Irrigation Development in Uganda: Constraints, Lessons Learned, and Future Perspectives

Joshua Wanyama[1]; Herbert Ssegane[2]; Isaya Kisekka[3]; Allan John Komakech[4]; Noble Banadda[5]; Ahamada Zziwa[6]; Tobias Oker Ebong[7]; Charles Mutumba[8]; Nicholas Kiggundu[9]; Ronald Kato Kayizi[10]; Dominic Banaga Mucunguzi[11]; and Florence Lubwama Kiyimba[12]

Abstract: Policy makers in sub-Saharan African (SSA) countries have identified irrigation as a key ingredient to boosting food security and income as well as a precursor for agricultural development. However, most SSA countries have hardly exploited their irrigation potential. The overarching aim of this paper is to critically examine factors constraining exploitation of irrigation potential in Uganda. Lessons learned from previous interventions and successes elsewhere from countries comparable to Uganda are drawn and future perspectives to guide effective irrigation planning and development are recommended. From this paper, it is evident that there is no single blanket solution to constraints of irrigation development in SSA. All strategies should be implemented in a holistic manner dictated by specific local conditions. The key to successful adoption of irrigation lies in building the national irrigation capacity, improving access to reliable water for irrigation in proximity of the farms, streamlining extension services for farmers, addressing economic aspects of irrigation, and streamlining land tenure systems and management. It is recommended to operationalize government policy on irrigation by developing national guidelines on irrigated agriculture.
DOI: 10.1061/(ASCE)IR.1943-4774.0001159.

Author keywords: Agricultural development; Food security; Rural livelihoods; Smallholder farmers.

[1]Lecturer, Dept. of Agricultural and Bio-Systems Engineering, College of Agricultural and Environmental Sciences, Makerere Univ., P.O. Box 7062, Kampala 256, Uganda (corresponding author). E-mail: wanyama2002@caes.mak.ac.ug

[2]Postdoctoral Appointee, Energy Systems Division, Argonne National Laboratory, 9700 South Cass Ave., Bldg. 362, Argonne, IL 60439.

[3]Assistant Professor, Kansas State Univ., SWREC/Biological and Agricultural Engineering, 4500 East Mary St. Garden City, KS 67846.

[4]Lecturer, Dept. of Agricultural and Bio-Systems Engineering, College of Agricultural and Environmental Sciences, Makerere Univ., P.O. Box 7062, Kampala 256, Uganda.

[5]Professor, Dept. of Agricultural and Bio-Systems Engineering, College of Agricultural and Environmental Sciences, Makerere Univ., P.O. Box 7062, Kampala 256, Uganda.

[6]Senior Lecturer, Dept. of Agricultural and Bio-Systems Engineering, College of Agricultural and Environmental Sciences, Makerere Univ., P.O. Box 7062, Kampala 256, Uganda.

[7]Research Officer, Agricultural Engineering and Appropriate Technology Research Centre, National Agricultural Research Organization, P.O. Box 7144, Kampala 256, Uganda.

[8]Research Officer, Agricultural Engineering and Appropriate Technology Research Centre, National Agricultural Research Organization, P.O. Box 7144, Kampala 256, Uganda.

[9]Lecturer, Dept. of Agricultural and Bio-Systems Engineering, College of Agricultural and Environmental Sciences, Makerere Univ., P.O. Box 7062, Kampala 256, Uganda.

[10]Assistant Commissioner, Dept. of Agricultural Infrastructure and Water for Agricultural Production, Ministry of Agriculture, Animal Industry and Fisheries, P.O. Box 102, Entebbe 256, Uganda.

[11]Senior Engineer, Dept. of Agricultural Infrastructure and Water for Agricultural Production, Ministry of Agriculture, Animal Industry and Fisheries, P.O. Box 102, Entebbe 256, Uganda.

[12]Senior Research Officer, Agricultural Engineering and Appropriate Technology Research Centre, National Agricultural Research Organization, P.O. Box 7144, Kampala 256, Uganda.

Note. This manuscript was submitted on April 28, 2016; approved on October 19, 2016; published online on January 24, 2017. Discussion period open until June 24, 2017; separate discussions must be submitted for individual papers. This paper is part of the ***Journal of Irrigation and Drainage Engineering***, © ASCE, ISSN 0733-9437.

Introduction

Irrigation has attained increasing importance the world over because of the growing demand for food by a rapidly growing world population. The current global population stands at 7.2 billion, growing at a rate of around 1.14% per year and is projected to increase to about 9.6 billion by 2050 (United Nations 2013). Africa, which has a population of 1.1 billion today, is projected to increase to about 2.1 billion by 2050 (Bongaarts 2009). In Uganda, the population is estimated at 34.9 million people, with an average annual growth rate of 3% (UBOS 2015). Correspondingly, pressures on Earth's finite natural resources, of which arable land is one, are rising in tandem with the growing human population.

The agricultural sector in Uganda contributes about 24.6% of the gross domestic product (GDP), provides livelihood for over 72% of the economically active population, and provides most of the raw materials to the mainly agro-based industrial sector (UBOS 2015). Agriculture in Uganda, which is predominantly rain-fed, is increasingly adversely affected by the climate change and variability manifested in erratic rain patterns, prolonged dry spells, and floods. As a result, farm-level productivity is far below the attainable potential for most crops (Fermont and Benson 2011). Under these conditions, irrigation is critical in aiding farmers against climate change and plays an integral role in transitions from subsistence to commercial farming by ensuring year-round production and farm employment (Machethe et al. 2004; Ngigi 2009; Van Averbeke et al. 2011; Kadigi et al. 2012; Haile and Asfaw 2015; Megersa and Abdulahi 2015). The national policy framework for the development of irrigated agriculture in Uganda guided by the National Water Policy, 1999, is anchored on poverty alleviation and economic growth (GOU 2010). The drafted National Irrigation Master Plan (NIMP) for 2010–2035 (MWE 2011) identifies drivers of irrigation development in Uganda, which include (1) Vision 2050, which calls for "a transformed Uganda society from a peasant to a modern and prosperous country within

30 years"; (2) climate change and variability; (3) new markets; and (4) an increasing number of major international investors looking to establish commercial agricultural assets in the region.

Despite previous efforts by the Government of Uganda (GoU) to promote irrigation, less than 1% of agricultural households practice irrigation in Uganda (UBOS 2010; MAAIF 2011). The area equipped for irrigation is less than 3% of the total potential irrigable area in Uganda estimated at 567,000 ha (MWE 2011). Therefore, there is still an opportunity to exploit the irrigation potential, which would ensure that Uganda is not only food secure but also an exporter of agricultural products. Information on irrigation development is scant and segmented in various documents, and a comprehensive assessment has not be done, thus undermining consensus on how to build on what already exists. This paper aims at critically examining factors constraining exploitation of irrigation potential in Uganda. Lessons learned from previous interventions and successes elsewhere from countries comparable to Uganda are drawn and future directions to guide effective planning, strategies, and development of irrigation recommended.

This paper is the end product of a systematic review of literature on irrigation in Uganda and sub-Saharan Africa (SSA). These included Government of Uganda documents such as the National Water Policy, National Irrigation Master Plan, and framework implementation plan for water for agricultural production; peer-reviewed journal articles; and other unpublished information from institutions involved in the irrigation subsector in Uganda. The study also involved analysis of secondary data on climate and water resources. Primary data were collected through reconnaissance surveys and key informant interviews with stakeholders. The coordinates of irrigated areas were obtained using a GPS through field visits. Mapping of climate and irrigated areas was done in *ArcGis 10.2*.

Natural Resources in Uganda

Geographical Setting

Uganda is a landlocked country situated in East Africa (Fig. 1). The Equator crosses through the southern region, and the geographical area of country lies within the latitudes of 4°12′N and 1°29′S and longitudes of 29°34′E and 35°0′E (NEMA 2009). The total surface area is 241,550.7 km^2, of which 41,743.2 km^2 (17.3%) is open water bodies and swamps and 199,807.4 km^2 is terra firma (UBOS 2009), of which 142,620 km^2 (59% of the total area of the country) is arable land (FAO 2015). The altitude above mean sea level (a.s.l.) ranges from 620 m on the Albert Nile in the Great East African Rift Valley to 5,110 m on Margherita peak in the Rwenzori Mountains (NEMA 2009). The largest part of the country lies between 900 and 1,500 m a.s.l. but is comprised of distinct landscape levels

Fig. 1. Map of Uganda and spatial distribution of major water bodies

generally made up of plains, plateaus, and mountains (NEMA 2009). Uganda is made up of predominantly old rocks from the Pre-Cambrian Era, mostly consisting of granites and gneisses, which are sometimes migmatized (UN-WATER/WWAP 2006). There are also younger rocks, mainly of sedimentary and volcanic origin, from the Cretaceous Era (NEMA 2009). Apart from the volcanic soils found in the east and southwest, the most dominant soil type, covering about two-thirds of the country, is the old ferralitic soils (NEMA 2009; FAO 2015).

Climatic Setting

Uganda has a tropical climate characterized by strong seasonality in rainfall as a consequence of the influence of variations in altitude, the seasonal latitudinal movement of the equatorial low-pressure trough, and the intertropical convergence zone (ITCZ). The El Niæo southern oscillation (ENSO) phenomenon is an additional feature of the East African climate (Indeje et al. 2000). Uganda's temperature shows little variation throughout the year, with maximum range of 25–31°C for most areas. The highest temperatures of over 30°C are experienced in the north and north-east of the country, while temperatures as low as 4°C are experienced in the southwestern highlands (NEMA 2009). About 70% of the country receives a bimodal rainfall with the peak rainfall periods in April to May and October to November. Areas around Lake Victoria receive the highest average annual rainfall of 1,200 to 2,000 mm, while the Eastern Karamoja plateau region receives the lowest average annual rainfall of 300 to 625 mm (NEMA 2009). Seventy five percent of the country has potential evaporation rates of 1,350–1,750 mm/year (MWE 2013).

Spatial variation of total net rainfall [difference between total rainfall (RF) and potential evapotranspiration (PET)] for the two historical rainy seasons of March to May and September to November is calculated based on data from FAO NewLocClim (FAO 2006) for 53 selected districts in different agroecological zones of Uganda. FAO NewLocClim (2006) provides average weather conditions at a given location using the FAO Agroclimatic database, which includes climatic series varying from 10 to 50 years. PET is calculated in *FAO NewLocClim* (2006) software using the FAO Penman Monteith Method. Negative values are indicative of the need for irrigation to meet the crop water requirement. Because this analysis covers 3-month period, areas whose positive values are low (<50 mm) also require external water input in addition to rainfall. Deficiency in moisture available at critical periods for plant growth because of inadequate and irregular rainfall patterns is a major factor contributing to significant yield reduction and often total crop failure. Classification of regions whose total net rainfall for the two historical rainy seasons of March to May and September to November is less than or greater than 50 mm is shown in Fig. 2. For the March to May time frame, 67% of the country requires some irrigation in addition to rainfall to meet crop water requirements (classified as <50 mm). In the September to November period, 56% of the country falls under similar conditions. The maps also depict regional shifts in irrigation requirements during the two periods.

Water Resources

In comparison with neighboring East African countries, Uganda is fairly well endowed with vast natural water resources (Nsubuga et al. 2014), which is the base resource needed for irrigation. Major water bodies include Lakes Victoria, Kyoga, Albert, George, and Edward while major rivers include the Nile which is the world's longest river, Kagera, Rwizi, Katonga, Kafu, Manafwa, Sio, Mpologoma, and Aswa. About 11% (26,571 km^2) of the country is covered by wetlands (swamps), of which one-third is permanently flooded (MWE 2013). About 98% of Uganda's total area lies in the Nile basin, while a fringe of 5,849 km^2 along the country's border with Kenya lies in the Rift Valley Basin (FAO 2015). It is thus crucial to consider the basin level implications of a major allocation of water to the agricultural sector in Uganda, in the likelihood that downstream riparian states (Sudan and Egypt) have concerns. According to MWE (2011), full development of Uganda's irrigation potential would require withdrawals of just over 4% of Sudan and Egypt's combined irrigation water abstractions. In reality, very little of the water flowing out of Uganda into Sudan actually makes it to the major irrigation areas of Sudan and Egypt, north of the Sudd swamps.

The total internal surface water resources (IRWR) are 39 km^3/year (FAO 2015), with an overlap between surface water and groundwater estimated at 29 km^3/year. External water resources of 21.1 km^2/year comprise inflow from Lake Victoria, of which 10.7 km^2/year flows from Tanzania and 8.4 km^2/year from Kenya, and 2 km^2/year inflow from the Democratic Republic of Congo by Lake Edward and Lake Albert (FAO 2015). The dependency ratio is thus around 35% and the total renewable water resources (TRWR) are 60.1 km^2/year as of 2013 (FAO 2015). The outflow of surface water leaving the country through the White Nile into south Sudan is estimated at 37 km^2/year.

The total water withdrawal of the country was estimated at 637 million m^2 in 2008 (GoU 2010) compared to 300 million m^3 in 2002 (FAO 2005), representing 1 and 0.5% of the TRWR respectively. The greatest water user is the domestic sector withdrawing 328 million m^2 (51%), followed by irrigation and livestock withdrawing 259 million m^2 (41%), and industry withdrawing 50 million m^2 (8%) (FAO 2015).

Although Uganda's water resources are quite abundant, predictions show a physical and economic water scarcity by 2020 because of climate change and population growth that is likely to grossly affect economic development and food security (MWE 2013). More water shortages and water-quality deterioration are likely because of increased demands for hydroelectric power production, agricultural production, domestic water supply, and industry. In addition, many water resources are at risk of degradation because of urbanization, industrialization, and poor land-use practices (Nsubuga et al. 2014).

Typology of Irrigation Systems in Uganda

Typology of irrigation systems provides an objective appraisal and comparison of irrigation systems, according to their common physical, management and social characteristics (Namara et al. 2011). The systematic classification of irrigation systems is crucial for identifying appropriate interventions for improving performance and productivity in this sector and for improving the planning of future irrigation development initiatives (Namara et al. 2010). Typology of irrigation in Uganda is classified by the size or scale of the irrigated area; ownership of the irrigation infrastructure; source of water (rivers, lakes, reservoirs, and swamps) and power; water conveyance and distribution (by gravity or pumps); and the in-field water application technique. The subsequent subsections expound on the irrigation typologies in Uganda.

Size of the Irrigated Area

There are three typologies defined by the size of the irrigated area: large-scale (>500 ha), medium-scale (100–500 ha) or small-scale (<100 ha). Based on the readily available data (Table 1 and Fig. 3),

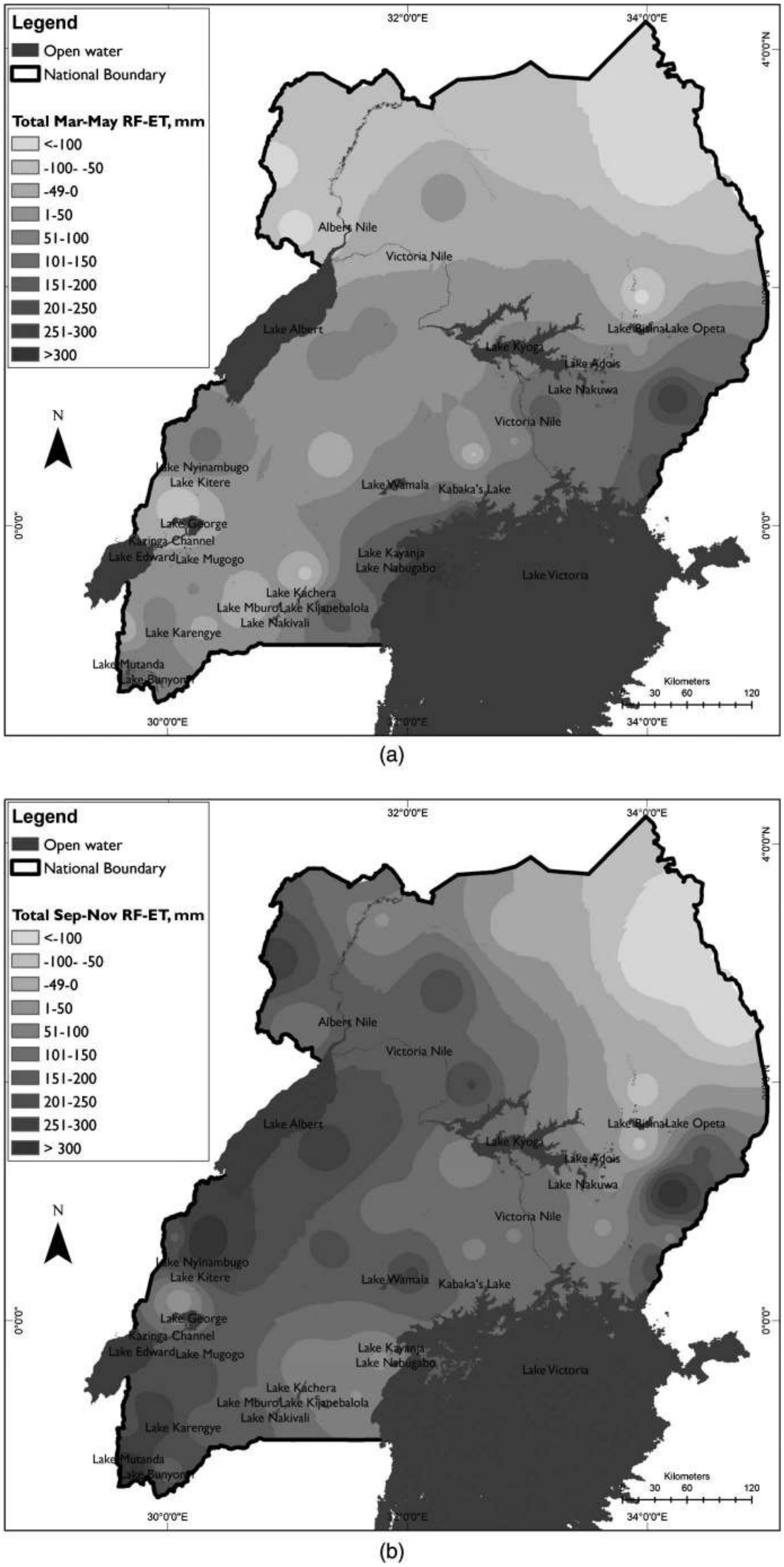

Fig. 2. Spatially explicit variation of total net rainfall [difference between rainfall (RF) and potential evapotranspiration (PET)] for the two historical rainy seasons of (a) March to May; (b) September to November

Table 1. Existing Formal Irrigation Schemes in Uganda

Number	Longitude (degrees)	Latitude (degrees)	Altitude (m)	Irrigation scheme	District	Region	Gross command area (ha), 2015	Scale	Ownership	Source of water	Abstraction method	Irrigation practice	Major crop types	Current status
1	30.121822	0.240245	1,061	Mubuku	Kasese	Western	750	Large-scale	Public	Run-of-river diversion-based (Rivers Sebwe and Mubuku)	Gravity-fed	Furrow	Maize, vegetables, rice, citrus	Functional
2	33.017708	3.800206	1,130	Agoro	Lamwo	Northern	745	Large-scale	Public	Run-of-river diversion-based (Agoro River)	Gravity-fed	Furrow	Maize, vegetables, rice	Functional
3	34	0.883333	1,105	Doho	Butaleja	Eastern	1,000	Large-scale	Public	Run-of-river diversion-based (River Manafwa)	Gravity-fed	Basin	Rice	Functional
4	33.0156	1.1154	1,055	Kiige	Kamuli	Eastern	369	Medium-scale	Public	Lake-based (Lake Nabigaga)	Pumping-fed	Sprinkler	Citrus	Dilapidated
5	33.439	1.4726	1,041	Odina	Soroti	Eastern	365	Medium-scale	Public	Lake-based (Lake Kyoga)	Pumping-fed	Sprinkler	Citrus, cashew nuts	Dilapidated
6	33.348704	1.448164	1,036	Labori	Serere	Eastern	284	Medium-scale	Public	Lake-based (Lake Kyoga)	Pumping-fed	Sprinkler	Citrus, mangoes, vegetables	Dilapidated
7	32.28726	1.69215	1,095	Atera	Apac	Eastern	809	Large-scale	Public	Run of river–based and lake based (River Nile)	Pumping-fed	Sprinkler	Citrus	Dilapidated
8	33.146	2.268	1,100	Ongom	Alebtong	Northern	300	Medium-scale	Public	Reservoir-based (Ongom and Owameri dams)	Pumping-fed	Sprinkler	Citrus, cashew nuts	Dilapidated
9	33.074451	2.168389	1,060	Olweny	Dokolo	Northern	650	Large-scale	Public	Swamp-based (Olweny swamp)	Gravity-fed	Basin	Rice	Undergoing rehabilitation
10	33.882167	0.537333	1,100	Kibimba	Bugiri	Eastern	3,900	Large-scale	Private commercial	Reservoir-based (Kibimba Dam)	Gravity-fed	Basin	Rice	Functional
11	33.2825	0.503611	1,220	Kakira	Jinja	Eastern	1,500	Large-scale	Private commercial	Lake-based (Lake Victoria)	Pumping-fed	Sprinkler/ center pivot	Sugar cane	Functional
12	32.940278	0.368889	1,204	Lugazi	Buikwe	Central	322	Medium-scale	Private commercial	Run-of-river diversion-based (River Sezibwa)	Pumping-fed	Sprinkler	Sugar cane	Functional
13	32.553849	0.144810	1,139	Greenhouse farms in the Lake Victoria area	Kampala/ Wakiso	Central	230	Medium-scale	Private commercial	Lake-based (Lake Victoria)	Pumping-fed	Drip	Flowers, horticulture	Functional
14	30.026727	0.095772	1,108	Muhokya	Kasese	Western	50	Small -scale	Community based	Run-of-river diversion-based (River Nyamwamba)	Gravity-fed	Furrow/ sprinkler	Rice	Functional
Total	—	—	—	—	—	—	11,274	—	—	—	—	—	—	—

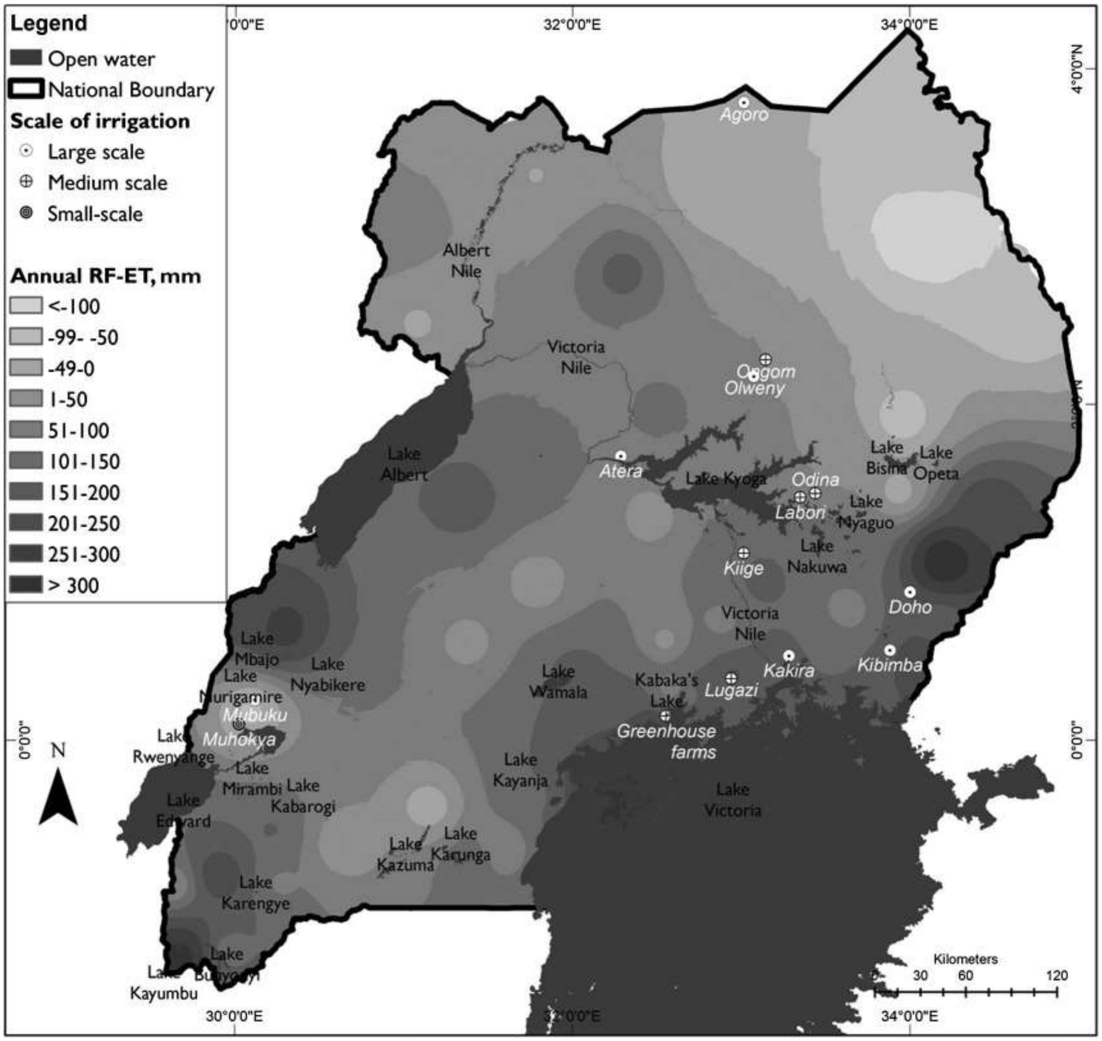

Fig. 3. Spatial distribution of existing formal irrigation schemes superimposed on the annual total net rainfall [difference between rainfall (RF) and potential evapotranspiration (PET)]

large-scale irrigation typology dominates currently functional irrigation schemes in Uganda or those under rehabilitation, accounting for 76% of the total command area under irrigation (about 8,500 ha of the total 11,200 ha). Fig. 3 compares the national distribution of functional irrigation schemes and areas that require irrigation because of lower or negative soil moisture deficit. Most of the irrigation schemes are clustered around Lake Victoria and Lake Kyoga, yet the majority of the northern, western, and eastern regions with lower or negative net rainfall have no formal irrigation scheme. Such areas should be targets for new private and public irrigation investments after feasibility studies on all factors that might hinder development of irrigation in these areas such as topography, soils, water resources, and so on.

Ownership of Irrigation Infrastructure

Irrigation scheme classification by ownership includes public, community-based, private commercial, and private small scale.

Public irrigation schemes are owned by the government and day-to-day operations are manned by the government or delegated to the farmer cooperative societies or water user association (WUAs). Beneficiaries pay an irrigation service fee toward operation and maintenance of the irrigation scheme. Development of public irrigation schemes was initiated from the 1960s onward (Carruthers 1970; FAO 2015). Presently, there are nine public irrigation schemes in Uganda (Table 1), with one scheme in western Uganda (Mubuku); four in eastern Uganda (Kiige, Labori, Odina, and Doho); and four in northern Uganda (Ongom, Atera, Agoro, and Olweny). Most of the public irrigation schemes fell prey to the past wars and insurgencies of the 1970s and 1980s, along with poor maintenance. Rehabilitation of the Agoro, Doho, and Mubuku irrigation schemes was completed in 2013, while rehabilitation of Olweny is ongoing.

Community-based irrigation schemes are co-owned and managed by the community. The infrastructure operations and maintenance plus water distribution are the sole responsibility of the community. The majority of community-based irrigation schemes started as informal irrigated areas located on the fringes of swamps and rivers. Labor for construction of these schemes is provided by farmers with financial support from the government and development partners.

Private commercial irrigation schemes include commercial farms or estates that produce sugarcane, rice, and high-value crops such as floricultural and horticultural crops, primarily for the export market. Most of the greenhouses were established in the 1990s by floriculture private sector farmers and are concentrated in the

J. Irrig. Drain Eng., 2017, 143(5): 04017003

Fig. 4. Typical informal irrigation on the fringes of swamps (image by Joshua Wanyama)

Lake Victoria area (FAO 2015) because of access to surface water resources (both quantity and quality). Irrigation of sugarcane farms at Kakira and Lugazi estates started in the 1970s and has continued to expand in response to prolonged droughts.

Private small-scale irrigation schemes are also referred to as self-help schemes. They include small irrigated farms (less than 10 ha and typically 0.1 ha) that are owned or leased and under the complete control of the farmer (MAAIF 2011). Farmers usually have direct access to surface water or groundwater and make their own decisions about how and when they will irrigate and how much water to apply. Small-scale irrigation has been practiced informally using traditional irrigation techniques for several years as a coping mechanism against erratic rainfall. Some of the small-scale irrigated areas belong to out-growers in the neighborhood of medium- to large-scale schemes. Although statistics are not available, evidence shows that the area managed by smallholder irrigators has increased over the years.

Water Supply Systems

Irrigation development in Uganda is predominantly surface irrigation (96%). A limited area, less than 4% (Table 1), is under pressurized irrigation (FAO 2015). The most common surface irrigation methods are basin irrigation and furrow irrigation, while the most common pressurized irrigation methods are drip irrigation, overhead sprinkler, or microsprinkler irrigation, and to a limited extent center-pivot irrigation only at Kakira Sugar Limited in eastern Uganda. Run-of-river diversion-based gravity-fed irrigation systems use a weir to divert water into a main canal that flows under gravity to the fields. Reservoir-based gravity-fed irrigation systems use water from an earth dam or reservoir system that is diverted to the fields by gravity through intake structures and canal systems. Lake pumping–based pressurized irrigation systems (sprinkler/drip) use fixed or mobile pumps and may have an intermediate storage reservoir between intake at the lake and actual sprinkling of water in the field. Run-of-the-river pumping-based sprinkler irrigation systems use pumps to draw stored water from a concrete weir and send it to a sprinkler system. Groundwater-based irrigation systems are primarily utilized in small-scale irrigation and rely on seasonal or permanent shallow wells. Dominant technologies used for water lifting and distribution from groundwater wells include rope and bucket systems and motorized pumps.

Informal Irrigation

Irrigation is considered formal when systems whether public or private are developed with proper planning and universally established technical standards (Gutierrez-Malaxechebarria 2014). On the other hand, irrigation is considered informal when farmers spontaneously develop systems without planning and with little or no technical assistance. Often the technology used is basic and sometimes inappropriate (FAO 2015). Farmers raise the water level of the river using self-made local weirs with bags of sand and wooden poles. Water is diverted in simple nonlined channels from which it is accessed by breaching the banks every time to allow it to flow into the furrows of the lower lying farms.

The majority of informal irrigated areas in Uganda are located on the fringes of swamps (Fig. 4) mostly in eastern Uganda around streams flowing into Lake Kyoga (Carruthers 1970). The area under informal irrigation increased from 23,000 ha in 1945 (Carruthers 1970) to 53,000 ha in 2005 with focus on irrigating rice, vegetable, and fruit production systems (FAO 2015). Although urban and periurban informal irrigated agriculture covers a small percentage of the total irrigated area, it accounts for between 60 and 100% of the consumed leafy vegetables in the urban areas depending on crop and season.

Why the Irrigation Potential in Uganda Is Not Exploited

Irrigation development in Uganda has been slow compared with other countries in the East African region like Kenya and Tanzania. The major constraints to irrigation development in Uganda are clustered under inadequate national irrigation capacity, economic aspects of irrigation, inadequate access to water for irrigation, and unfavorable land tenure systems and management.

Inadequate National Irrigation Capacity

Uganda lacks highly skilled irrigation personnel focused on irrigation, especially technicians to operate and maintain irrigation systems, because of the absence of irrigation courses at technical institutions. It is common to find irrigation technologies and structures rendered redundant because of minor faults or lack of technical know-how on proper use and maintenance. Namara et al. (2011) reported a general lack of local expertise in planning, design, and construction of standard irrigation projects in SSA, and hence, reliance on expatriates rendering the projects very costly to implement. Currently, there is inadequate funding for university programs, yet engineering programs have a practical component that allows students to learn by doing.. By and large, universities in Uganda have been receiving diminishing budgets that have had devastating consequences for training, especially in engineering fields. Theoretical fundamentals must be matched by practice.

Inadequate Extension Services for Farmers

Besides the shortage of extension workers, there is a lack of streamlined extension structures to coordinate and provide advisory services and technical backstopping on irrigation to farmers from the local level to the national level. Farmers lack knowledge of crop and climate responsive irrigation schedules, on-farm water application techniques, agronomic practices, and application rates of agrochemicals, resulting in poor water-use efficiency and reduced water productivity.

Economic Aspects of Irrigation

Irrigation does not make economic sense to most farmers because of low returns from farming. Firstly, the limited access to reliable alternative marketing channels and market participants allows few buyers to bid the price down. Secondly, prices of agricultural commodities are usually so unstable that it becomes risky to invest in irrigated agriculture. Thirdly, the operation costs of irrigation equipment from high fuel and electricity costs discourages the majority of smallholder farmers from considering irrigated agriculture. In addition, both irrigation equipment and its spare parts are commonly found in urban areas, especially Kampala city, making it costly or inaccessible to the majority of rural smallholder farmers who are located in the distant rural areas. The commercialization of farming is impeded by the high costs of transporting farm inputs and outputs from the farm gate to the market because of poor roads. Furthermore, there is a lack of access to agricultural finance in the form of subsidized credit facilities to support smallholder farmer investment in irrigation activities. Where credit is available, farmers are required to provide collateral by commercial financial institutions, which they usually do not have, and the interest rates are high (above 20%).

Inadequate Access to Water for Irrigation

In some areas there is physical water scarcity in times when it is needed, and in other areas farmers cannot abstract the water and deliver it to their farms because of the high operation costs of conventional pumps that rely on fuel and electricity. Utilization of alternative options of rainwater harvesting is limited because of a lack of awareness of appropriate low-cost techniques.

Unfavorable Land Tenure System and Management

The land tenure systems in Uganda, especially customary tenure, have not been clearly defined. This deters farmers from making long-term investments on land. In the present land tenure system, women's land ownership is not clearly defined and, thus, is vulnerable to the deprivation of access to land. In addition, land fragmentation induced by the increasing population results in small fragmented pieces of land belonging to different households, which is not economically viable for commercial farming. The relatively small farm sizes pose a special problem that is not usually faced in countries with developed irrigation. Most obvious of these is the problem of water conveyance and equitable distribution.

Uncoordinated Efforts in Irrigation from Village to National Level

Uganda lacks national guidelines on irrigation and WUAs, which constrains operationalization of the government policy on irrigation. There is a glaring lack of any coordinated effort that links farmers and/or farmer cooperatives to a well-coordinated network to support irrigation infrastructure setup and farmer advice. The private sector has come in to exploit this business opportunity, but poor smallholder farmers are below their radar.

Lessons Learned and Future Perspectives

A number of lessons learned in previous interventions and successes elsewhere from countries comparable to Uganda could guide policy recommendations to increase irrigation adoption. The six factors that are considered vital for sustainable irrigation development include building national irrigation capacity, streamlining extension services to farmers, addressing the economic aspects of irrigation, improving access to water for irrigation, securing access to land, and developing guidelines for irrigated agriculture and WUAs.

Building National Irrigation Capacity

Efforts to build national irrigation capacity should focus on training of irrigation technicians at certificate and diploma levels at technical institutions to operate and maintain irrigation systems. Tailor-made short courses for irrigation practitioners and extension officers should be developed and streamlined in academic institutions. There should be a deliberate effort to increase funding for university programs to match theoretical fundamentals with practical skills to produce graduates with hands-on experience in design, operation, and maintenance of irrigation projects.

Furthermore, an arrangement such that irrigation infrastructure is prioritized at the same level as other public infrastructure such as roads could help boost irrigation in developing countries in Africa and sustain agriculture's contribution to the national economy. The biggest lesson from Egypt, where irrigation is highly successful, is recognizing irrigation as a major component for enhancing agricultural productivity. For example, the Egyptian government has made considerable investments in irrigation and drainage projects, e.g., El-Salam Canal, the New Valley Project, and the West Delta Region Project. In all of these projects, the government constructs pumping stations and canal networks to deliver water to the farmers in a given region.

The potential for public-private partnerships (PPPs) for the expansion of irrigation schemes, in which government acts as facilitator but the schemes are financed by private investment and managed by farmers, should be explored. Experiences in Morocco and Egypt indicate the potential of this approach (Kadigi et al. 2012). Currently, the Ugandan government is exploring the possibilities of initiating community-based irrigation schemes in eastern Uganda at Busowa in the Bugiri District and Igogero in the Iganga District under a PPP.

Streamlining Extension Services to Farmers

A facilitated extension-service structure from the local to the national level should be streamlined to reach the majority of smallholder farmers. This should be backed up by recruitment of irrigation engineers and technicians to provide advisory services and technical backstopping. At the least, a demonstration center should be set up in every region so that farmers and extension staff can be trained. Within the existing irrigation schemes, the low efficiency of irrigation water use because of the low capacity of farmers on irrigation water management limits the potential area under irrigation.

Addressing Economic Aspects of Irrigation

Irrigation has the potential to enhance food security and economic growth. However, to achieve this, the investment must be profitable for the farmer (Kadigi et al. 2012; Ofosu et al. 2014). Farmers must be encouraged to focus on producing high-value crops to make investments in irrigation infrastructure cost effective (Inocencio et al. 2005). In addition, relative proximity and reliable physical linkages to a nearby market must exist. Thus, emphasis should be placed on a better rural infrastructure, especially feeder roads, to lower the cost of transporting produce to the markets. These are some of the factors that have led to the success of the Mubuku and Doho irrigation schemes, which are in close proximity (less than 10 km) to the towns of Kasese and Mbale respectively. In addition, effective monitoring systems are needed to ensure that farmers have access to affordable complementary crop yield–enhancing inputs of the right quality that include seeds, fertilizers, and agrochemicals. In order to scale up agricultural output and ensure timeliness of agricultural operations in medium- and large-scale irrigation schemes, provision of subsidized agricultural machinery should be considered. Furthermore, low-cost irrigation technologies should be promoted for smallholder farmers to improve water-use efficiency, expand the area under irrigation, and increase crop yields. These technologies are easy to use. They have a simple design, a low cost, and the potential to increase productivity and production, resulting in increased incomes, food security, and family nutrition, all of which make them an attractive option for poor farmers (Perry 1997; Abric et al. 2011; Blank et al. 2002; Ohikere and Ejeh 2012). These technologies include motorized pumps, manually operated treadle pumps, low-head drip irrigation kits, and greenhouse irrigation kits. Additionally, in order to reduce the cost of imported equipment, the option of manufacturing irrigation equipment locally (e.g., drip lines from petroleum by-products) should be considered. According to Kay (2001), improved access to credit will continue to be important to ensure that irrigation equipment and inputs are sufficiently affordable and accessible to farmers. This can be achieved through agricultural financing as a strategic intervention to boost irrigated agriculture. Also, to minimize production risks, options for low-cost crop insurance should be explored.

Improving Access to Water for Irrigation

Lessons from countries such as Israel and Egypt show that reliable access to water for irrigation in proximity of the farm in the right quantity, quality, and adequacy is critical for increasing adoption of irrigation. Water availability can be improved by increasing water storage in the form of valley tanks, dams, and farm ponds and by developing bulk water transfer infrastructure to harness unutilized reservoirs as a strategic intervention. Some form of subsidies and incentives to improve access to water for irrigation might be needed, and this could be in the form of tax holidays for water bills like in the case of Zimbabwe.

Widespread household-level rainwater harvesting should be promoted by the government as an option for improving access to water for irrigation. Even the driest areas of Uganda receive an average minimum of 600 mm/year, which can be harvested for irrigation. Multiple-use water supply systems should be promoted and operationalized for more sustainable water supply schemes that meet a wider range of needs in communities, including irrigation, livestock water supply, aquaculture, and domestic use, and thus make greater contributions to improving livelihoods and food security than is possible with single-purpose water supply schemes. Also, farmers should be trained in basic practices of soil water conservation such as no-till practices, reduced tillage, and residue management to ensure that a large proportion of crop water use is sustainable.

Securing Access to Land and Land Reforms

There is a need to streamline land tenure systems to ensure clarity and security of tenure, especially for women farmers who have been recognized to provide a significant amount of labor force in the agriculture sector, to promote investment in irrigated agriculture (Ofosu et al. 2014). In addition, pertinent land reforms toward land consolidation for sustainable commercial irrigation development should be supported (van Averbeke et al. 2011; Machethe et al. 2004).

Developing National Guidelines on Irrigated Agriculture and WUAs

There is a need to operationalize the government's policy on irrigation by developing national guidelines on irrigation and WUAs. Experiences in Tanzania and South Africa show that farmer participation in planning, development, and management of irrigation schemes is crucial to their sustainability (Kay 2001; Kadigi et al. 2012). The establishment of WUAs to take the responsibility for operation and maintenance of irrigation infrastructure is thus essential and needs to be strengthened. However, transfer of responsibilities to WUAs calls for clear guidelines and capacity development (Kay 2001). According to Kadigi et al. (2012), it should be recognized that the transfer of a scheme to farmers should take place when the scheme is running effectively and when extension services are in place for training. The national guidelines on irrigation should clearly define coordination mechanisms that link farmers and/or farmer cooperatives to a well-coordinated network to support irrigation infrastructure setup and farmer advice.

Conclusions and Recommendations

Drawing from the lessons learned, there is no single blanket solution to the constraints of irrigation development in Uganda. Several strategies must be implemented in a holistic manner to ensure a good success rate of uptake of irrigation in Uganda. Lessons from similar countries show that the key to successful adoption of irrigation lies in building the national irrigation capacity, improving access to reliable water for irrigation in the proximity of farms, streamlining extension services for farmers, addressing economic aspects of irrigation, and streamlining land tenure systems and management. Harnessing these with the typology of irrigation systems in Uganda dictates strategic interventions that include the following:

1. Government investing in irrigation schemes, which cannot easily attract private financing. An arrangement in which irrigation infrastructure is prioritized at the same level as other public infrastructure such as roads could help boost irrigation and sustain agriculture's contribution to the national economy.

J. Irrig. Drain Eng., 2017, 143(5): 04017003

2. Training of irrigation technicians at certificate and diploma levels at technical institutions to operate and maintain irrigation systems.
3. Increasing water storage through the construction of valley tanks, dams, and farm ponds and developing bulk water transfer infrastructure to harness unutilized reservoirs as a strategic intervention. Deliberate efforts should focus on promoting widespread culture of household-level rainwater harvesting coupled with soil and water conservation.
4. Government working toward consolidating land, providing irrigation infrastructure on this land, and allocating to farmers with clear tenure agreements and management. In Uganda this will require deliberate acquisition of land from the current occupants through compensation.
5. Operationalizing government policy on irrigation by developing national guidelines on irrigated agriculture.

Finally, a study should be conducted to harmonize information on the irrigation potential of Uganda because currently various sources quote different figures and the methodology adapted does not seem to give comprehensive and concrete information to guide planning for irrigation in the country.

Acknowledgments

The authors take responsibility for the scientific content. We are grateful to the research collaboration among the Ministry of Agriculture, Animal Industry, and Fisheries (MAAIF), the National Agricultural Research Organization (NARO), Kansas State University (KSU), and Makerere University Kampala (MAK) that supported this study. We also thank the three anonymous reviewers for their valuable comments that helped to improve this paper.

References

Abric, S., Sonou, M., Augeard, B., Durlin, D., and Gadelle, F. (2011). "Lessons learned in the development of smallholder private irrigation for high-value crops in West Africa." World Bank, Washington, DC.

ArcGIS [Computer software]. ESRI, Redlands, CA.

Blank, H. G., Mutero, C. M., and Hammond, M.-R. (2002). "The changing face of irrigation in Kenya: Opportunities for anticipating change in eastern and southern Africa." International Water Management Institute, Colombo, Sri Lanka.

Bongaarts, J. (2009). "Human population growth and the demographic transition." *Philos. Trans. R. Soc. B: Biol. Sci.*, 364(1532), 2985–2990.

Carruthers, I. D. (1970). "Irrigation development in Uganda: Past experiences and future prospects." *East Afr. Geogr. Rev.*, 8, 11–22.

FAO (Food and Agriculture Organization). (2005). "Irrigation in Africa in figures." Rome.

FAO (Food and Agriculture Organization). (2006). "NewLocClim 1.10: Local Climate Estimator software and global climate database." Rome, ⟨http://www.fao.org/NR/climpag/pub/en3_051002_en.asp⟩ (Sep. 10, 2012).

FAO (Food and Agriculture Organization). (2015). "FAO's information system on water and agriculture." Rome.

Fermont, A., and Benson, T. (2011). "Estimating yield of food crops grown by smallholder farmers: A review in the Uganda context." International Food Policy Research Institute, Washington, DC.

GoU (Government of Uganda). (2010). "National development plan (2010–2035)." Kampala, Uganda.

Gutierrez-Malaxechebarria, M. A. (2014). "Formal and informal irrigation in the Andean countries: An overview." *Cuadernos de Desarrollo Rural*, 11(74), 26.

Haile, G. G., and Asfaw, K. K. (2015). "Review paper irrigation in Ethiopia: A review." *Acad. J. Agric. Res.*, 3, 264–269.

Indeje, M., Semazzi, F. H. M., and Ogallo, L. J. (2000). "ENSO signals in East African rainfall seasons." *Int. J. Climatol.*, 20(1), 19–46.

Inocencio, A., et al. (2005). "Lessons from irrigation investment experiences: Cost-reducing and performance-enhancing options for sub-Saharan Africa." International Water Management Institute, Colombo, Sri Lanka.

Kadigi, R. M. J., Tesfay, G., Bizoza, A., and Zinabou, G. (2012). "Irrigation and water use efficiency in Sub-Saharan Africa." *Global Development Network Agriculture Policy Series-Briefing Paper Number*, Global Development Network (GDN), New Delhi, India, 1–8.

Kay, M. (2001). "Smallholder irrigation technology: Prospects for sub-Saharan Africa." Food and Agriculture Organization (FAO) of the United Nations, Rome.

MAAIF (Ministry of Agriculture, Animal Industry, and Fisheries). (2011). "Statistical abstract." Kampala, Uganda.

Machethe, C., Mollel, N., Ayisi, K., Mashatola, M., Anim, F., and Vanasche, F. (2004). "Smallholder irrigation and agricultural development in the Olifants River Basin of Limpopo Province: Management transfer, productivity, profitability and food security." Water Research Commission, South Africa.

Megersa, G., and Abdulahi, J. (2015). "Irrigation system in Israel: A review." *Int. J. Water Resour. Environ. Eng.*, 7(3), 29–37.

MWE (Ministry of Water and Environment). (2011). "Irrigation master plan (2010–2035)." Kampala, Uganda.

MWE (Ministry of Water and Environment). (2013). "National water resources assessment report." Directorate of Water Resources Management, Kampala, Uganda.

Namara, R. E., et al. (2010). "Typology of irrigation systems in Ghana." International Water Management Institute, Colombo, Sri Lanka.

Namara, R. E., Horowitz, L., Nyamadi, B., and Barry, B. (2011). "Irrigation development in Ghana: Past experiences, emerging opportunities, and future directions." Ghana Strategy Support Program Accra, Accra, Ghana.

NEMA (National Environmental Management Authority). (2009). "Atlas of our changing environment." Kampala, Uganda.

Ngigi, N. S. (2009). "Climate change adaptation strategies: Water resources management options for smallholder farming systems in sub-Saharan Africa." *The MDG centre, east and southern Africa*, The Earth Institute at Columbia Univ., New York, 189.

Nsubuga, F. N. W., Namutebi, E. N., and Nsubuga-ssenfuma, M. (2014). "Water resources of Uganda: An assessment and review." *J. Water Resour. Prot.*, 6, 1297–1315.

Ofosu, E. A., Van Der Zaag, P., Van De Giesen, N., and Odai, S. N. (2014). "Success factors for sustainable irrigation development in sub-Saharan Africa." *Afr. J. Agric. Res.*, 9(51), 3720–3728.

Ohikere, J. Z., and Ejeh, A. F. (2012). "Impact of small scale irrigation technologies on crop production by Fadama users in Kogi State Nigeria." *Adv. Appl. Sci. Res.*, 3(2), 854–861.

Perry, E. (1997). "Low-Cost irrigation technologies for food security in Sub-Saharan Africa: Irrigation technology transfer in support of food security." *Proc., Subregional Workshop*, Food and Africulture Organization of the United Nations, Rome.

UBOS (Uganda Bureau of Statistics). (2009). "2009 statistical abstract." Kampala, Uganda.

UBOS (Uganda Bureau of Statustcs). (2010). "Summary report on Uganda census of agriculture 2008/2009." Kampala, Uganda.

UBOS (Uganda Bureau of Statustcs). (2015). "Statistical abstract 2015." Kampala, Uganda.

United Nations. (2013). "World population prospects: The 2012 revision, key findings and advance tables." New York.

UN-WATER/WWAP (World Water Assessment Programme). (2006). "National water development report: Uganda-2005." New York.

van Averbeke, W., Denison, J., and Mnkeni, P. N. S., (2011). "Smallholder irrigation schemes in South Africa: A review of knowledge generated by the Water Research Commission, South Africa." *Water SA*, 37(5), 797–808.