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IRRIGATION DEVELOPMENT FOR CLIMATE RESILIENCE IN ZAMBIA: THE KNOWN KNOWNS AND KNOWN UNKNOWNS

By

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EXECUTIVE SUMMARY

Irrigation is increasingly seen as a necessary means to build resilience in smallholder rain-fed farming systems and to increase productivity to meet growing food demands in Sub-Saharan Africa. Irrigation was important in the Asian Green Revolution. Abundant surface and ground water and the under-exploited irrigation potentials offer real prospects for expanding irrigation in several Sub-Saharan African countries, Zambia inclusive. However, there are still several gaps—the known unknowns: what irrigation models work and are suitable for smallholder farmers in the context of climate change? What irrigation models are preferred and why? What are the likely impacts of climate change on water availability and what are the long-term implications for irrigation development?

This study contributes towards filling these gaps. First, it assesses what smallholder irrigation models are present in Zambia and their performance. Second, it analyses the prevalence of irrigation use among smallholder farmers, what drives its use and the impacts and implications of current and projected climate change on water resource availability in the country.

Combining qualitative field interviews, econometric and hydrological modelling, the main results suggest that public-private partnership and privately managed irrigation schemes are better models for smallholder irrigation schemes provided that farmers retain a sense of ownership of the scheme, have good governance structures and are well organized into collective production and marketing units with production financing and forward supply contract arrangements. While community-based schemes have the potential, they are usually too small and farmers are often poorly organized to get into formalized collective production and marketing arrangements. Public-private partnerships such as the three-tier model (combining a large-scale farm to supply water and provide market to medium- and small-scale farmers) hold potential, but it is still too soon to evaluate them. Albeit successful, outgrowing arrangements under private irrigation schemes create winners and losers, as they often entail significant changes to the ways land, livelihoods, and social relations are configured.

Informal irrigation for fruits and vegetables is more prevalent at 18% use rate than for field crops (ca.1%) among smallholder farmers in Zambia. The majority of the irrigated fields are located close to water sources (Dambos/wetlands) and manual bucket irrigation is the most prevalent irrigation technology used by more than 80% of smallholder farmers. In addition to proximity to water sources, access to credit, labour availability, secure land tenure and income are strong drivers for irrigation use among smallholder farmers.

With climate projections suggesting that Zambia will become hotter and drier, and the southern, western and eastern regions much more affected compared to the northern region, water scarcity can only worsen. Reduced rainfall and a hotter climate coupled with increased demand for water resources will require smallholder irrigators to adapt in some ways. Water scarcity will increasingly make it difficult for irrigators to rely on Dambos/wetlands. How exactly the irrigators will adapt largely depends on their location in the country, proximity to water sources, resilience and adaptive capacity, *inter alia*.

Based on the main results, we draw the following implications on smallholder irrigation development in Zambia:

- Current and future smallholder irrigation schemes will need to adopt more water efficient technologies such as overhead and drip irrigation systems as opposed to the prevalent surface irrigation methods. It is vital to understand the cost implications and feasibility of such a switch to more water efficient technologies.

- Governance and institutional arrangements of smallholder irrigation schemes will need strengthening to facilitate collective production and marketing arrangements.

- Reduced water availability will increase access and irrigation costs, which in turn may reduce its profitability among smallholder farmers as they tend to have limited capital and capacity to adapt to higher cost structures. In this vein, improved access to credit facilities and markets will be required.

Competition for the reduced available water resources will disadvantage the smallholder farmers. Policies to protect them against the large-scale users are required. This may entail strengthening the management, regulation, and monitoring of water use by ensuring that water user rights and fees become mandatory and are enforced, and the process of acquiring water rights transparent. Activities of Water Management Authorities require strengthening.

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LIST OF ACRONYMS AND ABBREVIATIONS

7NDP	Seventh National Development Plan
AR5	Fifth Assessment Report
CHIRPS	Climate Hazards Group Infrared Precipitation with Station database
CSO	Central Statistical Office
GCM	Global Circulation Models
GHGs	Green House Gases
GRZ	Government of the Republic of Zambia
IAPRI	Indaba Agricultural Policy Research Institute
IDSP	Irrigation Development Support Project
IPCC	Intergovernmental Panel on Climate Change
ITCZ	Inter Tropical Convergence Zone
KASCOL	Kaleya Smallholders Corporation Limited
MAL	Ministry of Agriculture and Livestock
MoA	Ministry of Agriculture
NAIP	National Agricultural Investment Plan
OLS	Ordinary Least Squares
PPPs	Public-Private Partnerships
RALS	Rural Agricultural Livelihood Survey
RCPs	Representative Concentration Pathways
SNAP	Second National Agricultural Policy
SSA	Sub-Saharan Africa
WARMA	Water Resources Management Authority
ZMW	Zambian Kwacha

1. THE PROBLEM

Climate change and rural livelihoods are more closely linked in regions with high dependence on rain-fed agriculture and where agriculture is an important economic sector. Sub-Saharan Africa (SSA) is a prime example. Throughout the region, rural households are more exposed (more likely to be affected) and vulnerable (lose more when affected) to the shocks of climate change because of their dependence on rain-fed agriculture (Hallegatte et al. 2016). Low adaptive and coping capacities constrain the extent to which these households can effectively manage climate shocks. This, in turn, exacerbates their vulnerability, and climate change emerges as one of the major threats to poverty alleviation in the region.

Climate change has both direct and indirect impacts on the livelihoods of rural households (Porter et al. 2014). Directly, climate change affects crop yields and therefore agricultural income, food security and the poor's ability to escape poverty. Climate change also directly affects asset stock accumulation and returns on assets. Indirectly, climate change affects output prices, wages, off-farm employment opportunities and alternative livelihood opportunities, and food systems (Olsson et al. 2014; Porter et al. 2014).

The challenge for the region, therefore, is to build climate resilience within the rain-fed farming systems given the economic significance of smallholder agriculture in SSA. We follow the fifth assessment report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) (IPCC 2014a) and define resilience in the context of this study as the capacity of rainfed farming systems to cope with current and projected climate change and variability, responding or reorganizing in ways that maintain their essential function, identity and structure, while also maintaining the capacity for adaptation, learning and transformation. Defined differently, resilience is the ability of a system to respond to transitory effects (shocks) or the more persistent adverse trends (stressors) (Hoddinott 2014).

Resilience is increasingly seen as a sine qua non for the attainment of climate-resilient pathways, which are development trajectories that combine adaptation and mitigation to achieve sustainable development goals (IPCC 2014a). With sustainable development as the ultimate goal and adaptation as a response strategy to anticipate and cope with impacts of the unavoidable, climate resilient pathways include strategies, choices, and actions that reduce climate change and its impacts on livelihoods, while rising risk management.

Irrigation offers real prospects to build the resilience of rain-fed farming systems and rural households to climate change and variability while raising crop productivity. It enables all year round production, increases productivity and household incomes, builds adaptive capacity and reduces climate-induced production risk (Koundouri, Nauges, and Tzouvelekas 2006). Irrigation was essential to the Boserup hypothesis of population growth and market access led agricultural intensification (Boserup 1965; Binswanger-Mkhize and Savastano 2017) and to the success of the Asian Green Revolution. However, recent experiences from Africa paint a different picture (Headey and Jayne 2014; Binswanger-Mkhize and Savastano 2017), highlighting the importance of context specificity of agricultural interventions.

Nevertheless, irrigation is vogue with current rural development discourse and garners strong political support at various levels. At regional level, irrigation is part of the first pillar of the Comprehensive African Agriculture Development Program (CAADP) and the Southern African Development Cooperation (SADC) regional agricultural policy, which among other things, aimed to double area under irrigation to 7% of arable land by 2015, improve agricultural water management and build water infrastructure (Akayombokwa, van Koppen, and Matete 2015). In Zambia, irrigation development is a priority for improving the resilience of farmers to climate change and for agricultural development as highlighted in national policies, including in the Second National Agricultural Policy (SNAP), the National Investment Plan (NAIP) and the Seventh National Development Plan (7NDP), among others (GRZ 2004, 2013, 2016, 2017). The government-led agriculture commercialization through farm block development intends, among other things, to increase area under irrigation in the country. These investments, while necessary and well-intended, need to be guided by empirical evidence on what irrigation models have worked well, what hasn't worked well and why?

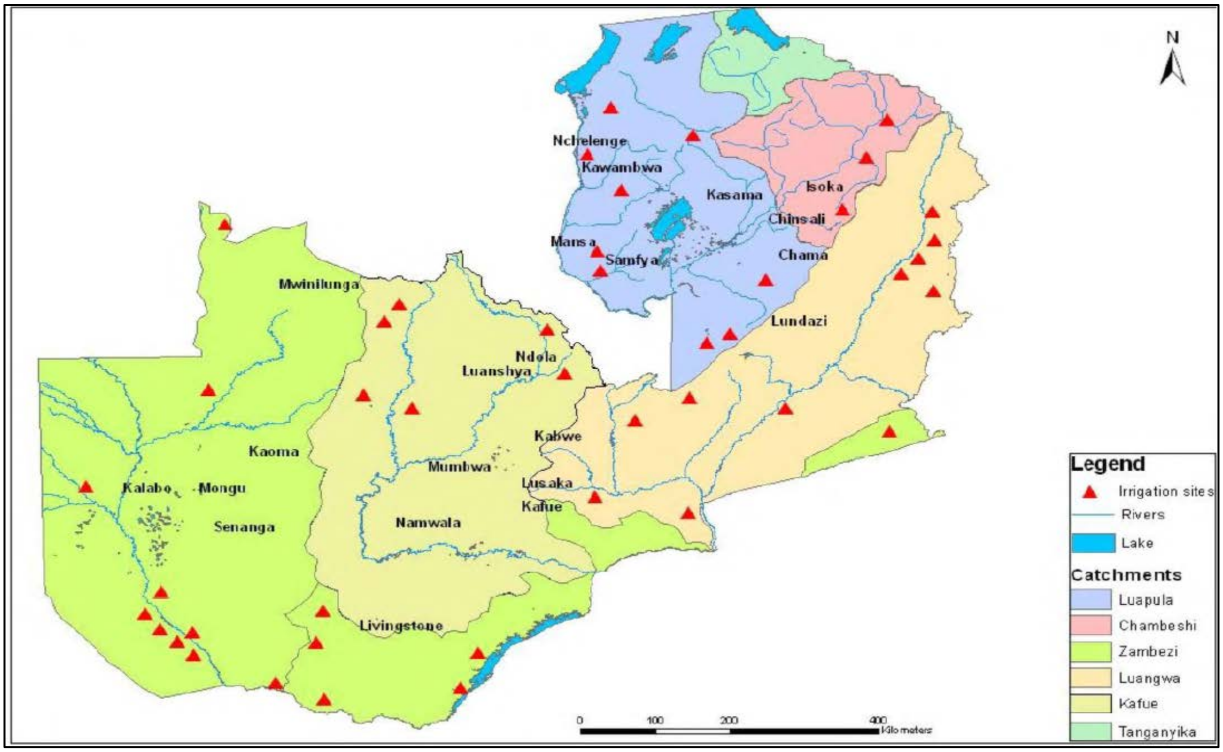
The National Irrigation Policy and Strategy of 2004 (under revision) guides irrigation development in Zambia (GRZ 2004). The overall policy objective is "*a well-regulated and profitable irrigation sector that is attractive to both private investors and Zambia's development partners*." The policy aims to remove constraints for existing irrigators, thereby encouraging new private investment that increases area of land under irrigation and productivity. In addition, the policy encourages the emergence and gradual commercialization of new irrigators from among traditional farmers. This policy emphasizes building irrigation infrastructure, which are immediately handed over to small-scale farmers (Akayombokwa, van Koppen, and Matete 2015).

The main smallholder irrigation models prevalent in Zambia include; (i) informal irrigation at individual household level, (ii) smallholder irrigation schemes (e.g., community-based, farmer or cooperative operated schemes), (iii) quasi-government schemes and (iv) private or commercial irrigation schemes (GRZ 2013). It is not well understood how these different schemes have performed comparatively in the country. This paper restricts itself to smallholder irrigation, defined in line with Burney and Naylor (2012) as the ability of smallholders to draw water from various sources, and use different access and distribution technologies to irrigate different types of crops. Our focus on smallholder irrigation should not be construed to suggest that irrigation is not important for the commercial farming sector; it is far more developed and organized in that subsector. Moreover, smallholders account for the majority of the farmers in Zambia, and they are more vulnerable and less resilient to climate shocks due to their low coping and adaptive capacities.

Out of the potential 2.75 million hectares (ha) irrigable land, of which 523,000 ha or 19% is economically viable, that only about 155,000 ha (about 6% of the total land area or about 1/3 of irrigable area) is irrigated in Zambia (GRZ 2013) suggests enormous potential to expand irrigation. Several stakeholders, including government, the donor community, non-government organization (NGOs) and the private sector support some form of irrigation in Zambia. Figure 1 (on the following page, although dated) shows the spatial location of the main smallholder irrigation schemes in Zambia.

Despite these efforts, recent nationally representative household data shows that only 1% of all smallholder farmers in Zambia irrigated some of their field crops in the 2010/2011 and 2013/2014 agricultural seasons, respectively and about 17 and 15% irrigated fruits and vegetables over the same period. For these households, the most prevalent method of irrigation was rudimentary, with more than 80% having used wells or streams or rivers as sources of water and buckets as the access and distribution technology. Understanding why this is the case is important for policy in order to guide investments in irrigation development in the country.

Figure 1. Location of Smallholder Irrigation Schemes in Zambia (Dated)



Source: GRZ (2004).

There is a dearth of knowledge on the socio-economic and biophysical constraints to irrigation development and generally, on how the different smallholder irrigation scheme types have performed in Zambia. On the one hand, there are known stylized facts: irrigation development is a necessary condition to enhance climate resilience for smallholder rainfed farming systems and for agricultural development—given experiences from the Asian Green Revolution. These are known knowns. On the other hand, there are several issues regarding smallholder irrigation that we know we do not know—the known unknowns. In this regard, several known questions remain unanswered (hence unknown): what irrigation models are preferred by smallholder farmers and why? What are the governance issues in irrigation schemes if any? What are the likely impacts of climate change on water availability and what are the long-term implications for irrigation development in Zambia?

This study combines socio-economic and biophysical assessments to contribute towards filling some of these gaps. Specifically, the study attempts to answer the following questions:

1) How prevalent is irrigation for field crops and for fruits and vegetables in Zambia?

2) What factors influence irrigation uptake among smallholder farmers?

3) What irrigation models are best suited for Zambia? What works and why?

4) What are the trends in water resources availability in Zambia, and how do these vary from one river basin to another and from year to year?

5) What are the likely impacts of climate change on water resources availability and what are the implications on water availability and use?

Results from this study will help inform the formulation of future water resource use policies to enhance coordinated planning for improved water resources management. In particular, it is hoped results in this study and those in a related study (Hamududu and Ngoma (2018)) can serve as inputs into the revised National Irrigation Policy. The assessment uses scientifically robust methods to assess the temporal and spatial availability and distribution of water resources in Zambia. The rest of the paper is organized as follows. Section 2 presents a brief overview of Zambia's water resources, irrigation potential and development and Section 3 presents the conceptual framework, while Section 4 presents the data sources. Section 5 describes the methods, results are presented and discussed in Section 6 and the paper concludes and draws policy implications in Section 7.

2. WATER RESOURCES, IRRIGATION POTENTIAL, AND DEVELOPMENT IN ZAMBIA

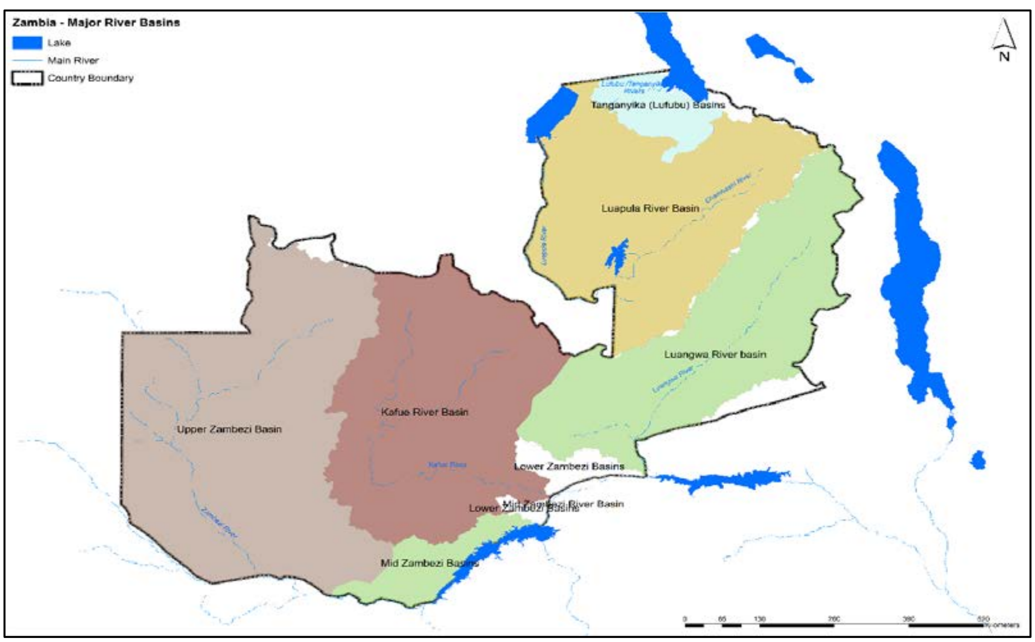
2.1. General Overview

Zambia, a landlocked country covering some 752,610 km^2 in Southern Africa is largely a plateau with an average elevation of 1,138 m above sea level (Holden 2001). The country has a unimodal rainy season influenced by the location of the Intertropical Convergence Zone (ITCZ). With rainy seasons spanning November to April of every year, the average annual rainfall is more than 1,000 mm in the high-rainfall areas in the north and less than 800 mm in the south. Zambia has sufficient water resources during the rainy season, but high climate variability coupled with inadequate storage infrastructure and management result in water scarcity during years of low rainfall. This has implications on food security and on efforts to reduce poverty.

Zambia is drained by two main river systems; the Zambezi River and the Congo River basins. The Zambezi basin covers a larger portion of the country and is fed by three rivers; upper Zambezi, Kafue and the Luangwa Rivers. The Luapula and the Chambeshi Rivers feed the Congo River in the north (Figure 2). Much of the water flowing into the Congo River is barely utilized while the Zambezi flowing southwards is highly utilized for various purposes, including irrigation and hydropower generation. An important question not addressed in this paper is whether it is feasible to transport the water resources from surplus areas in the north to the south where demand is high.

Optimal use of available water resources is key to diversify the economy and reduce Zambia's dependency on copper production and to enhance the resilience of smallholder farming systems to climate variability. Although, it is not very clear how much water resources are available to Zambia, the African Water Development Report of 2006 estimated that about 20% of the annual 399 km^3 water flows in southern Africa flows through Zambia. Other estimates suggest that between 45 and 60% of the surface and groundwater supplies in southern Africa is in Zambia. With an annual runoff

Figure 2. Major River Basins in Zambia



Source: Hamududu and Ngoma (2018).

of about 100 billion $m^3$and 60 billion m^3 stored underground in rivers, lakes, streams and swamps, Zambia, like many other countries in the region has enormous potential to expand irrigation (Xie et al. 2014). How best to do this remains an important known unknown. The NAIP suggests that investments in the order of US $ 169.25 million over the period 2014-2018 can potentially increase the irrigable land by 12% from the current 156,000 ha to about 175,00 ha in Zambia (GRZ 2013). Programs such as the Irrigation Development Fund (IDF) which was launched in the mid-2000s but was never implemented could be options. However, it is not very clear which smallholder irrigation scheme models would yield the highest returns on investment.

Moreover, since most of the major river systems in Zambia are shared watercourses with riparian countries, there is no guarantee of water availability and its subsequent use. This is worsened by climate change, which on average, is likely to reduce water availability (Timmermann et al. 2007; Shongwe et al. 2009; IPCC 2013). Future climate projections from the IPCC suggest that there will be reduced rainfall and higher temperatures in SSA by 2050 (de Wit and Stankiewicz 2006; Hamududu and Killingtveit 2012; IPCC 2013).

Recurrent droughts experienced over the past five agricultural seasons and the subsequent reduced hydropower generation and the ensuing energy deficits in the region are a clear testament. Hamududu and Killingtveit (2012) estimated that climate change would reduce water availability by 7.2% and hydropower generation by 9.6% by the year 2050 in SSA. Climate-induced water scarcity is likely to negatively affect irrigation development in Zambia, where it is estimated that about 88 and 12% of irrigation relies on surface and underground water sources, respectively (GRZ 2013).

Several issues hinder the full exploitation of water resources for increased production through irrigation in Zambia. These include; (i) lack of accurate data on availability and distribution of water resources and the likely impacts of climate change on these aspects, (ii) poor resource management, regulation and enforcement of legislation mechanisms, (iii) less well understood water abstraction and use rights, (iv) lack of an integrated approach to water resource management, (v) inadequate investment in water infrastructure, (vi) recurring droughts and floods and (vii) lack of a clear understanding of the most suitable and feasible irrigation development approaches or where this is not an issue; delayed, poor and lack of implementation of irrigation development programs is.

2.2. Background and Public Spending on Irrigation Development in Zambia

This section traces irrigation development and tracks public spending on irrigation from 1964 to present in Zambia. It briefly reviews *what* irrigation types were present, *how* they were managed and operated and by *whom,* and tracks public allocations/spending on irrigation development since 2010.

2.2.1. Post-independence Era: 1964–1990

The post-independence period of the first republic was characterized by socialist policies and heavy government involvement in running economic sectors. In the irrigation subsector, the post-independence period was characterized by government investing in irrigation schemes to meet the demand for various vegetables in the country. Public schemes were constructed by the Projects Division in the Ministry of Rural Development and managed by the Department of Agriculture (Akayombokwa, van Koppen, and Matete 2015). While investing in and running large-scale schemes such as the Mpongwe and Mkumpe irrigation schemes for wheat that were opened in the 1980s, Government also supported private sector investments in irrigation. A notable example is the support given to Zambia Sugar to set up the 120 ha Nakambala sugar estates in 1964 (Akayombokwa, van Koppen, and Matete 2015).

Once established, irrigation schemes were either run by Government or given to the smallholder farmers to manage. Either approach did not work very well: it became too costly for the government to manage irrigation schemes and farmers recruited to manage schemes did not have the technical expertise to operate and organize farmers into production clusters to tap into better, larger and collective markets. However, private-sector run schemes such as Nakambala estates and Kapulurira were more successful because of good market linkages.

2.2.2. Market Liberalization Period: 1990–2000

This period was characterized by market liberalization where government withdraws from interfering in the day to day running of economic activities in the country under the Structural Adjustment Programs (SAPs). Key changes in the agricultural sector included the withdrawal of Government from subsidizing production and reduced spending on several other support services such as extension and research and development. This abrupt and sudden withdrawal of Government support to agriculture threatened food security. The ensuing food insecurity, poverty and higher incidences of droughts in the early 1990s provided a rationale for the private sector, development co-operators and donors to invest in agricultural development in general and irrigation development in particular.

Although public spending on irrigation development plummeted during this period, this was compensated for by increased private sector investments in the subsector. To coordinate these efforts, Government created a specialized irrigation unit in the Ministry of Agriculture in the early 1990s (Akayombokwa, van Koppen, and Matete 2015). Several community-based and public-private partnership irrigation projects were initiated in this period with varying degrees of success, see Akayombokwa, van Koppen, and Matete (2015) for a review.

2.2.3. Accelerated Agricultural Development Era: 2000–2017

The post-2000s period has been characterized by increased donor and public spending on agricultural development and the irrigation subsector. The increase in the frequency and intensity of droughts and the need to raise productivity to meet growing food demands provided the moral justification to bolster public spending on irrigation development. Different types of irrigation models including (i) informal irrigation at the individual household level, (ii) smallholder irrigation schemes (e.g., community-based, farmer or cooperative operated schemes), (iii) quasi-government schemes and (iv) private or commercial irrigation schemes have been tried with various degrees of success in Zambia.

For the early 2000s, public policy towards irrigation development focused on setting up irrigation schemes by installing requisite infrastructure (GRZ 2004). Some of these schemes were run as public-private partnerships (PPPs), others as government schemes, and yet others were left for farmers to run. Again, experiences from the period show that government is not the best entity to run irrigation schemes: they can facilitate establishment but let the private sector to run the schemes. Schemes managed by the private sector appear to have been more successful compared to others, see Table 7. We return to this issue in section 6.3.

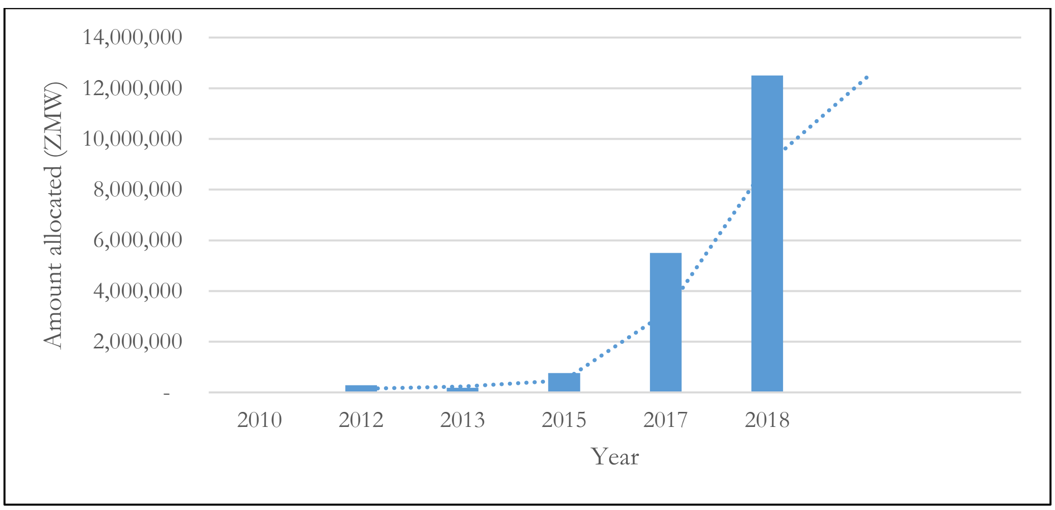
A more recent three-tier PPP irrigation model is currently being trialled under the Irrigation Development Support Project (IDSP). The idea is to have a core venture commercial farm, professionally operated and equipped with center pivots to manage bulk water, and supply it to emergent farmers cultivating 1-5 ha at the second tier and small-scale farmers cultivating less than 1 ha at the third tier. The core venture is expected to provide market linkages to tier two and three producers. Assessing how this model will perform is an interesting area for future research.

2.2.4. Public Spending on Irrigation Development: 2010–2017

This subsection tracks public expenditure for smallholder irrigation development. Even without including allocations to large or commercial schemes such as those under IDSP and other support activities to irrigation development in general, Figure 3 shows an increasing trend in allocations to smallholder irrigation schemes in Zambia. As of 2018, these allocations represented approximately 0.2% of the annual budget to the Ministry of Agriculture.

The aforementioned public and private investments have significantly increased the area under irrigation in Zambia. From a paltry 120 ha of irrigated commercial cane in 1964, irrigated area expanded rapidly reaching 10,000 and 27,000 ha by 1980 and 1988, respectively (Figure 4). Irrigated area has continued to increase since then to the current levels of about 155,000 ha (Akayombokwa, van Koppen, and Matete 2015) and can be increased further given the unmet potential.

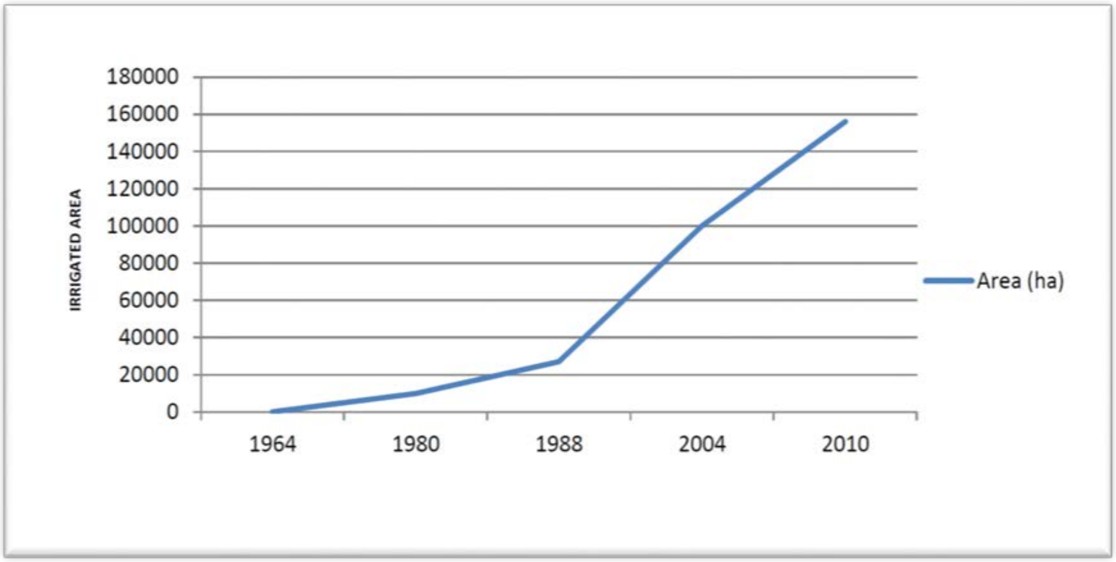
Figure 3. Public Allocations Towards Smallholder Irrigation Scheme Development in Zambia, 2010-2017



Source: GRZ Various Years.

Notes: These figures only capture allocations towards smallholder irrigation schemes. They do not include allocations for large commercial schemes such as those under the Irrigation Development and Support Project (IDSP). Adding these, for example, takes the 2018 allocation to about ZMW 400,000,000. The 2010 figure was less than ZMW 500,000, while figures for 2011 and 2016 could not be accessed in time for the report.

Figure 4. Trends in Irrigated Area (ha) in Zambia



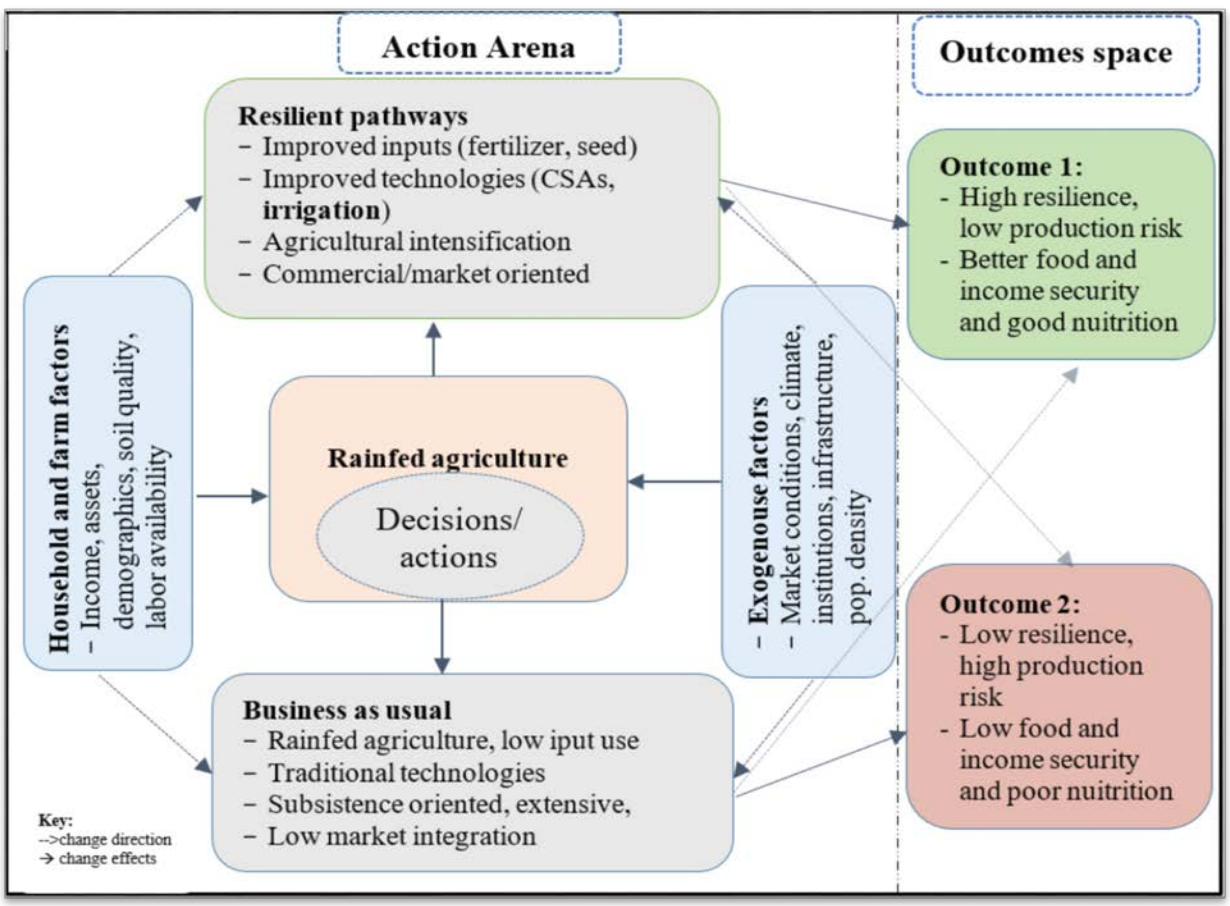
Source: Akayombokwa, van Koppen, and Matete (2015).

3. CONCEPTUAL FRAMEWORK: LINKING IRRIGATION TO RESILIENCE

The conceptual thinking is informed by some aspects of the livelihood framework (Ellis 1998) and takes the different capitals—human, financial, natural, physical and social—controlled by households as the starting point. Contingent on conditioning factors (household, farm and external factors), decisions based on these capitals—also called the behavioural and material determinants (Binswanger and Rosenzweig 1986)—determine the livelihood strategies and outcomes as depicted in Figure 5.

At the center of the action arena in Figure 5 is the subject matter—rain-fed agriculture, where households have to choose their livelihood strategies and make decisions on production methods, crops, and livestock. Two options are available here. Households can choose production methods that use improved inputs such as inorganic fertilizers and hybrid seed, climate-smart agriculture (CSA) principles such as conservation agriculture and irrigation. This pathway is commercially/market-oriented, with (or moving towards) intensive agriculture and builds household resilience. On the other hand, households can choose business as usual: low tech agriculture with low external input use, extensive, subsistence-oriented (full-belly) and not very well integrated into markets.

Figure 5. Conceptualizing Linkages between Resilience and Irrigation Adoption



Authors illustration, adapted from (IPCC 2014b; Cacho et al. 2018).

Different farm, household, and exogenous factors condition household choices of production methods. These include factors specific to households and farms such as asset stocks and returns on assets, soil health, socioeconomic characteristics and demographics, and exogenous factors such as market conditions, institutions, policies, climate and population density (Boserup 1965; Binswanger and Rosenzweig 1986; de Janvry, Fafchamps, and Sadoulet 1991; Ellis 1998; IPCC 2014b; Cacho et al. 2018).

Decisions made in the action arena can result in either of the two outcomes. Outcome one is *win-win* with high resilience and low production risk, better food and income security and good nutrition status. This exemplifies a micro-level climate resilient development pathway. Outcome two is *lose-lose* with low resilience and high production risk, resulting in food and income insecurity and poor nutrition outcomes. Suffice to mention here that even if a household chooses the resilient pathway in the action area, it is feasible that they could end up with the *lose-lose* outcome if the conditioning factors and antecedents change sufficiently and with low resilience.[1]

Because this paper focuses on smallholder irrigation as an enabler of the resilient pathway in the action arena in Figure 5, two pertinent questions arise: why should smallholder farmers adopt irrigation and what determines the adoption decision? As indicated earlier, not only does irrigation enable all year round production, it increases productivity, household incomes, adaptive capacity and reduces climate-induced production risks (Koundouri, Nauges, and Tzouvelekas 2006). It should, therefore, facilitate intensification and the CSA objectives.

Farmer decisions whether or not to adopt irrigation can be modeled using agricultural household models of Singh, Squire, and Strauss (1986). As rational economic agents, smallholders consistently choose livelihood strategies to maximize their welfare, given a myriad of constraints (de Janvry, Fafchamps, and Sadoulet 1991). In this context, non-recursive household models, taking into account both production and consumption decisions apply.

To fix ideas on a non-recursive theory model of irrigation uptake requires some assumptions. First, we assume that smallholders are risk averse and as before, resilience, e.g., through irrigation use reduces production risk and increases household adaptive capacity. Second, we assume a well behaved, twice differentiable production function which is a function of a vector of inputs such as labour, seed, and inorganic fertilizer, and irrigation water. Following Koundouri, Nauges, and Tzouvelekas (2006), we assume a water use efficiency factor, which is a function of the irrigation technology and that output and input prices are exogenous so that households are price takers. Farmers face a climate-induced production risk so that the outcome distributions can be considered random and exogenous to the farmer. The production function will then be a function of irrigation and other inputs and the water use efficiency factor.

A rational risk-averse smallholder farmer will compare the relative returns from adoption versus non-adoption of irrigation based on the expected utility in either state. Adoption occurs if this difference is positive. This basic framework can be extended in several directions. For example, Koundouri, Nauges, and Tzouvelekas (2006) shows that because a new irrigation technology is more water use efficient, risk-averse farmers who bear high-profit uncertainty are more likely to adopt to hedge against adverse climate conditions. The empirical estimation can be done via various discrete choice models; we used the Tobit model.

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[1] Needless to say that the representation in Figure 5 is neither axiomatic nor exhaustive, it can be extended in several directions.

4. DATA

The study used a mixed methods approach, combining qualitative and quantitative (household socio-economic and climate) approaches to collect data described in the separate subsections below.

4.1. Qualitative Data

Qualitative data on the institutional, market and governance arrangements for the different irrigation schemes and water use rights were collected through interviews with scheme users, managers and implementing stakeholders from five purposively selected smallholder irrigation schemes across Zambia.

To be included, an irrigation scheme needed to meet the following criteria. It should have been operational for at least one year prior to September 2017 and falling in one of the categories; community-based or small scale, government or quasi-government, private or market-oriented, and accessible. Five schemes (among several others that fit the criteria) were visited in September 2017. These include Fitungulula irrigation scheme located some 160 km from Mansa District centre in Luapula Province; Manyonyo and Magobbo irrigation schemes located 52 and 15 km, respectively, from Mazabuka District centre in Southern Province; Kapululira Irrigation Scheme situated 15 km from Chirundu District centre, also in Southern Province and Tutenzi Irrigation Scheme located about 15 km from Mbala District centre in Northern Province.

Manyonyo and Magobbo are examples of market-oriented irrigation schemes run by the private sector for and on behalf of the farmers. Tutenzi and Fitungulula exemplify community irrigation schemes initially based on temporal weirs but have since upgraded to permanent weirs. These are run by the community members themselves. Kapululira is one of the oldest irrigation schemes managed by a cooperative but individual farmers retain responsibility for their land parcels.

The aim of the qualitative interviews was to gather information on the operations of smallholder irrigation schemes with respect to beneficiary selection, access to water resources, production, and marketing arrangements, policy and institutional environment and the effects of climate change on the irrigation schemes. A total of 50 farmers participated in the focus group discussions and about 10 key informants from the Ministry of Agriculture and other stakeholders were interviewed across the five study sites.

4.2. Household Data

The household data used are from the Rural Agricultural Livelihoods Surveys (RALS) conducted by the Central Statistical Office (CSO) in partnership with the Ministry of Agriculture and Livestock (MAL) and the Indaba Agricultural Policy Research Institute (IAPRI). We used the two-wave panel data collected in 2012 and 2015, hereafter also referred to as RALS 2012 and RALS 2015, respectively. RALS 2012 interviewed a total of 8,839 households while RALS 2015 added new households and interviewed a total of 9,520 households. Both RALS 2012 and 2015 are statistically representative at the provincial and national levels and 7,254 panel households were successfully interviewed over the two-waves. Readers are referred to RALS 2012 and RALS 2015 survey reports for sampling details (CSO/MAL/IAPRI 2012, 2015). The RALS surveys collect the most comprehensive data on rural households' demographic characteristics, farmland use, crop production and input use, irrigation and other technology use, fruit/vegetable production and sales, livestock, prices, off-farm activities, other sources of income, household assets/implements among others, in Zambia.

4.3. Climate and River Flow Data

The climate and river flow data used in the biophysical assessments were obtained from various sources. Observed river flow and discharge data for the main river systems for the period 1940s–2016 were obtained from the Water Resources Management Authority (WARMA) in Lusaka, Zambia. These data were supplemented with data from the Global Runoff Data Centre. Temperature and rainfall data were obtained from the Climate Hazards Group Infrared Precipitation with Station database (CHIRPS), which is a quasi-global spatial database (50'S to 50'N) with a resolution of 0.05' (Funk et al. 2014). This gridded data was downloaded and processed using *R* to extract data based on the river basin boundaries. Where necessary, data from the Meteorological department of Zambia were also used. Other spatial data products such the World Bank Climate portal and the Climate Research Unit (CRU) at University of East Anglia were also used for climate data.

5. METHODS

This study has two main areas of focus. The first part, addressing questions one, two and three assesses the prevalence and spatial distribution of irrigation for field crops and fruits and vegetables among smallholder farmers in Zambia.[2] This part also assesses the socio-economic factors influencing access and use of irrigation and in particular, the role of access to credit and market access in farmers' decisions to use irrigation for field crops. To answer these questions, this study used the two-wave panel RALS data set (described in the data section) to generate descriptive statistics, presented as either tables, figures or maps in the results section. Panel data econometric methods, specifically—the random effects Probit and Tobit models were used to analyse the determinants of irrigation use while controlling for unobserved factors that could simultaneously influence access to credit and market access, and irrigation uptake and confound results.

In answering question three, we conducted qualitative interviews with irrigation scheme beneficiaries, managers and implementers in five purposively selected smallholder irrigation schemes in Southern, Northern and Luapula Provinces of Zambia. (Details on the selected schemes are given in the data section). The qualitative interviews assessed governance, marketing and institutional arrangements for the smallholder irrigation scheme types in Zambia.

The second part of the study addressing questions four and five is a standalone paper on the biophysical assessment of Zambia's water resources availability and distribution, and the impacts of climate change on water availability (Hamududu and Ngoma (2018)). In addressing these questions, the study employed the water balance model. This is a hydrological modeling approach where rainfall, evapotranspiration, landscape water yield and changes in surface water storage are used as inputs to produce river flows in the future based on the projected climate data. The water balance model was calibrated using current observed climate data (rainfall and temperature) and river flows and then later applied on the projected climate data to produce future river flows in a statistical downscaling process. Downscaling used the Global Circulation Models (GCM) outputs (i.e., projected future climate variables) resulting from different future climate scenarios under varying Representative Concentration Pathways (RCPs) described in the IPCC AR5. RCPs describe four possible climate futures depending on how much greenhouse gases (GHGs) are emitted in the years to come (Meinshausen et al. 2011).

The resulting runoff is then summarized on monthly basis and aggregated to annual values. The projected monthly and annual flows are then used in computing the available water resources in each river basin. These values are then aggregated to get the total water resources available for the country. The procedure used here is a water balance accounting process.

Variables used in the regression analysis were selected based on the theoretical underpinnings from the conceptual framework in section three, qualitative interviews and based on literature, e.g., (Koundouri, Nauges, and Tzouvelekas 2006; Burney and Naylor 2012; Simfukwe 2014). Summary statistics for each survey year are given in Table 5.

We control for human capital using separate dummies (= 1) if the head of the household is male and married, and using adult equivalents and education level of the household head. While, it is difficult to ascertain the influence of these variables on irrigation use, *a priori*, we would expect labour availability measured by adult equivalents to increase adoption intensity. Farm size measures natural capital, while loan amount and household income capture the financial and physical assets, all of

[2] Field crops refer to all crops other than fruits and vegetables that are grown by farmers during the farming season, e.g., maize, cotton, sorghum, sweat potato, millet, cassava, etc.

which are expected to increase irrigation use. Likewise, we expect the variables capturing social capital—years in the village and whether the head of the household or the spouse is related to the chief or headman—to increase irrigation use as do the measures of market access—the distance variables—as per Boserup hypotheses (Boserup 1965) and the von Thünen land rent theorem.

Because access to water is a crucial determinant of irrigation (Burney and Naylor 2012), we use a dummy (=1) if a field is located within a Dambo area or a wetland. If so, this variable implies that the water source is very close to the field and this should facilitate irrigation use.

6. RESULTS AND DISCUSSION

6.1. Prevalence of Irrigation among Smallholder Farmers in Zambia

This section distinguishes between irrigation use for field crops and for fruits and vegetables among smallholder farmers in Zambia. On average about 18 and 16% of the smallholders irrigated at least one of their fields during the 2010/2011 and 2013/2014 agricultural seasons (hereafter also called 2012 and 2015 survey years), respectively (Table 1). Of these households, a larger proportion about 17 and 15% irrigated fruits and vegetables in the 2012 and 2015 survey years, while only about 1% irrigated field crops across the two seasons (Table 1, Figure 9).

Assuming all land under an irrigated field to be irrigated land, Table 2 shows that about 2 and 3% of cultivated land was under irrigation in the 2010/2011 and 2013/2014 agricultural seasons, respectively (Table 2). Irrigated land under field crops represented less than 1% of cultivated over the study period. About 74 and 78% of irrigated fields were located in Dambos and/or wetlands in the two seasons (Table 2).

Table 1. Number and Proportion of Households That Irrigated at Least One Field in the 2012 and 2015 Survey Years

	RALS 2012		RALS 2015	
	No. of Households	% of households	No. of households	% of households
Households with at least one field in a Dambos	344,669	24.8	403,920	27.2
Households who irrigated at least one field	244,380	17.6	240,018	16.2
Households who irrigated at least one field for field crops	10,670	0.8	18,755	1.3
Households who irrigated at least one field for fruits and/or vegetables	233,742	16.8	225,552	15.2
Total number of smallholder households	1,391,876		1,483,153	

Source: CSO/MAL/IAPRI, RALS 2012, 2015.

Table 2. Size and Proportion of Land under Irrigation in the 2012 and 2015 Survey Years

	2012			2015		
	Total Hectares (ha)	% of cultivated land	% of irrigated land in Dambos	Total Hectares (ha)	% of cultivated land	% of irrigated land in Dambos
Land under irrigation (ha)*	75,741	2.2	73.7	84,195	2.9	77.5
Land under irrigation for field crops	5,971	0.2	65.6	17,284	0.6	67.2
Land under irrigation for fruits and vegetables	69,770	2.0	74.1	66,911	2.3	78.5
Total cultivated area	3,409,625			2,888,321		

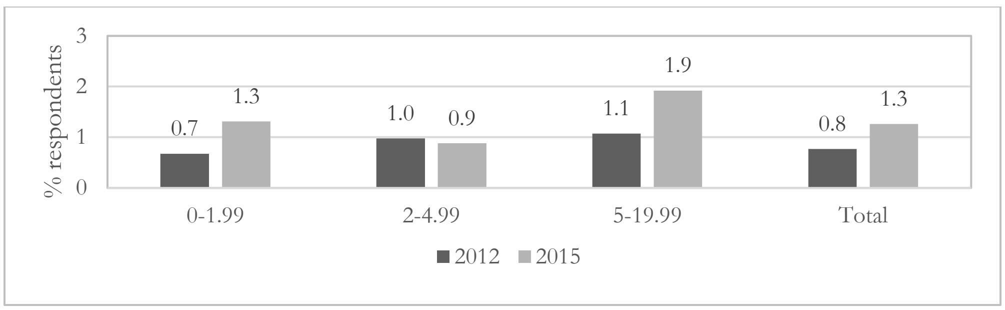
Source: CSO/MAL/IAPRI 2012, 2015.

Notes: * This table considers all land under an irrigated field as irrigated land.

Each household on average irrigated 0.06 ha and 0.22 ha during the 2010/2011 and 2013/2014 agricultural seasons, respectively or 0.14 ha across the two seasons. These findings of low irrigation intensity in Zambia are similar to those found in Binswanger-Mkhize and Savastano (2017) for Malawi, Tanzania, Niger, Nigeria, Ethiopia, and Uganda. In line with Headey and Jayne (2014), these findings suggest that currently, irrigation has a limited role in intensifying African agriculture. This should bolster and not reduce investments in irrigation development.

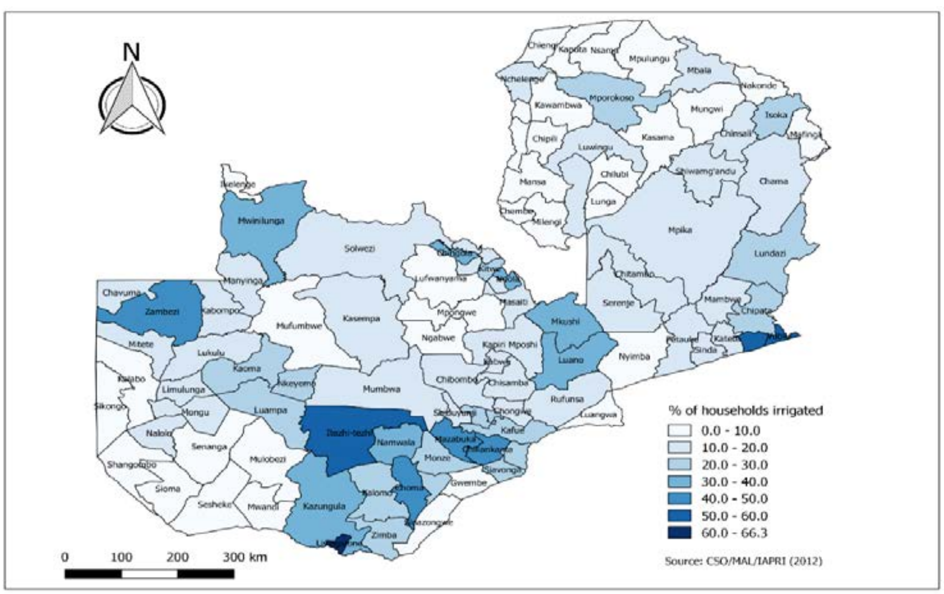
The use of irrigation (mainly for fruits and vegetables) is much more widespread across the country (Figures 7 and 8), although the loci appears to be concentrated around the southern, western and eastern parts of the country where water stress is significant. As expected, irrigation use is much more prevalent in the most agriculturally productive areas in the country. A similar pattern holds across the different farm size categories, but irrigation use was much more prevalent among those with 5–20 ha parcels of land (Figures 6 and 9).

Figure 6. Proportion of Households That Irrigated Field Crops in the 2012 and 2015 Survey Years, Segregated by Land Size



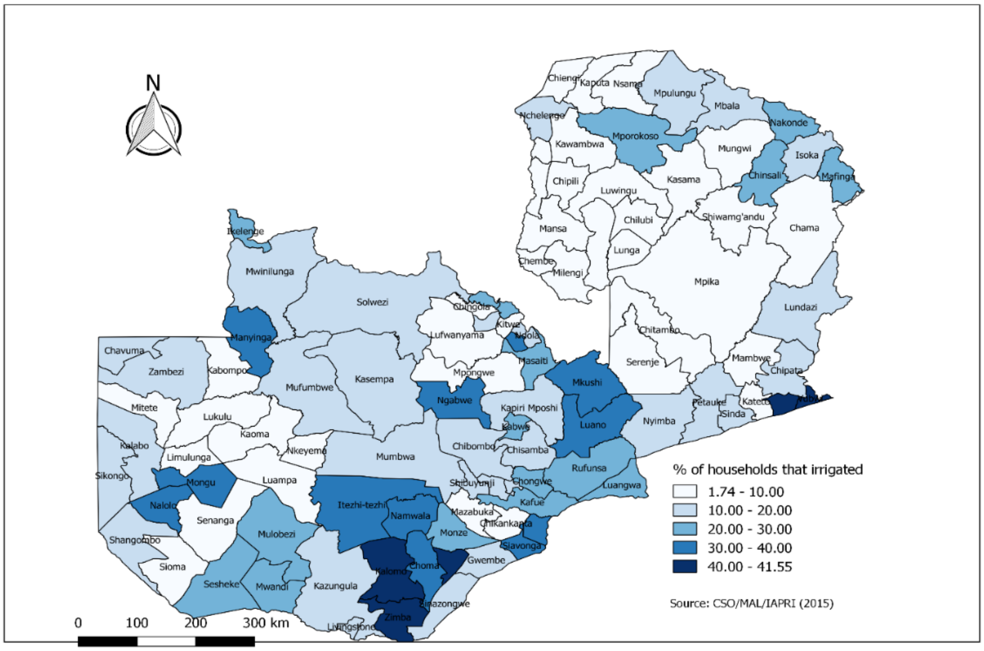
Source: CSO/MAL/IAPRI 2012, 2015.

Figure 7. Distribution of the Proportion of Households That Irrigated Field Crops in the 2012 and 2015 Survey Years



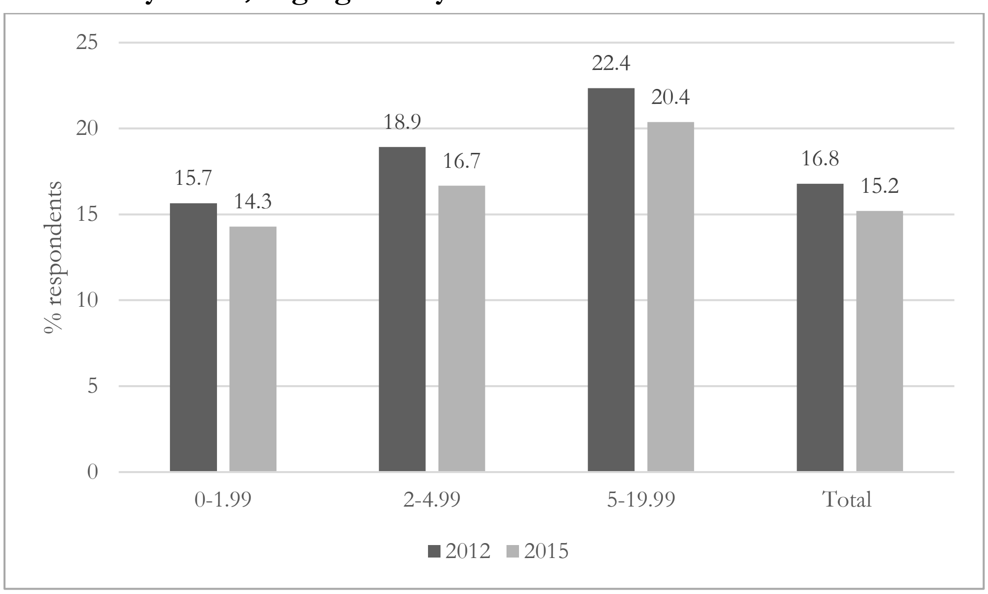
Source: CSO/MAL/IAPRI 2012, 2015.

Figure 8. Distribution of the Proportion of Households That Irrigated Field Crops in the 2012 and 2015 Survey Years



Source: CSO/MAL/IAPRI 2012, 2015.

Figure 9. Proportion of Households That Irrigated Fruits and Vegetables in the 2012 and 2015 Survey Years, Segregated by Land Size



Source: CSO/MAL/IAPRI 2012, 2015.

The irrigation technologies used for fruits and vegetables (and by extension field crops) is rudimentary at best, with more than 85% of all smallholder farmers in Zambia having used manual bucket irrigation (Table 3).[3] This is a system of irrigation where households manually draw water from wells or streams or rivers using buckets to irrigate crops.

This finding holds across different landholding categories (Table 4) and is in line with Colenbrander, Kabwe, and van Koppen (2012) who found that bucket irrigation was most prevalent in Mpika, Chibombo, Monze, and Sinazongwe Districts.

Other important irrigation technologies include surface/furrow irrigation and hand or treadle pumps used by at least 3% of the farmers in the 2013/2014 season. The trend, however, appears to be somewhat changing with motorized water pumps becoming more common among farmers in the 5–20 ha farm size categories. About 7% of farmers in this category used motorized pumps in the 2013/2014 agricultural season. Access to energy will increasingly become important to facilitate the use of motorized irrigation technologies.

Table 3. Main Type of Irrigation Used by Smallholder Farmers for Fruits and Vegetables in the 2012 and 2015 Survey Years

	2012	2015
Motorized pump	4.06	4.61
Piped public water	0.70	1.59
Well/river/stream and bucket	86.54	87.65
Hand pump or treadle pump	3.73	2.59
Irrigation canal (furrow)	4.91	3.56
Others irrigation types	0.07	0.00

Source: CSO/MAL/IAPRI 2012, 2015.

Table 4. Main Type of Irrigation Used by Smallholder Farmers for Fruits and Vegetables in the 2012 and 2015 Survey Years, Segregated by Landholding Size

	2012			2015		
Land size category (ha) →	0-1.99	2-4.99	5-19.99	0-1.99	2-4.99	5-19.99
Motorized pump	3.50	5.69	5.81	4.38	4.13	7.26
Piped public water	0.76	0.53	0.44	1.95	0.51	1.85
Well/river/stream and bucket	87.07	83.55	88.27	87.34	89.67	84.89
Hand pump or treadle pump	3.65	4.09	3.62	2.51	2.63	3.02
Irrigation canal (furrow)	4.93	6.14	1.85	3.83	3.05	2.99
Others irrigation types	0.09	0.00	0.00	0.00	0.00	0.00

Source: CSO/MAL/IAPRI 2012, 2015.

[3] The question on the type of technology used was only asked for fruits and vegetables in the survey data used here. We do not expect it to be very different for field crops.

6.2. Are Households That Used Irrigation Different from The Rest?

Before delving into the drivers of irrigation use, Table 5 defines and presents summary statistics for the main variables used in the analysis.

Table 5. Summary Statistics for the Main Variables and Difference in Means between Households That Used Irrigation and Those That Did Not

	(1)		(2)		(3)
	Did not irrigate		Irrigated		(1)-(2)
Variable	N	Mean /[SE]	N	Mean /[SE]	T-test Difference
Accessed ag. loan (yes =1)	11874	0.167	2632	0.193	-0.026***
		[0.003]		[0.008]	
Loan amount (ZMW)	11874	187.880	2632	181.938	5.942
		[28.377]		[22.159]	
Married, household head (yes=1)	11876	0.767	2632	0.780	-0.013
		[0.004]		[0.008]	
Adult equivalents	11876	4.874	2632	5.044	-0.170***
		[0.021]		[0.046]	
Education level, hh head (years)	11873	6.114	2632	6.091	0.023
		[0.034]		[0.073]	
Male household head (yes =1)	11876	0.803	2632	0.796	0.007
		[0.004]		[0.008]	
Farm size (ha)	11876	0.440	2632	0.424	0.016
		[0.010]		[0.013]	
Distance to district centre (km)	11875	3.945	2632	3.923	0.022
		[0.030]		[0.063]	
Distance to feeder road (km)	11874	0.177	2632	0.180	-0.003
		[0.006]		[0.011]	
Distance to ag. Camp extension (km)	11874	1.693	2632	1.655	0.037
		[0.022]		[0.043]	
Years in current village	11876	1.779	2632	1.886	-0.108***
		[0.017]		[0.036]	
Related to chief/headman	11876	0.152	2632	0.161	-0.010
		[0.003]		[0.007]	
Log gross household income	11863	12.482	2632	12.798	-0.316***
		[0.033]		[0.070]	
Seasonal rainfall (mm)	11873	884.698	2632	898.493	-13.795***
		[1.841]		[3.944]	
Secure tenure (yes = 1)	11876	0.046	2632	0.073	-0.027***
		[0.002]		[0.005]	
Field in Dambo/Wetland (yes)	11740	0.148	2632	0.753	-0.605***
		[0.003]		[0.008]	

Source: CSO/MAL/IAPRI 2012 and 2015. Notes: ***, **, and * indicate significance at the 1, 5, and 10 percent critical level. The value displayed for t-tests are the differences in the means across the groups. SE refers to standard error.

These results are for the pooled sample for 2012 and 2015 survey years, disaggregated by whether the household irrigated some of their field crops, and fruits and vegetables or not. Results are illuminating. Households that used irrigation seemingly had access to more labour (proxied by adult equivalents), a larger proportion accessed loans, had secure land tenure and had fields in Dambos/wetlands. These irrigating households had lived longer in their current villages, suggestive of higher social capital and had higher household incomes on average, and rather surprisingly, were located in areas with high seasonal rainfall (Table 5).

6.3. Drivers of Irrigation Uptake among Smallholder Farmers in Zambia

Table 6 presents empirical results on factors that affect irrigation use among smallholder farmers in Zambia. These results are derived from Pooled Ordinary Least Squares (OLS) in column (1), random effects Probit model in column (2) and random effects Tobit model in column (3), all applied to a balanced panel dataset of ca. 14,508 from CSO/MAL/IAPRI (2012) and CSO/MAL/IAPRI (2015) surveys.[4]

Table 6. Average Partial Effects of Factors Influencing Irrigation Use among Smallholder Farmers in Zambia

	(1)	(2)	(3)	(4)	(5)	(6)
	Pooled OLS	Random effects Probit Model	Random effects Tobit Model	Pooled OLS	Random effects Probit Model	Random effects Tobit Model
Accessed ag. Loans (yes=1)	0.008*	0.027***	0.011***	0.001	-0.003	0.001
	(0.005)	(0.008)	(0.003)	(0.004)	(0.007)	(0.003)
Age household head	-0.000**	-0.000	-0.000**	-0.000*	-0.000	-0.000*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Adult equivalents	-0.000	0.005***	0.002***	-0.000	0.005***	0.002***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)
Education level, household head	-0.001	-0.001	-0.001**	-0.001	-0.000	-0.000
	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)	(0.000)
Male household head (yes =1)	0.000	-0.019**	-0.005	0.002	-0.019***	-0.005*
	(0.005)	(0.009)	(0.003)	(0.005)	(0.007)	(0.003)
Farm size (ha)	-0.001	-0.005	-0.002	0.000	0.001	0.000
	(0.001)	(0.004)	(0.001)	(0.001)	(0.003)	(0.001)
Years in current village	0.002	0.003	0.002**	0.001	0.003	0.002**
	(0.002)	(0.002)	(0.001)	(0.002)	(0.002)	(0.001)
Related to chief/Headman (yes =1)	0.002	0.007	0.004	-0.000	-0.002	0.001
	(0.005)	(0.009)	(0.003)	(0.005)	(0.007)	(0.003)
Field in Dambo/Wetland (yes =1)	-	-	-	0.120***	0.316***	0.113***
	-	-	-	(0.006)	(0.004)	(0.003)
Distance district center /10	-0.000	0.000	-0.000	0.000	0.002*	0.001
	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)	(0.000)
Distance feeder road/10	-0.001	0.002	-0.000	-0.002	0.000	-0.001
	(0.002)	(0.005)	(0.002)	(0.002)	(0.004)	(0.002)
Distance ag. Camp extension/10	-0.001**	-0.001	-0.001	-0.001	-0.001	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)
Log gross household income	0.002	0.008***	0.003**	0.001	0.007**	0.002**
	(0.002)	(0.003)	(0.001)	(0.001)	(0.003)	(0.001)
Secure tenure (yes =1)	0.020**	0.072***	0.027***	0.023***	0.073***	0.029***
	(0.008)	(0.014)	(0.005)	(0.007)	(0.011)	(0.004)

[4] Further details on the methods and in particular why these methods are available from authors, upon request.

	(1)	(2)	(3)	(4)	(5)	(6)
	Pooled OLS	Random effects Probit Model	Random effects Tobit Model	Pooled OLS	Random effects Probit Model	Random effects Tobit Model
Seasonal rainfall/1000	0.001	0.006***	0.002***	0.001	0.007***	0.002***
	(0.004)	(0.002)	(0.001)	(0.003)	(0.001)	(0.001)
Squared rainfall	yes	yes	yes	yes	yes	yes
Year fixed effects	yes	yes	yes	yes	yes	yes
Constant	0.002	-2.218***	-0.992***	0.022	-1.486***	-0.802***
R-squared	0.088	-	-	0.003		
Log likelihood	-	-4,941***	-4,469***	-	-6,106***	-6,819***
Observations	14,486	14,486	14,486	14,486	14,486	14,486
Number of panel households	-	7,254	7,254	-	7,254	7,254

Source: CSO/MAL/IAPRI 2012, 2015.
Notes: The outcome variable in OLS and Tobit models is land under irrigation (ha) and a dummy for whether a household used irrigation or not for Probit models.

We present average partial effects for the parsimonious models in columns 1–3 and for models including the water access variable (Dambo) in columns 4–6, in Table 6, while the coefficient estimates are in Table A2 in the appendix.

Tobit is the main model since the outcome variable, land under irrigation is censored with only 18% of the sample having used irrigation. OLS and Probit models are used as base and comparison models, respectively and hence are not discussed. The outcome variable in OLS and Tobit models is land under irrigation (ha) and a dummy for whether a household used irrigation or not for Probit models.

Results from the parsimonious Tobit model in column 3 suggest that access to loans, household labor availability (measured by adult equivalents), length of stay in the current village, household income, secure tenure and seasonal rainfall are associated with higher irrigation intensity. All else constant, these results suggest that access to loans and secure tenure significantly increase irrigation intensity by about 1.1 and 3%, respectively. The other variables raise irrigation intensity by less than 1%.

The main results on access to loans change when we include proximity to the water source as an additional control in the less parsimonious model in column 6. While all other results remain qualitatively similar to those in column 3, the water access variable is statistically significant in column 6. This suggests that, if access to water is not an issue, access to credit could be important for irrigation use. (We leave it to readers to determine whether to consider results in column 3 or 6, both sets of results are intuitive).[5]

These findings on field location are in line with our earlier descriptive results in Table 2, suggesting that most of the irrigated fields are located in Dambos/wetlands. Again, this is not surprising because more than 90% of all irrigated fields were used for vegetables and fruits. It is not uncommon for vegetable gardens to be located near water sources, due to among other things, better social capital. However, projected increases in water scarcity due to climate change, among other things will negatively affect irrigators.

[5] While access to loans may be endogenous, we reduce this by controlling for several factors that could affect both access to loans and irrigation use and by using panel data methods to control for unobservables.

The results on household income, access to credit and years lived in the current village are in line with *a priori* expectations. A household with higher income or with access to credit may afford the upfront investments to set up an irrigation system, however rudiment it may be and such households may be more resilient to various shocks. Households who have lived longer in the current village will most likely be allocated the best land and possibly nearer water sources. The result on land tenure is in line with literature suggesting that tenure security facilitates on-farm investments (Place 2009).

Old age and being a male household head are associated with reduced irrigation use. Again, results on age are not surprising: older household heads may not have the physique required to invest in irrigation. Because most of the gardens are operated by females in Zambia, the result on male household heads isn't too surprising.

The result on rainfall is counterintuitive but could be expected: most of the irrigated fields in our sample are located in Dambos/wetlands and as such, water stress (low seasonal rainfall) does not appear to be an immediate driver of irrigation use, unless in so far as it affects water availability. The positive effect of seasonal rainfall in our results could be picking up the influence of higher rainfall on water availability—an issue that would require further investigation. It is important to note here that these results would be very different had irrigation for field crops been more prominent in the sample.

6.4. Smallholder Irrigation Schemes in Zambia, What Works and Why?

This subsection draws from qualitative interviews held with irrigation managers, stakeholders and beneficiary farmers from five smallholder irrigation schemes including Fitungulula irrigation scheme in Mansa District in Luapula Province; Manyonyo and Magobbo irrigation schemes in Mazabuka District in Southern Province; Kapululira irrigation scheme in Chirundu District centre, also in Southern Province and Tutenzi irrigation scheme in Mbala District in Northern Province.

Manyonyo and Magobbo are examples of private sector managed irrigation schemes. Tutenzi and Fitungulula exemplify community irrigation schemes while Kapululira is managed by a cooperative but individual farmers retain responsibility over their plots. Further details on these schemes are given in the Annex.

The aim of the qualitative interviews was to gather information on the operations of smallholder irrigation schemes with respect to beneficiary selection, access to water resources, production, and marketing arrangements, policy and institutional environment and the effects of climate change on the irrigation schemes.

Although all smallholder irrigation scheme models have their own advantages and disadvantages, findings summarized in Table 7 and literature, e.g., (Akayombokwa, van Koppen, and Matete 2015) suggest that schemes under PPPs such as the Kaleya Smallholder Company (KASCOL) and purely private sector schemes (like Magobbo and Manyonyo) are more likely to succeed. PPP and private sector irrigation schemes are normally large schemes with the requisite water infrastructure. Scheme members are better organized and able to access financing for production and engage in contract farming with long-term pre-season forward supply contracts. A key distinction and possibly the main success factor for PPPs and private sector irrigation schemes is that farmers are better organized and able to access financing with guaranteed markets.

Most smallholder irrigation schemes in Zambia use gravity based surface irrigation methods, which are not very efficient with water use. In view of the increasing water scarcity, partly due to increased demand and climate change, smallholder irrigation schemes in Zambia will need to adopt more water-efficient irrigation methods such as overhead irrigation systems (e.g., center pivots, drip irrigation). The feasibility and cost implications of such changes require further study.

There are several governance issues in smallholder irrigation schemes in Zambia. In line with Simfukwe (2014), our qualitative interviews show that most scheme models where farmers are poorly organized face challenges in resolving conflicts. Some of the main issues concern how best to sequence and schedule irrigation times for specific fields. Often, households who get their fields irrigated last feel aggrieved that they have to wait for everybody else to irrigate their fields first. Scheduling of irrigation is necessitated by the fact that it is not possible for most schemes to irrigate all fields under the scheme at the same time and it should be easily sorted out by good management.

Table 7. Types of Smallholder Irrigation Schemes in Zambia, Advantages and Disadvantages

Scheme type	Management/Operations	Advantages	Disadvantages
Community Schemes	- managed by communities and/or cooperatives	- farmers retain sense of ownership of the schemes because they are involved in the day to day running of the schemes and tend their own parcels of land - short line of command ensures quick conflict resolutions - cheaper to set up using locally available materials and labour - can accommodate many farmers - low operation and maintenance costs	- farmers are usually poorly organized such that there is no collective production and marketing of produce - farmers lack access to finance/ credit - conflict resolution may be onerous because farmers personally know the scheme managers and feel a strong sense of ownership for the scheme - most of such schemes are very small, with members only having a few limas or acres - often it is difficult to engage such schemes in contract farming because farmers are not well organized - difficult to enforce effective water management such as water user rights because water use is not monitored in most instances and farmers are not aware of the legislative provisions - poor water management resulting in high water losses - poor cultural practices which impede effective farmer coordination - inadequate extension services
Government Schemes	Managed by government, community or through private public partnerships (PPPs)	- can be fairly quick to set up if finances are allocated and disbursed on time - they are larger in scale and can benefit several farmers - offer possibilities for contract farming because smallholder producers are better organized - if managed well, offers real business prospects - with better organization, farmers can access credit and engage in forward supply contracts - easy to enforce water user rights	- high initial setup costs - high maintenance costs especially for the water infrastructure - high monitoring costs - erratic disbursements may affect operations at set up and when fully functional - success dependent on good partnerships between government and private sector. Any breach of contract by either part jeopardizes implementation - inadequate extension services
Private Sector	Managed by private sector firms for or on behalf of farmers	- can be fairly quick to set up if finances are allocated and disbursed on time - they are larger in scale and can benefit several farmers	- high initial cost outlays - high maintenance costs especially for the water infrastructure

Scheme type	Management/Operations	Advantages	Disadvantages
		- offer possibilities for contract farming because member producers are better organized - offers business prospects with farmers serving as shareholders/ employers - easy to enforce water user rights - farmers can access credit to finance production through the private entity managing the scheme - farmers retain sense of ownership in some variants where they manage their own plots within the scheme - with assured an assured market, farmers have incentives to work hard and produce more	- high management and operation costs associated with the private sector firm managing the scheme - high monitoring costs - lost sense of ownership since farmers do not participate fully in the day to day running of the schemes. This is worsened in cases where farmers have to donate part of their land to the scheme permanently - farmers may be subjected to unfair business dealings in cases where they have one major buyer who retains monopoly power on produce pricing, land rates and water rights, for example.

Source: Authors.

Neither do most scheme members know about the 2011 Water Act and its provisions to decentralize water resources management nor are they aware of the need to pay for water user rights as provided for in the Act. On the later, a respondent said that *ameshi yakwa Lesa* (water comes from God), emphasizing that there is no need to pay for its use. Sensitization could play a crucial role to change such perceptions.

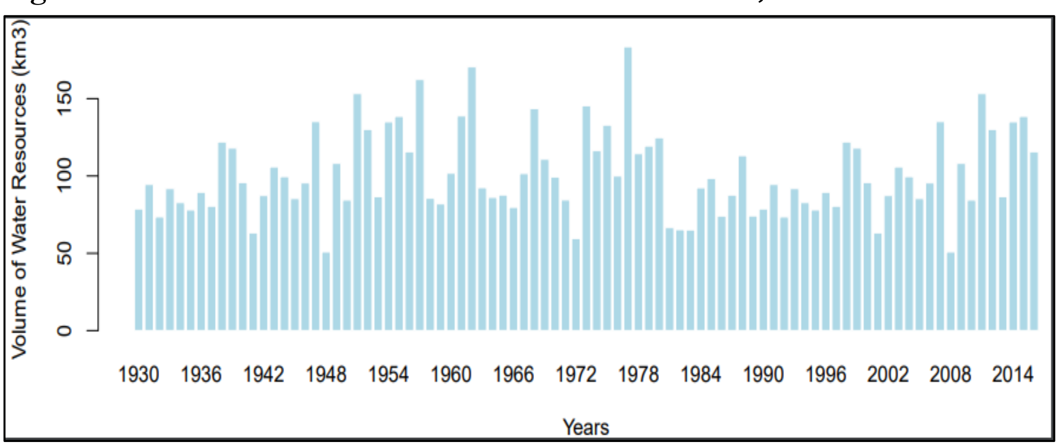
Irrigation schemes members noted several benefits. Some expressed happiness at the prospects of being employers under private sector models and having their family members employed by companies running the schemes. Membership to an irrigation scheme facilitate all year round crop production, which enables households to earn more money from crop sales and improves the resilience of smallholder farming systems to rainfall variability and related climate shocks. The earned income is used to pay for children's school fees and is invested in various assets such as bicycles, vehicles and better housing. Readers are referred to Simfukwe (2014) and Akayombokwa, van Koppen, and Matete (2015) for other benefits associated with irrigation schemes in Zambia.

6.5. Trends and Patterns in Water Resources Availability in Zambia[6]

Figure 10 shows the annual available water resources in Zambia from the 1930s to 2015. It is apparent from the figure that water resource availability is highly variable from year to year. Zambia has sufficient water resources during normal rainy seasons, but high rainfall variability coupled with inadequate storage infrastructure and management result in water scarcity during years of low rainfall. For example, there was reduced water availability in drought years of 1972, 1982, 1992, 1995, 2001, and 2008.

Water scarcity has implications on food security and on efforts to reduce poverty and buttresses the need to improve water resources management in Zambia as highlighted in the 2016 National Policy on Climate Change. This is further complicated by the fact that demand for water and the exploitable water resources of the country are unevenly distributed and climate change, as discussed in the next section, is likely to worsen water scarcity. In Zambia, there is a higher demand for water in the more agriculturally productive southern regions, compared to the northern regions.

Figure 10. Available Annual Water Resources in Zambia, 1930–2015



Source: Hamududu and Ngoma (2018).

[6] This section draws heavily from Hamududu and Ngoma (2018).

6.6. Impacts of Climate Change on Water Resources Availability in Zambia

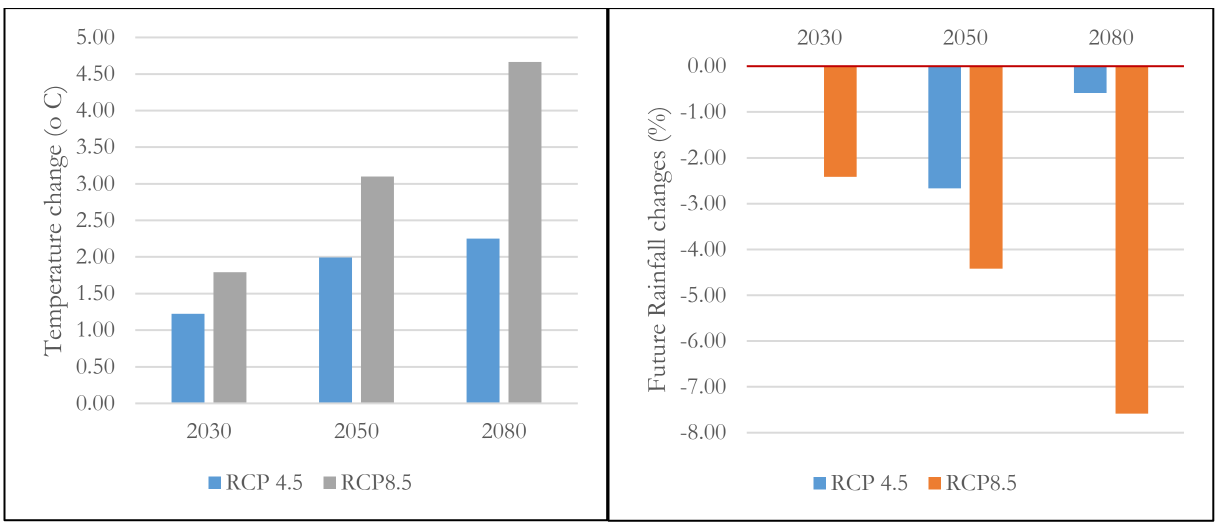
Drawing from Hamududu and Ngoma (2018), this subsection presents river basin level and indicative national-level estimates of the impacts of climate change on water availability in Zambia. The national level estimates are aggregated averages across all the main river basins in the country.

Compared to the historical period of 1960–2000s Zambia is projected to be hotter and drier by mid-century (ca. 2050). Under the more optimist RCP 4.5 scenarios, temperature is projected to increase by 1.9°C and 2.3°C by 2050 and 2100 in the country. Rainfall is projected to decrease by about 3% by mid-century (Figure 11). The southern, western and eastern parts will be much more affected compared to the northern region. Figure A1 shows the historical and future rainfall and temperature changes in Zambia.

In terms of the temporal distribution, the changes in the rainy season show that rainfall will reduce at the beginning of the season, thus, delaying the onset of rains. However, it also shows that there will be a slight increase at the end of the rainy season, with the last months (March and April) of the rainy season receiving higher rainfall amounts. These findings are in line with farmers' perceptions of climate change in Zambia (Mulenga, Wineman, and Sitko 2017).

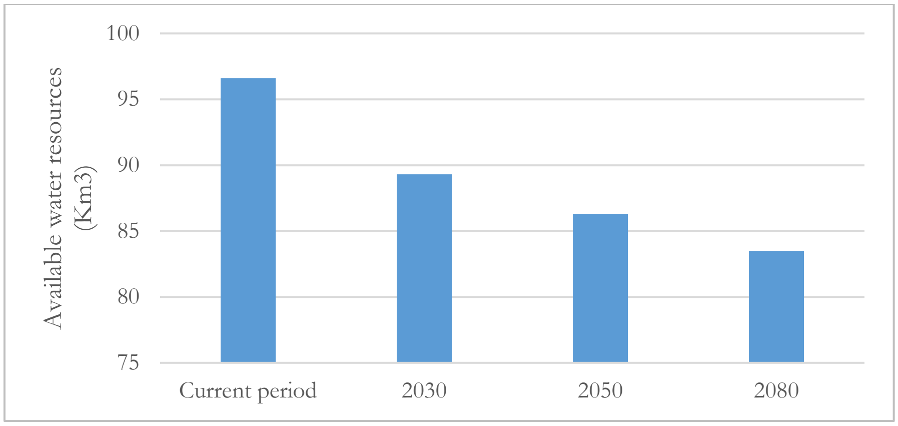
On aggregate, the changes in rainfall and temperature will reduce water availability by about 13% from current observed levels of about 97 km^3 to about 84 km^3 by the end of the century (Figure 12).

Figure 11. Projected Changes in Maximum Temperature and Rainfall in Zambia by 2030, 2050 and 2080



Source: Hamududu and Ngoma (2018).
Figure notes: These are aggregate average changes for the 30-year periods 2030 (2020-2050), 2050 (2050-2070) and 2080 (2080-2100). Representative Concentration Pathways (RCPs) describe four possible climate futures adopted by the IPCC AR5 and dependent on how much greenhouse gases are emitted in the years to come (Meinshausen et al. 2011).

Figure 12. Projected Water Resources Availability in Zambia (km^3)



Source: Hamududu and Ngoma (2018).
Figure notes: These are aggregate average changes for the 30-year periods 2030 (2020-2050), 2050 (2050-2070) and 2080 (2080-2100).

At basin level, the northern basins are likely to stay the same or experience slight increases in water resources (Table 8). However, as Table 8 shows, river basins in the eastern, southern and western parts such as Zambezi, Kafue and Luangwa basins are all projected to have less available water due to reduced rainfall and higher temperatures. Higher temperatures in these regions will result in increased evaporation and are likely to reduce river runoff and available water resources. The projected high temperatures will result in high losses of water stored in reservoirs, further reducing the effectiveness of storage in these parts of the country.

Table 8. Current and Future Water Resources Availability at River Basin Level in Zambia (Km^3)

	Zambezi River Victoria falls	Zambezi Lower Kariba	Kafue River Kasaka	Luangwa River Road bridge	Zambezi Lower Chirundu	Luapula River Chembe	Chambeshi River Pontoon	Lufubu River
current	32.3	6.6	22.3	15	3.5	16.5	5.5	0.4
2030	30.7	6	19.6	13.5	3	16.1	5.5	0.4
2050	29.4	5.8	19.2	12.7	3	15.8	5.4	0.4
2080	28.7	5.4	18.8	12.1	2.8	15.3	5.4	0.4

Source: Hamududu and Ngoma (2018).

7. CONCLUSIONS AND POLICY IMPLICATIONS

Irrigation is increasingly seen as part of the solution to both increase the resilience of rain-fed farming systems to rainfall variability and to raise productivity to meet growing food demands. However, there are still several gaps—the known unknowns—in our understanding of what works and is suitable for smallholder irrigation models in the context of climate change. What irrigation models are preferred and why? What are the governance issues in irrigation schemes if any? What are the likely impacts of climate change on water availability and what are the long-term implications for irrigation development in Zambia? In contributing towards filling these gaps, this study had two main purposes. First, to assess *what* smallholder irrigation models are present in Zambia and assess their performance. Second, it analysed the prevalence of irrigation use among smallholder farmers, *what* drives its use and the impacts and implications of current and projected climate change on water resource availability in the country.

Based on the main results from a combination of qualitative field interviews, econometric and hydrological modelling, we conclude that public-private partnership and privately managed irrigation schemes are better models for smallholder schemes provided that farmers retain a sense of ownership of the scheme, are well organized into collective production and marketing units with production financing and forward supply contract arrangements. Not only do these models make business sense, they also facilitate the enforcement of better water resource management. Community-based schemes have the potential but are usually too small and farmers often poorly organized to get into formalized collective production and marketing arrangements. Public-private partnerships such as the three-tier model holds potential, but it is still too soon to evaluate their performance. Although outgrowing arrangements under private schemes are generally considered a success, there are winners and losers, as they often entail significant changes to the ways land, livelihoods, and social relations are configured (Matenga 2017).

Informal irrigation for fruits and vegetables is more prevalent than for field crops among smallholder farmers in Zambia, with the majority of the irrigated fields located close to water sources (Dambos/wetlands). Manual bucket irrigation using surface water is the most prevalent irrigation technology among smallholder farmers. In addition to proximity to water sources, labour availability, access to loans, secure land tenure and income are strong drivers for irrigation use among smallholder farmers.

With climate projections suggesting that Zambia will become hotter and drier, and the southern, western and eastern regions much more affected compared to the northern region, water scarcity can only worsen. Reduced rainfall and a hotter climate coupled with increased demand for water resources will require smallholder irrigators to adapt in some ways. How exactly they do this will depend on their adaptive capacity, resilience and spatial location in the country.

Several known unknowns remain unanswered around smallholder irrigation development in Zambia. What is the optimal size for smallholder irrigation schemes? What irrigation schemes are more water use efficient, feasible and suitable for smallholders and the different regions of the country?

We draw the following implications on smallholder irrigation development in Zambia:

- Current and future smallholder irrigation schemes will need to adopt more water efficient technologies such as overhead irrigation systems (e.g., center pivots and drip irrigation) as opposed to the prevalent surface irrigation methods. Overhead irrigation systems can be powered by solar energy. It is vital to understand the cost implications of such a switch to more water efficient technologies.

- Governance and institutional arrangements of smallholder irrigation schemes will need strengthening to facilitate collective production and marketing.
- Reduced water availability will increase access and irrigation costs, which in turn may reduce its profitability among smallholder farmers as they tend to have limited capital and capacity to adapt to higher cost structures. In this regard, improved access to credit and markets will be vital.
- Competition for the reduced available water resources will disadvantage the smallholder farmers. Policies to protect them against the large-scale users are required. This may entail strengthening the management, regulation, and monitoring of water use by ensuring that water user rights and fees become mandatory and are enforced, and the process of acquiring water rights transparent. Some policy options could include setting up well-managed irrigation development funds for smallholder farmers.

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9. ANNEX

Qualitative Interview Reports from Smallholder Irrigation Schemes in Zambia

Government and various stakeholder were involved in the initial setup of the smallholder irrigation schemes covered in the study. These include Fitungulula irrigation scheme in Mansa District in Luapula Province; Manyonyo and Magobbo irrigation schemes in Mazabuka District in Southern Province; Kapululira irrigation scheme in Chirundu District, also in Southern Province and Tutenzi irrigation scheme in Mbala District in Northern Province. Manyonyo and Magobbo schemes are private sector managed and acquire their irrigation water through canals from the Kafue River. Tutenzi and Fitungulula are community managed and abstract water using permanent weirs, while Kapululira pumps the water from the Zambezi River and is run by a cooperative.

Manyonyo Smallholder Irrigation Scheme

The Manyonyo scheme was initially established by the Government of Zambia as a settlement area for the people displaced due to the construction of Lake Kariba in the 1950s and 1960s in Mazabuka District. The African Development Bank and the Government of Finland funded the establishment of the irrigation scheme from around 2005, but production only begun in 2011. The scheme mainly produces sugar cane, which is sold to Zambia Sugar—a subsidiary of the Illovo group of companies. The Manyonyo Irrigation Company runs the scheme on behalf of the farmers. Beneficiary farmers self-selected themselves and donated 4 hectares of their farmland to the irrigation scheme. The scheme comprises 145 farmers and is about 595 km in extent.

Magobbo Smallholder Irrigation Scheme

Formed in 1981 as a settlement scheme, the Magobbo scheme was incorporated into an irrigation scheme in 2010 and is located in Mazabuka District. Beneficiary farmers were selected based on their location and proximity to water sources at the time the scheme was established. The area cultivated is about 433 hectares with farm sizes of 4 and 6 hectares per household. Nanga farms is currently contracted to manage the scheme for and on behalf of the farmers. The Magobbo scheme produces sugar cane, which is also sold to Zambia Sugar.

Tutenzi Smallholder Irrigation Scheme

The Tutenzi Smallholder Irrigation Scheme was established in 2000 but crop production only started in 2005. The scheme is located in Mbala District and is managed by the community through project and maintenance committees. These committees manage the 6 km long furrow that supplies water to the scheme. The scheme initially used temporal weirs to divert water, but this has since been replaced by a permanent weir. About a third of the 6 km furrow is lined. Scheme members joined the scheme on a voluntary basis, and each member owns on average 2 to 10 lima. The scheme covers a total of 83.5 ha and produces various vegetables including onions, tomato, cabbage and rape among others. Without any formal marketing arrangements, the produce is marketed by individual farmers.

Fitungulula Smallholder Irrigation Scheme

The Fitungulula Smallholder Irrigation Scheme is located in Lupososhi village about 60 km from Chipili District centre in Luapula Province. Fitungulula has a total of 70 member farmers and covers an approximately 30 hectares of farmland, of which only about 6 hectares has been developed. The scheme was established with technical support from the Ministry of Agriculture and the Japanese International Cooperation Agency (JICA). Construction of the 4 km furrow started in February 2015 and was completed in April 2017.

Kapululira Smallholder Irrigation Scheme

The Kapululira Smallholder Irrigation Scheme is located about 15 kilometres from Chirundu Town in Southern Province. It comprises of 89 farmers and covers an approximately 89 hectares of farmland. The scheme was established after the departure of Italian volunteers who were managing the Kapululira Agriculture Training Centre in the 1970s. The settlers in Kapululira were in two categories: the first group are households that were given farm plots after completing scheduled trainings from the KATC, while the second category are those who were working for the centre and were given farm plots as compensation. Bananas are the only major crop grown in the scheme and each member markets their own produce.

Water Use, Benefits, Successes and Challenges Associated with Smallholder Irrigation Schemes

This subsection synthesizes findings from the qualitative interviews on water use rights, successes and challenges of smallholder irrigation schemes in Zambia. As will be apparent, there are some common themes, but there are also different nuances regarding institutional and marketing arrangements, and challenges across the irrigation scheme types covered in the study.

Water Use Rights

Except for Magobbo and Manyonyo, all the other smallholder irrigation schemes visited do not pay for water user rights. Moreover, only Magobbo, Manyonyo and Kapululira irrigation schemes have functional storage dams while the rest get their water directly from streams and rivers. Farmers from Manyonyo Irrigation Scheme were aware of the 2011 Water Act and its provisions and established the Manyonyo Water User association, which manages water use in the scheme. The rest of the schemes are not aware of the 2011 Water Act and its provisions. Farmers in these schemes were reluctant to agree that they would pay for water user rights, insisting that *amenshi ya kwa Lesa* (water is for God) and therefore they don't need to pay for using it. All the irrigation schemes visited use furrow irrigation system. Some of the main furrows are lined with concrete to reduce water losses.

Climate Change

All the farmers in the irrigation schemes visited were aware and had experienced some effects of climate change, through its negative effects on crop production. Farmers also said they have observed that floods and droughts are now more intense and frequent. Temperatures are warmer than average and that water levels in rivers and streams are reducing and there is an increased incidence of pests and diseases. They suggested to use a number of coping and mitigation measures including construction of water storage facilities such as dams, crop diversification and drilling of boreholes to tap into underground water.

Marketing Arrangements

Magobbo and Manyonyo Irrigation Schemes are contracted to produce sugar cane for Zambia Sugar. These schemes have forward supply contracts which allow them to produce specified quantities and quality of cane which is sold to Zambia Sugar at an agreed price. Because production and marketing under these schemes is organized and managed by private sector entities, they also make alternative arrangements to source requisite inputs on credit, for example from the Mazabuka Cane Grower Trust. These input loans are recovered from sugar cane sales. Farmers in the other community and cooperative managed irrigation schemes manage and finance their own production and marketing without any forward contracts.

Benefits/Successes

Several benefits were noted from the beneficiaries of the smallholder irrigation schemes. Members of the Magobbo and Manyonyo schemes expressed happiness at the prospects of being employers and having their family members employed by companies running the schemes. The other benefits of being a member of an irrigation scheme include being able to grow crops all year round, which enables households to earn more money from crop sales and improves the resilience of smallholder farming systems to rainfall variability and related climate shocks. The earned income is used to pay for children's school fees and some is invested in other things such as bicycles, vehicles, better housing and other property in town centres.

Challenges

The irrigation schemes visited face several challenges including lack finances and access to cheaper and affordable long- and short-term loans. They lack their own machinery and equipment and are made to borrow. The Kapululira, Tutenzi, Fitungulula use hoes to cultivate their farm plots. All the farmers in the irrigation schemes visited lacked specialized managerial skills and knowledge in agriculture. Climate change has brought extra costs such as costs incurred during dredging and deepening of canals. The farmers have experienced lower output per hectare. Animals like elephants and hippos constantly eat the bananas at the Kapululira irrigation scheme.

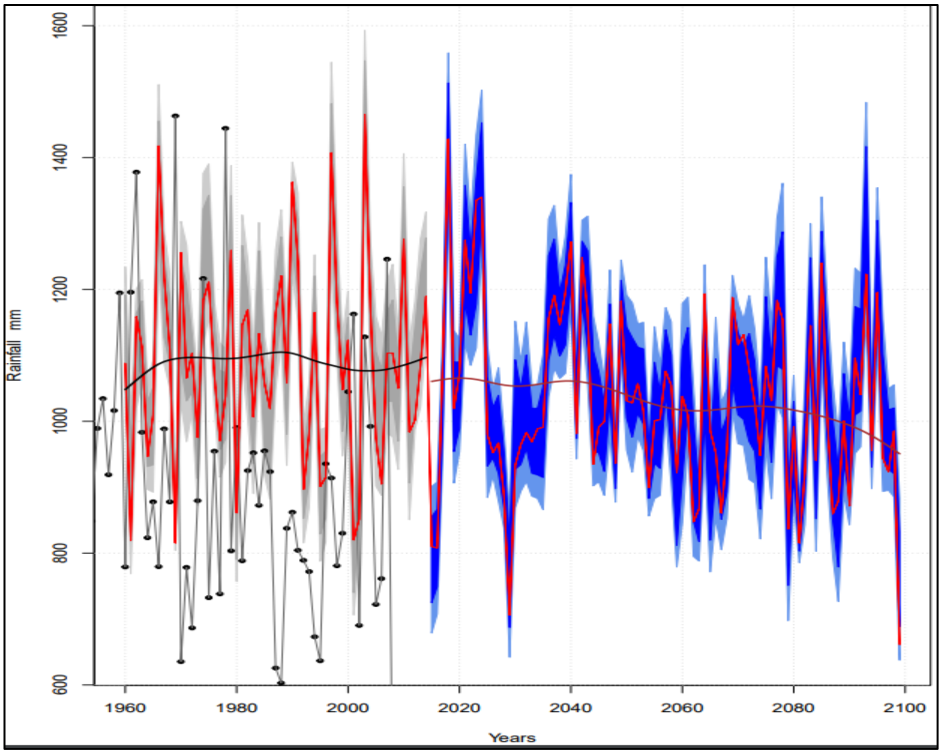
Table A1 presents the key characteristics of the irrigation schemes visited during the study .

Table A1. Characteristics of the Smallholder Irrigation Schemes Covered in the Study

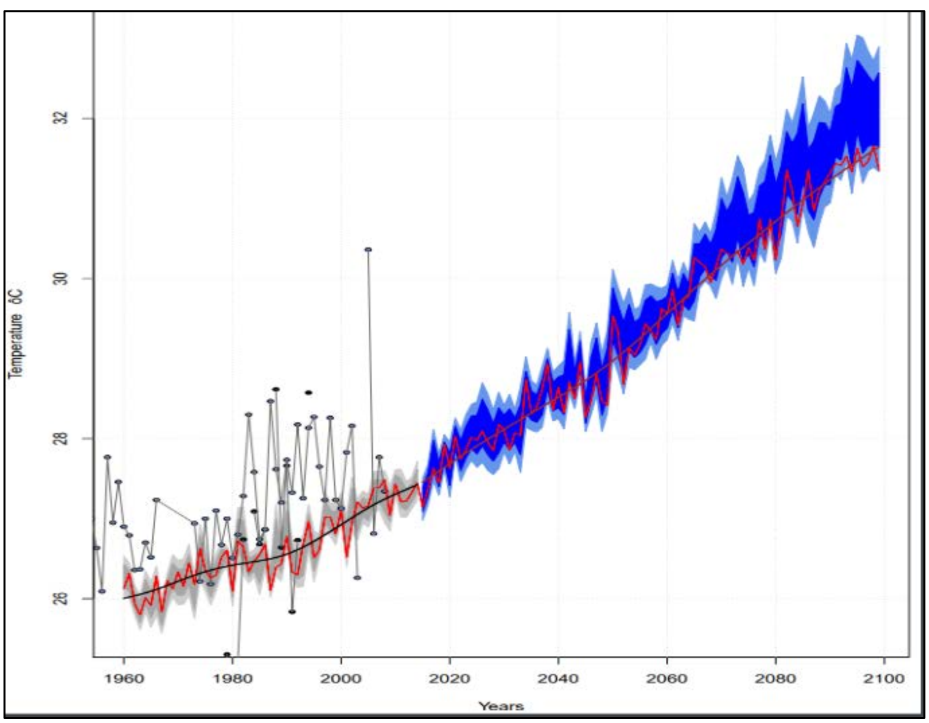
Irrigation Scheme	Area developed (ha)	District	Province	Crops grown	Number of farmers/ beneficiaries	Type of irrigation	Operational management	Marketing arrangements
Magobbo	433	Mazabuka	Southern	Sugar Cane	84	Furrow or canal irrigation. Water abstracted from the Kafue river is pumped into canals	Nanga Farms contracted to manage the scheme for and on behalf of the farmers	Contracted to grow cane for Zambia Sugar Plc.
Manyonyo	210 out of 595	Mazabuka	Southern	Sugar Cane	145	Furrow or canal irrigation. Water abstracted from the Kafue river is pumped into canals	Scheme managed by the Manyonyo Smallholder Irrigation Company	Contracted to grow cane for Zambia Sugar Plc.
Tutenzi	83.5 out of 524.2	Mbala	Northern	Onions, Rape, Cabbage, Tomatoes, Maize Egg plants	164	Furrow or canal irrigation. Water is diverted using a permanent weir and flows by gravity to the canal	Managed by the community	No formal marketing arrangements. Individual farmers market own produce
Fitungulula	6 out of 24	Chipili District	Luapula	Rape, Chinese cabbage, Tomatoes	50	Furrow or canal irrigation. Water is diverted using a permanent weir and flows by gravity to the canal	Managed by the community	No formal marketing arrangements. Individual farmers market own produce
Kapululira	89 out of 89	Chirundu	Southern	Bananas	89	Furrow or canal irrigation. Water abstracted from the Zambezi river is pumped into canals	Managed by Kapululira Corporative	No formal marketing arrangements. Individual farmers market own produce

Source: Authors.

Figure A1. Historical and Projected Rainfall and Maximum Temperature in Zambia, 1960-2100



Source: Hamududu and Ngoma (2018).



Source: Hamududu and Ngoma (2018)

Table A2. Coefficient Estimates of Factors Influencing Irrigation Use among Smallholder Farmers in Zambia

	(1)	(2)	(3)	(4)	(5)	(6)
	Pooled OLS	Random effects Probit Model	Random effects Tobit Model	Pooled OLS	Random effects Probit Model	Random effects Tobit Model
Accessed ag. Loans (yes=1)	0.008*	0.102***	0.060***	0.001	-0.018	0.005
	(0.005)	(0.032)	(0.017)	(0.004)	(0.038)	(0.016)
Age household head	-0.000**	-0.001	-0.001**	-0.000*	-0.001	-0.001*
	(0.000)	(0.001)	(0.000)	(0.000)	(0.001)	(0.000)
Adult equivalents	-0.000	0.018***	0.009***	-0.000	0.024***	0.009***
	(0.001)	(0.006)	(0.003)	(0.001)	(0.007)	(0.003)
Education level, household head	-0.001	-0.005	-0.004**	-0.001	-0.002	-0.003
	(0.001)	(0.004)	(0.002)	(0.001)	(0.004)	(0.002)
Male household head (yes =1)	0.000	-0.073**	-0.026	0.002	-0.101***	-0.028*
	(0.005)	(0.033)	(0.017)	(0.005)	(0.038)	(0.016)
Farm size (ha)	-0.010	-0.174	-0.086	0.000	0.004	0.001
	(0.008)	(0.144)	(0.077)	(0.001)	(0.015)	(0.007)
Years in current village	0.016	0.122	0.088**	0.001	0.014	0.009**
	(0.016)	(0.079)	(0.041)	(0.002)	(0.009)	(0.004)
Related to chief/Headman (yes =1)	0.002	0.026	0.020	-0.000	-0.011	0.003
	(0.005)	(0.034)	(0.018)	(0.005)	(0.039)	(0.016)
Field in Dambo/Wetland (yes =1)	-	-	-	0.120***	1.666***	0.668***
	-	-	-	(0.006)	(0.029)	(0.015)
Distance district center /10	-0.002	0.004	-0.003	0.000	0.008*	0.003
	(0.006)	(0.041)	(0.022)	(0.001)	(0.005)	(0.002)
Distance feeder road/10	-0.010	0.066	-0.004	-0.002	0.001	-0.004
	(0.019)	(0.199)	(0.106)	(0.002)	(0.023)	(0.010)
Distance ag. Camp extension/10	-0.011**	-0.050	-0.039	-0.001	-0.004	-0.004
	(0.005)	(0.057)	(0.030)	(0.001)	(0.007)	(0.003)
Log gross household income	0.002	0.031***	0.015**	0.001	0.035**	0.014**
	(0.002)	(0.012)	(0.006)	(0.001)	(0.014)	(0.006)
Secure tenure (yes =1)	0.020**	0.274***	0.154***	0.023***	0.383***	0.170***
	(0.008)	(0.052)	(0.027)	(0.007)	(0.059)	(0.024)
Seasonal rainfall/1000	0.001	0.001	0.009	0.001	-0.014	0.006
	(0.004)	(0.022)	(0.012)	(0.003)	(0.026)	(0.011)
Squared rainfall	yes	yes	yes	yes	yes	yes
Year fixed effects	yes	yes	yes	yes	yes	yes
Constant	0.002	-2.218***	-0.992***	0.022	-1.486***	-0.802***
R-squared	0.088	-	-	0.003		
Log likelihood	-	-4,941***	-4,469***	-	-6,106***	-6,819***
Observations	14,486	14,486	14,486	14,486	14,486	14,486
Number of hid	-	7,254	7,254	-	7,254	7,254