discussions on key features of the study irrigation schemes water delivery. The schemes considered are diverse in terms of their water sources, headworks, conveyance and flow control. Listing all issues would not be practical and therefore this section highlights priority challenges and entry points.

i. *Mismatch between field irrigation water demand and water diversion*: Water shortage is one of the main constraints to irrigated agriculture as raised by the irrigation water users in several of the study irrigation schemes. This farmers claim contrasts with the RIS results which revealed that real water shortage actually occurs only at Hare weir, Hare diversion and Megech schemes. At all other schemes, there were excess diversions as high as 6.8 and 7.0 RIS value at May-Nigus and Gelana schemes respectively. Even at these two schemes farmers at the tail ends claim serious water shortages. Water diversion in many cases was not based on detail assessment of field water demands. Experts and local institutions lack capacity and the means to control the volume of water that flows into the system and ultimately to farm. This has negative consequences both for the irrigation systems and downstream ecosystem services.
Capacity building in terms of training of irrigation planners and managers on matching irrigation water diversions with field demands over the cropping seasons is required. Water diversions should consider cropping patterns and hence irrigation demands. For this training of local administrations, development agents and IWUA on compilation of appropriate agronomic data and hence cropping pattern before the start of each irrigation season is required. So before irrigation, diversion schedules have to be set and implemented. This reduces the excess diversions, saves water and reduces negative impacts such as waterlogging.

ii. *High water losses in the conveyance and distribution systems*: Poorly constructed, maintained and leaky conveyance and distribution systems contribute to the largest share of water losses particularly on semi-modern schemes. It was observed that water losses in the conveyance and distribution systems for semi-modern and traditional schemes are 100% of the excess diversions. However, for the modern scheme, the water loss in the conveyance and distribution systems is only about 26%. This is one of the major causes for low irrigation intensity and shrinkage of the irrigable areas (mainly for the semi-modern typologies). In many of the schemes routine maintenance is not adequate, and hence sedimentation and growth of grasses in the canals significantly reduces canal discharge capacities, causing very low conveyance and distribution efficiencies. Distribution canals and farm structures have to be generally maintained by the farmers themselves. Routine and major canal maintenance is key for effective water management and efficient irrigation water use in these schemes. Asset management training is an essential element of irrigation management in this regard. To this end, capacity building training on maintenance types, principles, guidelines, and techniques to the farmers is essential.

iii. *Absence of flow control structures:* Absence of flow control structures and flow measurement are also major constraints for equitable water distribution and efficient water use. Regulation and control of irrigation flows is a major criterion for modern irrigation scheme. In the absence of control structures, flows cannot be adequately regulated and distributed. It hence apparently causes excesses in one part of the scheme and shortages in another. Particularly in traditional schemes, control and regulation structures are lacking, and in semi-modern schemes, even though they exist at some points, they are not functional. In some cases, farmers themselves demolish the gates so as to have access to more water. The only exception in this regard is Koga scheme which has well functional and orderly control structures.

iv. *High head, middle and tail water delivery inequity levels*: This is related to nonexistence of flow control structures, and the weakness of institutional setups for water management. These favours head offtakes in terms of water delivery. The aggregated RIS at field levels indicated that the average over supply across all schemes in the head reaches is about 14%, while on average middle and tail reaches are 18 and 48% under-supplied respectively. Flow control is key for effective water distribution and efficient water use. Installation of flow control gates at major flow divisions and bifurcations in the distribution systems to enable effective flow regulation and distribution are important. Putting in place appropriate irrigation scheduling at irrigation block levels, or at irrigation water user association level, if not for individual farmers for all irrigation typologies, is required. To ensure well-functioning of the irrigation schedule, training canal riders (as they are called traditionally 'water fathers') and provision of simple practical water optimization tool is useful. Flow measurement (monitoring) is considered as a major element for efficient and equitable water use. Installation of simple flow measurement structures at the heads of major supply canals to quantify flow delivery and ensure the right volume delivery for areas of intervention. For this, structures like V-notches, Parshall flumes or weirs made of concrete or masonry at main supply points can be considered.

4. Conclusion

This study focused on water delivery performance evaluation of 10 smallholders' irrigation schemes in Ethiopia representing diverse water sourcing, distribution, irrigated areas and agro-ecologies. Methodologies involving household survey, flow measurement, irrigation schemes typology building, and employment of performance indicators (RIS, Ii, CI, FWAD, SIL, equity and FAI) were employed. The conclusions drawn are of two sets: i) Methodological which is mainly related to typology building and ii) Performance evaluation. For the purpose of simplicity, we embedded conclusion related to performance evaluation into the typology building as presented below.

The customary way of classification of irrigation schemes in Ethiopia, which mainly depends on existence or absence of fixed water diversion and control structures, does not necessarily imply the state of the schemes' performance. The irrigation typology developed in this study, which took several factors of the irrigation schemes into account, enabled the identification of three relatively homogeneous typologies: modern, semi-modern and traditional. Based on the pre-defined criteria, among 10 irrigation schemes considered in this study, only Koga came out to be 'modern' in contrast with traditional approach which may classify 80% of the study schemes as modern.

The study revealed that all schemes irrespective of typologies suffered from injudicious water management as demonstrated by the values of one or more indicators. It should be emphasised that modernity itself is a relative concept as revealed here. For example, the Koga scheme wastes tremendous volume of water on farm. Semi-modern schemes on average divert the highest amount of excess supplies, more than both modern and traditional. Though there are variations from one scheme to another, on average almost all the excess diversion in these schemes is being lost in the conveyance and distribution systems, except for modern schemes where the major water loss point is on farm. Major issues that emerged during farmer stakeholder consultation and field observation involve the water infrastructure development without appropriate operation, maintenance and asset management plans in place. Faulty operation, damaged flow control structures, leaky canals, and hence high head, middle and tail inequity are the major causes for low efficiency.

Despite substantial improvements made in terms of homogeneity of irrigation typology, the observed values of indicators do not encourage the conclusion of an irrigation typology as sustainable or not sustainable. This is mainly related to the fact that an irrigation typology is good in terms of the values of one indicator, but weak in another. For example, the RIS value for traditional irrigation is preferable, while the values and water distribution fairness were the lowest. This suggest that policy directions based on arbitrarily developed topologies could be misleading and to minimize such disarray, future efforts need to be devoted to developing composite sustainability indices to evaluate performances of smallholders' irrigation schemes.

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