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A review of trends, constraints and opportunities of smallholder irrigation in East Africa

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ABSTRACT

Smallholder irrigation expansion would significantly increase agricultural production, and reduce food insecurity and poverty levels in East Africa. This paper reviews literature on trends, constraints and opportunities of smallholder irrigation in four East African countries: Ethiopia, Kenya, Tanzania and Uganda. Irrigation development has been slow in these countries, and has been mainly through traditional schemes. Recently, individual irrigation technologies such as small motorized pumps, drip kits, treadle pumps, rope and washer pumps are being promoted. Adoption of these technologies and expansion of smallholder irrigation however face a number of challenges including land tenure issues; lack of access to appropriate irrigation technologies, improved agricultural inputs, reliable markets, finance and credit services, and research support; poor transport and communication infrastructures; poor irrigation water management; poor extension systems; and the over dependence on national governments, NGOs and donors for support. Despite these challenges, opportunities exist for smallholder irrigation expansion in East Africa. Such opportunities include: high untapped irrigation potential; rainwater harvesting to improve water availability; high commitment of national governments, NGOs and donors to smallholder irrigation expansion; low cost irrigation technologies adaptable to local conditions; traditional schemes rehabilitation; growing urbanization; and increased use of mobile phones that can be used to disseminate information.

1. Introduction

1.1. Background

Worldwide, 20% of the total land cultivated receives irrigation water to produce about 40% of the world's total food (FAO, 2015a). Sub-Saharan Africa (SSA) has with its 4%, the lowest percentage of irrigated land to the total area cultivated globally (Burney et al., 2013) whilst having the highest depth of food deficit i.e. the highest amount of energy needed for people who are undernourished to attain the average dietary requirement (Fig. 1). For the four East African countries considered in this paper, namely: Ethiopia, Kenya, Tanzania and Uganda, Ethiopia has 289,600 ha of irrigated land out of the 16.5 million ha of cultivated land; 103,200 ha are under irrigation in Kenya with total cultivated area of 6.1 million ha; in Tanzania, 184,300 ha are irrigated out of the 16.7 million ha that are cultivated, and in Uganda, only 8716 ha out of the total cultivated area of 9.2 million ha (FAO, 2015a). On average, 2% of the four countries' cultivated area is under irrigation. Nevertheless, irrigated land although minimal in SSA when compared to the total cultivated land, it produces about 20% of the total agricultural output (Foster and Briceño-Garmendia, 2009). The estimated irrigation potentials for Tanzania, Ethiopia, Kenya and Uganda are as shown in Table 1. The irrigation potentials and area irrigated in these countries however vary strongly among sources. When comparing irrigation in SSA with that in Asia, 41% of the cultivated area in Asia was under irrigation in 2000 (Portmann et al., 2010); which is a tenfold that of the irrigated area found in SSA. Irrigation together with mechanization of agriculture, use of improved seeds, and use of inputs such as fertilizers and pesticides in the 1960s significantly contributed to the Green Revolution in Asia (Hazell, 2009). As such, sustainable irrigated agriculture expansion in SSA presents opportunities to reproduce conditions that led to production gains witnessed in Asia over the last 50 years (Fujiie et al., 2011).

Agricultural production in Eastern Africa is mainly rainfed despite rainfall being highly variable and in many areas, insufficient. Risks and vulnerabilities of climate change and variability in the world are now noticeable (Adger et al., 2003); the Intergovernmental Panel on Climate Change (IPCC) warns that climate change and variability will add more

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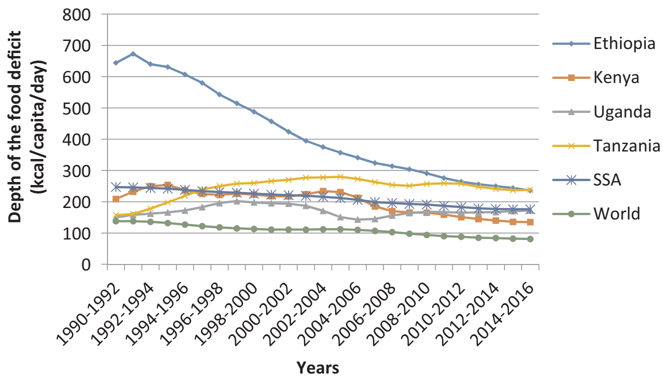

Fig. 1. 3-year average of depth of the food deficit.
FAOSTAT database

Table 1
Irrigation potentials of the four countries.
Source: FAO AQUASTAT database

Country	Irrigation potential (1000 ha)
Ethiopia	2700
Kenya	353
Tanzania	2132
Uganda	90

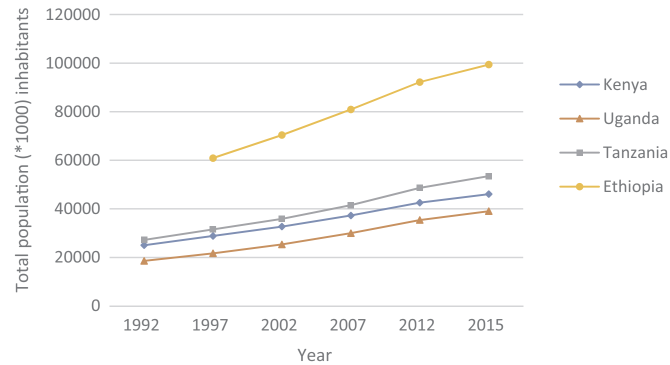

Fig. 2. Population growth of the East African countries.
FAO AQUASTAT database

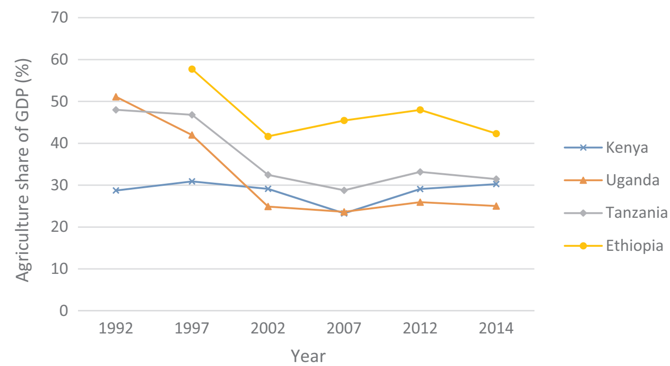

Fig. 3. Agriculture, value added to GDP.
FAO AQUASTAT database

pressures on water availability, accessibility and demand in Africa (Boko et al., 2007). Heavy dependence on rainfed production makes communities in these countries more prone to droughts and periods of water scarcity which significantly affect crop and livestock production. For instances, during the financial year of 2010/11, Uganda's Ministry of Agriculture, Animal Industry and Fisheries (Ministry of Agriculture, Animal Industry and Fisheries (MAAIF)) reported a 16% decline in cash crops (i.e. coffee, cotton, tea, tobacco, sugar cane, flowers and horticultural crops) production due to poor rains and droughts across parts of the country (Ministry of Agriculture, Animal Industry and Fisheries MAAIF, 2011). As a result of a 40 – 55% reduction in cumulative rainfall observed in the October – December rainy season of 2016 from the long-term average, a 70% reduction in maize production was recorded when compared to the average of the previous five years in the southeastern cropping areas of Kenya that include counties of Kitui, Makueni, Tharaka Nithi, North Meru and Embu (FAO, 2017). In the coastal cropping counties of Kenya, the October – December cumulative rains were 55 – 90% below the long-term average leading to total failure of the maize crop (FAO, 2017). As such, in January 2017, about 2.2 million people were estimated to be in need of humanitarian aid. The IPCC projects that reductions in yields in some African countries due to climate change and variability could be as high as 50% by 2020; with smallholder farmers being the most affected (Boko et al., 2007).

Smallholder farmers, defined here as farmers who carry out farming activities on pieces of land that are 2 ha or less, dominate agricultural production in Eastern Africa (Salami et al., 2010; Livingston et al., 2011). In addition to the unreliable rainfall, these farmers further face a number of challenges including volatile food and energy prices, lack of access to technologies, inputs, markets and credit to name a few. All these factors have contributed to the low agricultural productivity that is witnessed in most communities in East Africa. Although the population in these countries increases every year (Fig. 2), agriculture's contribution to these countries' Gross domestic product (GDP) has not followed a similar trend (Fig. 3) despite over 70% of each of the countries' population deriving their livelihood from agriculture (Toenniessen et al., 2008). Increase in food production in sub-Saharan Africa in the past has been through increasing the area cultivated and using more labor (DFID, 2004; Toenniessen et. al, 2008). Due to current dense population patterns, cultivatable land is now scarce, and agricultural production thus needs to be intensified in order to increase yields that will ensure economic growth, food security and poverty reduction in especially the rural communities. Schultz et al. (2005) notes that 90% of the required increase in food production has to be achieved from already existing cultivated land and the other 10% will be from newly reclaimed land. Sustainable intensification is thus needed for both rainfed and irrigated agriculture, however, irrigated agriculture has shown to have a higher potential for intensification (FAO, 1997).

With the ever increasing population, dwindling land holdings, and rainfall being erratic in many areas, irrigation is an important tool to curb food shortages that are a recurrent problem in several communities of East Africa. Irrigation also plays a major role in moving farmers from subsistence to commercial farming. In areas where water sources are dependable both in quantity and quality, supplemental irrigation can be used to grow crops during the rainy seasons when rainfall is not sufficient, and in the dry seasons, high value cash crops that require reliable and timely water applications, can be grown. Irrigation thus allows for more than one crop season in a year making irrigated agriculture a significant contributor to food security (Burney et al., 2013). Having a more reliable and all year round supply of water and other production inputs also makes it possible to manipulate production times so as to coincide with higher seasonal prices of particular agricultural products. Furthermore, the positive impact of irrigation on livelihoods in Africa has been shown in several studies (Ngigi et al., 2000; Mati, 2008; Bacha et al., 2011; Hagos et al., 2012; Namara et al., 2013; Shah et al., 2013; Amede, 2015). Field survey of 1554 smallholder farmers in nine SSA countries, showed that irrigation added value per acre as well as per family worker (Shah et al., 2013). A study carried out in Ambo District in Ethiopia showed that poverty rates were significantly lower in households that were practicing irrigation compared to households that only depended on rainfed agriculture (Bacha et al., 2011). Mati (2008) also showed that the poverty and food insecurity rates of smallholder farmers in the surveyed smallholder irrigation (SI) schemes in Kenya reduced in a period of 2–3 years of practicing irrigation.

1.2. Why the emphasis is being put on smallholder irrigation (SI)

The majority of the four East African countries' population is found in rural areas (Table 2). The rural economies in these countries strongly depend on crop and livestock production. In Kenya and Ethiopia, more than 80% of the total population derives their livelihood from agriculture and other agricultural related activities. In Uganda and Tanzania, income from agriculture provides for livelihoods of about 75% of the population (IFAD, 2013). These agriculturally based systems are largely based on smallholder farms (2 ha or less) as well as traditional agro-pastoralists and fishers. Of all farms in SSA, 80% of them are smallholder farms, averaging 1.6 ha, and producing up to 90% of the total production in the region (Wiggins, 2009). About 85% of the rural population in Eastern and Southern Africa cultivates land that has been noted to have medium to high potential for increased agricultural productivity (IFAD, 2015). Agricultural intensification, with SI as one of the catalysts, can therefore play a major role in improving rural livelihoods.

Smallholder irrigation (SI) in this paper includes all irrigation activities carried out by smallholder farmers who manage individual plots or are part of a community managed irrigation scheme. Although a scheme might be large in terms of land area it covers, it is classified as SI in this study when it is comprised of farmers who manage individual plots of less than 2 ha, and who completely control the water distribution and other key services in the scheme without interference from government institutions (Adams, 1990; Kay, 2001). Brown and Nooter (1992) noted that it's on plots managed by individuals who control their own water supply, over time and space, that successful irrigations are more likely to occur. Successful irrigation here refers to "on-demand" water application which supports intensification and diversification, leading to positive financial impact on the smallholder farms. This impact arises because farmers can then more securely invest in improved seeds, agrochemicals, labor, and other good production practices since the water resource is now more readily accessible when needed.

Smallholder farmers are majorly subsistence farmers who mainly use traditional technologies. SI farmers in SSA get water for irrigation from shallow wells, streams, rivers, lakes and ponds using manual or motorized lifting technologies. Conveyance of the water is mostly through open channels, overland flexible pipes and buckets. SI in SSA is often based on simple and low cost technologies which do not require high investment, operation and maintenance costs. Moreover, large irrigation projects in SSA often require large investments, do not perform as efficiently as they are intended due to technical and management issues, and are not accessible to majority of the smallholder farmers in the community who are often widely spread out in the community (Fujiie et al., 2011; Venot and Krishna, 2011; Pavelic et al., 2013). Smallholder irrigators however normally suffer from economic water scarcity. Water resources might be available in a community, but individual smallholder farmers might lack resources that allow them to access and use these water sources adequately. In such cases, need arises to work in groups (e.g. farmer cooperatives), take up credits or be dependent on government or donor contributions. Thus, making water accessible to smallholder irrigators has been suggested as having the greatest potential of achieving food security in SSA (Burney et al., 2013). SI thus is now a priority in SSA to accelerate agricultural growth and improve the livelihoods of rural communities (Grimm and Richter, 2008; Burney et al., 2013; Shah et al., 2013; Pavelic et al., 2013; Kamwamba-Mtethiwa et al., 2016). This paper therefore reviews relevant literature on SI in 4 East African countries including Ethiopia, Kenya, Uganda and Tanzania to: (i) assess the status of SI development in East Africa, (ii) identify challenges that are inhibiting SI development, and (iii) highlight opportunities that can be explored in these countries to foster more utilization of the countries' irrigation potentials, with the view of enhancing agricultural production in these countries.

Table 2
Population ($\times 10^6$ inhabitants) (2013).
Source: FAO AQUASTAT database

Country	Rural population	Total population	Percentage of rural population to total population
Ethiopia	77.6	94.1	82
Kenya	33.4	44.4	75
Tanzania	35.6	49.3	72
Uganda	31.4	37.6	84

2. Smallholder irrigation development in East Africa: from past to present

2.1. Kenya

Application of water to supplement rainfall for crop production is not new in East Africa. In Kenya, spate irrigation is believed to date back to more than 400 years ago along River Tana and in Marakwet, Keiyo, West Pokot and Baringo districts (Ngigi, 2002; Muthigani, 2011). In the early 19th century, rice was irrigated along river valleys around Kipini, Malindi, Shimoni and Vanga. During the construction of the Kenya-Uganda railway, the Asian workers on the railway undertook some irrigation activities between 1901 and 1905 around Kibwezi and Makindu (Ngigi, 2002; Muthigani, 2011). In the mid-1930s, crop production started in some swampy areas in Central Kenya. Around this time, production of cash crops such as coffee, pineapples, sisal and lucerne was introduced. This marked the start of the construction of public irrigation schemes including Mwea, Hola, Perkerra, Yatta and Ishiara (Ngigi, 2002). Land in these schemes was owned by the government and the schemes managed by a government agency. The 1960s saw the development of the first SI schemes in Kenya, which happened in Turkana and in the North-East Province (Adams, 1990). Wind pumps were tried in the established SI scheme at Kakorongole in Turkana but deemed unsuccessful. Subsequently a reservoir dam was built to enable gravitational irrigation. Since the 1970s, irrigation in Kenya has expanded through private large-scale farmers and smallholder farmers, some of whom are working in government or non-governmental supported schemes producing coffee, flowers and other high value crops.

As individual farmer initiatives and non-governmental organization (NGO) support have increased over the past decades, Kenya has experienced a significant increase in SI (Table 3), primarily through surface water irrigation of horticultural, floricultural and rice crops. Examples of farmer initiatives include: bucket irrigation on the shores of Lake Victoria, diverting and impounding water from streams and rivers for rice production in Kano plains of Kisumu District, and ranch furrows that were used to grow fodder in the 1960s and 70s in Laikipia, Nyeri District are now being used to irrigate crops (Scheltema, 2002). In 2010, 87% of the irrigated area reportedly used surface water (FAO, 2015a). Smallholder farmers also use manual (treadle "money-maker" pumps) and small motorized pumps[1] (normally 1–5 horsepower that

[1] The adoption of small motorized pumps is rapidly expanding in SSA (Dessalegn and Merrey, 2015) as farmers who can afford them are taking advantage of the less time and labor requirements, and the ability to access more and deeper water from both ground and surface water sources when compared to manual lifting technologies.

Table 3
Smallholder irrigation development in Kenya.
Source: Ngigi (2002); Tafesse (2003).

Year	Area under smallholder irrigation (1000 ha)	Total area under irrigation (1000 ha)	Percentage of smallholder irrigated area to total irrigated area (%)
1975	2.4	20.9	12
1983	3.5	30.5	12
1990	18.9	51.4	37
1992	18.9	52.8	36
1995	33.0	79.0	42
1998	34.7	84.4	41
2002	36.2	91.4	40

run on diesel or petrol) to draw water from surface and groundwater sources for irrigation. The treadle pump[2] was introduced in Kenya in 1996, and has been adopted by some smallholder farmers (Sijali and Okumu, 2002). Groundwater irrigation in 2010 was only 13% of total irrigation (FAO, 2015a), and is mainly by private commercial farmers who use boreholes and tube wells to grow vegetables, flowers and fodder (Scheltema, 2002). Until the introduction of low-cost drip kits (comprising of a bucket or tank, and drip tubing or tape) in 1995 (Ngigi et al., 2000), drip irrigation in Kenya was only being used by large-scale farmers for flowers and horticultural crops because its initial investment cost was too high for smallholder farmers (Sijali and Okumu, 2002). The technology has since spread especially among women through its use in kitchen gardens thus replacing the laborious use of buckets to irrigate their vegetables.

2.2. Uganda

In Uganda, smallholder irrigation is believed to have started in Acholi, Northern Uganda in the early 1900s where water was diverted from rivers and streams, stored in trenches and applied to crops when needed (Watson, 1952). Planting rice in swampy areas started prior to World War II in Eastern Uganda. In 1943, reclaiming swamps to grow various crops started in Kigezi, southwestern Uganda (Carruthers, 1970). The construction of public irrigation infrastructure started in 1948 when diversion structures and bunds for spate irrigation, river diversion, small dams, tanks and windmills were constructed in Northeastern Uganda. Head works and canals were constructed in 1957 in Oruchinga valley in Ankole and Nyakotonzi in Toro, southwestern Uganda, to provide farmers with water for crop production. These projects suffered several setbacks including flooding of farmers' plots during heavy storms. The 1960s saw the start of the development of larger irrigation schemes by the government including Odina, Kiige, Labori, Ongom and Atera schemes. However by 1969, most of the activities on these schemes had closed down (Carruthers, 1970). Mobuku irrigation project in western Uganda, government funded and the largest irrigation project in Uganda so far in terms of land area covered and cost of investment was established in the 1960s to encourage smallholder farmer settlement and farming, and is currently still operational. Several schemes both public and private including Kakira sugar estate, Kibimba, Doho and Agoro were established around this time. Various crops are grown in these schemes using either furrow or sprinkler irrigation. Rehabilitation works were in 2013 completed on Mobuku, Doho and Agoro public schemes (FAO, 2015b).

Results of the 2008/09 Uganda Census of Agriculture (Uganda Census of Agriculture UCA 2008/09) showed that less than 1% of the smallholder farmers in Uganda practice irrigation; of the 3.6 million households that depend solely on agriculture for their livelihoods, only 31,000 of these households carried out some form of irrigation activity. Uganda Census of Agriculture UCA 2008/09 (2010) also reported that 58% of irrigation households use groundwater and the rest surface water although some households indicated to using both water sources. According to FAO (2015b), about 72% of the area equipped for irrigation is under surface water irrigation using mainly gravity flow, and 25% under sprinkler irrigation. The bulk of the sprinkler irrigation is found at two sugarcane commercial farms (Kakira and Lugazi sugar estates) and is used to irrigate sugarcane seedlings (FAO, 2015b). Drip irrigation and micro-sprinklers are used on only 3% of the area equipped for irrigation, and are used by private floriculture farmers whose farms are located around Lake Victoria. Drip kits and treadle pumps are of recent being promoted in Uganda; documentation of their extent of use and adoption, however, is not available. 'Informal' SI which is comprised of cultivation in unequipped wetlands (or swamps), flood recession cultivation and spate irrigation through unplanned initiatives of smallholder farmers with almost no technical assistance covers the largest land area of the total agricultural water managed land in Uganda (Table 4). Ministry of Agriculture, Animal Industry and Fisheries MAAIF (2011) reported that in 2010, about 53,000 ha were being irrigated informally by farmers growing mainly rice, and also sugarcane, vegetables and citrus in swamps. In 2009, 80,000 out of the 3.6 million households that depended on agriculture used spate irrigation whereas 206,000 used flood recession cultivation along edges of lakes and rivers (Uganda Census of Agriculture UCA 2008/09, 2010).

2.3. Tanzania

Indigenous irrigation systems are reported to date back hundreds of years in Tanzania (Ministry of Water and Irrigation, 2009). These systems, now commonly referred to as traditional irrigation schemes, are characterized by temporary diversion weirs and unlined canals with no gates to control flow. The weirs often get washed away by floods during the rainy season and have to be reconstructed after each rainy season. Due to lack of control structures and unlined canals, water losses in these schemes are high (Matlock, 2008). These traditional systems use furrow irrigation (Tagseth, 2008). In 1948, the Kilangali rice irrigation farm of 1000 ha was established by the government in Morogoro Region. More farmer managed traditional schemes were established by smallholder farmers starting in the 1950s. These smallholder farmers received some support from government through improvement of the schemes' infrastructures and provision of extension services through agricultural officers (Ministry of Water and Irrigation, 2009). Even with the improvements of some of the traditional schemes' infrastructures by the government, performance was low due to poor designs, poor management and maintenance, and low water use efficiencies. As a result, some of the schemes were abandoned. With external support, establishment of new irrigation schemes picked up again in 1985, but performance of the schemes remained low. In 1994, the government embarked on a plan to improve existing schemes; the few schemes that have since received some rehabilitation are still considered unsatisfactory (Ministry of Water and Irrigation, 2009).

Most of the irrigated areas in Tanzania are irrigated under schemes using surface water mainly by smallholders; only 0.2% of the irrigated areas are under groundwater irrigation (Ministry of Water and Irrigation, 2009). Of the 1428 schemes inventoried by the National Irrigation Master Plan (NIMP) in 2002, 1328 were smallholder schemes, 85 private and 15 government managed schemes. Smallholder schemes are river diversions, spate flows and rainwater harvesting schemes. Under surface water irrigation, water is conveyed by lined and unlined canals and applied through furrows and basins; about 99% of the schemes use gravity-fed irrigation systems, while the rest use motorized pumps. A few large-scale commercial farmers use sprinkler irrigation. Sprinkler irrigation and drip irrigation are not commonly used among smallholder farmers. The treadle pump was introduced by NGOs in Tanzania in 1997, and some farmers are reported to have adopted the technology (Sijali and Okumu, 2002). The two main irrigated crops in Tanzania are paddy rice and maize. Other irrigated crops include beans,

[2] Treadle pumps are foot-operated pumps that pull water from up to 7 m depth.

Table 4
Trends in irrigated equipped area, actually irrigated area, and total agricultural water managed area.
Source: FAO AQUASTAT database; Droogers et al. (2011); MAAIF (2011); Mati (2008); Ngigi (2002); Tafesse (2003).

Country	Year	Area equipped for irrigation (1000 ha)	Area equipped for irrigation and actually irrigated (1000 ha)	Total agricultural water managed area[a] (1000 ha)	Percentage of area equipped for irrigation to irrigation potential (%)	Percentage of actually irrigated land to irrigation potential (%)
Ethiopia	2001	289.6	–	289.6	10.7	–
	2002	–	161.8	–	–	6.0
	2006	–	–	–	–	–
Kenya	1965	14.0	–	–	4.0	–
	1975	40.0	20.9	–	11.3	5.9
	1983	–	30.5	–	–	8.6
	1985	42.0	–	–	11.9	–
	1990	–	51.4	–	–	14.6
	1992	66.6	52.8 − 66.6	73.03	18.9	15.0 − 18.9
	1995	70.0	79.0	–	19.8	22.4
	1998	–	84.4	–	–	23.9
	2002	–	91.4	–	–	–
	2003	103.0	97.2	109.6	29.2	27.5
	2005	103.0	–	–	29.2	–
	2008	–	106.6	–	–	30.2
	2010	–	–	150.6	–	–
Tanzania	1965	–	28.0	–	–	1.3
	1975	52.0	–	–	2.4	–
	1985	127.0	–	135.2	6.0	–
	1993	–	–	150.0	–	–
	1995	150.0	–	–	7.0	–
	2002	–	–	184.0	–	–
	2005	184.0	–	–	8.6	–
Uganda	1965	3.0	–	–	3.3	–
	1975	4.0	–	–	4.4	–
	1985	9.0	–	–	10.0	–
	1987	9.0	–	9.1	10.0	–
	1995	9.0	–	–	10.0	–
	1998	–	5.9	58.9	–	6.6
	2005	9.0	–	–	10.0	–
	2008	–	7.0	–	–	7.8
	2012	11.1	10.6	64.5	12.4	11.8
	2013	–	10.6	–	–	11.8

[a] In these countries, in addition to areas equipped for irrigation, there are areas without irrigation facilities where water is managed informally because the supply is not reliable and control is limited. These areas include cultivated wetlands, spate irrigation areas, flood recession cropping areas and inland valley bottoms. The total agricultural water managed area is the sum of the total area equipped for irrigation and areas with forms of informally managed water.

onion, tomato, leafy vegetables, bananas, cotton, sugar cane, tea and coffee.

2.4. Ethiopia

Documented evidence of the history of indigenous irrigation methods in Ethiopia is insufficiently available. Formal irrigation in the form of private commercial farms using river diversions or motorized pumps to grow horticultural crops, cotton and sugarcane began in the 1950s in the Upper Awash valley and expanded to other parts of the Rift Valley region in the 1960s (Awulachew and Yilma, 2007). These schemes used and still predominantly use furrow irrigation. In the mid 1970's, these private farms were nationalized. During this period, the government embarked on development of modern communal schemes using diversion of streams and rivers with some having micro-dams for water storage. Farmers operated and maintained these schemes through water users' associations, but also received some support from the government including construction of head works and main canals, irrigation technical support and some on-farm support. When the country's leadership changed in 1987, the new government withdrew support and development of the communal schemes and shifted its attention to supporting (technically and materially) traditional smallholder schemes, mainly based on river diversions. In these schemes, households use their own initiative and traditional means to irrigate various crops including vegetables, fruits, pulses, and cereals on plots ranging from 0.2 to 0.5 ha. These farmers form water users' associations to manage the traditional schemes. Some private medium to large scale farms also re-emerged in the 1990s.

Most of the documented irrigated area in Ethiopia is located in the Rift Valley region, specifically in the Awash basin. FAO (2005) reported that in 2001, 62% of the irrigated area was located in the Rift Valley Region with 39% of it being in the Awash basin. About 29% of the irrigated area is in the Nile Basin and 9% in the Shebelli-Juba Basin. About 99% of the irrigated areas were reported to use surface water sources in 2001 (FAO, 2015a) including lakes, rivers and streams; under river/stream diversions or motorized pumping. Flow to the fields is mainly by gravity, with furrow irrigation as the main water application method. The use of groundwater for irrigation started in recent years (MoA, 2011b), and in 2001, it was reported to be only 1% of total irrigation (FAO, 2015a). Groundwater irrigators mainly use ropes and buckets to lift water. Manual pumps including rope and washer (or rope) pumps and treadle pumps have recently been introduced in Ethiopia by NGOs. Some smallholder farmers are now using small motorized pumps to pump water from both surface and groundwater resources. About 2% of the irrigated area is irrigated using sprinkler irrigation to produce sugarcane by government farms and some private commercial farms (MoA, 2011b). Drip irrigation is being used by some commercial farms and for demonstration purposes in some research centers, but none is reported for smallholder farmers. In the lowland areas, spate irrigation and flood recession cropping are practiced.

A summary of sources of water for irrigation, irrigation methods and technologies, and implicit and explicit policies and strategies on irrigation in each country is as shown in Table 5.

SI in SSA is normally unplanned, has little or no technical support

Table 5
Water sources for irrigation; irrigation methods, technologies, policies and strategies in the four East African countries.
Source: FAO (2015a); FAO (2015b); MAAIF (2014); Ministry of Water and Irrigation (2009); MoA (2011a); MoA (2011b); MoALF (2015);

Country	Sources of water for irrigation	Irrigation methods	SI technologies	Past and present implicit and explicit strategies and policies on irrigation
Ethiopia	surface water (99%)[a], groundwater (1%)	surface irrigation (n.a.)[b], sprinkler irrigation (2%), drip irrigation (n.a.)	buckets, treadle pumps, rope and washer pumps, small motorized pumps, drip kits	Agricultural Development Led Industrialization policy (1994), Water Resource Management Policy (1999), Water Sector Policy (2001), Sustainable Development and Poverty Reduction Programme (2002/03–2004/05), Plan forAccelerated and Sustained Development to End Poverty (2005–2010), Growth and Transformation Plan I (2010/11–2014/2015), Growth and Transformation Plan II ((2014/15–2019/20), Agricultural Sector Policy and Investment Framework (2010 –2020)
Kenya	surface water (87%), groundwater (13%)	surface irrigation (n.a.), drip irrigation (n.a.)	buckets, treadle pumps, small motorized pumps, drip kits	Sessional Paper No. 4 of 1981 on National Food Policy, Sessional Paper No. 1 on Economic Management for Renewed Growth, Sessional Paper No. 2 of 1994 on National Food Policy, Economic Recovery Strategy (2003–2007), Strategy for Revitalizing Agriculture (2004–2014), Water Act (2002), Agriculture Sector Development Strategy (ASDS 2010–2030), Kenya Vision 2030 and draft National Irrigation Policy (2015)
Tanzania	surface water (99.8%), groundwater (0.2%)	surface irrigation (99%), sprinkler irrigation (1%)	buckets, treadle pumps, small motorized pumps	Agricultural and Livestock Policy (1997), Agricultural Sector Development Strategy (2001), Rural Development Strategy (2001), National Water Policy (2002), Tanzania Development Vision 2025, National Irrigation Master Plan (2002), National Strategy for Growth and Reduction of Poverty (2005), Agricultural Sector Development Programme (2006), National Irrigation Policy (2010)
Uganda	surface water (42%), groundwater (58%)	surface irrigation (72%), sprinkler irrigation (25%), drip irrigation and micro-sprinklers (3%)	buckets, treadle pumps, drip kits, small motorized pumps, sprinklers	Water Resources Policy (1995), National Water Policy (1999), Irrigation Sector Development Plan part of the Plan for Modernization of Agriculture, Uganda Vision 2040, Agricultural Sector Development Strategy and Investment Plans (2005/06–2007/08) and (2010/11–2014/15), National Development Plans (2010/11–2013/14) and (2015/16–2019/20), National Irrigation Master Plan for Uganda (2010–2035)

n.a. refers to data not available.
[a] Percentage of the total irrigation water used.
[b] Percentage of the total irrigated area.

and the technologies used are basic. Thus, regular capturing of data on such irrigation activities in each of these four developing countries is a challenge. In only a few cases is the proportion of smallholder irrigated area quantified or specified. For instance, of the 183,988 ha actually irrigated in Tanzania in 2002, 122,630 ha (67%) were reported to be under traditional irrigation schemes that are managed and controlled by smallholder farmers, 25,511 ha were under traditional irrigation schemes that were improved by some external agency, and 35,847 ha were under modern irrigation schemes with complete irrigation facilities and were under management by a government agency or some other external agency (United Republic of Tanzania URT, 2005). In the same year, 95,320 ha out of the total 161,790 ha irrigated (59%) were under SI in Ethiopia, and 36,190 ha out of the total 91,410 ha irrigated (40%) in Kenya (Tafesse, 2003). Up until 2002, Kenya saw a gradual increase in SI parallel to the gradual increase in total irrigated area (Table 3). Both traditional and modern smallholder schemes, 86% of total irrigated area, consisted of smallholder farmers managing their own activities through water users' associations or local cooperatives.

Although there have generally been increases in both total irrigated area and smallholder irrigated area over the years in each of the countries, the rate of expansion has been slow (with the exception of Kenya (Table 4)) and irrigation development is far below each country's potential. Consequently, agricultural production has not kept up with the ever increasing population.

3. Constraints to smallholder irrigation development in East

Irrigation in East Africa has been and is still facing numerous challenges that have contributed to the slow rates of development shown in Table 4. Although some smallholder farmers have reported increases in income from commercial farming with SI (Ngigi et al., 2000; Bacha et al., 2011; Shah et al., 2013), adoption of various SI technologies has been low and the plight of the most vulnerable households and communities to food insecurity has not improved. Most of the constraints presented here run across the four countries although some may be unique to individual countries.

3.1. Land tenure, access to land and land management

The land tenure systems present in the four countries result in several problems among which are insecurity of tenure, lack of land registration, unequal access to rural land especially for women, conflicts between customary land rules and formal laws, weak land conflicts resolution mechanisms, and weak land rights transfer mechanisms (ECA, 2004; Mbote, 2005; Holden and Otsuka, 2014). All these issues affect what will be done on the land in both short and long terms, and how well the land will be managed (Doss, 2001). In Uganda and Tanzania, for example, only about 10% and 3% respectively of the total land area is reported to be registered (National Planning Authority, 2010; OECD, 2013). The rampant land title alterations in Uganda have resulted into land conflicts which inhibit development activities on these plots of land (National Planning Authority, 2010). Secure and easily transferable land rights are believed to foster agricultural development because land can be transferred to users that are more productive and efficient, higher level investments can be done on the land, plus a land title can be used to access credit from financial institutions (Gebreselassie, 2006). However in Ethiopia, land sale and long-term leasing of rural land are forbidden since the 1975 land reform where land was made public property, and occasionally, the Ethiopian government redistributes land to accommodate the growing population. This challenges improvements and investments on the land as farmers are apprehensive of the next land redistribution (Kebede, 2002; Gebreselassie, 2006; De Graaff et al., 2011). Some poor people in Kenya are landless due to the massive unequal distribution of land in a country where only about 20% of the land area is reported to have a high to medium potential of agricultural productivity (Jayne et al., 2014; Narh et al., 2016).

Aside from the issues on land rights, the land holding sizes are decreasing. The average farm size for smallholder farmers in Kenya is 0.47 ha, 1.01 ha in Ethiopia, 0.9 ha in Tanzania and 0.66 ha in Uganda (FAO, 2015c). Land in these East African countries is continually being subdivided into smaller units as some cultures encourage sub-dividing of the deceased household head's land among his immediate relatives especially his sons (Krishna et al., 2006). As a result, production units become smaller and uneconomical (Salami et al., 2010), hindering profitable use and adoption of improved technologies and inputs (Gebregziabher et al., 2014). Productivity of these units is further threatened by land degradation resulting from soil erosion and sub-optimal agricultural practices. The declining levels of soil fertility in the East African agricultural lands is attributed to: lack of soil and water conservation structures or measures in farm lands, cultivation of steep slopes and hillsides (e.g. Ethiopian highlands), wetland cultivation, repeated ploughing before seeding (a common practice of Ethiopian farmers using the ox-drawn *maresha*), deforestation, excessive consumption of crop residues by livestock as a result of free grazing, overstocking of pasture lands, no crop rotation, and no fallow or shortened fallow cycles due to decreasing farm sizes (Nkonya et al., 2004; IFAD and IFAD and UNEP, 2013; Jayne et al., 2014; Gashaw et al., 2014; Matano et al., 2015). Slightly sloping semi-arid areas in Tanzania for example are estimated to lose 1–2 mm of top soil annually (Kimaru and Jama, 2006). In Uganda, up to 12% of annual loss of GDP is attributed to land degradation (Kimaru and Jama, 2006).

3.2. Poor or inadequate irrigation infrastructure and other infrastructure including roads and electricity, and competing uses for the available water resources

Access to land and water resources is highly linked to poverty as the world's poorest are also reported to have the least access to land and water (FAO, 2011). Some parts of these countries are endowed with sufficient water resources that could be used for agricultural production however, economic water scarcity here is the major problem that limits use of these resources. Infrastructure to facilitate access to these water resources for irrigation is missing or inadequate in many of these areas (Inocencio et al., 2003). The traditional irrigation scheme structures that are commonly available often fail due to poor designs, use of low quality construction materials, floods, vandalisms and poor management (Gillingham, 1999; Ngigi, 2002; Plusquellec, 2002; Aberra, 2004). Canals are often unlined as such, seepage losses through the unlined canals are high especially in sandy soils (Aberra, 2004; Amede, 2015). Several schemes' canals face high siltation problems as there are no soil erosion control structures along the canals (Swallow et al., 2007; Amede, 2015). As a result, operation and maintenance of schemes with regular de-silting of the main canal as one of the major components becomes costly to the farmers as they either have to pay someone or invest their own labor (Smith et al., 2014). The latter potentially limits labor productivity in agricultural production. Failure to appropriately maintain the schemes' infrastructure leads to their deterioration with time. This has resulted to scheme abandonment in the past.

Aside from infrastructural challenges, there are some institutional challenges such as the weak functioning of water users' associations (WUAs) leading to ineffective control systems, inadequate monitoring, and ineffective enforcement of activities around the scheme (Smith et al., 2014; Yami, 2013). Water management in SI schemes is usually inefficient; farmers whose plots are upstream in the scheme will receive ample water unlike downstream farmers who especially under conditions of reduced water supply often do not have water reaching to their plots (Checkol and Alamirew, 2008; Haileslassie et al., 2016). Kulecho and Weatherhead (2005) reported that the temporal unreliable supply of water due to climatic seasons and mismanagement, and poor quality of the irrigation water (water was saline or with suspended sediments in some areas) that corroded metal parts of the drip kits or clogged emitters led to smallholder farmers in some parts of Kenya to discontinue the use of low-cost drip kits.

Irrigation faces a lot of competition with other water uses and often is not considered in water use planning of available water resources (Smits et al., 2010). In Ethiopia for example, household hand-dug shallow wells usually have multiple uses including domestic use, livestock feeding and also irrigation (Calow et al., 2010). As it is often the only source of water for the household, and with the amount of water available varying throughout the season, the allocation for crop production is often not prioritized in the household. Although deeper aquifer access is likely to increase water availability, smallholder farmers usually do not have financial and technical capacities to dig and lift water from deeper wells (Calow et al., 2010; Amjath-Babu et al., 2016).

In 2012, only 27%, 23%, 18%, and 15% of the population in Ethiopia, Kenya, Uganda and Tanzania respectively, had access to electricity (The World Bank, 2015). Electricity outages due to inadequate electricity supply in Kenya are rampant and greatly affect vegetable smallholder farmers' irrigation, cold storage and processing activities (Monteiro et al., 2010). In Uganda, power tariffs are high and the transmission and distribution networks of electricity are inadequate (National Planning Authority, 2010). Access to non-solid fuel in 2012 was estimated at 2.2%, 16.2%, 4.2% and 2.6% of the population in Ethiopia, Kenya, Tanzania and Uganda respectively (The World Bank, 2015). Both the low electricity access and the low access to non-solid fuel limit the use of pumping technologies that would make water resources more accessible for agricultural production (Amjath-Babu et al., 2016). Adequate transport infrastructure such as rail lines and paved roads facilitate access to markets, inputs and delivery of agricultural products to various areas with minimal distribution costs. However, between 2005 and 2010, road density in Ethiopia was 4 km per 100 square km of land area; 11 for Kenya and 10 for Tanzania; only 14%, 14%, and 15% of the roads in Ethiopia, Kenya and Tanzania respectively were paved (FAO, 2014). No data is available for Uganda.

3.3. Limited awareness and access of improved smallholder irrigation technologies

Irrigation technologies include water access technologies such as pumps (e.g. motorized pumps, treadle pumps, solar pumps, wind pumps and rope and washer pumps) and water distribution technologies (e.g. drip, buckets/watering cans and sprinkler systems) (Burney and Naylor, 2012). According to Fraiture and Giordano, 2014, 80% of smallholder farmers in SSA use manual irrigation methods including watering cans and buckets. As these require a lot of time and effort, irrigation is often limited to small plots. Moreover, social norms of the community also affect technology use and adoption. In some cultures in East Africa for instance, women operating the treadle pump is considered inappropriate (Burney et al., 2013). Since vegetables are mostly grown by women in these same communities, coupled with the high energy requirement these pumps need for operation (Jackson, 1998), adoption of the treadle pump in such communities is low.

Although a number of NGOs like the International Development Enterprises (iDE) have introduced, disseminated knowledge and built capacity on lower-cost irrigation technology development and operation, several rural communities are still not aware of some of these promising technologies (Keller, 2001). For newly introduced practices and technologies to be adopted by farmers, a lot of time investment in farmer awareness, learning and experimentation is often required (Carter and Danert, 2006). With time and with successful demonstrations, farmers start to take up the technology or the practice and even start realizing benefits (Lankford, 2003). However, there is usually no long term presence of the technology promoters who are usually research organizations, NGOs, and government agents, in beneficiary communities to offer longer term support (including technical support, market linkages, linkages to suppliers to mention a few) to smallholder farmers (Merrey and Sally, 2008). As such, as projects come to an end, so do the use of the various technologies being promoted. Governments' support on dissemination of information and promising technologies is still very low, as a result some farmers are not aware of various products and services including technologies, markets, and financial services.

When technologies are produced in the country, the trained manufacturers often produce very locally, lack good distribution and communication systems resulting in unavailability of technologies to farmers in other or neighbouring communities. As such, manufacturers fail to reach a greater number of smallholder farmers that might be interested in the technologies. Moreover, the governments encourage private sector development through importation of expensive technologies from abroad with very little support if any to the local manufacturers (Purcell, 1997). Import duties and taxes have also significantly increased the prices of technologies; Gebregziabher et al. (2014) reported 37% import duty and tax of the price of a motor pump in Ethiopia. Less expensive motorized pumps mostly from China are now available in markets in the four East African countries, however, these pumps are less durable and require frequent repairs (De Fraiture and Giordano, 2014). Local manufacturers also lack access to credit services that can help them build their capital base to be able to produce more. For several farmers, access to appropriate technologies is also hampered by the lack of credit providers in the communities for irrigation technologies.

3.4. Maintenance and repair problems of SI technologies and access to spare parts

Many pumps' performance is poor due to lack of regular servicing. Although farmers may learn how to use a technology, training on routine maintenance, troubleshooting or repair of the technology is normally not intensively given (Merrey et al., 2008). In these countries, farmers have little experience in motor pump repair and often have to rely on private-sector repairers who are sometimes located far, delaying repairs and increasing repair costs. These extra costs sometimes deter the farmers from promptly seeking repair services thus causing break downs in irrigation activities. For imported technologies, the spare parts are not readily available in the rural communities, and if they are, they are costly (Grimm and Richter, 2006). As such, farmers abandon the use of the technologies due to difficulties in obtaining spare parts and being unable to pay for the repair. A survey carried out in 2002 in some parts of Kenya showed that smallholder farmers discontinued the use of standalone low-cost drip kits majorly due to lack of spare parts and the absence of technical support to repair breakages, leaks, and clogged emitters (Kulecho and Weatherhead, 2005).

3.5. Lack of reliable markets

Smallholder farmers normally sell their surplus produce in weekly or bi-weekly markets in their communities (Gebremedhin et al., 2012). It is common to find most farmers growing the same crop at the same time of the year resulting in saturation of local markets and a decline in market prices (ASFG, 2003). As production increases, the local markets become insufficient for some of these farmers however, the bigger and more reliable markets in most cases are located far from the production areas and transport is unreliable and expensive. As a result, these farmers depend on middlemen to buy their produce. The bargaining power of the farmers is low as they are often not aware of the prices in bigger markets. As such, farmers do not normally receive fair prices for their produce from the middlemen, and end up not receiving enough income to cover the investments they made in inputs and technologies (Mati, 2008). Even grouping of farmers in cooperatives can have some drawbacks on return of investment. In Kenya for example, farmers can sell their produce through cooperatives but due to poor management and corruption, farmers are sometimes not paid for their produce

(Purcell, 1997). Furthermore, due to lack of good storage facilities, there is a need to immediately sell perishable fruits and vegetables after harvest (Bekele, 2014). The storage constraints together with fast dropping market prices during peak season production times results in farmers often selling at low prices that do not cover the costs of production (Burney and Naylor, 2012; Amede, 2015). Returns from irrigation are thus severely limited which discourages further investments and development of smallholder irrigated agriculture.

3.6. Lack of improved agricultural inputs including seeds, fertilizers, and pesticides

Access to improved agricultural inputs boosts subsistence farmers' transition to commercial farming. Improved inputs (e.g. seeds, fertilizers and pesticides) are normally imported, costly and often not available to rural farmers (Shiferaw et al., 2007). Hence, their use to intensify agricultural systems remains limited in a number of East African communities. The high input prices are also due to the high distribution and transportation costs as a result of poor transport and communication infrastructure, and the normally small quantities of inputs to be distributed (Doss, 2001; Otsuka and Kalirajan, 2006). As a result, yields for smallholder farmers are often below their potential as the required inputs to deal with low soil fertility, low yields and occurrences of pests and diseases are often not easily accessed. For the case of seeds, farmers instead continue to use the more readily available local variety seeds that are lower yielding (Toenniessen et al., 2008).

Ethiopia's seed supply chains is challenged by a lack of consistency in seed quality and untimely deliveries to markets (Spielman et al., 2012). Only about 6.3% of farmers in Uganda use improved seeds (Aturinde, 2012) whereas in Tanzania, improved seed availability has increased over the years mostly from private suppliers to about 17% of rural households (data 2010/11, The World Bank, 2012). In Kenya, high seed prices, unavailability of appropriate varieties and poor seed quality are some of the reported constraints to the use of improved seeds (Muhammad et al., 2003). The challenges of seed supply and adoption is a complicated process that involves both the producers and the farmers. For maize seed supply for example, Langyintuo et al. (2010) reports that although the number of registered maize seed companies have doubled in these East African countries over the past decade, the total supply of maize seed has not increased as much. The companies are reported to supply seed enough for only about a third of the maize area. The companies face constraints such as high investment costs, lack of access to credit, long variety release processes, long customs processes for imports, poor rural infrastructures, poor extension services, and low rates of adoption, that limit their efficient functioning despite maize being the most important crop in these countries (Langyintuo et al., 2010). At the farmers' end, reasons for low adoption include: lack of awareness of improved seeds and farmer retention of local seed from previous harvests to reduce planting costs as costs of improved seeds are considered too high.

About 75% of farm land in SSA is said to have major soil fertility issues (Toenniessen et al., 2008). It's estimated that the annual nutrient depletions of nitrogen, phosphorus and potassium in Ethiopia are 122, 13 and 82 kg/ha respectively; 112, 3 and 70 kg/ha respectively in Kenya; and 173, 60, and 41 kg/ha respectively in Uganda (Haileslassie et al., 2005, 2007). Data on Tanzania is not available. Yet, mean annual NPK application rates for arable crops are 30, 14, 5 and 1 kg/ha in Kenya, Ethiopia, Tanzania, Uganda respectively (Salami et al., 2010) because mineral fertilizers are relatively expensive for smallholder farmers. Manure use in rural communities of these countries is limited by low quantities available and the low quality of the manure due to the small number of large and small ruminants owned, the free grazing system, and labor availability to collect, transport and apply manure whilst the low quality of feed results in the low quality of nutrients present in the manure (e.g. available N) (Delve et al., 2001; Waithaka et al., 2007). In some communities in Ethiopia, manure use is further limited by manure being burned as fuel which is prioritized over it being used as an organic fertilizer (Mekonnen and Köhlin, 2008). Crop residues in several East African communities are usually used as livestock feed or burned as fuel, and are thus not available for soil incorporation (Waithaka et al., 2007). Without replenishing the losses in nutrients, land productivity increasingly deteriorates. This has been the case with smallholder farming systems in the four East African countries.

Commonly irrigated crops like vegetables and rice are very susceptible to attacks from several pest and diseases (Sithanantham et al., 2002). Pests and diseases have contributed significantly to yield losses in both food and cash crops in Africa (Goldman, 1996). This has forced smallholder farmers to increasingly depend on pesticides and fungicides to curb yield losses. The high prices of pesticides and fungicides, and their low availability in several agricultural communities in East Africa have limited their use (Mlozi et al., 1992). Also, awareness of integrated pest management practices in the rural communities is very low (Sithanantham et al., 2002).

3.7. Access to financial and credit services

A survey conducted in 21 districts in Ethiopia showed that access to credit significantly affects smallholders' rate of use and adoption of agricultural inputs (e.g fertilizers and improved seeds) (Abate et al., 2015). Irrigation technologies frequently require a high initial investment which without credit might be challenging for many smallholder irrigators. Motorized pumps investments for example depending on the capacity often require high investments leading to only a small group of farmers being able to afford the technologies if they lack access to credit. Smallholder farmers who have collateral, which in most cases is a title to their land (Doss, 2001), who produce cash crops and are in close proximity to reliable markets stand a good chance of receiving credit from financial institutions for SI technologies and other agricultural inputs. But often these conditions are lacking, especially for farmers that are just starting to venture into commercial farming, that live in low population density areas, that do not hold land titles, and are located quite far from good markets with transport and communication infrastructures being inadequate (Grimm and Richter, 2008; Burney et al., 2013).

Commercial banks and microfinance institutions do not often venture into rural areas as the costs and risks of doing business in the rural areas are high (Grimm and Richter, 2006). When they are present, few agricultural loans are offered when compared to loans in other services like trade (Salami et al., 2010). Poor record keeping and inadequate customer follow-up are some of the constraints of the weak institutional capacity that characterizes the rural finance and credit providers. The number of customers they can serve is also often limited. It's not only the range of products offered and number of loans that are often limited, but also the durations of the loan repayments are limiting to smallholder farmers who have to wait to harvest and sell their produce before they can payback the credit. The 2008/09 Uganda Census of Agriculture reported only 10% of the Agricultural households in Uganda had access to credit in the five years prior to the survey. Reasons given for lack of credit access included: high interest rates, lack of collateral, and lack of credit facilities or having no knowledge on existence of credit facilities in their communities (Uganda Census of Agriculture UCA 2008/09, 2010). In Kenya, the financial sector is considerably more developed and diverse, however, credit for agricultural purposes is not readily available (Grimm and Richter, 2006). Currently in Ethiopia, more than 60% of the loans held by microfinance institutions and cooperatives are to support smallholder rainfed agriculture. These microfinance institutions and cooperatives are small in size and mostly give loans for fertilizers and improved seeds and not so much other agricultural technologies (Abate et al., 2015). De Fraiture and Giordano (2014) reported that 80% of owners of irrigation equipment use their own savings to purchase these equipment as credit services are not readily available. Savings and insurance services are also not readily available in agricultural communities of East Africa. Agriculture in SSA in general is considered a risky venture owing to many issues including erratic rainfall, pests, diseases and volatile food prices and thus without insurance for harvests, some financial institutions are not willing to offer farmers credit (NEPAD, 2013).

3.8. Inadequate farmer knowledge and skills, extension services and research support

Thirtle et al. (2003) showed that investments in agricultural research in SSA add value to agricultural products which in turn improves the profitability of agricultural production at rates that can pay for the agricultural research investments needed to generate the required technologies. They also found that through investments in agricultural research, the cost of pulling a person out of poverty (at a poverty line of $1/day) is lower for SSA at $144 when compared to Asia and Latin America where the cost is $180 and $11,400 respectively (Thirtle et al., 2003). The number and quality of national agricultural research staff in the four countries has increased over the decades (Beintema and Stads, 2004). In 2000, there were 742, 833, 542 and 250 full-time equivalent agricultural researchers in Ethiopia, Kenya, Tanzania and Uganda respectively; 74% of these researchers had postgraduate-level training (InterAcademy Council IAC, 2004). There are however high turnovers of the agricultural research staff in these countries due to the low remuneration packages for staff in national universities and national research centers (InterAcademy Council IAC, 2004). FAO (2014) reported only 0.8%, 1.3%, 1.2%, and 0.5% of the share of agricultural GDP in Ethiopia, Kenya, Uganda and Tanzania respectively was spent on public agricultural research in 2008. Most of the funding for agricultural research in these countries is reported to come from government or donor sources; funding from the private sector is very minimal (Beintema and Stads, 2004).

Additionally, the research that has been carried out on agriculture, and specifically irrigated agriculture by both research organizations and universities has not flowed down to the farmers due to gaps in the information chain (Aturinde, 2012). Farmers lack knowledge on agronomic management and appropriate irrigation application and scheduling methods (Mati, 2008; Etissa et al., 2014). The result has been wastage of water, high fuel and labor cost. Also, lack of knowledge on proper selection, use and benefits that can be derived from a number of irrigation technologies has resulted in low technology adoption rates (Smith et al., 2014).

There is therefore need to invest in higher agricultural education to train large numbers of personnel who can modify and adapt applied research, and then extend the knowledge to farmers (Mellor, 2014). Extension services are a source of knowledge on various agricultural packages to farmers. The four East African countries lack qualified extension workers, lack optimum numbers of extension staff to reach fair shares of farmers, and also lack incentives to retain them. In Kenya for example, the extension staff to farmers' ratio is 1:1500 (Akuku et al., 2014), and the extension officers are limited by lack of fuel for the motor bikes they use to reach farmers (InterAcademy Council IAC, 2004). According to the 2008/09 Uganda Census of Agriculture, 19% of the agricultural households reported having been visited by an extension worker in the five years prior to the time of the survey. The number of extension workers in Ethiopia has increased over the years; the smallest administrative unit, the kebele, may have up to six extension agents thus reaching a bigger portion of farmers (Mellor, 2014). However, their impact on improving farmers' livelihoods through promotion of various agricultural packages has been mixed; some farmers have adopted some of the promoted packages while others have not (Spielman et al., 2012). Lempérière and Van der Schans (2004) noted that extension workers in Ethiopia lack skills needed to advise farmers on their actual needs and interests. Without adequate dissemination of practical knowledge and information, productivity of smallholder agricultural systems will still remain low. In Uganda for instance, improved upland rice varieties called NERICA have potential to give high yields of 3–4 t per hectare under favorable water and soil fertility conditions as they are more drought tolerant (Otsuka and Kalirajan, 2006). However, farmers' yields average only 1 t per hectare mainly due to rainfall being erratic, sub-optimal irrigation (e.g. absence of bunding, insufficient leveling) and also because the rice farmers lack good management practices of the high yielding varieties as a result of inadequate training and extension services (Otsuka and Kalirajan, 2006).

3.9. Over dependency on governments, NGOs and donors

Belete (2006) noted that when some farmers in poor and rural communities become accustomed to receiving food aid that they resist interventions aimed at fostering improvement of livelihoods, including irrigation, as they perceive that they will lose the aid when they adopt such interventions. Additionally, some development organizations give free handouts to farmers, and this has become the expectation of several farmers in the rural agricultural communities thus hindering technology adoption, innovativeness and hard work as farmers will work only when inputs including seeds, fertilizer, and SI technologies are freely handed out to them. Handing out free things is directly linked to inefficiency of use (Bohn, 2013). Furthermore, governments and other external agencies often construct SI schemes' infrastructures without fully involving the beneficially farmers. The project developers may offer technical support in operation and maintenance of these schemes at the beginning of the project but later leave the management and maintenance to the beneficiary farmers. However, many farmers expect that they will always be provided with this support and are not willing to contribute to such activities from their own time and resources due to lack of ownership of the project, leading to deterioration of these structures.

4. Opportunities for smallholder irrigation development in East Africa

4.1. Unrealized irrigation potential

Irrigation potentials for the four East African countries, as reported by FAO AQUASTAT database, are shown in Table 1. The potentials consider physical land and water resources availability and suitability, irrigation water requirements as determined by cropping patterns and climate, environmental and socio-economic considerations including distance and slope. Area equipped for irrigation, i.e., area equipped with irrigation facilities are areas where water is managed formally. The database also reports area actually irrigated out of the area equipped for irrigation (Table 4). Area actually irrigated differs from area equipped for irrigation due to several reasons including: (i) the current available water is no longer sufficient to irrigate the entire area as the demand for water from various water resources by various water sectors has increased over the years, (ii) land degradation, (iii) poor management of some of the irrigation facilities with the available water being lower than the need for the originally planned area, and (iv) absence of farmers. The areas equipped for irrigation and the areas actually under irrigation in each of the countries are far less than the potential irrigable areas in each of the countries (Table 4). There is thus a lot of potential for irrigation development and expansion in the four East African countries.

The four East African countries' potential to expand irrigated agriculture is still high when both land and water resources are considered. Overall, these East African countries have ample water resources that are untapped (Svendsen et al., 2008). The annual total renewable water resource (both surface and groundwater) is estimated at 122, 31, 96, and 60 km^3 for Ethiopia, Kenya, Tanzania and Uganda respectively (FAO, 2015a). On average, 76% of the inventoried withdrawals in these four countries are used for agriculture (FAO, 2005). Yet agricultural water withdrawal as a percentage of the total renewable water resource is only 4, 7, 5 and 0.45 for Ethiopia, Kenya, Tanzania and Uganda respectively (FAO, 2015a). The annual total renewable groundwater resource is estimated at 20, 3.5, 29 and 30 km^3 for Ethiopia, Kenya, Uganda and Tanzania respectively (FAO, 2015a). However, as seen in Section 2 above, groundwater irrigation is still very low in each of the four countries, hindered by challenges such as the high costs of drilling wells, low electricity access, low access to non-solid fuel, poor market access, and poor road infrastructure (Amjath-Babu et al., 2016) to mention but a few. This indicates that there is significant potential for developing water resources further for irrigation in order to enhance agricultural productivity and add value to crop and livestock production (Svendsen et al., 2008; Altchenko and Villholth, 2015).

4.2. Food insecurity and poverty in East Africa, and the growing urbanization and promising regional markets

Food shortages remain a serious threat to many households in East Africa (Silvestri et al., 2015). Fig. 1 shows the depth of the food deficit, which is higher in these four countries compared to the world in general. East African smallholder farmers still have the opportunity to move from extensive farming to more intensification in order for food and feed production to be able to meet national, regional and global demands that are increasing with increasing population and urbanization in several countries (Jayne et al., 2014). Investments in bundles of interventions including improved seeds, fertilizers, irrigation technologies and other agricultural machinery, pest and disease control, post-harvest storage facilities, and transport and communication infrastructures are needed for the intensification of agriculture. Greater use of irrigation presents a chance to boost and diversify agricultural production, and curtail the reliance on rain and the related climate change impacts (Burney et al., 2013). Profitable investments will not only make more food available to communities, but will improve the livelihoods of communities and also increase employment opportunities in rural areas of East Africa.

The increasing population and urbanization in many countries in sub-Saharan Africa increases the demand for food, feed and livestock products (NEPAD, 2013). With urbanization comes the demand for diversity in diets and higher value-added products as urban consumers demand more fish, meat, dairy products, fruits and vegetables (Kanu et al., 2014). This not only creates new jobs for communities, but also markets for agriculture produce. There is therefore need to promote agricultural trade between African countries through developing regional infrastructure, reducing transport costs, and making cross-border operations less complex (Kanu et al., 2014). Partnerships between farmers, private sector, NGOs, government institutions, research organizations, banks and community service organizations are also needed to help improve agricultural productivity and provide markets for farmers' produce. For example, Lipton (Unilever) buys tea from 500,000 smallholder tea growers in Kenya through the Kenya Tea Development Authority (Pretty et al., 2011). Through farmers' field schools, Lipton teaches farmers new techniques like fertilizer use, harvesting techniques, and planting native trees on farms. As a result, farmers' yields have been reported to increase by 19% (Pretty et al., 2011).

4.3. Rainwater harvesting (RWH)

Due to the high dependency of African farmers on rain, there is need to optimize rainwater productivity in order to increase agricultural yields and improve rural livelihoods (Wallace, 2000; Vohland and Barry, 2009). Periods of heavy rainfall occur in several parts of these countries. During these times, water flows unimpeded; flooding low-lying areas, blocking roads, and washing away bridges. Rockström and Falkenmark (2000) showed that on-farm yields in SSA can be significantly increased through soil and water management practices that increase infiltration of rainfall into the soil and increase water stored in the soil profile, and measures that replenish soil nutrients. Plant water availability through in-situ rainwater harvesting and/or runoff collection can be greatly increased through promotion of both individual and integrated community soil and water conservation practices such as, roof water harvesting; runoff collection or control practices and structures including ponds and spate irrigation; in-situ RWH practices aimed at increasing infiltration of rain into the soil (e.g. mulching, and conservation tillage); micro-catchment techniques like terraces, stone/grass bunds; sub-soiling and ripping to break up restrictive soil layers to improve infiltration of water into the soil (Gowing, 2003; Ngigi, 2003; Mutiro et al., 2006; Pachpute et al., 2009; Biazin et al., 2012). On-farm research on supplemental irrigation using spate irrigation for example doubled sorghum yields, increased pepper yields by 400%, and increased availability of animal feed due to increased biomass production in the northern part of Amhara state in Ethiopia (Van Steenbergen et al., 2008). Livestock production thus becomes complementary to crop production when, in addition to providing draught power and manure to soils and crops, livestock benefit from crop residues. Spate irrigation also presents an opportunity for use of alluvial deposits as a source of nutrients to plants, thus improving crop productivity (Van Steenbergen et al., 2011).

Storage reservoirs such as ponds and tanks in which runoff can be captured and stored for later use, are simple to construct and can even be managed by groups of farmers (Yosef and Asmamaw, 2015). Through supplemental irrigation, water collected in reservoirs can increase the productivity of agricultural landscapes in semi-arid areas, and also make them more resilient to climate change and variability (Lal, 2001) through: (i) prevention of crop water stresses during critical crop growth stages, (ii) provision of conducive conditions for growing high value crops and use of improved agricultural inputs like improved seeds, fertilizers and pesticides, and (iii) extension the growing season (Moges et al., 2011). In a semi-arid area in Kenya for example, maize grain yields increased by 48% due to supplemental irrigation from a small hand-dug reservoir (total volume of 300 m^3) combined with application of N-fertilizer (Barron and Okwach, 2005). Ngigi (2003) estimated that about 32% of the rice produced in Tanzania comes from fields where rainwater harvesting is practiced indirectly by bunding fields. These soil and water conservation practices also increase groundwater recharge thereby increasing water flows and availability for dry season irrigation (Altchenko and Villholth, 2015).

4.4. Current high commitment of the national governments, donors and NGOs to support irrigation development

Governments have increased their attention to recognizing the role of smallholder farmers and SI in improving and increasing agricultural production (Livingston et al., 2011). All four countries now recognize the need to shift from the over-reliance on rainfed agriculture and focus on promoting smallholder irrigation. Each country has developed policies and strategies to guide it in this regard. In Ethiopia for example, the Growth and Transformation Plan I (GTP I) (2010/11–2014/2015) gave smallholder irrigation expansion as a priority and also emphasized community-based soil and water conservation aimed at reducing soil erosion and thus improving agricultural productivity (MoFED, 2010). The Growth and Transformation Plan II (GTP II) (2014/15–2019/20) is building on GTP I and is aiming to expand irrigation use in Ethiopia (AfDB, 2015). Furthermore, Ethiopia has progressively increased its agricultural sector budget over the years in order to promote agricultural and rural development (MoARD, 2010). Some of Ethiopia's Agricultural Sector Policy and Investment Framework (PIF) 2010–2020's aims include: sustainably increasing agricultural production with priority investment in irrigation development, extension workers and farmers' skills development, seed and fertilizer supply, soil fertility management, development of livestock sector and research;

commercialization of agriculture and developing the agro-industry; reducing land and water degradation; and protecting vulnerable households from food insecurity and other natural disasters (MoARD, 2010). The Tanzanian government's agricultural sector development programme and strategy aim at reducing over reliance on rainfed agriculture and boosting agricultural production through irrigation development and improvement including rehabilitation of SI schemes and promoting more rainwater harvesting (United Republic of Tanzania URT, 2005). Tanzania's National Irrigation Policy's objectives include: improving water management and water productivity in existing irrigation schemes, developing new schemes, developing new and improving traditional water harvesting infrastructure, strengthening research and build capacities in irrigation development and management, promoting use of appropriate irrigation technologies, strengthen institutional set-ups and coordination mechanisms for the irrigation sector, and making sure that the government makes funds available for irrigation interventions. The National Irrigation Master Plan for Uganda for 2010–2035 recognizes: (i) farmers currently practicing subsistence farming, (ii) farmers combining both subsistence and commercial farming and (iii) purely commercial farmers, as major contributors to irrigation development in the country and aims to support them through development and rehabilitation of irrigation infrastructure, and enabling a conducive environment with the necessary institutions required for agricultural growth (Ministry of Water and Environment MWE, 2011). The recently drafted National Irrigation Policy for Kenya aims at increasing irrigated area by 40,000 ha per annum; promoting irrigation in each sub-county; increasing rainwater harvesting and storage facilities; increasing national budget allocation to irrigation by at least 5% and mobilizing more resources for more investments in irrigation; promotion of capacity building of various stakeholders; supporting commercial farming chains and formulating necessary policies for achievement of the above objectives (MoALF, 2015).

The four countries are focus countries under the United States Agency for International Development's (USAID's) Feed the Future initiative. Donors’ support and several NGOs’ activities are also in line with the development and improvement of SI, as donors are now funding projects that are supporting smallholder farmers in areas of irrigation, agricultural marketing, value chain development, rural finance, agricultural research, infrastructure development, soil and water management, and farmers’ organizations (Awulachew et al., 2005). The African Development Bank (AfDB) for example, under its Strategy for 2013–2022, whose objectives include achieving growth in Africa that is inclusive and sustainable (AfDB, 2013), has aligned with Kenya's Second Medium Term plan (2013–2017) that has increased investments in irrigation and supports smallholder irrigation in rural communities of Kenya in order to reduce the country's dependence on rain-fed agriculture as one of its priorities (GoK, 2013). The four countries have considerable smallholder and rural development funding from a number of donors including USAID and the International Fund for Agricultural Development (IFAD) through projects focusing on inputs, training, finance, markets, infrastructure (including irrigation infrastructure) and the environment (Pfitzer et al., 2010). However, institutional support is still needed by the governments in strengthening policy design processes, and efficient and accountable implementation of agricultural and irrigation policies and strategies (NEPAD, 2013).

4.5. Low cost irrigation technologies and research support

Efficient irrigation technologies that are low cost can immensely improve food security, farmers’ incomes and also expand SI in East Africa (Purcell, 1997). Individual lower cost irrigation technologies such as treadle pumps, drip kits, small motorized pumps, rope and washer pumps etc. are becoming more available as they are being promoted by a number of NGOs. Adoption of technologies would improve if the technologies were adapted to local conditions and made with locally available raw materials and knowledge (Sims et al., 2006). The adaption should take into consideration the ergonomic requirements of women, youth and elderly farmers by making technologies easier to operate and maintain. Thus, investment opportunities exist in research and development of appropriate technologies and/or adaptation technologies to local situations, and dissemination of information that can help farmers in technology awareness and selection. Hagos et al. (2012) reported that use and adoption of agricultural water management technologies including treadle pumps, motorized pumps, river diversions, and micro dams have significantly reduced poverty levels among agricultural households of Ethiopia; 22% less poverty incidence was reported among users when compared to non-users. For the East African and Indian Ocean countries including the four countries being studied in this paper plus Rwanda, Burundi and Madagascar, Xie et al. (2014) estimated that motor pumps, treadle pumps, small reservoirs, and communal river diversions have potential to profitably increase total smallholder irrigated area in these countries by 7, 6, 6, and 5 million ha respectively.

4.6. Traditional irrigation scheme rehabilitation and better water management

Most traditional schemes still have unlined canals, wooden gates and weirs, and earthen dams that have deteriorated over the years. In order to lessen on seepage losses and decrease the amount of maintenance work that needs to be done in these schemes, scheme structures need to be upgraded to concrete and metal with engagement and participation of the beneficiary farmers and community (Smith et al., 2014; Amede, 2015). Evans et al. (2012) shows that rehabilitation of schemes especially the main canals improves the farmers’ ability to control and manage water and this translates into higher crop productivity for these farmers. Keraita et al. (2012) compared two schemes in Tanzania: Mkindo, an improved traditional scheme, to Hembeti, an unimproved scheme and found that paddy rice yields were about twice as much in Mkindo as those produced in Hembeti. Major investments in infrastructure and strengthening of governance structures are therefore needed for more effective use of water resources (NEPAD, 2013). For more effective distribution and allocation of water, there also needs to be allocation of water rights to the various water users per source in regard to both the volume of water to abstract, and the operation and maintenance of a particular irrigation scheme (De Fraiture et al., 2010).

4.7. Capacity building and training

In the four East African countries, there exist opportunities for improving and increasing the knowledge and skills of extension workers, policy makers, development agencies, and other public and private actors in the agricultural sector through education and training on irrigation design and management, agronomy, soil and water conservation, sustainable management of water resources, use of agro-chemicals, and post-harvest processes among others. Evans et al. (2012) argue that professional development programs need to be regularly provided to extension workers for them to be aware of new farming systems, practices and technologies. This way they can have up-to-date information on various agricultural services that farmers need. Post-secondary level agricultural education and training in sub-Saharan Africa is characterized by inadequate facilities, limited human resources for teaching and research and limited funding (Spielman et al., 2008). Addressing these constraints would foster innovations that would positively influence agricultural production, economic growth and poverty reduction.

4.8. Investing in knowledge dissemination and farmer awareness programs including information and communication technology (ICT)

SI has the potential to spread through sharing success stories from both within and outside the country to agricultural communities in the

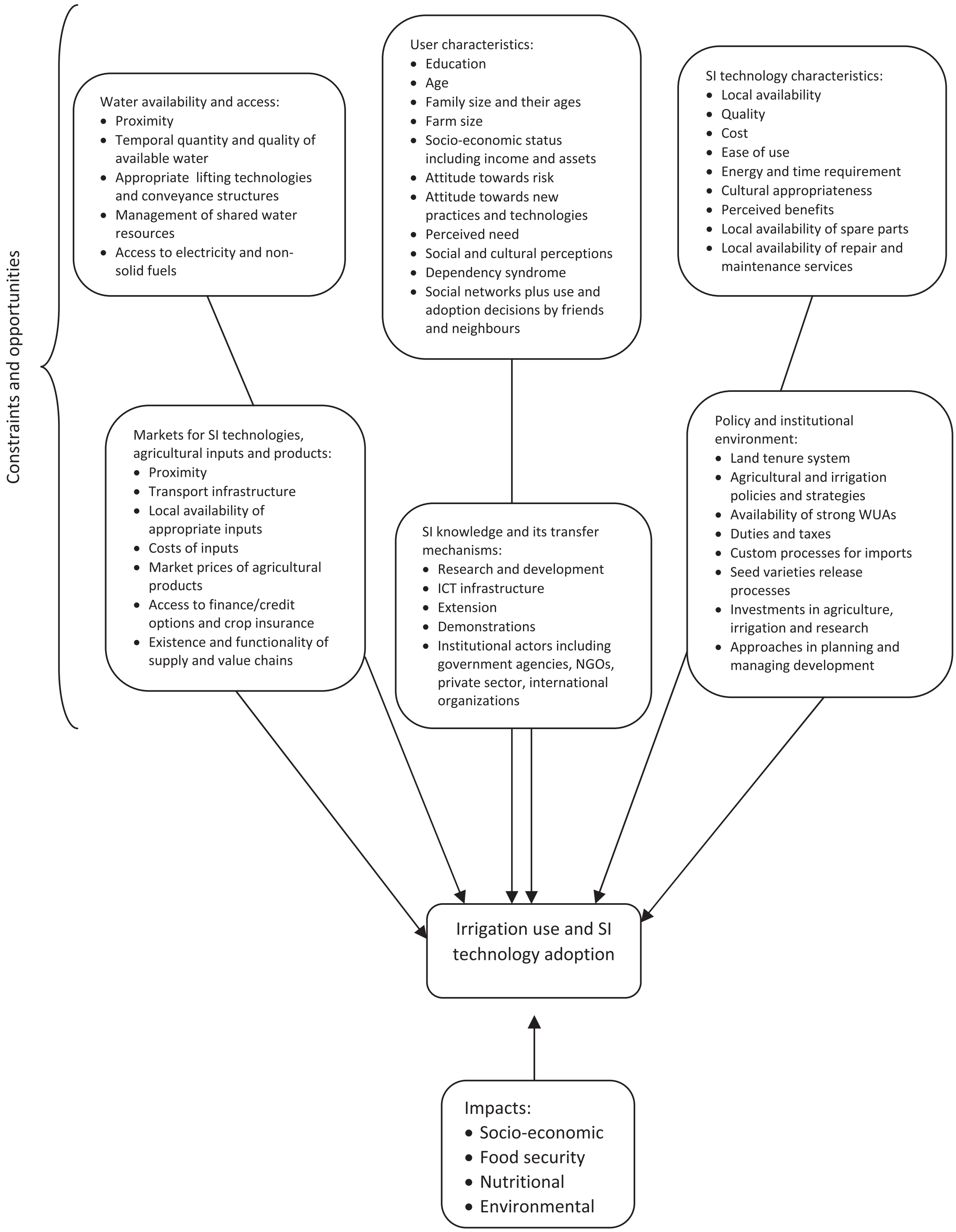

Fig. 4. Conceptual framework showing constraints, opportunities and impacts of SI adoption.

East Africa countries. When farmers see positive results and can relate to the farmers in the stories, they may emulate these examples (Gebregziabher et al., 2014). Effective avenues through which agricultural households receive information on agriculture such as farmer-to-farmer transfer, farmer field schools, radios and mobile phones need to be explored. Evans et al. (2012) argued that giving training to farmers improves their skills and their livelihoods. FAO (2008) reports that as a result of farmer field schools in Agule, Pallisa District in Uganda yields of groundnuts increased from 400 kg to 2 t per hectare. Also, when farmers share their experiences, they become more aware of their farming environment, and they build on to their knowledge to better manage droughts, pests, diseases, and any other problems they may be facing (FAO, 2008). Evaluation of FAO's farmer field school (FFS) project carried out in Kenya, Tanzania and Uganda between 1999 and 2008 showed a 61% average increase in agricultural income due to farmer participation in farmer field schools; the greatest impact was reported among women, farmers with no formal education and farmers between 1 and 3 ha of land (Davis et al., 2012). Farmers also need to be trained on proper on-field water management techniques and optimal use of agricultural inputs in order to minimize the environmental impacts of agricultural intensification that are already being witnessed in some communities where intensification is high. The Mkindo watershed in Tanzania for example, is reported to have water quality issues arising from agricultural intensification (De Fraiture, 2011).

In SSA, information and communications technology systems are expanding. The number of mobile cellular users is more than that of internet subscribers or users of fixed telephone lines (FAO, 2014). In 2011, 17 people out of every 100 people had cell phones in Ethiopia; 68 in Kenya, 48 in Uganda and 56 in Tanzania (FAO, 2014). Mobile phones link farmers and help them access market information (Pretty et al., 2011). Farmer's Friend, a mobile phone application, using the Google SMS search platform was introduced in Uganda in 2009 by Google, MTN (a telecommunications company) and Grameen Foundation's Application Laboratory. Farmer's Friend supplies farmers with agricultural advice including plant diseases, weather forecasts, prices and markets; farmers send text queries and their location and receive replies (The World Bank, 2011). The weather forecasts are provided by the Meteorology department whereas agricultural advice comes from a database that was developed with the support of the Busoga Rural Open Source Development Initiative (The World Bank, 2011). In 2014, the Ethiopia's ministry of agriculture and the Agricultural Transformation Agency (ATA) started testing a system where farmers can call or send SMS to receive free agricultural information (agronomic, irrigation and weather information) and advice that has been organized and automated (Agricultural Transformation Agency ATA, 2014). The service also notifies farmers on current or projected agricultural issues, and advises on possible strategies farmers can employ in order to minimize the impacts of the current or emerging issues (Agricultural Transformation Agency ATA, 2014). Farmers in Kenya and Tanzania are also using mobile phones to access market information and also for banking services (Mukhebi, 2004; Olson et al., 2010). There are therefore opportunities to use mobile phones, radios and television to increasingly spread agricultural information and bridge the gap information between the extension systems, markets and the smallholder farmers. Also, the increasing accessibility of money transfer services using mobile phones such as the M-BIRR service in Ethiopia, M-Pesa in Kenya and Tanzania, and MTN mobile money in Uganda, allow farmers to access commercial banks and other financial institutions' services despite poor road networks in the rural communities and the absence of these banks services and financial institutions in the local communities (The World Bank, 2011).

A conceptual framework summarizing the constraints and opportunities above, and the impacts of SI and how they influence smallholder farmers' decisions on use and SI technology adoption is as shown in Fig. 4.

5. Conclusion

Ethiopia, Kenya, Tanzania and Uganda have resources (both land and water) whose potential has not yet been fully tapped. The lack of development of irrigation potential has contributed to the low productivity of agricultural systems, food insecurity and high poverty rates. Although the benefits of irrigation are well known and recognized worldwide, expansion of irrigated agriculture in East Africa has been low. Challenges to SI development include: land tenure issues; lack of access to improved inputs, markets, improved irrigation technologies and spare parts, extension services, research support, and finance and credit services; lack of knowledge and skills in irrigation water management; and poor irrigation, communication, and transport infrastructures. Overcoming these challenges and creating a conducive environment that promotes investments in SI will create opportunities for economic growth and poverty reduction for smallholder farmers in East Africa.

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