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**Irrigation-nutrition linkages under public and farmer-led irrigation arrangements in rural
Kenya**

DISSERTATION

For the award of the degree of Doctor of Agricultural Sciences (Dr. agr.)

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Submitted by

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Declaration

According to the §17 of the Doctoral Examination Regulations of the Faculty 09, from July 7 2004, last changed on May 29 2019

I declare: this dissertation submitted is a work of my own, written without any illegitimate help by any third party and only with materials indicated in the dissertation. I have indicated in the text where I have used texts from already published sources, either word for word or in substance, and where I have made statements based on oral information given to me. At any time during the investigations carried out by me and described in the dissertation, I followed the principles of good scientific practice as defined in the “Statutes of the Justus Liebig University Giessen for the Safeguarding of Good Scientific Practice”.

.....

Date

.....

Nixon Murathi Kiratu

Preface

Food and nutrition security has always been at the core of my interests for as long as I can remember, inspired by my experiences at a remote school in Kirinyaga County called Kang'aru Primary School. Often eating our carried lunches under a tree, it was common to see several kids with nothing to eat. Thus, abetted by childhood generosity, our lunches always turned out to be sharing-out buffets. The most puzzling thing was that the County (a district by then) was not only among the richest and agriculturally productive but hosted the largest irrigation scheme (to date) in East and Central Africa (area of study for this research). Something was wrong! This is another effort to rectify that wrong and ensure no other child unwillingly skips a meal.

This turned into a passion in my undergraduate degree at Egerton University (Kenya), Masters under the African Economic Research Institute, Egerton University and University of Pretoria (South Africa) and now at Justus-Liebig University Giessen (Germany). At every opportunity, finding ways to influence food and nutrition security policy; be it at the African Economic Research consortium, the Kenya Institute for Public Policy Research and Analysis, the Presidency and at the National Treasury and Economic Planning. This is still an effort towards that childhood inspired goal. Stimulated by a project proposal done by Dr. Aarnoudse, my research focus on food and nutrition security took a broader perspective to incorporate agricultural water use management and its related aspects.

This research took place during the Covid-19 crisis. Lockdowns, flight cancellations, difficult research approvals, and meticulous data collection and analyses during a crisis taught me about the tenacity of navigating uncharted waters and value each breath (literally). I am glad that despite these challenges, through the use of social-distance, sanitizers and masks, it was still possible to conduct key informant interviews, focus group discussions and face-to-face interviews. Using this data to learn and re-learn econometrics methods has been a joy and a testament to its quality and robustness.

One thing that this dissertation has taught me is to finish what you start even when its challenging, or seemingly doesn't make sense at the moment; finish it! But also, it has opened my understanding into inclusive growth in every aspect of life, but mostly family. As one of my lecturers in my masters told me (I can still hear him in his deep authoritative voice), "family and career is not mutually exclusive", I have seen my wife empowered in her career and studies (after all why leave her behind as I try to empower women in irrigating farm households?), children grow in number and every aspect of their lives and most of all learn to take care of them more potently and came to realize that in a world demanding my attention, I should give it to the ones who demand it least but treasure it the most. Lessons that have been impactful and will be for the rest of my life.

For the reader, this work will make you delve in commonly neglected research and policy area. It will unbundle irrigation, and the vast differences its socio-technical aspects have on its use, and how this affects both the preliminary effect on the products that the households produce, their farm proceeds, empowerment of the primary female decision maker and the means through which their diets are impacted. In this respect, this research is directed at facilitating a paradigm shift for the researcher, policy maker and implementer, civil society, development partners and stakeholders in irrigation and a mindset change for the smallholder farm households.

Extracts from Chapter Seven and Eight of this dissertation have been published as Kiratu et al. (2025) and (Kiratu et al., 2024b) respectively. In addition, several works related to this study have been presented in several conferences including the 32nd Triennial International Conference of Agricultural Economists (ICAE-2024) (Kiratu et al., 2024a, 2024b), Tropentag 2023 (Kiratu et al., 2023a, 2023b), Tropentag 2022 (Kiratu et al., 2022a, 2022b) and Tropentag 2020 (Kiratu et al., 2020).

Lastly, though this work was done in the advent of artificial intelligence, out of choice, it wasn't applied. This was mainly because I wanted this to be among works done with sole human intelligence. I however look forward to the next phase of research that substantially incorporates artificial intelligence in research.

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My heartfelt gratitude goes to my family, especially my beloved wife, Mrs. (and Dr. to be) Tabitha Kavuli Itotia, who actually was momentous in pushing for the application to do this degree and at Justus-Liebig University-Giessen instead as opposed to the Technical University of Munich; this later turned out for good for the family as regards the kids family life (time, housing and kitas) and your PhD work at the Paul-Ehrlich-Institut (PEI) and Philipps-University Marburg. Who also took care of our family in Kenya and as we studied in Germany. My deep appreciation to my lovely dear sons Owen Kiratu Murathi, Zane Muriuki Murathi and Aziel Kuria Murathi, you have been a joy and comfort in this journey. Thank you for the times you accompanied me to the office and were patient with my absence in Kenya and Germany and am looking forward to making it up for you from now on. I also appreciate my dad and mum Mr. Eutychus Kiratu Mwangi and Mrs. Peninnah Nyambura Kiratu, your unwavering support in every situation lights my world. I extend this gratitude to my siblings Mr. Nicholas Kuria Kiratu and Mr. Gideon Nguhiu Kiratu and their families who have been there for us through this journey. My thankfulness to the Giessen community that made life easier, merrier and enriching in Germany, especially Mr. Taita Mitei, and the Kenyan community under the name “Post-Covid” (now “Buddies 4 life”) crew and the members at the International Baptist Church – Giessen.

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I am grateful to the funders of this research: DAAD for the scholarship and fieldwork research funds, Foundation Fiat Panis for the research grant used for my fieldwork and Justus-Liebig University Giessen for the JLU's Gender Equality Concept dissertation completion grant.

Finally, and eminently, am grateful to You, the Ancient of Days, My Rock and Refuge; oh, how You have carried and covered me throughout this time. Truly, You remain true and faithful to the end. Looking forward to see what you make of this, now and eternally; and this I lay down at Your feet as Yours, for it is Yours indeed.

Dedication

To my brilliant, lovely beautiful wife **Kavuli** and my handsome, energetic and ingenious sons **Kiratu, Muriuki** and **Kuria** who showed me the value of time and the life therein and the Lord GOD who made it possible for the enemy to not rejoice over me; when I fell, I rose; when I sat in darkness, He became a light to me, so that *I may* know the love of Christ which passes knowledge and be filled with all the fullness of God.

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List of abbreviations

3SLS	Three-Stage Least Squares
ADC	Agricultural Development Corporation
ASAL	Arid and Semi-Arid Lands
ATE	Average Treatment Effect
ATT	Average Treatment Effect on the Treated
A-WEAI	Abbreviated Women's Empowerment in Agriculture Index
CAPI	Computer-Assisted Personal Interviews
DAAD	German Academic Exchange Service
FAO	Food and Agriculture Organization of the United Nations
FHI	Family Health International 360
IFAD	International Fund for Agricultural Development
IID	Independently and Identically Distributed
IPCC	Intergovernmental Panel on Climate Change
IWMI	International Water Management Institute
IWUAs	Irrigation Water Users' Association
KSH	Kenyan Shilling
LR	Likelihood Ratio
MDD-W	Minimum Dietary Diversity for Women
MNL	Multinomial Logit
NGO	Non-Governmental Organizations
NIA	National Irrigation Authority
NIB	National Irrigation Board
PSM	Propensity score matching
PVC	Polyvinyl Chloride
SSA	Sub-Saharan Africa
UN	United Nations
UNICEF	United Nations Children's Fund
USD	United States Dollar
VIF	Variance Inflation Factor
WEAI	Women's Empowerment in Agriculture Index
WFP	World Food Programme
WHO	World Health Organization
WUA	Water User Association

1. INTRODUCTION

1.1. Background information

It is almost a decade since the Millennium Development Goals (MDG) report showed tremendous improvement in nutrition trends. At the time, the report showed that the proportion of undernourished people would reduce by almost half from 23.3% in the 1990 – 1992 period to 12.9% in the 2014 – 2016 period (United Nations, 2015a). Unfortunately, following the consequences of Covid-19 pandemic and ongoing wars across the globe (with the war in Ukraine playing a big role) the global food and nutrition crisis is deteriorating, thus reversing the progress achieved over the last two decades. The figures show that about 28% (approximately 2.3 billion people) suffer from moderate to severe food insecurity which is higher as compared to pre-pandemic levels in 2019 (FAO et al., 2023, 2025). Under the effects of the Covid-19 pandemic and the Ukraine war alone, it is projected that about 119 million people will be undernourished by the year 2030; a significant year in eradicating hunger and malnutrition under the Sustainable Development Goals (SDGs) (FAO et al., 2023; United Nations, 2015b). Though progress has been made towards recovery, food insecurity rates are increasing in the regions of Africa, Caribbean and Latin America and statistics still show that food insecurity levels are still higher than the pre-Covid-19 period and if no interventions are done, the goal of eradicating food insecurity and hunger by 2030 is far out of reach (FAO et al., 2025).

Covid-19 and the Ukraine war negative effects on food security (Kornher & von Braun, 2023; F. Lin et al., 2023; Rahut et al., 2022) come at a point when climatic related crises are on the rise. Extreme weather and climate events have been on the rise in the last decade exposing a large proportion of the global population to food and nutrition insecurity. The Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report showed that about 3.6 billion people live under high climate change vulnerable areas and the human mortality from floods, droughts and storms have increased 15 times between 2010 and 2020 (IPCC, 2023). In addition, research shows that the warming global temperatures is reducing agricultural production (W. Liu et al., 2023; D. Wang et al., 2023; Zhu et al., 2022). This presents a further challenge of feeding the burgeoning population forecasted to reach over 9 billion by the year 2050 (De Wrachien et al., 2021).

Irrigation has increasingly gained interest as a pivotal solution in increasing the world's agricultural output. This is due to irrigation's potential to increase agricultural output (De Wrachien et al., 2021; Mueller et al., 2012; Sauer et al., 2010; X. Wang et al., 2021; Wichelns & Oster, 2006), galvanize agricultural production from weather and climatic risks (Agathokleous et al., 2023; BenYishay et al., 2023; Rosa, Chiarelli, Sangiorgio, et al., 2020; L. Wang et al., 2022) and bring underutilized water-stressed lands into cultivation (Altchenko & Villholth, 2015; Shahid & Al-Shankiti, 2013; L. Wang et al., 2022).

However, even as the world aims at increasing agricultural output, it is imperative that nutrition aspects take the center stage. Unfortunately, much of the world's increase in agricultural production has leaned towards caloric supply. Nevertheless, despite the increase in caloric supply

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in all the regions of the world for the last six decades as depicted in Figure 1. Figure 1 below, the global nutrition situation has continued to deteriorate. This neglect of nutrition aspects has led to a situation of manifold malnutrition where the world grapples with stunting, wasting and micronutrient deficiency, under a concurrent situation of increasing overweight and obesity (FAO et al., 2023; Haddad et al., 2016; Sukhdev et al., 2016).

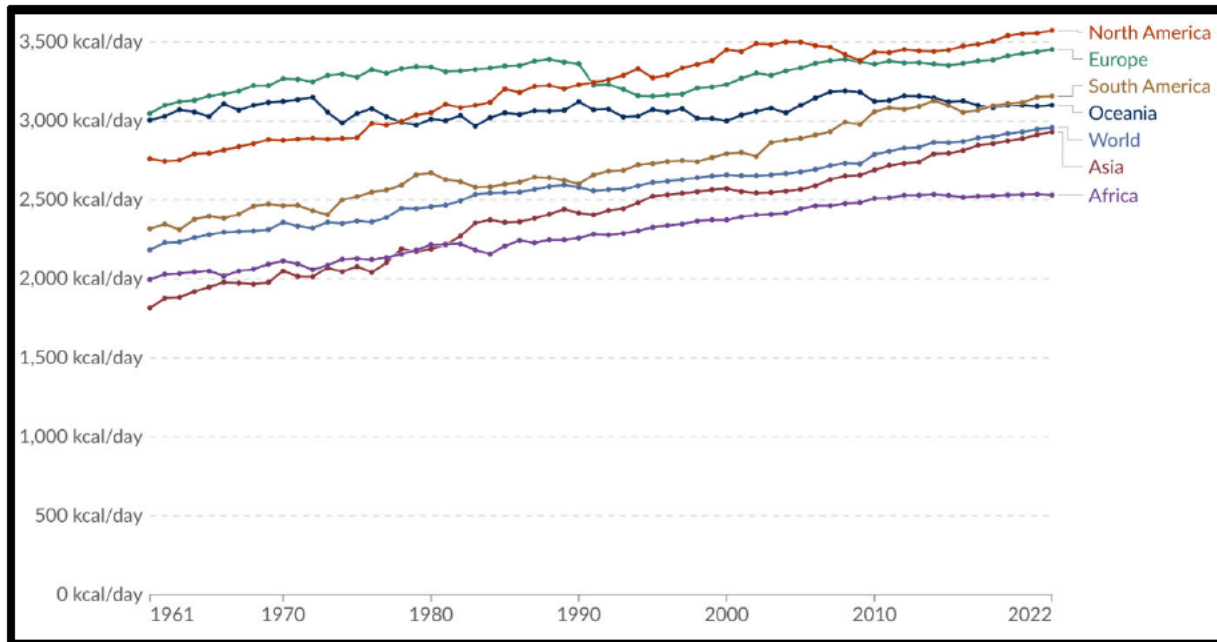


Figure 1: Per capita kilocalorie supply from all foods per day, 1961 to 2022

Data source: UN Food and Agriculture Organization (FAO).

Visualization: Our World in Data. <https://ourworldindata.org/food-supply#caloric-energy-supply>. Accessed on 2nd October, 2025 at 14:03 hours.

The challenge of food and nutrition insecurity are unfortunately more prevalent in rural populations whose main livelihood is in agriculture. This is especially the case for smallholder farmers who own less than two hectares of land. It is estimated that that these farmers number about 600 million and even though they make up about 84.2% of the share of farm in the world, they only control 10.7% of the share of agricultural area (Lowder et al., 2021). However, despite this low share of agricultural area, they produce about 40% of the global food supply and approximately 31% of the total crop production (Ricciardi et al., 2018). Unfortunately, rural populations (among whom smallholder farmers comprise of) suffer the highest rates of undernutrition with current statistics showing that over a third suffer from moderate and severe food insecurity with peri-urban and urban areas having lower rates (FAO et al., 2023, 2025). Increasing the food and nutrition security of this specific population is key to the world achieving its Sustainable Development Goals by the year 2030.

Irrigation has the potential of not only improving the livelihoods of smallholder farmers, but also has the potential to alleviate rural malnutrition and supply the surplus to a world in need of food. However, with the interlinkages between the smallholder farmers applying irrigation and

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achieving nutritional outcomes being non-linear, under the above stated circumstances, this study set to look at the pathways through which irrigating smallholder farm households can achieve food and nutrition security outcomes. In particular, the study goes further into investigating how the different institutional set-ups of irrigation affect the pathways through which irrigation affects smallholder farm households' nutrition.

1.2. Statement of the problem

Sub-Saharan Africa remains the region with the highest prevalence of undernourishment in the world in absolute terms. Projections show that about 60% of persons facing hunger in the world by the year 2030 will be located in the African continent (FAO et al., 2025). In 2022, prevalence of moderate or severe food insecurity affected 67.2% of its population (FAO et al., 2023). While in 2024 there has been a slight decline in these rates with the prevalence of moderate or severe food insecurity dropping to about 58.9%, this is still more than two-fold the world's average which stands at 28% and the absolute number of people facing hunger has increased to about 307 million people and those facing chronic undernourishment has risen by approximately 113 million since the launch of the SDGs in 2015 (FAO et al., 2025). In addition, 5.9% of the children under five years suffered from wasting, 32.3% from stunting in 2020, and 40.7% of the women of reproductive age had anemia in 2019 (FAO, 2023).

Kenya, though one of the economic powerhouses in the sub-Saharan region, faces a myriad of malnutrition challenges. Latest data shows that over a quarter of her population is undernourished. However, this number varies greatly in the country with some arid and semi-arid areas experiencing a prevalence of moderate or severe food insecurity level of up to 70% (FAO et al., 2023). The prevalence of wasting and stunting in children under five years in 2022 was approximately 4.9% and 18.4% respectively and 28.7% of the women of reproductive age had anemia in 2019 (FAO, 2023, 2023; World Bank, 2023a). On the other hand, overnutrition has been on the increase in the last decade. In 2022, the prevalence of overweight in children under five years was at 3.8% and the 2016 data showed that the prevalence of obesity in the adult population was at 28.7% (FAO et al., 2023). This makes nutrition a key policy priority for the government of Kenya.

However, Kenya faces an immense agricultural production limitation in that only about 17% of its land area is suitable for rain-fed agriculture (Hornum & Bolwig, 2020; Njoka et al., 2016) with much of it already being utilized, and most of the land categorized as either semi-arid or arid as shown in Figure 2 below. In addition, climate change related effects (Gebre et al., 2023; Marigi, 2017) have made drought cycles more common, of which in 2021-2023 period culminated in one of the most severe droughts in the last 40 years due to five consecutive failed rainy seasons (Devi, 2023; Leal Filho et al., 2023; Salm-Reifferscheidt, 2023).

Irrigation thus is an essential technology for the country's food production and nutrition security. In this line, the country's development blueprint, Kenya Vision 2030, designates the expansion of irrigation as a pivotal component in augmenting agricultural production and fortifying it against

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climatic shocks. Luckily, the country has a huge irrigation potential with only about 19% of its irrigation potential developed (National Irrigation Authority, 2019).

The map was removed from the online version for reasons of copyright.

Figure 2: Arid and semi-arid areas in Kenya

Source: Shibia (2024)

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Therefore, with production being the main source of food, the focus on calorie-rich grains and export crops predisposes the rural population to nutrition security especially the vulnerable members of the households; women and children. Recent data shows that in Africa, rural populations consume less meals away from home as compared to their urban and peri-urban counterparts which underpins the importance of ensuring that the rural households have access to nutritious foods. Therefore, as the country endeavors to expand its irrigated agriculture, there is a pressing need to focus on how it can lead to improved nutrition outcomes (Muthayya et al., 2013; Ruel et al., 2018).

Unfortunately, while irrigation has for long been held as a critical factor to agricultural production, the linkage between irrigation and nutrition is still vaguely understood (Ringler et al., 2018). One of the reason is attributed to a global focus of agricultural intensification on grain production that focuses on supplying additional grains to the market thus persistently overlooking nutrition aspects (Fan & Pandya-Lorch, 2012, p. 2; Hawkes & Ruel, 2012, pp. 75–76). This has led to a delink between agriculture and nutrition (Gillespie & van den Bold, 2017). This is the case in Kenya where a majority of irrigation developments are skewed towards the production of calorie-rich grains like rice and high-value horticultural crops, predominantly for export with only a small fraction allocated to vegetable production for local markets (Hornum & Bolwig, 2020; B. M. Mati, 2008). Consequently, irrigation has minimal to no impact on the country's nutrition security especially the rural population who depend on agriculture as a source of livelihood and also food source.

The debate about what kind of irrigation to implement in sub-Saharan Africa has been a matter of debate in the global and African policy arena (Lankford, 2009; Woodhouse et al., 2017). This also has been as a result of a dismal performance of irrigation investments in the 1970s and 1980s (Woodhouse et al., 2017), thus emphasizing the need for consideration of the different approaches to irrigation.

Research shows that water management is interlinked between the water infrastructure and the water users (people) which forms the sociotechnical conditions (Kloezen & Mollinga, 1992; Mollinga, 1998; Narain & Singh, 2017; Uphoff, 1986, pp. 1–2). However, in most studies, irrigation has been considered as a single input factor disregarding that irrigation is socially constructed through social relations and interactions (Mollinga, 2003; Van der Kooij et al., 2015). In particular, among smallholder farmers, research shows that the establishment, functioning and maintenance of irrigation infrastructure cannot be separated from social relations (Coward Jr, 1990).

However, the different types of irrigations that arise due to these sociotechnical differences have been greatly overlooked in literature despite its evidence in affecting water management and related policies (Naz & Subramanian, 2010). The different sociotechnical settings of access and use of irrigation water is referred to as irrigation arrangements in this study. Given that a household's social relations are affected by the household socioeconomic factors, these socioeconomic factors were used to find out their contributions to these irrigation arrangements. Therefore, this study takes a viewpoint that the different socio-technical setup in which irrigation

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takes place affects both the irrigation-nutrition pathways as well as the nutrition outcomes. In this study, pathways refer to the means and course through which irrigation affects nutrition outcomes.

This is exacerbated by the scarcity of empirical evidence on the link between agriculture and nutrition and when it is available it remains weak (Ruel et al., 2018; Webb & Kennedy, 2014). This has been attributed partly to lack of strong and robust study designs and survey methods that lead to results that are weak and lack the ability to be generalized with nutrition effects remaining hidden (Domènech, 2015; Jaenicke & Virchow, 2013; Webb & Kennedy, 2014).

Similarly, the pathways through which irrigation impacts on nutrition outcomes are understudied, with only few rigorous studies available (Domènech, 2015; Hanjra & Williams, 2020). This underscores the need for a comprehensive investigation on the linkages between irrigation and nutrition in a manner that takes into account various socio-technical irrigation arrangements and their differential effects on nutrition outcomes.

The socio-technical arrangements in much of sub-Saharan Africa is quite unique than other regions. Irrigation schemes are mostly public (often with development partners' support) funded comprising of costly irrigation infrastructure. In addition to this unilateral challenges, obstacles such as financial limitations to undertake these costly irrigation investment (Kafle et al., 2020; Wazed et al., 2018; Xie et al., 2021) and the absence or unclear policy and institutional support frameworks (Chokkakula & Giordano, 2013; Closas & Rap, 2017; Hjalmarsdottir, 2012) hinder the irrigation development in SSA. This single-mindedness on irrigation schemes in Africa has led to the disregard of irrigation development that is farmer instigated, owned and driven. However, this type of irrigation arrangement has been expanding despite little policy recognition (Mati, 2023). This type of irrigation arrangement has been termed as farmer-led irrigation development (FLID). The World Bank describes farmer-led irrigation as “when farmers drive the establishment, improvement, and/or expansion of irrigated agriculture and influence the location, purpose, and design of irrigation development through small-scale, on-farm, locally relevant, and market-oriented solutions” (World Bank, 2021). In this study, irrigation is separated in these two distinct socio-technical conditions comprising of public irrigation scheme arrangements and farmer-led irrigation arrangements.

In the context of this research, the socio-technical arrangements that the farmers choose to be part of are the farmer-led irrigation arrangement or the public irrigation scheme arrangement. The land use rights in the study area (not ownership rights) are transferable not only annually but also across seasons (Kabutha & Mutero, 2002; Washington-Ottombre & Evans, 2019). Therefore, the farmer who wants to irrigate has the option to source land that is in either of the two socio-technical arrangements. This access to land use in the study area is critical to the study and more so to the policy directions derived from the study due to the choice that the farmers are able to make on the irrigation arrangement to adopt as regards the two different socio-technical institutional arrangements.

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Therefore, this dissertation contributes to the bridging of this gap in knowledge by systematically investigating the pathways through which different irrigation arrangements influence the nutrition outcomes of smallholder farm households in rural Kenya. To do this, it was hypothesized that the different household socioeconomic factors affect the choice of irrigation arrangements. Sequentially, the households achieve their nutrition outcomes through different impact pathways and the socioeconomic factors affect these impact pathways differently. Lastly, the different irrigation arrangements lead to a difference in the smallholder farm household's nutrition outcomes. To achieve this, three irrigation-nutrition pathways of production diversity, farm income, and women's empowerment are examined as potential intermediate outcomes of the different irrigation arrangements. After ascertaining the effect of irrigation arrangements on these outcomes, further analyses are carried out to investigate the effects of these outcomes under different irrigation arrangements on dietary diversity, which is used as a proxy for nutrition. In so doing, this study provides evidence-based insights that can inform policy and practice for enhancing both agricultural productivity and nutrition well-being in Kenya.

1.3. Research questions

In order to ensure that this research is purposeful, focused and meaningful to policy and contribution to knowledge, there are several core enquiries for this research that aided in guiding it. The research questions were instrumental in providing the direction, specific objectives, defining data requirements, the choice of research methods and ensuing analyses. This study's research questions were:

- 1) What is the array of households' socioeconomic factors determining the farmers choice between public irrigation scheme arrangement and farmer-led arrangement?
- 2) To what extent does irrigation, public irrigation scheme arrangement and farmer-led arrangement, impact production diversity?
- 3) What is the effect of irrigation, public irrigation scheme arrangement and farmer-led arrangement on farm income?
- 4) How does irrigation, public irrigation scheme arrangement and farmer-led arrangement, influence women's empowerment?
- 5) What is the impact of irrigation, public irrigation scheme arrangement and farmer-led arrangement on dietary diversity?
- 6) What are the dominant pathways through which public irrigation scheme arrangement and farmer-led irrigation arrangement affect household nutrition outcomes?

1.4. Objectives

1.4.1. Main objective

The main objective of this research was to examine how the different socio-technical irrigation arrangements affect the irrigation-nutrition impact pathways and nutrition outcomes of smallholder farm households in rural Kenya.

1.4.2. Specific objectives

In order to achieve this main objective, the research focused on these sub-objectives:

- 1) Explore the socioeconomic factors that determines farm households' choice to irrigate and choice of the socio-technical arrangement (public irrigation scheme arrangement or farmer-led irrigation arrangement);
- 2) Determine the impact of irrigation, public irrigation scheme arrangement and farmer-led irrigation arrangement on production diversity;
- 3) Determine the impact of irrigation, public irrigation scheme arrangement and farmer-led irrigation arrangement on farm income;
- 4) Determine the impact of irrigation, public irrigation scheme arrangement and farmer-led irrigation arrangement on women's empowerment;
- 5) Determine the impact of irrigation, public irrigation scheme arrangement and farmer-led irrigation arrangement on dietary diversity;
- 6) Determine the dominant irrigation-nutrition impact pathway(s) for public irrigation scheme arrangement and farmer-led irrigation arrangement.

1.5. Organization of the dissertation

The thesis is methodologically organized into separate sections in order to allow for the systematic understanding of the reader in a manner following the research objectives. After providing the background information, statement of the problem, research questions, objectives and hypotheses in Chapter One, Chapter Two delves into a comprehensive literature review, offering an overview of global and sub-Saharan Africa irrigation, insights into irrigation in Kenya, policy frameworks and also related research previously done by researchers. This chapter also explores smallholder farm households' economics and relates it to this particular study. Chapter Three gives this study's conceptual framework. It also gives the literature background of the conceptual framework.

The details regarding the data collection methods and procedures such as sampling design and sample size as well as a description of the study area and how the variables were defined is explained in Chapter Four. The chapter also lays down the logic and specification of econometric models used in the study and the procedures done to test for multicollinearity and heteroscedasticity. The descriptive statistics are given in Chapter Five with the various variables split into the different irrigation arrangements as a groundwork to subsequent analyses.

Chapter Six presents the results of a probit- and multinomial logit- regression on the smallholder farmers' household socioeconomic factors influencing irrigation and irrigation arrangements respectively. The following chapter gives the average treatment effects results on the effect of irrigation and irrigation arrangements on production diversity, farm income, women's empowerment, and dietary diversity. The information in Chapter Seven creates a bases for further analyses to investigate the irrigation-nutrition pathways.

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The assessment of irrigation-nutrition pathways is presented in Chapter Eight with the analysis providing results for aggregated irrigation and disaggregated results of the public irrigation scheme- and farmer-led irrigation- arrangements. Chapter Nine of this dissertation summarizes the research findings, suggests areas of further investigation, gives the policy recommendations and recognizes the study's limitations.

A comprehensive summary and executive summary of the whole thesis is also given both in English and in German. The thesis then ends with the references and the appendices giving further details of tests for multicollinearity and heteroscedasticity, tests for overidentification restriction, the focus group discussion guide, and the household questionnaire used in this study.

2. LITERATURE REVIEW

2.1. Overview of the global and sub-Saharan Africa irrigation

While the world is grappling with the effects of climate change, sustainably increasing food production is increasingly leaning towards intensification as opposed to extensification. Extensification involves converting natural lands like forest covers into agricultural lands oftentimes with adverse effects on the world's climate and biodiversity (Green et al., 2019; Laurance et al., 2014; Potapov et al., 2022). On the other hand, intensification is the increase of productivity of the already utilized land especially ones that are underachieving in terms of output (Jain et al., 2023; Mueller et al., 2012; Pretty, 2018; Rockström et al., 2017).

Irrigation allows for intensification by either putting land that is constrained by rain-fed agriculture into optimal use or lands that are water stressed in production (Beltran-Peña et al., 2020; Rosa, Chiarelli, Rulli, et al., 2020; Rosa, Chiarelli, Sangiorgio, et al., 2020; Rosa et al., 2018; Takeshima & Mano, 2023; X. Wang et al., 2021). Currently, irrigation plays a critical role in the world's food production. The lands under irrigation produce twice as much as non-irrigated ones and while covering about 22% of the world's cropland or around 341 million hectares, it produces approximately 40% of the food supply (Rosa, 2022; World Bank, 2023b). Irrigation is thus seen as a way of the world to increase its production further thus closing the gap in food demand that is experienced and will exacerbate further given the increasing world population. Therefore, propelled by the rising population, it is projected that the global land under irrigation will increase to almost double the current size by the year 2050 (Boretti & Rosa, 2019).

However, this increase in irrigation is expected to increase water demand on a resource that is already globally constrained (Boretti & Rosa, 2019; Burek et al., 2016). Irrigation is a large consumer of water resources accounting for about 70% of the world's water extractions and above 85% of anthropogenic water consumption (D'Odorico et al., 2018; Jägermeyr et al., 2017; Rosa, 2022). This huge utilization of water resources has been a concern in light of the changing climate. In addition, this presents a threat to food and nutrition security since irrigation produces calories for approximately 3.4 billion people, however, about 1.3 billion of these calories are unsustainably produced in that it either extracts more water than it can be naturally renewed, diminishes the freshwater stocks or damages the environmental water flows (J. Liu et al., 2017; Rosa et al., 2019; Rosa, 2022; S. W. Turner et al., 2019).

Apart from sustainability challenges, the increasing temperatures also pose a threat to agricultural production. Rural communities who rely on rain-fed agriculture face the greatest risk of a reduction in productivity and worsening food security due to global warming (Jägermeyr et al., 2021; Kummu et al., 2021; Ortiz-Bobea et al., 2021; Ray et al., 2019; Wing et al., 2021). This places irrigation at the center of not only increasing their production, but also solution for mitigating the effects of climatic changes (IPCC, 2022).

In light of these happenings, the ability of the world to increase irrigation sustainably without degrading natural ecosystems will mainly be embedded in transforming rain-fed areas that are below production rates (Droppers et al., 2021; Rosa, Chiarelli, Sangiorgio, et al., 2020; X. Wang

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et al., 2021). Sub-Saharan Africa, presents one of the most appropriate areas to increase irrigation sustainably without extensification.

While irrigation has been proven to increase agricultural production and positively impact food and nutrition security (Kafle et al., 2020), irrigation development is low in SSA. Irrigation only covers about 6% of the area under cultivation in SSA and estimates show that only about 1% of the region's irrigation potential is utilized (Durga et al., 2024; Pavelic et al., 2021; van Maanen et al., 2022, 2022; You et al., 2011). One of the reasons for this low development has been a focus on irrigation schemes that require substantial investments (Durga et al., 2024).

This is a shortfall for a region that hosts 33 of the 46 Least Developed Countries (LDCs) (UN/DESA, 2021) and grapples with the highest prevalence of food insecurity worldwide. Nutrition data for the region shows that approximately 23.2% of individuals in 2021 experienced undernourishment, 5.9% of children under five suffered from wasting and 32.3% from stunting in 2020 and about 40.7% of women of reproductive age had anemia in 2019 (FAO, 2023).

However, while it may be a shortfall, it also presents an immense opportunity for the regional and global food and nutrition security. The region presents the word with the opportunity to irrigate millions of hectares that can significantly increase food production (Altchenko & Villholth, 2015; Frenken, 2005; You et al., 2011).

In addition, as shown in Figure 3 below, the region not only has almost non-existent areas under unsustainable irrigation, but also one of the highest potentials for sustainable irrigation expansion onto rain-fed croplands under higher climatic temperatures (Rosa, 2022). Sustainable irrigation is defined by Rosa (2022) and Rosa et al. (2019) as "irrigation practices that do not exceed the availability of local renewable water and freshwater reserves and can show sustainability regarding irrigation water volume".

Sub-Saharan Africa's therefore holds vast, yet unexploited irrigation potential that could improve not only the regional, but also global food and nutrition security. However, to do this, there is a need to ensure that policy takes into consideration the unique socio-technical conditions in which irrigation takes place (referred herein as "irrigation arrangements") and also the different pathways that the irrigation arrangements lead to nutrition outcomes.

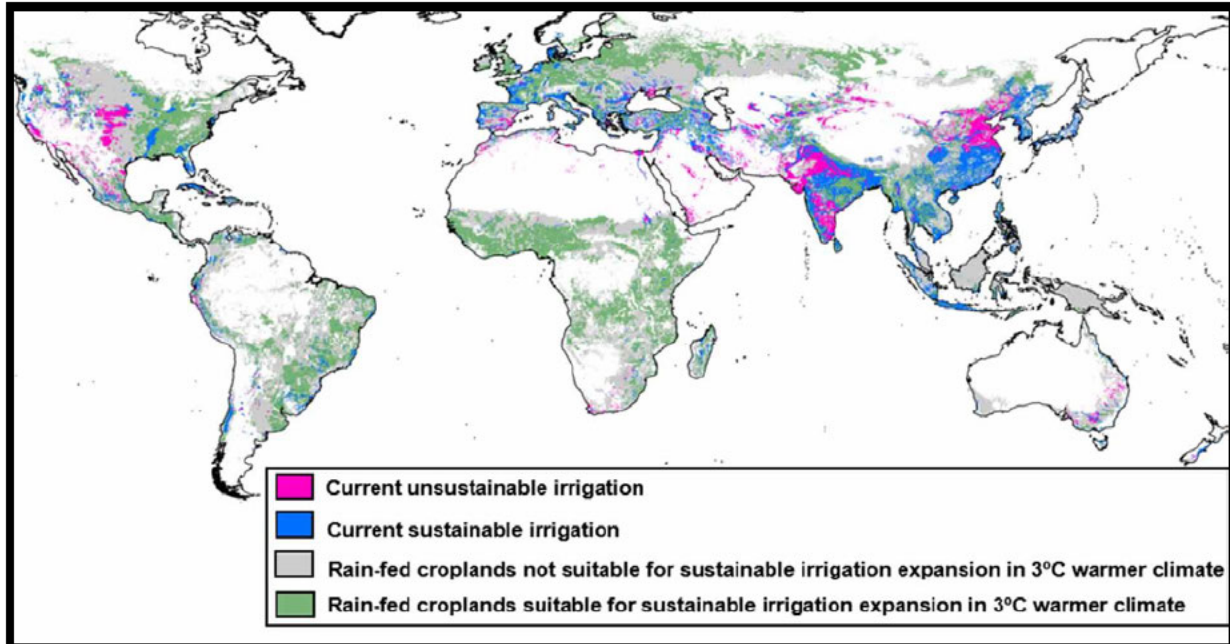


Figure 3: Sustainable and unsustainable irrigation over currently irrigated croplands, and potential for sustainable irrigation expansion onto rain-fed croplands under 3 °C warmer climate. Source: Rosa (2022)

2.2. Irrigation in Kenya

2.2.1. Kenya irrigation policy overview

While there has been evidence of the irrigation development in Kenya in pre-independence era as far as over 500 years ago, much of it was majorly done without policy documentation (Ngigi, 2002). Such developments include the already existing indigenous irrigation systems, slave-labor driven irrigation development especially in the Coastal areas that was driven by majorly Arab-owned slave-labor, irrigation developments developed by Indian workers working on the Kenya-Uganda railway line and irrigation developments established in the World War II era (Freeman & Silim, 2000; Ngigi, 2002). After the World War II, the colonial government embarked on planned irrigation development through the establishment of an organization called the African Land Development Unit as a way to contain uprisings due to land conflicts in Kenya (Ragwa et al., 1998). Between 1950s and 1960s, the detainees of Mau Mau uprising (freedom war fought from 1950s to 1960s by the Kenyans against British colonial authorities with an aim to reclaim stolen ancestral land and achieve the country's freedom) were also used by this organization in establishing irrigation schemes including Mwea Irrigation Scheme in which this study was carried in, Perkerra and Hola irrigation schemes (Elkins, 2000; Ngigi, 2002).

After gaining independence in 1963, the National Irrigation Board was formed through the Irrigation Act Cap. 347. This Act began the formal irrigation policy in the country. Mainly, the National Irrigation Board (NIB) was given the mandate of the defunct African Land Development Unit, which included developing and managing irrigation schemes and settling the landless in

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these schemes. Following the enactment of the Irrigation Act Cap. 347, the Irrigation Regulations of 1972 were also passed which defined further the management of schemes, tenancy and also penalties.

Irrigation in Kenya has not had a coherent policy ever since the passing of the first Act. Therefore, most of the drivers of irrigation policy have been guided by the national planning and development blueprints, related agricultural policies and agricultural Acts of parliament.

However, guided by the country's development blueprint, the Kenya Vision 2030, the National Irrigation Policy 2017 was passed by the Cabinet, which is the Government's uppermost policy making organ. The National Irrigation Policy 2017 is quite comprehensive on irrigation. It encompasses the basis for the policy, irrigation development strategies, development, operations and management of irrigation developments, capacity building, resource mobilization and financing, legal and institutional framework, monitoring and evaluation of policy implementation, and implementation framework for the policy (Government of Kenya, 2017).

A notable difference in the institutional framework of the National Irrigation Policy 2017, is the inclusion of the County Governments in the implementation of the policy. The National and County Governments institutions are envisioned to work towards irrigation development by working in accordance to inter-governmental relations prescribed in the Constitution of Kenya 2010 (Government of Kenya, 2017).

The implementation of the envisaged irrigation development is captured in the National Government's Medium-Term Plans covering 3-year periods and the County Governments' County Integrated Development Plans that are five-year strategies but all geared towards the achievement of the Kenya's Vision 2030. In particular, the National Government is given the responsibility of large irrigation schemes while the County Governments have the responsibility over small-scale schemes.

To instrument and implement the National Irrigation Policy 2017, the Irrigation Act Cap. 347, was enacted. The Act repealed the Irrigation Act Cap. 347 of 1966. The Irrigation Act Cap. 347 restricts all irrigation development in the country to be done in accordance to the Act. It therefore applies to the development, management, financing, support services and regulation of the entire irrigation sector in Kenya (Government of Kenya, 2019a).

Section 6 of the Irrigation Act Cap. 347 also mandates the Cabinet Secretary (Person in charge of a Government Ministry) responsible for irrigation to provide irrigation policy guidelines. In line with this provision, the Guidelines for Promotion, Development and Management of Irrigation in Kenya 2019 were developed. The guidelines cover matters relating to irrigation stakeholders, scheme development, support services, financing, and scheme management and irrigation water users' association dynamics. A summary of the Table 1.

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Table 1: Policy landscape on irrigation development in Kenya in chronological order (in bold are the current policy documents in operation)

Timeline	Policy landscape instrument
National planning and development blueprints:	
1981-1985	Sessional paper No.4 of 1981 on National food policy
1986-1993	Sessional paper No.1 of 1986 on Economic Management for Renewed Growth
1994-2002	Sessional paper No.2 of 1994 on National Food Policy
2003 - 2007	The Economic Recovery Strategy
2008-Current	Kenya Vision 2030
Policies and strategies:	
2004 - 2014	The Strategy for Revitalizing of Agriculture
2010 - 2020	The Agriculture Sector Development Strategy
2017 - Current	National Irrigation Policy
2019 – 2029 (Current)	The Agricultural Sector Transformation and Growth Strategy
Acts of parliament and regulations:	
1966-1972	Irrigation Act Cap 347 of 1966
1972-1985	Irrigation Regulations
1986-2019	The Agricultural Act Cap 318
2019 - Current	Irrigation Act Cap. 347
Guidelines:	
2019- Current	Guidelines for Promotion, Development and Management of Irrigation in Kenya (2019)

Source: Author

However, as one can note in the discussion, the policy documents in the country are still geared towards irrigation scheme systems. This elbows out such farmers under the farmer-led irrigation. For example, Table 2 gives some definitions related to irrigation practices quoted from the Irrigation Act Cap. 347 and how they differ from the farmer-led irrigation.

Table 2: Key definitions related to irrigation practices from the Irrigation Act Cap. 347 in relation to farmer-led irrigation practices

No.	Item	Definition in the law	Difference with the application of Farmer-led irrigation
1)	Irrigation scheme	a systematic and orderly irrigation system covering a defined area of land regardless of the type or system of irrigation employed;	Given that this irrigation is done by individual farmers or group of farmers, farmer-led irrigation practices tend not to be systematic and orderly. Actually, it may not form as an irrigation system but rather a group of irrigation application methods.

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No.	Item	Definition in the law	Difference with the application of Farmer-led irrigation
2)	National irrigation scheme	An area of land designated as such by the Authority through a notice.	In most cases, the National Irrigation Authority is not involved in the establishment, expansion or commencement of farmer-led irrigation.
3)	Large scale irrigation scheme	A scheme which acreage size covers over three thousand acres, and is developed and managed by the Authority, and is established for national strategic purposes, or such schemes as implemented by the private sector.	The land size, development and purpose of establishment disqualify farmer-led irrigation from fitting in.
4)	Medium scale irrigation scheme	A scheme which in acreage size covers over one hundred acres to three thousand acres, and is implemented by the Authority, or another state agency in collaboration with county government, or such schemes as implemented by a private entity.	The land size, development and purpose of establishment disqualify farmer-led irrigation from fitting in.
5)	Small scale irrigation scheme	A scheme which in acreage size covers less than one hundred acres and implemented by a county government, or by the national government through Authority in case of transboundary or inter county schemes or strategic schemes or such schemes as implemented by a private entity.	The land size, development and purpose of establishment disqualify farmer-led irrigation from fitting in.
6)	Smallholder irrigation and drainage scheme	An irrigation scheme that is developed, owned and managed by communities as irrigation water user groups or individual farmers.	This is the closest the law comes to getting close to a farmer-led irrigation practice. However, by the predefinition given of an “irrigation scheme” in the first row above, this elbows out farmer-led irrigation from fitting in.

Source: Definitions from Irrigation Act Cap. 347 (Government of Kenya, 2019b)

A common feature in the definitions is that irrigation development happens in scheme-like arrangements only. While there is evidence that irrigation schemes do provide a good conditions for the development of farmer-led irrigation (Mati, 2023), this renders the irrigation that is implemented outside the schemes or in the schemes by individual or farmer groups as an unrecognized irrigation development.

As evidenced in Table 2, none of the above would fit in the definition of a farmer-led irrigation farmer. By so doing, this critical policy document elbows out farmer-led irrigation development. This narrow framing of irrigation development robs the country of an ability to make use of the opportunities arising from farmer-led irrigation development such as providing an alternative form of expanded irrigation, thus improving agricultural production. In addition, by rendering the farmer-led irrigation unrecognized in law, this form of irrigation arrangement continues to be ignored by the irrigation stakeholders thus fostering inequity in the sector especially given that most of these farmers would be smallholder farmers and mostly involving women who take advantage of the available unutilized or underutilized resources from the irrigation schemes.

This disregard of farmer-led irrigation arrangement is one of the shortfalls of the current irrigation policy documents. It is also one of the endeavors of this research to bring this into light. Therefore, at the conclusion of this thesis, a suggestion on the amendment of both the National Irrigation Policy 2017 and the Irrigation Act Cap. 347 are given. The suggested amendments are intended to be presented to the current Ministry of Water, Sanitation and Irrigation, which handles matters to do with irrigation in Kenya.

2.2.2. Arrangement of irrigation in Kenya

Irrigation development in Kenya is categorized into four distinct arrangements. The categorization is based on work done by Blank et al. (2002) under the International Water Management Institute (IWMI) and the reconnaissance in the area of study. The categorization gives distinct irrigation arrangements that are diverse in terms of both institutional factors and socioeconomic factors of the actors involved.

Therefore, in this study, it is claimed that the unique socioeconomic factors in the farm households (intra-household characteristics) not only determines whether a farm household irrigates or not but also influences the choice of the irrigation arrangement that the farm household will engage in, be it farmer-led irrigation arrangement or public irrigation scheme arrangement. In particular, the study investigates which specific factors they are and how they determine the households' outcomes as relates to production diversity, farm income, women's empowerment and nutrition.

A summary of the characteristics of the different irrigation arrangements is provided in Table 3. This is of particular interest to this study as previous studies have shown that institutional and socioeconomic dimensions of irrigation have a decisive impact on farmers' crop choice and market participation (Blank et al., 2002; de Bont et al., 2019; De Fraiture & Giordano, 2014;

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Mapedza et al., 2016; Washington-Ottombre & Evans, 2019). This in turn has implications on consumption of nutritious food and diverse diets in local food systems.

Table 3: Characteristics of irrigation arrangements

Characteristics of the irrigation arrangements		Public Irrigation Scheme arrangement	Smallholder Irrigation Schemes arrangement	Private commercial farms irrigation arrangement	Farmer-led irrigation arrangement
Infrastructure	Ownership	Public	Water undertaker	Private	Private
	Development	Well developed	Semi-developed	Well developed	Rudimentary
Watering technology	Type of technology	Advanced e.g. artificial canal systems	Semi-advanced e.g. earthen canals	Advance technology e.g. Centre-pivot irrigation	Basic technology E.g. small diesel or petrol pumps
Institutional framework	Legal status	Government agencies and established Water users' associations	Farmer organizations (mostly non-registered)	Private companies	Non-registered individual farmers or group of farmers
	Cost of water access	Statutory fees for access and maintenance of infrastructure	Statutory fees for access of water	Yearly statutory fees	Though statutory fees of access exist, payment is rarely done

Source: Blank et al., (2002) and reconnaissance visit

2.2.2.1. Public irrigation schemes arrangement

These schemes are owned by the Government either through the Ministry of Agriculture, defunct National Irrigation Board (current National Irrigation Authority (NIA)), Regional Authorities or the Agricultural Development Corporations (ADC). However, they are usually jointly managed by these public entities and farmer organizations such as Water Users Association (WUA) through a tenant-farmer arrangement (Blank et al., 2002). Consequently, most of these schemes are characterized by small land holding (except for Galana-Kulalu and ADC Farms) and mono-cropping with the exception of Perkerra and Bura irrigation Schemes.

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The country has eight public irrigation schemes spanning about 24,000 hectares (about 60,600 acres) which is about 18% of the total irrigated land area (Government of Kenya, 2019a). The schemes are established on public land and developed by the NIA. NIA was established in 2019 by the current Irrigation Act Cap. 347 and it is a successor to the National Irrigation Board and it is mandated by the same Act to provide for the development, management and regulation of irrigation in the country. However, the schemes are run in collaboration between the NIA, government agencies and/or water users' organizations. Table 4 gives details on the establishment, coverage by land size, water source and the number of farm households of the public schemes under NIA development.

Table 4: Establishment, land coverage and water source of public irrigation schemes in Kenya

No.	Public scheme	Year of establishment	Gazetted area (in acres)	Area under production	Irrigation water source	Number of farmers
1)	Mwea Irrigation Scheme	1954	30,350	30,600	Rivers Nyamindi and Thiba	18,070
2)	Bura Irrigation Scheme	1978	12,000	10,000	River Tana	2,245
3)	Tana Irrigation Scheme	1953	12,630	5,000	River Tana	1,450
4)	Perkerra Irrigation Scheme	1956	5,800	3,000	River Perkerra	1,625
5)	Ahero Irrigation Scheme	1966	4,176	10,810	River Nyando	120,000
6)	Bunyala Irrigation Scheme	1959	534	1,880	River Nzoia	1,394
7)	West Kano Irrigation Scheme	1974	4,450	2,830	Lake Victoria	1,300
8)	Lower Kuja Irrigation Scheme	1980's	-	2,600	Lake Victoria	-

Source: National Irrigation Authority (2024)

2.2.2.2. Community-based irrigation schemes irrigation arrangement

These irrigation arrangements are mostly managed by community groups be it through Irrigation Water Users' Association (IWUAs), cooperatives or self-help groups but the irrigation infrastructure and water distribution are done by a water undertaker (Blank et. al., 2002; FAO, 2016). The latest government statistics show that the community-based irrigation schemes cover about 110,000 hectares (about 275,000 acres) and are estimated to be about 3,600 in number (Government of Kenya, 2019a). The development is done in collaboration with the farmers; the financial support is often by development partners and Non-Governmental Organizations (NGOs).

These kinds of irrigation arrangements are characterized by low technology with the funding of such projects providing basic infrastructure such as water intake and distribution but farmers use methods such as farrows or siphoning to get the water to their farms (FAO, 2016). Although sometimes such arrangements have encountered problems of poor community or group mobilization and participation, the farms are usually highly productive owing to their smallholding nature, have a high crop diversity and also produce high-value crops for domestic and export markets (FAO, 2016).

2.2.2.3. Private commercial farms irrigation arrangement

These are investments made and owned by individuals or firms and they are characterized by modern technologies such as pivot irrigation systems, large landholding and largescale production (FAO, 2016). They are usually involved in the production of high value export crops such as flowers. This type of irrigation arrangement covers about 40% of the irrigated land in the country and covers about 88,000 hectares (approximately 220,000 acres) (Government of Kenya, 2019a). Such investments include large farms by multinational companies such as Del Monte, Finlays, Kakuzi, and Oserian.

2.2.2.4. Farmer-led irrigation arrangement

In the last few years, there has been development of irrigation arrangements that are farmer instigated and driven which is referred to as farmer-led irrigation. The World Bank defines farmer-led irrigation as “when farmers drive the establishment, improvement, and/or expansion of irrigated agriculture and influence the location, purpose, and design of irrigation development through small-scale, on-farm, locally relevant, and market-oriented solutions” (World Bank, 2021). Farmer-led irrigation has been on the increase in the country and it is estimated that it covers about 15% of irrigated area in Kenya (De Fraiture & Giordano, 2014). The management is usually done by individual farmers or by “informal” farmer groups (J. A. Burney et al., 2013) who commonly come together to cost share on the capital machinery (e.g. pump) irrigation infrastructure (such as PVC pipes) or operational costs (such as fuel). While low-technology such as the use of buckets, farrow irrigation and human-powered pumps still characterize farmer-led irrigation, in the last few years there has been a high penetration of technology with most of the farmers and farmer groups adopting the use of motorized pumps and solar-powered pumps (J. A. Burney et al., 2013). Due to the large number of farmers and their diversity in both capability and market integration, there kind of irrigation is usually characterized by crop diversity and production of high value horticultural crops for domestic and export crops. Additionally, even though it is usually done on small land holdings, they are highly productive and efficient (J. A. Burney et al., 2013).

Though there is a renewed interest in developing irrigation in sub-Saharan Africa after an over two-decade hiatus due to its deemed failure, with about 40% of the total African agricultural area being under farmers who own less than 2 hectares, the next irrigation frontier must focus on smallholder farmers (Lowder et al., 2016; Shah et al., 2013; Woodhouse et al., 2017). This has spurred deliberations on the right irrigation arrangements regarding technology, management

(individual, collective, small-scale or large-scale) or whether to establish new schemes or renovate existing ones (Lankford, 2009). While it seems as a rational to focus irrigation on smallholder farmers, the ability of these farmers to initiate this (farmer-led irrigation), is not only largely understudied but also given less attention in the policy arena and more common than not regarded as incompetent, unproductive and old-fashioned (Beekman et al., 2014; de Bont et al., 2019; Svendsen et al., 2009; Woodhouse et al., 2017). However, much of the increased area under irrigation in the past decade in sub-Saharan Africa is as a result of farmer-led irrigation (Wiggins & Lankford, 2019).

Given the foregoing information from literature, this study finds it imperative to study this emerging irrigation arrangement in comparison to the existing public irrigation scheme. In so doing, the study will not only fill the knowledge gap that exists on the link between irrigation and nutrition but also give a deeper understanding on the farmer-led irrigation institutional and socioeconomic arrangement.

2.3. Smallholder farm households' economics

Smallholder farm households form a unique economic unit. Therefore, its fit into economic modelling has always been a challenge because of both the intertwining of economic objectives in the household and the challenges facing them from the external environment. By definition, smallholder farm households fits into the definition of peasant according to Ellis (1993). This is that they use family labor in agriculture which is their main economic activity. These households also participate in imperfect markets (have high transaction costs (Omamo, 1998; E. Ouma et al., 2010), information is disproportionate (Courtois & Subervie, 2015; de Brauw et al., 2021) and has aspects of monopoly and monopsony (Doyle, 2015; Ncube, 2020)). These households are part of a community that accesses common property resources but are often subjugated by a ruling class (Ellis, 1993, pp. 7–16). From literature and the reconnaissance visit, the farmers in the area of study, fell under the definition given above as it will be described later on in the next chapters.

Therefore, in considering household behaviors, this study considered three main theories that form the basis of studying household behavior which are grounded in utility, profit and risk relating to utility maximization, profit maximization and risk aversion respectively (Chayanov, 1986; Mas-Colell et al., 1995; Roumasset, 1976; Sadoulet et al., 1996; Schultz, 1966; Singh et al., 1986). However, in this study it is presumed the utility maximization basis to be a closer theory based on the diversity of the pathways in consideration. In addition, as compared to the profit maximization theory, utility maximization has been shown to be more accurate in predicting agricultural production patterns and behavior (W. Lin et al., 1974). As it relates to risk aversion, there has been developments linking risk aversion to utility (Norstad, 1999; Schechter, 2007; Zhang et al., 2014).

However, as pointed above given that the study deals with smallholder farmers and their uniqueness as it relates to supply and demand of agricultural products, even in leaning towards the utility maximization theory, it was paramount to also consider the application of the separation theory especially as it relates to decision making. Decision making was considered a

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critical part of this study as it relates to women empowerment aspects such as resource control, ownership of assets, workload apportioning and community leadership and thus the applicability of the separation theory.

The foundation of the separation theory is the distinction between supply and demand side and in this case between farm household's production and consumption decisions (Benjamin, 1992; Card, 1987; Delforce, 1994). But as a condition for the separation between production and consumption, perfect markets have to be operational. If the markets are imperfect, then the separability of the decisions cannot hold. In this case, these smallholder farm households like in most of sub-Saharan Africa, operate in an imperfect market (Dillon et al., 2019; Dillon & Barrett, 2017). Therefore, under this theory its application was considered under imperfect markets. Another advantage of the separability theorem is that while most smallholder farm households' research view them as unresponsive to economic behavior, this theory shows that they act in response to market failures and not due to irresponsiveness to market changes (De Janvry & Sadoulet, 2016, pp. 788–790; Janvry et al., 1991; Merfeld, 2020).

Therefore, in this study, a combination of the utility maximization and separation theories was found to be foundational in mapping out the likely scenario of the behavior of households in different irrigation arrangements. The utility maximization theory helps in understanding the households' production and consumption decisions as concerns the production and farm income pathways while the separation theory helps us embed the gender aspect of decision making as it relates to women's empowerment pathway.

This study therefore found the work by De Janvry & Sadoulet (2016, pp. 776–809) to be foundational to the study given the different aspects of impact pathways being studied and their difference in economic goals. Given the market imperfections explained above, in smallholder households there is often an intertwining of production, consumption and labor allocation decisions (Janvry et al., 1991; J. E. Taylor & Adelman, 2003). For instance, in this study production diversity and farm income objectives might be conflicting due to an opportunity cost of diversifying over specialization and women's empowerment objectives might also be different or hidden as expressed by Ellis (1993, pp. 171–172). Therefore, the smallholder farm household is taken as making both production and consumption decisions. In so doing, the theory of the firm is utilized in the production side while the theory of consumer behavior handles the consumption side, this forms the farm household behavior model. In this model, the household is simplified to having labor and time resources. Therefore, the theory of the firm functions in deciding the labor allocations while the theory of consumer behavior allocates time between labor and leisure.

The household has access to a fixed amount of time T and land ($\bar{A}$). The household's utility function is then a factor of income (Y) and leisure T_z . Therefore, the utility function can be written as:

$$\text{Max } U(Y, T_z)$$

Equation 1: Household's utility function

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The household can allocate the time to leisure (T_Z) or to work (L_S). In this case, the smallholder farmers' time allocated to work is either used in the farm (T_F) or hired out as labor thus earning a wage (T_W) while the labor allocated to the farm can also be added by hiring labor (L_{IN}) to have a total labor input (L) depending on the resource endowment of the household. As a simplification to the model, the wage earned for working at the family farm (w_S) is taken as lower than the wage when labor is hired out (w_H). This takes into consideration the transaction cost of hired labor that are higher due to the imperfect market the farm households operate in.

Therefore, assuming that technology is given, the household's production function is given as $Q(L, \bar{A})$. Given a price (p), then the total output earning will be pQ . However, the total income would be a factor of the total output earnings plus the earnings from the labor hired out minus the labor hired in.

Therefore, the farm household behavior model can be expressed as:

$$Max_{T_F T_W T_Z L_{IN}} U(Y, T_Z)$$

Equation 2: Farm household behavior model

Where

$Y = pQ + w_S T_W - w_H L_{IN}$ is the income equation

As a factor of the production function: $Q(L, \bar{A})$

Which is subject to the total labor use in the farm: $L = T_F + L_{IN}$

and the household time constraint: $T = T_F + T_W + T_Z$

Making the assumption that all workers are equal, then given that family labor is cheaper as pointed out above, then there is no moment that there can be simultaneity of family labor hired out while labor is hired in. When solving for this model, the key factor then is the size of land in relation to the family labor gives five scenarios summarized on the Table 5.

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Table 5: Scenarios based on land and labor endowments under the farm household behavior models

Farm household type	Household characteristics	Behavioral model
Consumer-worker household	Landless household (therefore the theory of the firm collapses and corresponds to the theory of consumer behavior)	$\text{Max}_{T_W T_Z} U(Y, T_Z)$ Subject to: $Y = w_s T_w$, income equation $T_F + T_Z = T$, time constraint
Applicability to the study: This scenario is not applicable. The target households are the ones involved in farming (whether the land is owned or rented).		
Pure producer	- Sufficient land - Uses only hired labor - Family labor in leisure or beyond the model's scope (theory of consumer behavior collapses and corresponds to the theory of the firm whose goal is to maximize profit (restricted))	$\text{Max}_L \Pi = pQ - w_H L$ Subject to: $Q(L, \bar{A})$, production function
Applicability to the study: The definition of “sufficient land” still remains in the definition of smallholder farmer but in this case, it is sufficient to make profit that also pays for hired labor used for production. In this case, it is postulated that this will involve irrigating farmers growing commercial crops for the market (mostly farm households in the farmer-led irrigation arrangements and some farmers in the public irrigation scheme arrangement).		
Chayanovian pure family farmer	- Does not participate in the labor market (uses all its labor in the family farm thus $L=T_F$ and thus the change in production function) - Self-sufficient in labor use	$\text{Max}_{T_F T_Z} U(Y, T_Z)$ Subject to: $Q = Q(T_F, \bar{A})$, production function $Y = pQ$, income equation $T_F + T_Z = T$, time constraint

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Farm household type	Household characteristics	Behavioral model
Applicability to the study: The “self-sufficiency” in labor is not only a factor of use of family labor, but also a factor of imperfect markets in labor market that makes hiring of labor difficult and haphazard. In addition, the households also lack enough resources to hire labor for use in the family farm. In this study this scenario was deemed to represent both irrigating and non-irrigating farm households involved in subsistence farming.		
Sub-family farmer	▪ Small land ▪ Abundant family labor (family labor sufficient for the family farm and surplus hired out (therefore $L=T_F$ and thus changes the production function)) Allocate surplus farm labor to the labor market	$Max_{T_F T_W T_Z} U(Y, T_Z)$ Subject to: $Q = Q(T_F, \bar{A})$, production function $Y = pQ + w_s T_W$, income equation $T_F + T_W + T_Z = T$, time constraint
Applicability to the study: The aim of this smallholder farm household is still subsistence farming. As such the labor use in the family farm is prioritized over use in the labor market. It was hypothesized that this will be the case for farmers particularly in the public irrigation scheme arrangement and also non-irrigating farmers.		
Small commercial farmer	▪ Large land endowment ▪ Inadequate family labor ▪ Hire in labor	$Max_{T_F T_Z L_{IN}} U(Y, T_Z)$ Subject to: $Q = Q(L, \bar{A})$, production function $Y = pQ - w_H L_{IN}$, income equation $L = T_F + L_{IN}$, total labor used in the farm $T_F + T_Z = T$, time constraint
Applicability to the study: This was postulated to be the case for few farmer-led irrigation and few public irrigation scheme arrangements.		

Source: Theory development adopted from De Janvry & Sadoulet (2016, pp. 805–807)

A key consideration of this study was women's empowerment. In this regard, the need to consider the above scenarios in light of the gender composition at household level. Therefore, the above-mentioned scenarios and their outcomes are also deemed to be affected by the household gender composition especially as it relates to decision making. As highlighted earlier, to bring in the gender aspect, the study makes an economic argument based on the separability theory adapted from the works of De Janvry & Sadoulet (2016b, pp. 805–807).

The different gender roles are assumed to affect the smallholder household's efficiency and equity of resource use in production and consumption. In this case, the household is composed of a primary female (F) and male (M) decision makers with different utilities defined as $U_F(q, a)$ and $U_M(q, a)$ respectively where q and a are household consumption and household's actions respectively. For simplicity, a case of income is given here. The utilities are maximized subject to a budget constraint given as:

$$pq = Y_F(a) + Y_M(a) + T_M + T_F$$

Equation 3: Budget constraint

Where p is the price of the consumption good, $Y_F(a)$ is the income from actions a earned by the primary female decision maker, $Y_M(a)$ is the income from actions a earned by the primary male decision maker and T_F and T_M are unearned income transfers received by the primary female decision maker and the primary male decision maker respectively. This then leads to two models under which the household can make decisions on the actions a to take and consumption goods q to consume. The two models are summarized in Table 6.

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Table 6: Gendered actions and consumption decision making in the smallholder farm households

Household decision making model	Household characteristics	Model specification	Resulting outcomes
Unitary model	- Decision by one person, jointly or their utilities are equal $[U_F(q, a) = U_M(q, a) = U(q, a)]$	$Max_{q, a} U(q, a)$ Subject to: $pq = Y_F(a) + Y_M(a) + T_F + T_M$	- Perfect separability between production and consumption in the household (efficient; and at Pareto optimal condition) and therefore: - Income is maximized, pooled and allocated to the household members for consumption.
Applicability to the study: This scenario helps us to see the effect of women empowerment for the different households in the different irrigation arrangements. The synergy in decision making between the head of family and the next main decision maker (either being male or female) at household level will positively affect the impact pathways as well as the outcome variable which is the household nutrition. For instance, farm households in the farmer-led irrigation arrangement will fall into this model as it regards income maximization. It is thus presumed that the households' common goal is to increase income of the household by commercially growing marketable crops. Generally, in any of the irrigation arrangements, jointly making decisions would not only lead to higher incomes, but for the study's interest, empower the women in these households.			
Bargaining model	- Two genders have different utility functions $[U_F(q, a) \neq U_M(q, a)]$ (McElroy, 1990) - Household maximize a weighted function of the two utilities	$Max_{q, a} U_M(q, a) + \mu U_F(q, a)$ Subject to: $pq = Y_M(a) + Y_F(a) + T_M + T_F$ Where μ is the bargaining power between the two genders. This gives two possible outcomes: when the bargaining power decision on q and a is	Exogenous - Separability holds thus the household is efficient (Pareto optimal) and income is pooled and allocated depending on the bargaining weight which is determined by the primary female (F) and male (M) decision makers' external opportunities. Endogenous - Household is inefficient because this affects the bargained outcome, thus no income pooling - No income pooling

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Household decision making model	Household characteristics	Model specification	Resulting outcomes
		exogenous and when the bargaining power decision on q and a is endogenous	▪ Distributional gains leads to resources being inefficiently allocated (Bourguignon & Chiappori, 1994, pp. 2–3)
Applicability to the study: This scenario gives an understanding into households whose gender goals conflict. This would lead to a negative effect of both the impact pathways and the household's nutrition outcome. In the context of this study and as a proposition, this scenario gave a case of women disempowerment. This is so because the decisions will still have to be made and, in this case, will most likely be made by a person of the opposite sex.			
Source: Theory development adopted from De Janvry & Sadoulet (2016, pp. 805–807)			

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With the background on the expected structures based on land and labor endowments and the anticipated effect on consumption decisions of gendered actions of the smallholder farm households, the farm household behavior models and the separability theory gave this study a good platform into understanding how resource endowments and decision making among the different genders interact. This is especially of great importance given that while production diversity and income pathways have been relatively studied in the field of economics, very few studies engrain the women's empowerment pathways especially quantitatively. Therefore, being able to comprehend how this gender decision affects the resource endowment and the resultant outcomes through the two aforementioned theories as eye opening.

In this way, it was evident of the need to look at each of these pathways not only as an entity on its own but as complementary to each other. In other words, it is possible for a household to attain their nutritional outcomes through multiple pathways. This is given the realization that the resource endowment in the farm household behavior model and decisions based on the households' gender composition are not mutually exclusive, but experienced simultaneously.

This realization illuminated research on how to dissect the dynamics of the production diversity, farm income, and women's empowerment irrigation-nutrition pathways and its resulting effect on the nutrition outcomes at the household level based on the households' resource endowment and decision making across the different genders. However, while this section provides the economic theoretical basis, the proving or furthering of these theories is beyond the scope of this dissertation and the two theories were solely used in grounding the research, construction of research questions, hypotheses, approaches, and the study design.

3. CONCEPTUAL FRAMEWORK AND HYPOTHESES

3.1. Conceptual framework

3.1.1. Introduction

This chapter discusses the conceptual framework of this study. It lays the foundation on which this study is based upon and shows how the socioeconomic aspects of the farm household are conceptualized to influence the irrigation-nutrition pathways as well as the nutrition outcome of the household. This section also shows how the irrigation-nutrition impact pathways are hypothesized for the different irrigation arrangements. For the linkage between irrigation and nutrition, this study's impact pathways are based on the frameworks by Herforth et al., (2012) and Herforth and Harris, (2014) that links agriculture and nutrition.

3.1.2. Background to the conceptual framework

Herforth et al., (2012) while developing guidelines for including nutrition outcomes in agricultural and rural development projects, based their work on two of the oldest frameworks on agriculture-nutrition pathways: the United Nations Children's Fund (UNICEF) and the World Bank frameworks.

The UNICEF framework looks at the causes of malnutrition in children (UNICEF, 1991). It suggests three causes of children nutrition status; food access, ability to access health services and healthy environments, and maternal and child care practices. It further puts forward that agriculture has influence on food security, care practices and health. The UNICEF framework elucidates that agriculture affects food security through food access by making food comprised of diverse diets available and provision of incomes. On the care practices, the framework suggests that agriculture leads to food and nutrition security by affecting the women's generation of income, time management, knowledge build-up time and ability to make household decisions all of which affects maternal and child care practices. It also links agriculture to health outcomes especially negative ones like the use of chemicals and vector disease harboring via stagnant water. The framework also acknowledges the ability of agriculture to affect the underlying causes of undernourishment such as environmental resources and poverty.

On the other hand, the World Bank framework suggests five main pathways to nutrition outcomes in agriculture namely; income from sale of own produced products, consumption of household produced food, empowerment of women, economic development and food prices reduction (Hawkes & Ruel, 2008; Herforth et al., 2012).

Building on the earlier works given above, Herforth & Harris (2014a) suggested an agriculture-nutrition framework primarily focuses on children's and mother's nutrition. In this framework they proposed multiple and non-linear pathways with various interactions. They came up with three main pathways which are food production, agricultural income and women's empowerment. They extrapolate that agriculture affects food production through both food availability in the household as well as the prices of the diverse food, agricultural income spent (food and non-food expenditures) and women's empowerment through their income

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generation, ability to care for the household and their use of energy (human energy). The authors also identify four enabling environment components that affects nutrition of households, consumers and communities which are: food market environment; natural resources; health, water and sanitation; and nutrition/health knowledge and norms.

Domènech (2015) through a literature review identified five impact pathways that link irrigation to nutrition and health outcomes. One of the ways was the irrigation as a source of income mainly through the sales of produce in the market and also as a source of income from engaging in agricultural production as an employment. Additionally, she identified that irrigation can lead to more diversification of crops produced as well as increase in production thus leading to more diversified foods consumed at the household level. Irrigation also acts as a source of water for the households including for sanitation and hygiene as well as rearing of livestock and fish. Irrigation also leads to more control of resources and assets thus contributing to women's empowerment. However, she also identified that irrigation can also negatively affect nutrition and health outcomes by being vector-breeding habitat such as providing breeding habitats for malaria causing mosquitos in the tropics and through water pollution from chemical use in agriculture.

Passarelli et al. (2018) followed the pathways discussed above by Domènech (2015) but adopted them to the agriculture-nutrition conceptual framework by Herforth & Harris (2014) that was discussed earlier. Therefore, in doing this, irrigation was included in the framework. Irrigation was included in the framework as a productive asset thus enabling it to depict how irrigation creates an impact on agricultural livelihoods nutrition through the four pathways of food production, agricultural income, water supply, and women's empowerment (Domènech, 2015; Herforth & Harris, 2014a; Passarelli et al., 2018).

3.1.3. Study's conceptual framework

In this study, irrigation is taken as a form of agricultural production at the household level and seeks to show its linkages to nutrition outcomes. In doing so, the conceptual framework linking agriculture to nutrition was therefore taken as appropriate in that it gives the basis under which to ground the research. The conceptual framework developed by Herforth & Harris (2014a) is used in linking agriculture to nutrition outcomes. To do this the methodology by Passarelli et al. (2018) was adapted where irrigation is a production innovation for the smallholder households to achieve their nutrition outcomes through the food production, agricultural income, and women's empowerment pathways as suggested by Domenech & Ringler (2013). By taking irrigation as an agricultural innovation component, the distinguishing of irrigating and non-irrigating households and the different irrigation arrangements is thus made possible.

As regards, irrigation, this study hypothesizes that the use of irrigation can enable a household to grow more diverse foods and thus enable it to access more diverse and nutritious food . In addition, irrigation also enables households to smoothen their production over dry seasons especially in the growing of short-term crops such as green leafy vegetables also gives these households access to nutritious foods (Baye et al., 2022; Biru et al., 2025; Passarelli et al., 2018).

3. CONCEPTUAL FRAMEWORK AND HYPOTHESES

Postulating that irrigation increases the household's farm income, this variable is also included in this study as a pathway to increasing nutrition outcomes of households. Though not linear (SPRING, 2014a), it is anticipated that this enables the household to have more disposable income to access nutritious foods (Rao & Pingali, 2018). This includes more expensive nutrient-rich foods such as off-season fruits and vegetables and protein foods.

There exists quite substantial evidence that women's empowerment is linked to nutrition outcomes, though a quite debate-arousing area (Bold et al., 2013; SPRING, 2014b; Heckert et al., 2019; Quisumbing et al., 2021; Santoso et al., 2019). This study thus claims that irrigation does influence women's empowerment and women's empowerment in turn affects nutrition.

While the crucial role socioeconomic factors play have been widely acknowledged in economic disciplines, studies that look into their role in irrigation and particularly the household outcomes in participating in irrigation has been largely understudied (Hatch et al., 2022; Kamwamba-Mtethiwa et al., 2016; van Maanen et al., 2022). In this study, it is postulated that the socioeconomic factors of the smallholder households not only affect the choice to irrigate and which irrigation arrangement to engage in but also the agricultural- and irrigation-nutrition linkages and the nutrition outcomes of the household. Therefore, the socioeconomic factors are crucial in understanding the context as to why the farm households are in specific irrigation arrangements and how also it affects the nutritional outcomes. The framework was thus further modified to take into account the household's socioeconomic aspects.

The socioeconomic aspects of each household are composed of unique aspects depending on the household members. In addition, some aspects of the socioeconomic factors such as female member's education and control over resources are affected by other considerations such as socio-cultural aspects thus making the causal effect of socioeconomic factors on irrigation and outcomes of irrigation uniquely localized. Therefore, the socioeconomic factors of the households are factored in this study to give the contextual information of the factors that determine households' choice of irrigation arrangement and how they affect the household outcomes in the form of production diversity, farm income, women's empowerment and nutrition.

In addition, with the study leaning towards a study of two different institutional set-ups in irrigation, they do not operate in a vacuum devoid of societal socio-economic and -cultural aspects. It is notable that several studies have shown the importance of taking into consideration the specific cultural and social context in which irrigation takes place (Lefore et al., 2019; Woodhouse et al., 2017). In this respect, taking into consideration that this study also looks at variables susceptible to influence by a household's socioeconomic factors i.e. nutrition outcome, production diversity, farm income and women's empowerment, it is paramount for the study to consider these factors. For instance, women's empowerment has been shown to be affected by household dynamics and cultural norms especially as regards institutional set-ups around water users (Lefore et al., 2019; Theis et al., 2018; Woodhouse et al., 2017; Yami, 2013).

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Therefore, in this study, it is claimed that the socioeconomic factors in the farm households influences whether a farm household irrigates or not. Furthermore, these factors also influence the choice of the irrigation arrangement that the farm household will engage in, be it farmer-led irrigation arrangement or public irrigation scheme arrangement. It is then hypothesized that the different households in diverse irrigation arrangements have different pathways for which they achieve their nutrition outcome (while taking into account the socioeconomic variances). However, the choice of the socioeconomic factors to include in the study necessitated a critical and robust look at literature. In this regard, the section below discusses the socioeconomic factors.

The measurement of the age of the household-head and the primary female decision-maker was of key importance to this study as they are the two key decision makers at the household level. The age, especially of decision makers at the household has been shown to influence production especially as it regards technology and farming practices such as irrigation (G. Guo et al., 2015; M. Li & Sicular, 2013). In addition, age has been previously correlated to both the experience in farming as well as the risk taking attitude especially towards a new technology including irrigation (Makate et al., 2018; Senapati, 2020; Sepahvand & Shahbazian, 2017). It is postulated that as a person ages, their experience increases based on their exposure, learning and an increase in the sources of information based on incremental formal, informal or social networking. On the other hand, the older a person is, the less willing they become to adopt a new technology or take the risk that comes with such an undertaking (Nielsen et al., 2013). In this regard, younger farmers are often more willing to take risks and adopt new technologies, which has been shown to lead to increased income (Wu, 2022).

The education level of the two main decision makers of the opposite sex in a household was also considered as an important variable of interest in this study. Education was postulated to expose the households to new technologies and make them willing to take risks associated with it (Koundouri et al., 2006; Reimers & Klasen, 2013; Wu, 2022), enable them to build more robust social networks that may enhance irrigation technology use (Hunecke et al., 2017) and improve on other soft skills such as farm management and book keeping that enhance the ability of one to use the resources under their disposal (Möhring et al., 2020). It is postulated that higher levels of education can lead to better access to financial resources, improved access to markets, and better access to credit, which are also key variables in this research. In this respect, evidence shows an increase in agricultural income as education level increases (Awasthi & Bhat, 2016; Tran et al., 2023). On the other hand, a higher level of education among women can lead to increased agricultural production and higher incomes, which can result in greater economic autonomy and empowerment (Anik & Rahman, 2021; Doss, 2018; Mobarok et al., 2021). Research also shows that higher levels of education predisposes one to have better access to nutrition information and consume healthier diets (Fard et al., 2021) including among women (Dunneram & Jeewon, 2015; Hong et al., 2016). Therefore, higher years of learning are postulated to influence not only irrigation but also the type of irrigation a household adapts.

The gender of the household-head was also included as a variable in the study. The definition of a household-head was adapted from Christian et al., (2023) who defined it as “an adult male or

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female who is responsible for the organization and care of members of the household and is considered the head by members of that household”. The inclusion of the gender of the household-head was guided by research that shows that the gender of the household head affects, production diversity (Argaw et al., 2021), farm income (Kandulu et al., 2025; C. D. Smith & Stevens, 1988), women empowerment (Chakrabarti, 2021; Larson et al., 2019; H. J. L. Malapit et al., 2013) and nutrition outcomes (Bezie et al., 2025; Felker-Kantor & Wood, 2012; Gosselin-Pali, 2025; Kairiza & Kembo, 2019; E. Kennedy & Peters, 1992; Sibhatu et al., 2015a),

Household assets are a critical factor to household food and nutrition security outcomes and thus was considered in this study (B. Guo, 2011; Mutisya et al., 2015). A household’s assets holding has been associated with not only long-term food insecurity effects such as low cognitive skills in children but also with the smoothening the household’s food intake as well as reducing the effect of income fluctuations (Guo, 2011; Kainz et al., 2012). Additionally, availability of assets such as land, livestock, and capital can improve agricultural productivity and increase the potential for increased production. Assets give access to improved assets such as mechanized equipment, improved seed varieties, and fertilizers that play a role in improving production, incomes, nutrition and empower women (Barrett & Reardon, 2000; Brück et al., 2019; Quisumbing et al., 2015; Riddle et al., 2023)

One of the clear effects of livestock ownership is on the improvement of nutrition especially through the diversity of diets (Bellows et al., 2020; Gupta et al., 2020). This is especially possible even for poor rural households through the keeping of small livestock such as goats, rabbits, chicken and ducks that provide the households with proteins in the form of milk, eggs, and meat.



Figure 4: Small livestock (goats and rabbits) found among the smallholder farm households
Source: Fieldwork photos

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While, empowering of women in livestock keeping can lead to improved household nutrition (Price et al., 2018), at the same time, livestock keeping can lead to women disempowerment through an increase in labor demands (Bain et al., 2020) or ownership structure (Mwambi et al., 2021; Quisumbing et al., 2015; Ragsdale et al., 2018). In this respect, the variable was also used in the analysis. For this study, the household livestock ownership was measured using the tropical livestock units (TLU) following the work by Jahnke (1982). The TLU uses biomass as reference point for different livestock species with the camel assigned a TLU of 1 per head based on a mean weight of 250 kilograms. Based on the standard weight of the camel, the TLUs per head for the other animals are assigned as 0.8 for horses, 0.7 for cattle and mules, 0.5 for donkeys, 0.2 for pigs, 0.1 for sheep and goats and 0.01 for chicken (Jahnke, 1982; Rothman-Ostrow et al., 2020).

Land access is a critical factor of agricultural production. In this study, it was measured through four variables namely land owned, land rented-in, land rental price and land title holding. These four variables also captured land tenure. The choice of the variables was informed by literature that links food consumption and security to land tenure (Dabara & Chiwuzie, 2022; S. T. Holden & Ghebru, 2016; Maxwell & Wiebe, 1999; Miggiano et al., 2010), and thus the need to include these different aspects of land access was deemed important. Land title holding refers to the property rights aspects of legally owning land while land owned refers to the ability to access the land for productive purposes without a charge. With secure access to land, farmers are better able to invest in agricultural production, and thus increase the quantity and quality of output (Deininger & Ali, 2008; Domeher & Abdulai, 2012; Place, 2009). This, in turn, leads to significant increases in income and nutrition for both men and women (Gillespie & van den Bold, 2017; Pellegrini & Tasciotti, 2014; Van den Bold et al., 2015). On the other hand, land rented-in measures the amount of land that the farmer hired in totality or above the land owned.

The land rental price measures the amount of land per acre that the place the household owns costs annually. The land rental price reference for those who rented-in land was the current price they paid and those who did not rent-in land was based on the current market rental price. While this study is based on cross-sectional data, the land rental rate was included as it captures a base price of land access. In this respect, the standpoint that the rental price reflects the farm values under current land trends was taken (Gutierrez et al., 2007; Ibendahl & Griffin, 2013; Saguatti et al., 2014). In addition, land rental market was also important to this study in that not only did it show that land in any of the irrigation arrangements (farmer-led irrigation, public irrigation scheme and non-irrigating) could be accessed (thus showing that the situation isn't static) but also land rental markets has been suggested as a strategy for development that is efficient and equitable in irrigated areas (Baumann, 2023; Jin & Deininger, 2009; Sadoulet et al., 2001). This is particularly important in irrigation since the land rental price not only captures the price of renting land but also related to irrigation capability such as distance to a possible irrigation water source, ease of water extraction and irrigation and other irrigation related costs (De Fraiture et al., 2014). In this respect this variable takes not only the land leasing market price but also the price of land without irrigation as compared to land with irrigation or irrigation possibility (Berbel et al., 2011). While this is a good aspect of the variable, the study took cognizant of the potential endogeneity (where a dependent variable is correlated with the error term in the model) that it may have as it relates to irrigation. This is especially cognizant of research that shows that the

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irrigation infrastructure revalorizes land rental markets (Baumann, 2023). In this respect, the use of methods that can address this concern of endogeneity were used as discussed in the next chapter.

Household access to credit was also included in the study with the postulation that it does influence whether a household irrigates or not and the choice of the irrigation arrangement. Considering the gender perspective of the study, the primary female decision-maker's access to credit was also included in this study. This was of importance as it is also used as a proxy for the primary female decision-maker's ability to make credit access decision in the household. Even though access to formal financial credit dominates much of credit access in Kenya, in-kind credit is still operational in Kenya. In-kind credit is often preferred especially in instances where technology penetration such as mobile money is low (Berkouwer et al., 2021) and also as a matter of social capital especially between women (Kusimba, 2018). In this regard, in-kind credit was also included in the study with a hypothesis that it positively influences irrigation and due to its social-capital connection and that it influences the irrigation arrangements especially in the sharing of resources (e.g. pump) and also information flow. Credit access also affects nutrition (Annim & Frempong, 2018) and the empowerment of women (Pal & Gupta, 2023).

Household size and the single adult household type were also included in that they are connected to the labor availability and decision making for smallholder farm households. For smallholder farmers, the members of the household are the main source of labor (Gollin, 2014; Mugwe et al., 2009; Tiftonell et al., 2010) thus having implications on production (Ellis, 1993 [pg. 17, 121]; Udry et al., 1995), income (Ellis, 1993 [pg. 139]; Tschirley & Benfica, 2001), women's empowerment (Gladwin et al., 2001; Lado, 1992; Tschirley & Benfica, 2001) and nutrition (Glick & Sahn, 1998; Lado, 1992; Mango et al., 2014).

Non-farm income has been shown to have a considerable effect on household income and production decisions (Barrett et al., 2001; S. Holden et al., 2004) which in this study it is postulated to in turn affect nutrition outcomes. The ability to access extra income outside of the farm in term of finances (or in kind as it replaces the need to spend finances on the items) through credit also affects the households' ability to produce (especially as regard technologies such as irrigation).

The aspect of group membership was included as a measure of social capital and leadership especially as regards women's empowerment. Social capital is an important aspect in rural Africa as it influences the ability to access other important inputs of production including farm inputs and implements and information on new technologies and markets (Kibirige, 2016). The membership of women into groups (community and self-help groups) has also been linked to their empowerment (Brody et al., 2015) but may also lead lower household nutrition as a result of workload and time trade-offs (Cunningham et al., 2015). In addition, membership to community groups for the households as well as the primary female decision-maker was included in the study as an indicator of social-capital linkages, decision making and as an indicator of leadership related to women empowerment (H. J. Malapit et al., 2017)

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Also included in the study is the distance of the household to the nearest piped water for domestic consumption. This is an important variable in this study as it doesn't directly relate to irrigation and its outcomes but also an important component of improvements in water supply and hygiene pathway that links irrigation and nutrition outcomes (Bryan et al., 2019a; Herforth & Harris, 2014b). Additionally, the households' distance from the market was included in the study in order to investigate its interaction with the variables on interests namely production diversity, farm income, women's empowerment and nutrition outcome.

The resulting conceptual framework incorporates the aspect of irrigation and how it is influenced by the households' socioeconomic factors in determining whether a household irrigates or not. In a similar manner, the socioeconomic factors are also investigated on their effects on the type of irrigation arrangement the household adapts; farmer-led irrigation or public irrigation scheme arrangement. The next step, the effect of irrigation and each of the irrigation arrangements on production diversity, farm income, women's empowerment and nutrition outcome are intellectualized while controlling for the individual households' socioeconomic factors. In the last conceptualization, it is hypothesized that the production diversity, farm income and women's empowerment are three potential pathways through which households in the two irrigation arrangements can achieve the desired nutritional outcomes while controlling for the households' socioeconomic factors. In this regard, the resulting conceptual framework is presented in Figure 5.

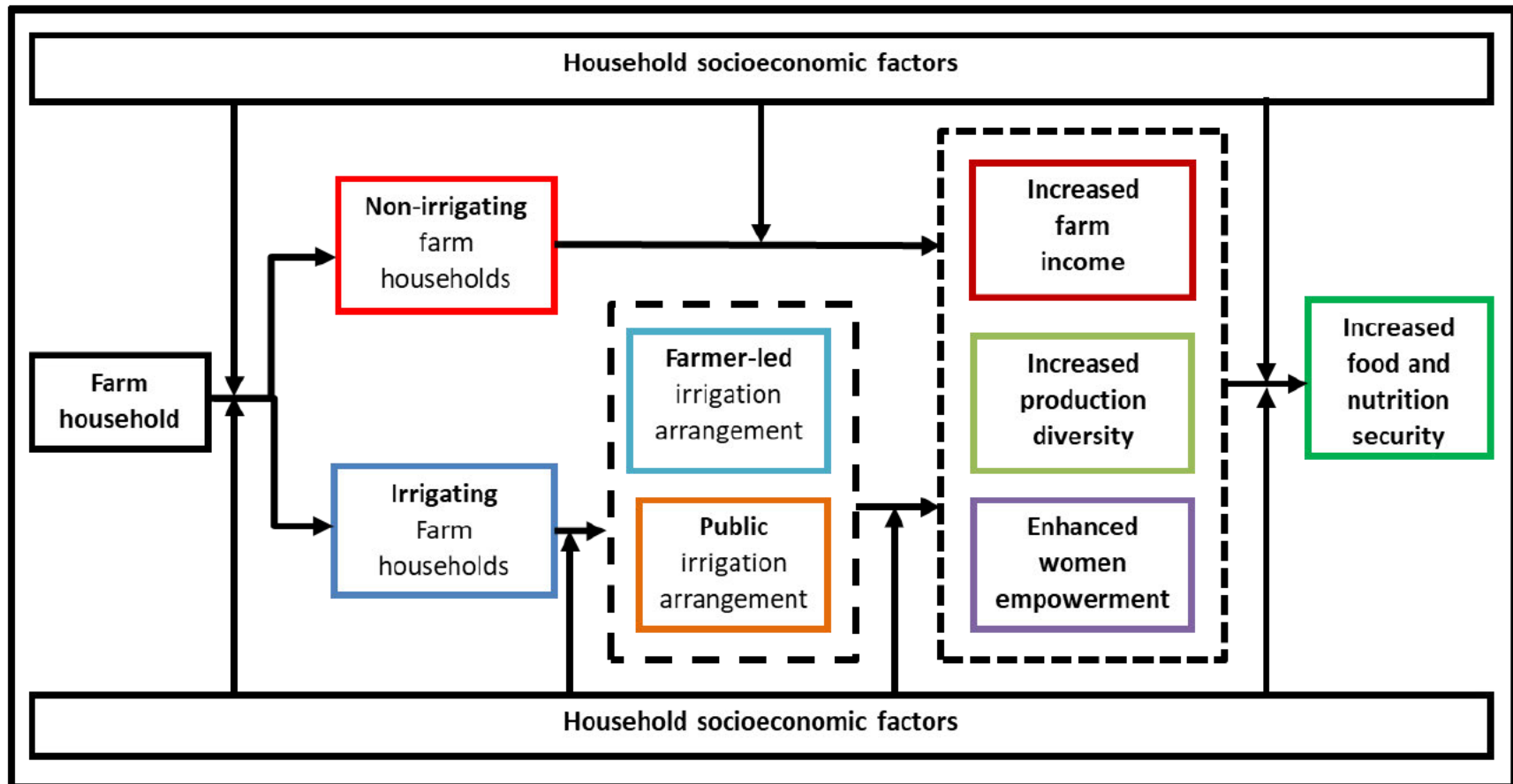


Figure 5: Conceptual framework for the Pathways from irrigation to nutrition.

Source: Author's own conceptualization. Pathways adapted from Herforth & Harris (2014) and Domènech (2015)

3.2. Hypotheses

Having laid out a foundation of the intended study, it was also imperative for the study to have concise hypotheses to be tested. In this regard, in carrying out the study, the following hypotheses were tested:

Hypothesis 1: Households' socioeconomic factors.

Hypothesis 1.1: *Households' socioeconomic factors influence irrigation.* In reviewing the irrigation arrangements, it has been established that they operate under different infrastructural, technological and institutional frameworks. In this regard, it is conjectured that the each of households' unique socioeconomic factors interact differently with these frameworks thus affecting the households' choice to irrigate or not. Therefore, the households' socioeconomic factors are conceptualized to influence irrigation.

Hypothesis 1.2: *Households' socioeconomic factors influence the household's choice of irrigation arrangement.* In a similar manner, the household's socioeconomic factors enable it to interact uniquely with the infrastructural, technological and institutional frameworks. Additionally, these frameworks differ significantly between public irrigation scheme and farmer-led irrigation arrangements which affects the households' interface with them based on its socioeconomic factors. Hence, it is postulated that the choice of the household to irrigate under public irrigation scheme arrangement or the farmer-led irrigation arrangement is affected by its socioeconomic factors.

Hypothesis 2: Production diversity.

Hypothesis 2.1: *Irrigation increases production diversity which in turn increases household dietary diversity.* It is postulated that irrigation helps households to produce across seasons, it therefore leads to the production of a higher number of food groups. In this regard, the irrigating households have a higher production diversity than non-irrigating households. This increase in production diversity enables the household to access a variety of food groups thus leading to better dietary diversity.

Hypothesis 2.2: *Farmer-led irrigation increases production diversity which increases household dietary diversity.* It is conceptualized that households in the farmer-led irrigation arrangement grow crops in response to market demand. Consequently, they grow a larger number of food groups in order to benefit from varying market demand across the seasons. On the other hand, households in the public irrigation scheme arrangement will be less diversified due to monocropping. Therefore, the households in the farmer-led irrigation arrangement will have a have more diversified production as measured by the number of food groups grown. This diversified production increases the number of food groups available to the household and thereby improving the nutritional outcomes of the household members.

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Hypothesis 3: Farm income.

Hypothesis 3.1: *Irrigation increases farm income which leads to a higher dietary diversity in the household.* It is claimed that irrigation allows households to produce across seasons, engage in more intense production by land area and respond to market demand. In this regard, these factors allow access to avenues that increase their farm income. This enables them to access high value foods through the markets thus leading to an increased household dietary diversity.

Hypothesis 3.2: *Farmer-led irrigation increases farm income which increases the household's dietary diversity.* It is hypothesized that farmers in the farmer-led irrigation arrangement grow high value crops in response to market demands. In addition, they are able to have a more cyclically-intense mode of production that enables them to constantly market more products across the seasons. In this regard, it is postulated that this leads to a higher farm income as compared to the to the households in the public irrigation scheme arrangement. In turn, this leads to the ability for them to access a more diversified diet from the markets that improves their nutritional wellbeing.

Hypothesis 4: Women's empowerment.

Hypothesis 4.1: *Irrigation leads to women's empowerment which also improves the household's dietary diversity.* It is hypothesized that irrigation allows women to have greater control over households' resources (productive decisions, assets, credit, income, leadership and time). Subsequently, this access to greater resources lead to a better household nutritional outcome through the application of the mentioned resources in nutritional related engagements.

Hypothesis 4.2: *Farmer-led irrigation increases women's empowerment which increases the household's dietary diversity.* Due to the unique nature of the farmer-led irrigation arrangement (i.e. privately owned or accessed irrigation infrastructure, non-complex technology, and "avoidance" of statutory fees), it is postulated that it allows women to have more control over households' resources as compared to the public irrigation scheme arrangement. This increases access to household resources (productive decisions, assets, credit, income, leadership opportunities and more time through a reduced workload), enables them to invest more on nutrition activities that improves the households' nutritional outcome.

Hypothesis 5: Dietary diversity.

Hypothesis 5.1: *Irrigation positively affects household dietary diversity.* In this research, irrigation is postulated to positively affect dietary diversity due to the linkages given up above. As such, irrigating household are hypothesized to have a higher dietary diversity. This is based on the earlier hypothesized direction of effect in hypotheses 2.1, 3.1 and 4.1.

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Hypothesis 5.2: *Farmer-led irrigation has a greater positive effect on household dietary diversity.* For the irrigation arrangements, it is hypothesized that the households in the farmer-led irrigation arrangement will have a higher dietary diversity. This is based on the earlier hypothesized direction of effect in hypotheses 2.2, 3.2 and 4.2.

Hypothesis 6: Irrigation-nutrition pathways.

Hypothesis 6.1: *The irrigation-nutrition pathways for aggregated irrigation is production diversity, farm income and women's empowerment.* It is postulated that when aggregated, irrigation will lead to increased nutrition outcome through the three pathways; production diversity, farm income and women's empowerment. This is postulated so due to the earlier claim that irrigation leads to an increase in production diversity, farm income and women's empowerment (refer to hypotheses 2.1, 3.1 and 4.1) which sequentially leads to a higher nutritional outcome.

Hypothesis 6.2: *The irrigation-nutrition pathway for the public irrigation scheme arrangement is the income pathway.* For the households in the public irrigation scheme arrangement, it is postulated that the dominant irrigation-nutrition pathway will be the income pathway. This is claimed due to the growing of value crops such as rice by the farmers. While it is expected the households in the public irrigation scheme arrangement to have a lower increase in farm income as compared to households in the farmer-led irrigation arrangement (refer to hypothesis 3.2), it is hypothesized that there will be a significant increase in farm income nonetheless as compared to the plausible comparison group. The reason why production diversity and women's empowerment pathways are not theorized as probable impact pathways is because of such characteristics as monocropping, patriarchy nature of land access, and institutional factors such as memberships to water users' associations (mostly the head of household would be the member and this is often a male member) and statutory fees for access and maintenance of irrigation infrastructure (refer to hypotheses 2.2 and 4.2).

Hypothesis 6.3: *The irrigation-nutrition pathways the farmer-led irrigation arrangement is the production diversity, farm income and women's empowerment pathways.* It is hypothesized that the households in the farmer-led irrigation arrangement will have the dominant nutrition impact pathway as a combination of the three. In this regard, it is claimed that production diversity, farm income and women's empowerment will both lead to an improvement in the nutrition outcome of the household. The claims of the positive effect of farmer-led irrigation arrangement on production diversity, farm income and women's empowerment are discussed on hypotheses 2.2, 3.2 and 4.2.

It is imperative to note that the above statements only give a tentative predicted relationship and direction among the key variables of the study. However, these hypotheses need to be empirically investigated. In the next chapter unpacks how the components therein in these hypotheses were captured and unbundles how they were tested statistically. This includes the processes of variable definition, data collection and analytical methods.

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4.1. Fieldwork and data collection procedures

4.1.1. Introduction

This section of the chapter provides the details on how the data collection for the study was carried out. It lays out the basis on why different data collection methods were applied and their contribution to the study.

The research was undertaken with funding from the German Academic Exchange Service (DAAD) and the Foundation Fiat Panis. The data collection activities in Kenya started on August 2021 with the application of the research license from the National Commission for Science, Technology and Innovation (NACOSTI) and with data collection ending on April 2021. This chapter was inspired by the work done by Petrick (2001) on the “Documentation of the Poland farm survey 2000”.

The main objective of this research was to examine how the different socio-technical irrigation arrangements affect the irrigation-nutrition impact pathways and nutrition outcomes of smallholder farm households in rural Kenya. To achieve this main objective, six specific objectives were drawn in order to ensure a stepwise achievement of this main objective as pointed out in the Chapter One of this dissertation.

With this in mind, the aim of the database was to collect data that is versatile enough to allow both descriptive statistical analysis and economic modelling. As such, it was found necessary to conduct a reconnaissance visit, undertake key informant interviews and focus group discussions before conducting a household survey which is the standard method of collecting data for statistical and econometric inference and modelling.

The total household sample consisted of 384 farm households. The households were drawn from Kirinyaga County, two Sub-Counties namely Mwea East and Mwea West, fourteen Locations, and twenty-seven Sub-Locations. The distribution of the sampled households is given in finer details in a later section of this chapter.

4.1.2. Data collection techniques

This study applied a combination of complimentary methods to collect the data required to achieve the study's objectives. With the literature surrounding irrigation arrangements and its linkages to nutrition being scarce, the first part of the data collection was reconnaissance visit with an aim to establish the presence and distribution of the targeted irrigation arrangements in the area. This was followed by key informant interviews and focus group discussions with farmers in these different irrigation arrangements in a bid to get an in-depth understanding into the irrigation arrangements. The reason for the use of these complementary data collection techniques was to triangulate findings and thus allow for significant inference of the quantitative data by the use of the qualitative information garnered from the reconnaissance visit, key informants' interviews and focus group discussions. The sections below discuss how the methods were used and how they subsequently homogenized into the quantitative data collection tool.

4.1.2.1. Reconnaissance visit

Having reviewed literature on the area, this technique involved getting information through observation and visits to the area of study. In particular, it was essential in identifying the areas with different irrigation arrangements especially for the farmer-led irrigation arrangement for which there is very few documentations in literature on the spread, methods of irrigation and also organization. In this respect, farmers in their fields, villagers and passers-by (see Figure 6 and Figure 7) were asked information on the general information on farming, fees, relationship with authorities, marketing and challenges they face.



Figure 6: Roadside discussions with passers-by

Source: Fieldwork photo.



Figure 7: Visits at the farm households' home and viewing of the ox used for tilling and inspecting the rice product

Source: Fieldwork photo.

In addition, observations were made on the distinguishing factors for the different types of irrigation arrangements including the sources of water, means and technologies of drawing water, modalities of accessing water sources, products produced and places of marketing the produce. This showed the co-existence of the different irrigation arrangements and also the dependence of the farmer-led irrigation arrangement on the infrastructure provided by the public irrigation scheme as shown in

Figure 8Error! Reference source not found..

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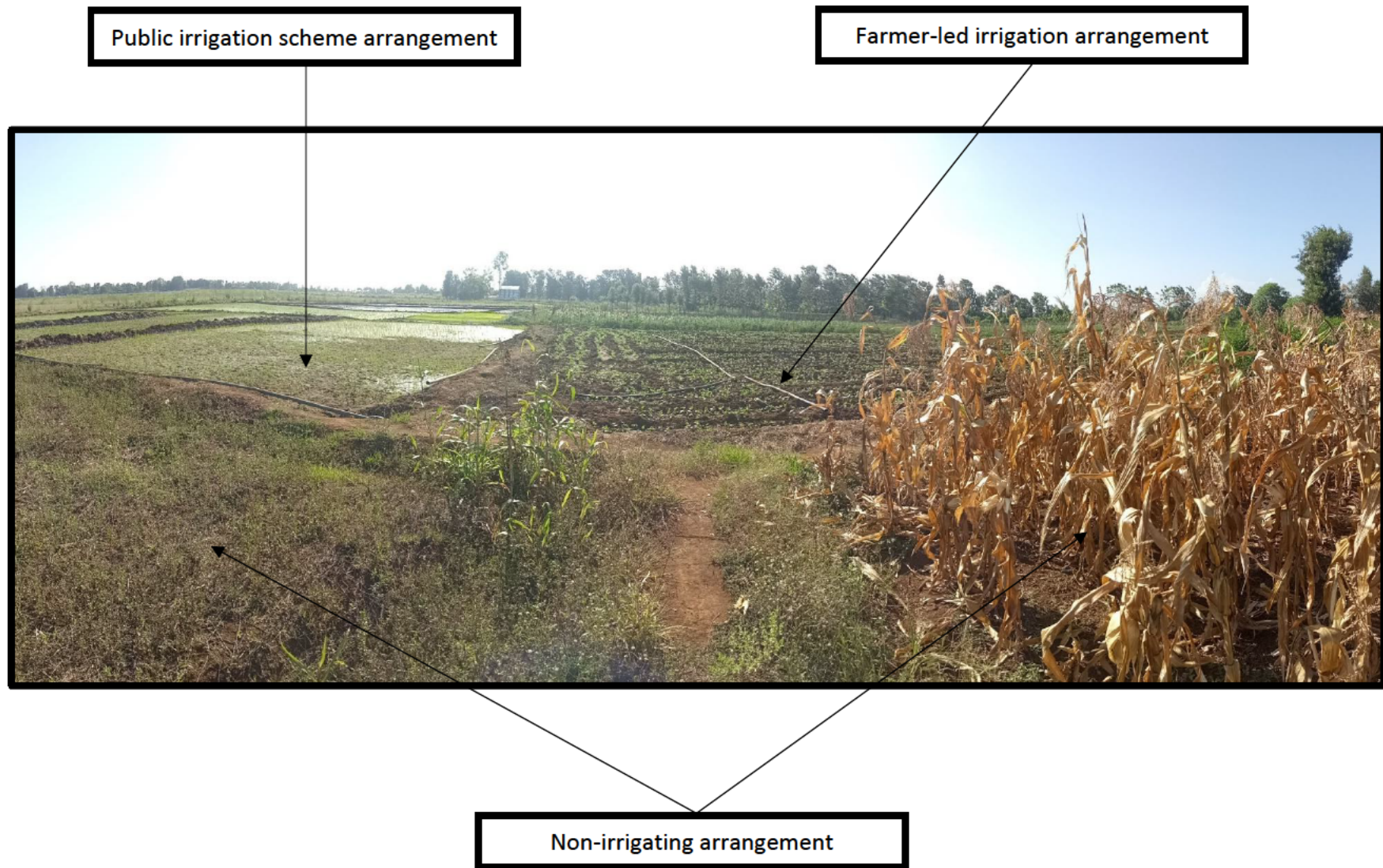


Figure 8: Field observation picture on the co-existence of the three irrigation arrangements
Source: Fieldwork photo.

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These activities were very informative in structuring the necessary authorities and persons who needed to be interviewed and also to get the key contacts of the people with whom the farmers interact with on a day-to-day basis. Additionally, it formed and shaped the areas on which the different irrigation arrangements. In particular, three irrigation arrangements were identified in the area: public irrigation scheme arrangement, farmer-led irrigation arrangement and community-based irrigation schemes irrigation arrangement. However, the community-based irrigation schemes irrigation arrangement was not included in this study. The main reason for excluding the farmers in this irrigation arrangement was in order to avoid having a small sample that cannot be compared as this has been one of the methodological flaws of studies on irrigation and nutrition pathways (Domènech, 2015).

In summary, the reconnaissance visit helped in:

1. To substantially relate the area layout and farming practices in the area to literature;
2. Get key contacts from the farmers for subsequent contact and interviews such as village heads, extension workers and organizations working in the area;
3. Observe the different kinds of irrigation practiced;
4. Narrow down on the target population and area; and
5. Grasp how the farming practices are done in relation to the different farmers' and government agencies.

4.1.2.2. Key informant interviews

After the reconnaissance visit, key informants' interviews were carried out in the area. Irrigation systems especially the ones that are funded by the government involve interaction between different government agencies. Furthermore, after the liberalization of the Mwea Irrigation Scheme, the number of stakeholders increased (Kabutha & Mutero, 2002). It was therefore paramount to get information on how systems work in the scheme before embarking on the data collection. The participants of the key informant interviews were chosen purposively by selecting persons well placed to give insights on the farming practices, irrigation and the community.

In this regard, 16 key informant interviews were carried out with management of the Mwea Rice Growers' Multipurpose Cooperative Society Limited, National Irrigation Board, agricultural extension officers, traders, researchers at Mwea Irrigation Agricultural Development, Mwea Irrigation Development-JICA Project, administration officers (Sub-county Commissioner, Chiefs and Ward officers), Mwea Water Users Association management and farmer leaders in the public irrigation arrangement, farmer-led irrigation arrangement and non-irrigating farmers' households.

Through the key informant interviews, some of the key information obtained was:

1. The history of the public irrigation scheme and the structure of operation;
2. The crops grown in the area of study and the main markets;

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3. Farmer associations and organizations and the fees paid by the farmers per season and/or per year;
4. Marketing of products and pricing;
5. Research done in the area in relation to irrigation;
6. The areas to best conduct the focus group discussions and key contacts of village heads in the areas.

4.1.2.3. Focus group discussions

The focused group discussions were held with farmers who were purposively chosen in the three categories: non-irrigating households, households in the public irrigation scheme arrangement, and households in the farmer-led irrigation arrangement. The participants were gotten with the help of key informants and they included representative members of the villages or sub-groups in the villages. Apart from the key informants, two research assistants from the area were also sourced and they were instrumental in acting as guides in the area.

The information was gathered with the help of a guide which had questions to the participants. However, moderate discussions outside but related to the question guides were allowed. The guide included topics on:

1. Crop production;
2. Livestock production;
3. Irrigation and irrigation arrangements;
4. Land access;
5. Non-farm activities; and
6. Decision making

A total of eight focus groups were conducted with each of the groups having homogeneous participants in accordance to the irrigation arrangements. Two of the focus group discussions included farmers in the farmer-led irrigation arrangement meaning that it consisted of smallholder farmers who irrigate their farms using petrol and diesel pumps. There were also some few farmers who used electric pumps to directly pump water from the rivers.



Figure 9: Smallholder farmers in the farmer-led irrigation arrangement connecting an electric pump in a river

Source: Fieldwork photo



Figure 10: Diesel and petrol pumps used to pump water from the different water sources

Source: Fieldwork photo

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In order to get diverse information, one of the focus groups in this irrigation arrangement comprised of farmers who use a canal by the National Irrigation Board (the canal was primarily targeted to provide water to the Prison Department farm) while the other one comprised of farmers who irrigated using water directly from the Thiba river.



Figure 11: Focus group discussions sessions

Source: Fieldwork photo.

The farmers in the public irrigation scheme were mainly farmers involved in rice farming. One of the focus groups involved farmers who are outside of the gazetted public scheme meaning they are farmers outside the original set area for the public irrigation scheme. This means that they

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have title deeds for their land and also that they sometimes use pumps to irrigate the rice fields due to challenges in water access. The other focus group was from inside the irrigation scheme which means that they have easier water access.

For the non-irrigating farmers, it involved farmers who depend on rain-fed agriculture for their farming activities. For comparison purposes, one of the focus group participants were from the Thiba basin while the ones were from an area under the Nyamindi basin.



Figure 12: Focus group discussions sessions for the different irrigation arrangements
Source: Fieldwork photo.

The other two were done with farmers in a community-based irrigation schemes irrigation arrangement. While this target population household data was excluded from the study, it was found to be enriching to the study to understand the difference in operation of such irrigation arrangements. However, as pointed out, including this irrigation arrangement would spread the sampled households too thinly across the identified categories thus exposing the study to methodological flaws that may give weak, non-generalizable and biased results which are one of the weaknesses associated with small samples in nutrition related studies in literature (Domènech, 2015; Jaenicke & Virchow, 2013; Webb & Kennedy, 2014).

The focus group discussion proved to be essential as an input to the quantitative study by:

1. Timing of the survey as regards the cropping calendar;
2. The challenges faced by farmers in irrigation such as fees;

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3. Make clear pre-conceived notions and findings e.g. peculiar practices noted in the reconnaissance visit such as irrigating at night;
4. Helped in uncovering ideas and issues that were not initially considered;
5. Refining the questions, categories and providing fine tuning details to questions like the list of crops grown;
6. Discover the decision-making process at the household level for different household types (has both male and female decision makers, only a male decision maker, and only a female decision maker);
7. Planning the quantitative data collection especially in targeting of the areas and households; and
8. Diving deeper into issues that came up during the discussions but outside the intended guiding questions.

4.1.2.4. Household survey

With the input from the reconnaissance visit, key informant interviews and the focus group discussions, the first task was to align the quantitative questionnaire to the insights given in these activities. The change to the questionnaire design was so impactful that finally the study had a new instrument from the one that was designed earlier.

The questionnaire consisted of closed and open questions depending on the section. For instance, in the information for the food group diversity indicator, the study adopted an open recall method as opposed to a closed list –based method (FAO & FHI 360, 2016). In the open recall method, the enumerators asked the respondents of the foods consumed with the last twenty-four hours and probes for any snacks or bites taken in between the means. In addition, the enumerators recorded all the ingredients for the dishes and were coded later in the predefined food groups during data management. By doing this, the study obtained much finer consumption data and also enabled the ingredients in mixed dishes to be isolated into specific food groups. As such, the predefinition of the foods into food groups were left to the researcher rather than the enumerator reading a list of foods and beverages to the respondent as used in the closed list-based method.

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Figure 13: Some of the enumerator training sessions
Source: Fieldwork photo.

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The tool was then coded into the Kobo Toolbox® platform to allow for a Computer-Assisted Personal Interviews (CAPI) as opposed to the paper questionnaires. However, there were challenges noted in the tool ability to handle large questionnaires and thus the questionnaire was recoded into the Survey CTO® platform.

Fourteen enumerators were also hired to conduct the survey and trained on how to conduct the survey. Emphasis was placed on the ability to ask the questions in the local language while maintaining the intended responses. In order to ensure this, pre-tests were done with all the enumerators as a training to them and to see whether the tool was well adapted to the local context and then changes to both the questionnaire and the CAPI tool were made.



Figure 14: Enumerator debriefing sessions in the evening

Source: Fieldwork photo

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The final questionnaire collected information on:

1. Demographic characteristics of household members;
2. Land holding in acres;
3. Non-labor purchased input use;
4. Crop utilization;
5. Irrigation;
6. Irrigation pump use;
7. Livestock production and marketing;
8. Access to credit;
9. Labor inputs;
10. Time allocation and decision making;
11. Land markets;
12. Extension and group participation;
13. Group membership;
14. Business and informal labor activities;
15. Salaried wage employment/permanent employment activities;
16. Access to rural savings/bank accounts;
17. Dietary recall;
18. Household food insecurity access scale (HFIAS);
19. Climate change;
20. Cell-phone usage;
21. Household assets;
22. Infrastructure;
23. Storage facilities for staples; and
24. Homestead characteristics.

The quantitative data was collected at household level with the household head being the main respondent. However, with the study having a gendered aspect, the spouse to the household head were also separately collected specifically involving the following:

1. Group membership;
2. Access to credit;
3. Decision on production;
4. Decision on income generation;
5. Access to productive capital; and
6. Time allocation.

In addition, the dietary intake of the household head the spouse was also collected. This involved using a 24-hour dietary recall questionnaire. To allow for data plausibility, this data was collected on two different days in order to account collect data on the normal food intake (Gibson & Ferguson, 2008).

4.1.3. Area of study

Kirinyaga County is one of the 47 Devolved Government Units in Kenya. The County's area is about 1,478.1 square kilometers in size while the altitude is a wide range as it hosts the second highest mountain in Africa with a peak of 5,380 meters above sea level and the lowest level is 1,158 meters above sea level. The population of the County is predominantly rural (about 78%) with about 87% of the population depending on agriculture for their livelihood and the gender composition almost equal comprising of female 308,369 and male 302,011 (Kenya National Bureau of Statistics, 2019; MoALFC, 2021). Of Kenya's Gross Domestic Product (GDP), Kirinyaga's Gross County Product (GCP) contributed about 1.3 per cent. However, the average Kirinyaga County contribution to agriculture, forestry and fishing activities from 2018-2022 was about 2.3 percent and contributes approximately 42 percent of GCP. The County is administratively subdivided into five Sub-Counties; Mwea East, Mwea West, Kirinyaga East, Kirinyaga Central and Kirinyaga West.

The study area lies in two of these Sub-Counties; Mwea West and Mwea East. The two Sub-Counties are demarcated by River Thiba which is one of the sources of the irrigation water for the Mwea Irrigation Scheme with the other source being Nyamindi River. Thiba and Nyamindi rivers are tributaries to the Tana River, Kenya's largest river. Tana river drains which is about 21% of the country's area which is about 126, 026 square kilometers, about 80% of its basin is in the arid and semi-arid area and the rain distribution ranges between 500 milliliters in Lower Tana to 2,400 milliliters in the highlands of Upper Tana but an average of 697 milliliters per year (Paron et al., 2013). However, the study area lies between semi-humid to semi-arid agro-climatic zones with a rainfall distribution of about 600 mm to 1100 mm per year (Mburu 2008). The two rainy seasons run from March to May (long rains) and October to November (short rains) are often not sufficient for growing the crops and therefore irrigation water is used to complement the rains.

The gazette area measures about 12,282 hectares but currently the approximate area under irrigation is 10, 522 hectares comprising of 8,903 hectares for growers in the main scheme and about 1,619 hectares farmed by farmers beyond the gazetted area (National Irrigation Authority, 2019). However, the scheme has the potential to be expanded by another 4, 000 hectares (Emongór et al., 2009; National Irrigation Authority, 2023; Ndiiri et al., 2013). The farmers outside of the gazetted area comprises of farmers who were not in the original area of the public irrigation scheme but have individual title ownership. Therefore this is as a result of expansion of the public scheme's infrastructure and are not subject to some of the regulations of the scheme such as land ownership and also do not have the same level of access of the water (also referred to as 'unplanned' rice growing (Mwangangi et al., 2010). Given these conditions, most of these farmers innovatively use their own resources or pooled-resources to irrigate their fields. Therefore, in this study, it is expected that most of the farmer-led irrigation will be found in the fringes of the irrigation scheme. It is approximated that the scheme has about 7, 022 households and the main crop grown in the scheme is Basmati rice with the scheme producing about 80% of the rice consumed in the country (National Irrigation Authority, 2023; Njagi & Mano, 2022).

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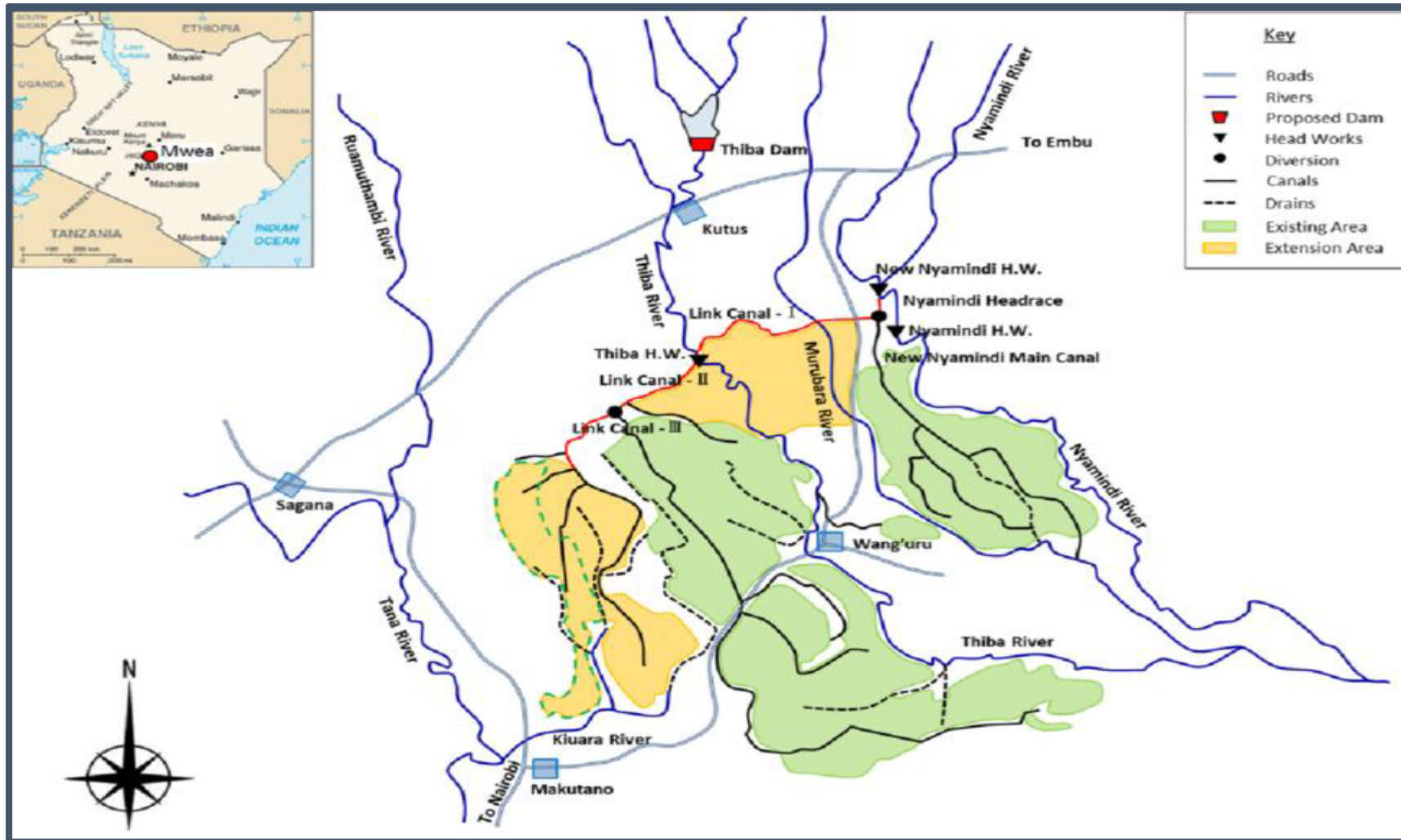


Figure 15: Map of the Mwea Irrigation Scheme showing infrastructure development

Source: Narita et al., (2020)

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The scheme consists of a conveyance system consisting of partially lined canal with the water coming from Thiba and Nyamindi rivers via gravity intake weirs, a distribution system of earthen canals and the main application is the basin or flood irrigation system as commonly used in rice farming (National Irrigation Board, 2018). Due to the availability of the water primarily for the irrigation scheme, the area has also developed as an agricultural region with several irrigation arrangements being common in the area and thus making it ideal for the study (Momanyi et al., 2019; Tomizuka et al., 2019). This existence of different irrigation arrangements (public irrigation and farmer-led), made the area ideal for the study. Tomatoes, onions, French beans, maize and other horticultural crops are also grown but more predominantly in the fringes of the scheme.



Figure 16: An irrigated onion crop using planting pits to conserve water

Source: Fieldwork photo

For most of the horticultural crops grown in the scheme, it is usually during the dry seasons especially in blocks that have water stress, especially the lower section of the scheme (Abdullahi et al., 2003) and thus not able to sustain the large water quantity required for rice farming (Tomizuka et al., 2019). Most of the horticultural crops are grown at the fringes of the irrigation scheme by farmers who access water drained from the main irrigation scheme (Kundu et al., 2017).

[illegible]

4.1.3.1. History of Mwea Irrigation Scheme

Mwea Irrigation Scheme has its inception roots from the colonial times by the British Government. It was started in 1954 using of forced labor from the Mau Mau freedom fighters especially those arrested when a state of emergency was declared in 1952 by the colonial government (Hornby, 1973; Njihia, 1984 cited in Turner et al., 1997; T. E. Turner et al., 1997).

Post-independence, the scheme was subdivided and given to the detainees. However, the ownership of the land remained with the Government while non-transferable land-use rights being reassigned to the detainees with each household being allocated about 1.6 hectares (4 acres) (Kabutha & Mutero, 2002). These land-use rights were limited and under high surveillance and management for they were not only transferable but also the cropping and its sale thereof was dictated by the now defunct National Irrigation Board (NIB) (replaced by the National Irrigation Authority (NIA)). On the contrary, the land outside and around the scheme was bought from the Colonial Government by the Government and resold to farmers as “freehold” land. These lands have title deeds which gives property rights to transfer both the ownership, inheritance and land-use rights (Kabutha & Mutero, 2002; Meijerink et al., 2007).

However, conflict between the NIB and the farmers started shortly after fueled by the curtailing of land-use rights, mismanagement and also political agitations of opposing a one-party state as the country moved to a multiparty government system which was achieved in 1992. With the area referred to as an opposition stronghold in the post-multiparty era, this played a key role in agitating for reforms of the scheme’s management (Brownhill & Turner, 2016; Kabutha & Mutero, 2002). This culminated in violent protests in 1997 fueled by a demand for more secure land rights (both ownership and use rights), alienation of farmers in NIB management, high input cost coupled with low selling prices and a prevailing drought that exacerbated farmers’ discontentment further (Kabutha & Mutero, 2002; Washington-Ottombre & Evans, 2019). This led to restructuring of the scheme’s management in the following year with changes such as the liberation of land use especially on crop choice and transferable landownership (use of allotment numbers though the lands do not have title deeds) (Washington-Ottombre & Evans, 2019). In addition, the Mwea Irrigation Scheme Water Users Association was formed to manage the scheme including the upkeep of tertiary canals while the NIA maintained the primary and secondary canals. Such changes in management and operation of Mwea irrigation scheme was similar to other reforms in SSA (Aarnoudse et al., 2018).

This “liberalization” of the scheme led to an expansion of the scheme as the farmers in the freehold land accessed water through extension of tertiary canals, pumping or siphoning water from the scheme’s canals or from the rivers traversing the scheme. Some of these farmers were incorporated in the scheme and they pay membership fees to the Mwea Water Users Association but a substantial member relies on their individual or group investments in water access technologies such as pumps to access irrigation water. In addition, the ability to transfer land use and ownership rights expanded the land market and enabled the ability of the farmers to choose farming in side of outside the irrigation scheme.



Figure 18: Pipes siphoning water from a canal for irrigation

Source: Fieldwork photo

4.1.4. Sampling design

4.1.4.1. Sampling procedure

For the construction of the sample, it was necessary to take into consideration the financial limitations and also the need to have precision and representation of the irrigation arrangements of interest which were farmers in the farmer-led irrigation arrangement, farmers in the public scheme arrangement and non-irrigators who act as the control sample in the impact analysis. In this regard, Mwea East and Mwea West were purposively chosen for the study as they are the two sub-Counties that host the Mwea Irrigation Scheme. The area was also chosen due to the availability of these arrangements. Households East of Nyamindi River were not included in the study due to the presence of several smallholder irrigation schemes funded by the donor community and excluded from the study as earlier discussed in Section 2 of this document.

In addition, the smallholder irrigation schemes and private commercial irrigated farms were also excluded from this study in a bid to overcome analytical limitations facing agriculture and nutritional studies associated with sampling challenges. One such limitation is the lack of vigorous and solid study designs and survey methods that give weak results that cannot be generalized and the nutrition effects remain hidden (Jaenicke & Virchow, 2013; Webb & Kennedy, 2014). In addition, sampling methodological flaws such as small samples, sampling bias such as self-selection and having an inadequate control sample for comparison has been identified as one of

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the reasons for an understudy of irrigation pathways to nutrition (Domènech, 2015). Given the above reasons and considering the limitations associated with the study time and financial resources, the study sought to overcome these challenges by having a sufficiently large and heterogeneous sample size of the farmers in the two irrigation arrangements as well as farmers who are not irrigating to act as a comparison.

In this regard, Kirinyaga County and subsequently Mwea East and Mwea West Sub-Counties were purposively chosen due to the availability of public water irrigation facility and the subsequent infrastructure. The presence of a public irrigation scheme also provided a good network of canals, overflow channel and drainage lines that are suitable for water provision from other forms of irrigation arrangements. The presence of the two rivers also provided another source of water for irrigation. The map of the study area is shown in as the study area as shown in Figure 19. This was informed by the presence of the Mwea Irrigation Scheme as well as the unique features of the Scheme as discussed earlier in Section 4.13 of this chapter on the “Area of the study”.

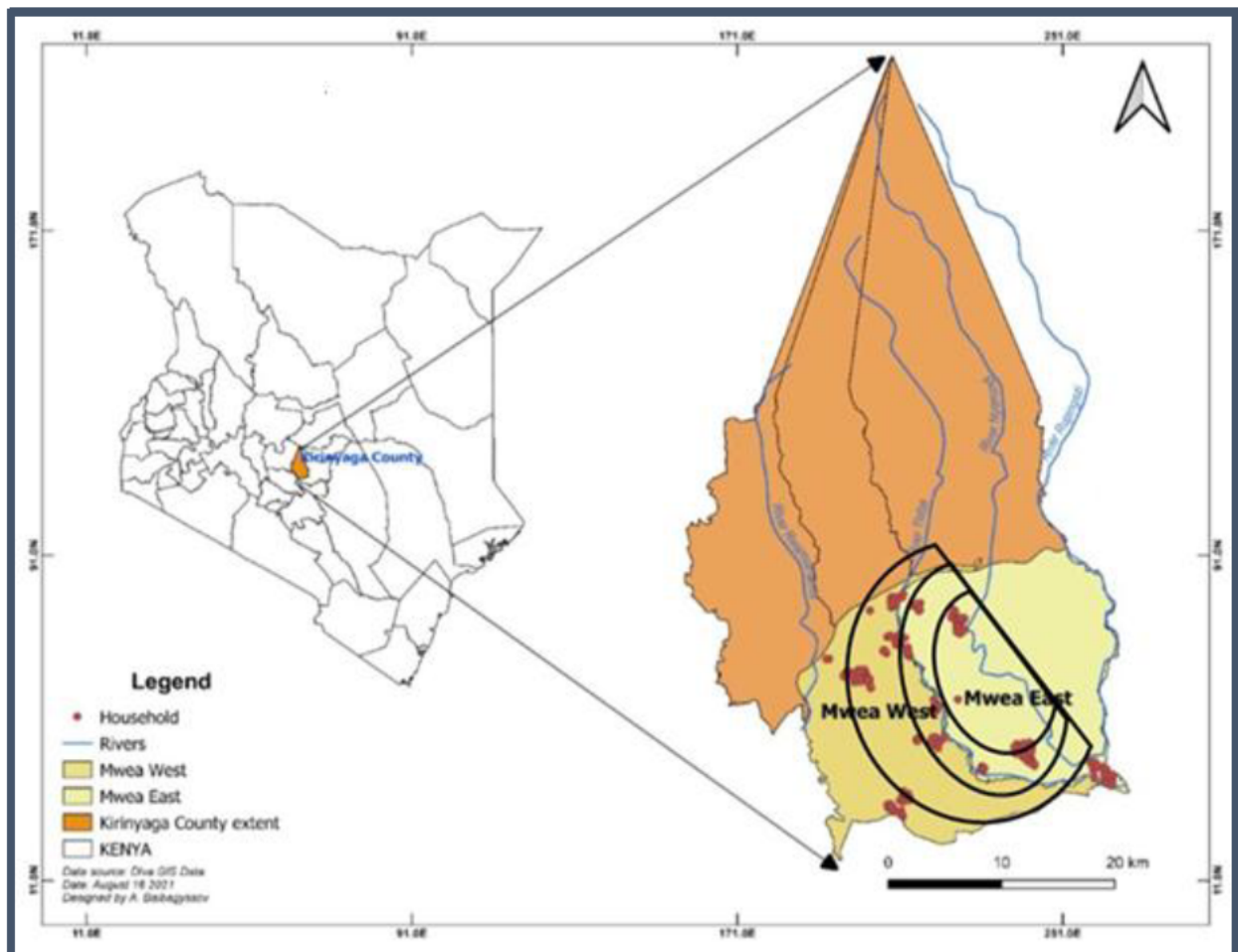


Figure 19: Administration map of the area and the sampled households

Map design: Azim Babagyssov

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With the information gathered from the reconnaissance visit, key informant interviews and the focus group discussions, the area was split into three semi-circular strata. The strata were based on the distance from this river that also has the headway to the main one of the headways of the main canal. In addition, the area East of Nyamindi acted as the boundary to the semi-circles with the area removed from the sample as discussed earlier. This was deemed necessary so as to have a good distribution of farmers in both the public scheme irrigation arrangement, farmer-led irrigation arrangement and non-irrigators. This method was deemed fit over a simple random sampling in getting the precision needed to have a sufficient sample in these different irrigation arrangements that allows for comparative analysis as illustrated in (Deaton, 2019, p. 13).

However, even if the study needed a sample that can be comparable as regards irrigation arrangement, with water resources being a key factor in irrigation (or rather the basic substance), following the basin of these rivers or the subsequent canals in the irrigation system would produce a biased sample. In this respect, the administrative subdivisions consisting of Sub-Counties, Locations and sub-locations in these three stratified areas based on distance were chosen in random. The distribution of these administrative divisions and the sample size in each area is shown in Table 7. From a list of seventeen locations derived from the Sub-County Commissioner, fourteen were chosen randomly in the stated semi-spherical stratified areas. In these Locations, there was a total of thirty-seven Sub-Locations from which twenty-seven Sub-Locations were randomly chosen.

At the Sub-Location, households from seventy-five villages were chosen randomly. However, at the village level, there lacked a list of all households in a village. As such the study used a list of existing security grouping of ten households referred to as “nyumba kumi” as a sampling frame. In each village, farmers were chosen in their groupings randomly with replacement if the chosen household was not available.

“Nyumba kumi” literal translation from Swahili means ten households, It is a Community Policing strategy that primarily works at household level (Brown et al., 2016; National Police Service, 2017; Ndonso et al., 2019). The concept brings ten households together to foster a safer neighborhood. Having the key variables of clustering these households as security reasons based on physical proximity made this grouping ideal for sampling as they are not in any way related to farming practices especially irrigation and also were representative of the community. In addition, with the households in the villages not having a distinct home address, these groupings provided a much-needed list for random sampling. Therefore, households were picked from these security groupings in the village selected. Despite field visits and questionnaire testing by the enumerators, households were sampled regardless of their irrigation arrangement with the classification of the arrangements left to the researcher as opposed to the enumerators.



Figure 20: Field visits during enumerator training

Source: Fieldwork photo

4.1.4.2. Sample size

Following the work by Cochran (2007) and Israel (1992) three critical factors were considered in calculating the sample size of this study; level of precision, confidence level and degree of variability. The level of precision or sampling error gives the range for the estimation of the real values of the population. In this respect a value above or below the level of precision is accepted as representing the range of the true value of the population (in the different irrigation arrangements). Based on the Central Limit Theorem, the confidence level gives the percentage of the sample values that will be within the range of the level of precision. As such it gets higher as it nears 100%. The degree of variability refers to the distribution of attributes in a population.

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The more the population is varied the larger the sample size. However, this gives that 50% is the largest level of variability as it gives the largest number of the population with or without an attribute.

With the option of doing a census being financially impossible, the other way of determining the sample size would have been using prescribed published tables for sample calculation. In this method, one needs to know the actual distribution of the population with the attributes of interest, in this study the households in the two irrigation arrangements and non-irrigators in the area. However, this information was not available especially with the farmer-led irrigation arrangement being an arrangement missing even in the country's policy documents. In addition, while published tables, like the ones by Yamane (1967), give the estimation of the sample size based on the level of precision, it does not offer a researcher the freedom to define the level of confidence.

Therefore, with the three key criteria deemed important for the research, the study adopted the sampling formula by Cochran (1963) to get the appropriate sample size for the study. The formula is defined as:

$$n_0 = \frac{Z^2 pq}{e^2}$$

Where n_0 is the total sample size, Z is the z-value from the Z table and represents the area under a normal curve, p is the approximated proportion with the desired attribute, q is equal to $1-p$ and e is the margin of error or the desired precision level. Since the proportion of households in this area under the two irrigation arrangements and non-irrigators was unknown, the study assumed the maximum level of variability of 50%. The normally recommended level of confidence of 95% was adopted and a precision level of 5%. This then gave a total sample size of 384 smallholder farm households calculated as shown below:

$$n_0 = \frac{Z^2 pq}{e^2} = \frac{[(1.96^2)(0.5)(0.5)]}{0.05^2} = 384$$

Equation 4: Sample size formula

The distribution of the sample in the administrative sections discussed earlier is shown in Table 7. The table begins at the Sub-County level to the Sub-Location level.

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Table 7: Distribution of the samples across the administrative sections in the study area

Sub-County	Location	Sample size per location	Sub-Location	Sample size per sub-location
Mwea West	Kinyaga	4	Muthigi	1
			Kiunga	3
	Makutano	30	Kirwara	5
			Kiandegwa	25
	Mutithi	31	Kiamaciri	16
			Kianjogu	15
	Thiba	32	Kiratina	24
			Mbui Njeru	8
	Kangai	40	Komboini	10
			Mathigaini	30
	Kathiga	43	Karikoini	4
			Mbeti	39
	Nguka	8	Karira	8
	Sub-total			
Mwea East	Thiba	2	Kiratina	2
	Tebere	30	Muthigi	2
			Kiamaciri	1
			Wanguru	14
			Nderwa	13
	Kiarukungu	53	Muthigi	1
			Mikimaini	26
			Kiumbu	26
	Gathigiriri	39	Gathigiriri	39
	Nyangati	54	Mathangauta	4
			Kimbimbi	50
	Kirimara	4	Kirimara	4
	Kutus	14	Kithiriti	11
			Kamaigua	3
Sub-total				196
Total				384

Source: Author based on fieldwork survey

4.1.5. Calculation of key variables

In this section, a discussion on the key variables is given. While the study does use many socioeconomic, institutional and farm characteristic variables, there are five main variable that are fundamental. These are dietary diversity, income, production diversity, abbreviated women's empowerment in agriculture index and irrigation. This section discusses these variables, the justification for using them and the manner in which they were constructed and used.

4.1.5.1. Dietary diversity

With the construction of a proxy for nutrition being a paramount component of this study, careful precision in the capturing of this variable was taken into consideration. In order to have a plausible measure of nutrition, the 24-hour dietary recall method was used in collecting the dietary intake data. The 24-hour dietary recall method collects an individual's diet on the type, quantity, ingredients and preparation of the food and drinks taken in the last 24 hours (Gibson & Ferguson, 2008). This included collecting data on foods and drinks consumed over the previous 24 hours including any meals taken outside normal meal times such as snacks while probing about the food or drink components particularly the ingredients and other aspects such as preparation method and quantity. This kind of data collection has been shown to be robust to measure nutrient and food groups intake and diet patterns (Gibson et al., 2017).

In assessing diet intake, seasonality is of importance. In this regards, it is needful to note that there are two main rainy seasons in the area: short rains in October and November and long rains from March to May with irrigation water supplementing these rainy seasons (Narita et al., 2020; Samejima et al., 2020). In this regard, to reduce any errors and also ensure that the data reflects the normal intake of the sampled households (Gibson et al., 2017; Gibson & Ferguson, 2008), the data was collected in two different days at the beginning (before the onset of the long rains) and end (during the long rains) of the data collection period a while avoiding non-normal days such as festivals, celebrations and Sundays. The timing and administering of the 24-hour dietary recall questionnaire was aimed at not only ensuring the capturing of true and robust data but also designed to reduce any seasonality bias of dietary diversity between the irrigating and non-irrigating farmers given that this is a cross-sectional study.

Dietary diversity is the number of different food types if different food groups consumed within a specified reference period (G. Kennedy & Ballard, 2011; Ruel, 2003b). Over the years, dissimilar approaches to measuring and validating dietary diversity have been developed. Key among them is the household dietary diversity score which has 12 food groups consumed over the last twenty-four hours (G. Kennedy & Ballard, 2011; Swindale & Bilinsky, 2006) and the food consumption score with eight food groups over a seven day recall period (WFP, 2008). There is also the minimum acceptable diet and minimum dietary diversity both having eight food groups taken over a twenty-four hours period (WHO, 2010, 2017). The women dietary diversity score consists of 9 food groups consumed over a twenty-four hour period but it was superseded by the minimum dietary diversity for women (MDD-W) which has ten food groups eaten over a twenty-four hour period (FAO & FHI 360, 2016; G. Kennedy & Ballard, 2011). However, the MDD-W while it classifies food groups into the ten food-groups, it is often used as a dichotomous measure that indicates if a women of productive age (between 15 and 49 years) consume at least five of the food groups (FAO, 2021a). However, in this study, while the classification of the food-groups was done as per the guidelines given for MDD-W (FAO, 2021a; FAO & FHI 360, 2016), its application was not based on the simple dichotomous measure (yes or no) of consuming the five food-groups. Therefore, a key distinction made in this study, is that while the groupings of the food follows the MDD-W framework, the dietary diversity was taken at individual level and for the primary female decision maker was taken. Thus, while the framework for the MDD-W was used,

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the study adopts the simple term of dietary diversity in order not confuse the readers with the dichotomous measure used in the afore-mentioned framework.

While coming up with the necessary diet to achieve the needed nutrition threshold is a multifaceted concept, having a diverse diet comprising of varied food groups is indorsed as a viable approach to improving nutrition (including micronutrient nutrition). By consuming a diverse diet, consumers are able to sustain the intake of healthy food as nutrient rich food groups are added in the diet (Arimond & Deitchler, 2019; FAO, 2021b). In addition, dietary diversity has been strongly associated with intake of adequate nutrients including better development of children in developing countries even in instances where differences in socioeconomic factors are accounted for (Ruel, 2003a). Evidence from a cross country analysis of ten nations showed that dietary diversity is linked to both the consumption and energy availability thus making it a good proxy of food security especially when defined in terms of energy availability (Ruel, 2003a).

As such, a key question arises as to why the study used the MDD-W food-groupings. Consisting of ten food groups, the MDD-W is a stricter measure of dietary diversity designed to capture the micronutrient adequacy of women of productive age which is one main aspect of diet quality. The MDD-W targets women of reproductive age are targeted due to their requirement for more nutritious foods due to the biological and physical susceptibility related to factors such as breastfeeding and pregnancy (Black et al., 2013; Torheim & Arimond, 2013). This nutrition vulnerability predisposes women of reproductive age to a higher nutrition need compared to men of the same age category as well as developmental health risks to them and their infants (Arimond et al., 2010; Branca et al., 2015; Cusick & Georgieff, 2016; Lee et al., 2013; Martin-Prevel et al., 2017). However in most developing countries, the diets are not diverse but rather consists of repetitive starchy staples that do not meet the micronutrient threshold needed (Arimond et al., 2010; Lee et al., 2013; Martin-Prevel et al., 2017).

As such, MDD-W was designed as a measure that enables researchers to capture the nutrition intake of not only the main food groups but also micronutrients intake. By acting as a proxy for micronutrient adequacy, MDD-W captures this important aspect of diet quality unlike the other measures of dietary diversity. In this regard, the indicator has been robust in this measurement and using datasets from six countries, MDD-W had been shown to be measure of 11 nutrients which are iron, calcium, zinc, thiamine, riboflavin, niacin, folate, vitamin A, vitamin B-6, vitamin B-12 and vitamin C (FAO, 2021).

With the MDD-W going beyond being a stricter measure of dietary diversity energy availability by capturing the nutrient adequacy (especially micronutrients intake) of women of productive age, it was deemed to be a better fit for a proxy for nutrition in this study as compared to the other dietary diversity classifications. In its construction of the indicator, using the data from the questionnaire, the different foods and beverages were placed in these ten pre-defined food groups shown in Table 8 below adapted from the Food and Agriculture Organization of the United Nations (FAO, 2021a).

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Table 8: Aggregation of the different food types into food groups for construction of the MDD-W indicator

Food types	Food groups
A. Foods made from grains	1. Grains, white roots and tubers, and plantains
B. White roots and tubers and plantains	
C. Pulses (beans, peas and lentils)	2. Pulses (beans, peas and lentils)
D. Nuts and seeds	3. Nuts and seeds
E. Milk	4. Milk and milk products
F. Milk products	
G. Organ meats	5. Meat, poultry and fish
H. Red flesh mammal's meat	
I. Processed meat	
J. Poultry and other white meats	
K. Fish and seafood	
L. Eggs	6. Eggs
M. Dark green leafy vegetables	7. Dark green leafy vegetables
N. Vitamin A-rich vegetables, roots and tubers	8. Other vitamin A-rich fruits and vegetables
O. Vitamin A-rich fruits	
P. Other vegetables	9. Other vegetables
Q. Other fruits	10. Other fruits

Source: Food and Agriculture Organization of the United Nations (FAO, 2021a)

Given that some foods are composite in nature, information on the individual ingredients was also collected. However, in favor of accuracy in ensuring that an adequate amount of the specified ingredients was consumed and given that the adequacy of the amounts needed in servings was not possible (foods weights measurements not taken), small quantities were excluded (Arimond et al., 2010; FAO, 2021a; Gewa et al., 2014; Martin-Prével et al., 2015). Therefore, all ingredients were only included as consumed if they exceeded a tablespoon (approximately 15 grams) which is a standard cut-off point in most studies especially relating to micronutrient adequacy (FAO, 2021a).

Each of the ingredient was then placed in the food types and then each coded in the food groups. As such, for each of the food group a dummy code of zero was assigned if the respondent did not take foods in the particular food group and one if they did. A summation of the scores was then done thus producing a score ranging from 0 to 10. However, as mentioned earlier on, in this study a cut-off point of 5 points was not adopted. This was to achieve a continuous index rather than a dummy variable of the people below and above the five cut-off points (FAO, 2021a). As such, the higher the dietary score, the more diverse the diet and the better nutrition adequate a diet was (FAO, 2021a; Martin-Prével et al., 2015).

4.1.5.2. Income

Income calculation and analysis is one of the most common variables of analysis in agricultural economics and rarely would a quantitative study touching on socioeconomic aspects lack it. However, as simple a variable as it sounds, it does not have a single viewpoint. Following in the work by Hill (2018, p. 3) and Finger & El Benni (2021), the study considered two views of income. The first view is that income is the value generated from the factors of production such as land, capital and labor. In this way, it looks at the profits and surpluses from the farm to the other sectors. The other view of income is from a farm-household-level standpoint where the income of the farm household determines the consumption of the household. With this study taking the household as the unit of analysis, the second viewpoint was chosen in defining the income.

By taking the farm-household-level perspective, both farm and non-farm income were considered. While there has been a view that rural farm households' focus on farm activities, mounting evidence has shown that non-farm income is a critical component of farm households' income (Davis et al., 2017; Musumba et al., 2022; Nziku & Struthers, 2021; Reardon et al., 1998). But with the study focusing on farm activities as the main source of livelihood for the farm households, not isolating non-farm income from the households' income would lead to a misguided judgement and also policy recommendations. In addition, as pointed out in the conceptual framework, this study presupposes that farm income as an intermediate factor between irrigation and nutrition. In this regard, it was imperative to separate non-farm income from the households' total earning so as to ensure that the analyses results are plausible in accordance to the study's objectives.

In calculating the farm income, farm sales comprising of crop sales, sale of livestock and livestock products was calculated from the farmers' responses. In this regard, it is of importance to note that the reference to farm income in this study refers to the gross amount and not the net. On the other hand, the non-farm income was calculated by adding income from activities such as business, wages, salary and remittances. The inclusion of remittances in the calculation of the non-farm income was informed by growing evidence of the inclusion of remittances in the rural agricultural households in Africa. Remittances are also an important predictor to agricultural labor productivity and food and nutrition security, and other household expenditure patterns (Ajefu & Ogebe, 2021; Aryeetey & Isinika, 2010, pp. 153 and 207; Djurfeldt, 2015; Gupta et al., 2009; Sulemana et al., 2019; Wonyra & Ametoglo, 2020, 2020) which are important variables and parts in this study.

The total household income was an aggregation of the farm and non-farm income. For comparability purposes in subsequent studies, the income was converted into United States Dollar equivalent. The Dollar rate used was the mean of the Central Bank of Kenya's indicative exchange rates from 1st February 2020 to 28th February 2021 which covered the data collection reference period.

4.1.5.3. Production diversity

The measure of which a farm's production is diversified in literature has been measured in several ways. Biodiversity indicator and genetic diversity indicator are one of the ways of measuring production diversity (Ayenew et al., 2018; Di Falco & Perrings, 2005; Smale et al., 1998). The former looks at the number of species in an environment while the latter looks at the number of genes within each specie in the environment. Both of them take a sum of the outputs in the farm's production output (Ayenew et al., 2018). The other approach is to aggregate of all the farm's food types into unique food groups (Ayenew et al., 2018). This study employed this aggregation method as it better fits into the studies purpose has as given that this method gives the ability to measure the contribution of the aggregated food types into the dietary diversity indicator (Ayenew et al., 2018).

However, while the aggregation method was selected, the principal concern remained the methodology to be employed to classify food types into their respective food groups. Motivated by the studies 'objectives, several researches have used different food groups in coming up with a production diversity index in relation to the dietary diversity index (e.g. Ayenew et al., 2018; Jones et al., 2014; Muthini et al., 2020; Sibhatu et al., 2015). However further analysis and publications have shown that in associating the diet of a household to its production, a measurement of the production diversity and dietary diversity under the same food grouping gives better plausible analysis especially for rural subsistence farm households that primarily consumes food produced in the farms (Berti, 2015; Sibhatu et al., 2015b). The use of the same category for production and dietary diversity also gave the study the advantage of accounting for crop and livestock production in the households as well as their related products (Berti, 2015; Koppmair et al., 2017).

As such, in this study, the production diversity is measured as the variety of crops, livestock and livestock products on the farm in the period of reference (12 months). To make the production index more robust and plausible, the study overcame the double counting a specie twice (e.g. cow and milk production) by using the same groupings as MDD-W given in the earlier section as well as only including products produced in the period (i.e. the ownership of a cow does not equal milk production unless there was milk production recorded in the reference period).

4.1.5.4. Abbreviated Women's Empowerment in Agriculture Index

Adapted from the work by Dimitrievski et al., (2019), women's empowerment in this study means increasing the personal, political, social or economic strength of women. The inclusion of women's empowerment has become an integral part of microeconomic analysis literature due to its connection to economic development and mainly focusing on political, social, psychological and economic spheres (Fox & Romero, 2017).

There are many measures of women's empowerment that vary depending on the discipline and the intended use and outcome. In this study, the Abbreviated Women's Empowerment in

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Agriculture Index (A-WEAI) is used as it fits the domain of the study (women in agriculture) and due to its ability to capture the different aspects of empowerment as discussed hereafter.

The A-WEAI is a successor of the Women's Empowerment in Agriculture Index (WEAI) intended to capture women's inclusion and empowerment in the agricultural sector and designed by the International Food Policy Research Institute (IFPRI), the Oxford Poverty and Human Development Initiative (OPHI), and the U.S. Agency for International Development (USAID) (Alkire et al., 2013). The A-WEAI has the advantage over the WEAI in that it is a shorter and more streamlined. Just like the WEAI, the A-WEAI is a standardized measure of women's empowerment in five domains: agricultural production decisions; access to, and decision-making power over, productive resources; control over use of income; leadership roles within the community; and time allocation (H. J. Malapit et al., 2017). The first three domains on production, resources and income are related to economic empowerment, while leadership and time allocation relay to decision making and representation and equitable workload balance.

The advantage of the A-WEAI over other indexes is in its ability to monitor and show gender equality at by showing the agency and empowerment profiles of women and men at an individual level and household level (Alkire et al., 2013). By having the household as the unit of analysis, the index was appropriate to the study especially since it has domains that are also related to the other three key variables. This makes the research output of the study more applicable to policy interventions since the tool has been validated. It was thus an endeavor of the study to use the A-WEAI discern how irrigation and different irrigation arrangements have an impact on women empowerment (Alkire et al., 2013; Dimitrievski et al., 2019).

Following the works by Alkire et al., (2013) and the instructional guide by (H. Malapit et al., 2015), the indicators, cut-off and weighting of the five domains are shown in Table 9. The summation thus gave the weighted proportion of dimensions in which an individual has attained empowerment.

Table 9: Domains, questionnaire variables, cut-offs, and weights in the construction of the A-WEAI

Domain	Indicator name	Inadequacy cut-off	Weight
Production	Input in productive decisions: • Food crop farming, • Cash crop farming, • Livestock raising, • Fish culture	▪ Inadequate if individual participates BUT does not have not at least some input in decisions; or she does not make the decisions nor feels she could.	1/5
Resources	Ownership of assets • Agricultural land, • Large livestock, • Small livestock, • Chicks etc.;	▪ Inadequate if household does not own any asset or if household owns the type of asset BUT she/he does not own most of it alone	2/15

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Domain	Indicator name	Inadequacy cut-off	Weight
	• Fish pond/equip • Farm equip (non-mechanized) • Farm equip (mechanized) • Nonfarm business equipment • House • Large durables • Small durables • Cell phone • Non-agricultural land • Transport		
	Access to and decisions on credit	▪ Inadequate if household has no credit OR used a source of credit BUT she/he did not participate in ANY decisions about it	1/15
Income	Control over use of income • Input in decisions on the use of income generated from: Food crop, Cash crop, Livestock, Non-farm activities, Wage& salary, Fish culture? • Extent one can make your own personal decisions regarding: non-farm economic activities, own wage or salary employment and major and minor household expenditures?	▪ Inadequate if participates in activity BUT has no input or little input in decisions about income generated, or does not feel she/he can make decisions regarding wage, employment and major household expenditures	1/5
Leadership	Group membership • Membership to any group	▪ Inadequate if is not part of AT LEAST ONE group; inadequate if no groups reported in community	1/5
Time	Workload • Worked more than 10.5 hours in previous 24 hours.	▪ Inadequate if works more than 10.5 hours a day	1/5

Source: Adapted from (H. J. Malapit et al., 2015)

4.2. Econometric analyses

4.2.1. Analytical procedures

After laying out the data collection procedures in the last section, the task ensues of how to use the data in answering the specific objectives of this study outlined in Chapter One of this dissertation. This research uses an econometric analysis that can be broken down into four econometric processes that follow the logical flow of this study's objectives. In the first analysis, a binary approach is used to look at the factors that affect irrigation arrangement. For this analysis, a probit regression was used. However, given that the study's main claim is that irrigation is disaggregated, a second analysis based on a multinomial logit regression is applied. The multinomial analysis allows for the simultaneous analysis of the irrigation arrangements while using the non-irrigators as the base outcome.

However, it is preempted that the reader may be inquisitive as to why the study found it necessary to lump irrigation and irrigation arrangements in a binary and multinomial analyses. The main reason of using these two analyses was to investigate the socioeconomic factors inherent in the households that affects irrigation and irrigation arrangements. In this way, the results of these analyses provide a building blocks of the ensuing analyses in order to gain a more nuanced understanding of the irrigation-nutrition pathways as well as how irrigation eventually affects nutrition.

The study then embarks on looking at whether irrigation and irrigation arrangements have an effect on the production diversity, farm income, women's empowerment and the envisaged nutrition outcome (captured through dietary diversity). This is particularly important as it gives the ability to quantify these effects thus providing key empirical evidence in research and policy. In order to achieve this, a propensity score matching approach is applied as the third analysis.

In the last analysis, the study applied a three stage least squares analysis to investigate the irrigation-nutrition impact pathways for irrigation and irrigation arrangements. In following this flow of econometric analysis, the study sought to answer questions that may arise on the why irrigation analysis should be approached as disaggregated based on the factors affecting them, the overall impact they have on the irrigation nutrition pathways, and the difference in the impact pathways. Figure 21 shows the order of the econometric analysis in respect to the conceptual framework presented in Chapter Three.

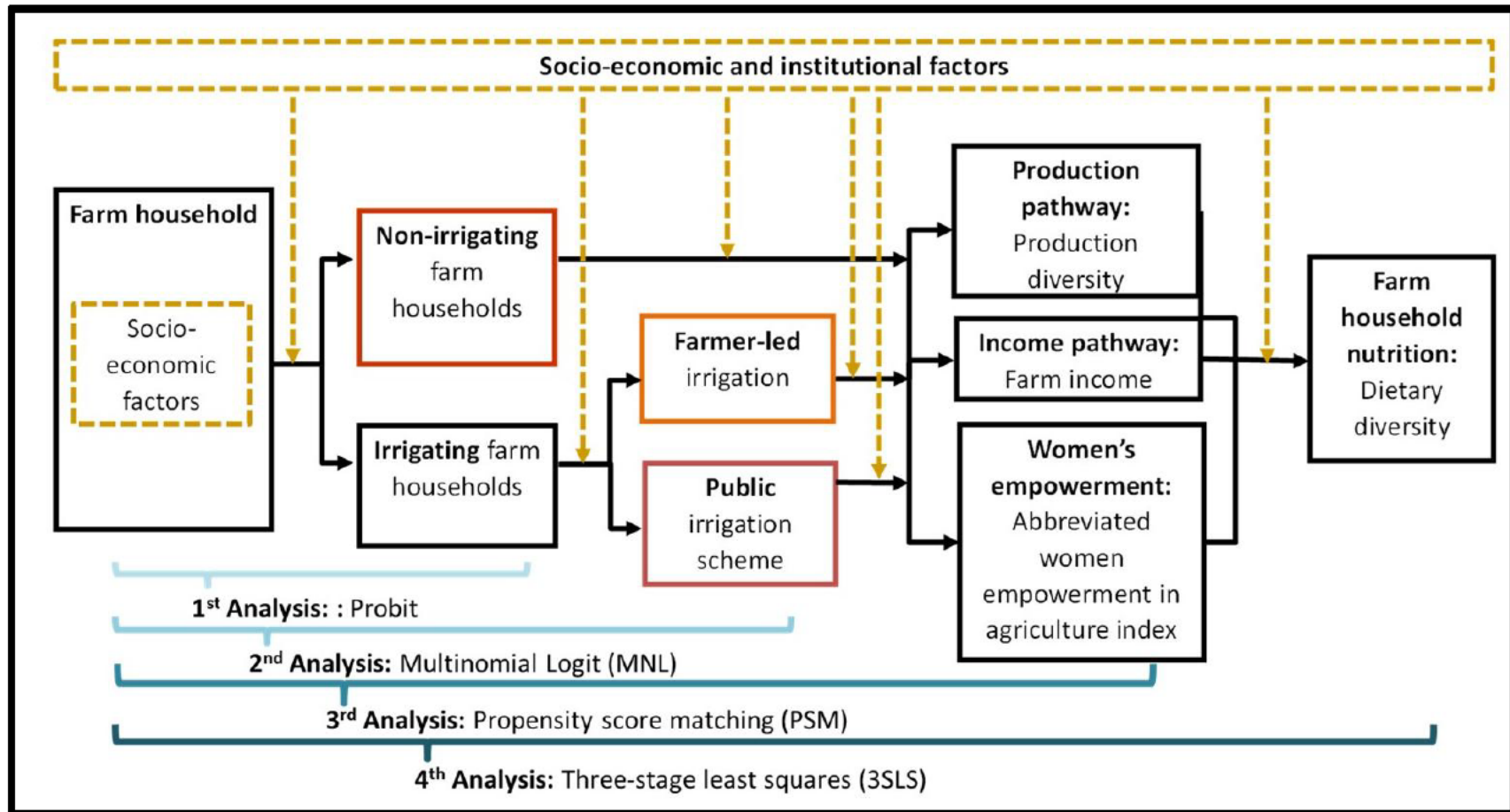


Figure 21: Analytical procedures across the conceptual framework

Source: Author's own conceptualization. Pathways adapted from Herforth & Harris (2014) and Domènech (2015)

4.2.2. Probit model

The model was applicable to this analysis given that irrigation and irrigation arrangements as defined earlier in this document is discrete in nature. Therefore, under the definitions of irrigation and irrigation arrangements, a farm household is either an irrigator or not and in one of the two irrigation arrangements defined.

4.2.2.1. Logic behind the probit model

The Probit model is attributed to the works of Bliss (1934). However, the structural estimation of the model given below is based on the works by Greene (2008, pp. 139, 770–776), Gujarati (2002, pp. 608–619), Marco (2021), Wooldridge (2002, pp. 386–388; 2019, pp. 560–571). Thus, assuming to have latent variable denoted as:

$$I_i = \beta x_i + \varepsilon_i$$

Equation 5: Probit model latent variable

In Equation 5, ε_i is a random error term having a standard normal distribution while the output z_i is associated to the latent variable I_i in that:

$$z_i = \begin{cases} 1 & \text{if } I_i \geq 0 \\ 0 & \text{if } I_i < 0 \end{cases}$$

Equation 6: Latent variable random error term standard normal distribution

Therefore imputing Equation 6 on Equation 5 and taking the probability, the equation can be expressed as:

$$\begin{aligned} P(z_i = 1|z_i) &= P(y_i \geq 0|x_i) \\ &= P(\beta x_i + \varepsilon_i \geq 0|x_i) \\ &= P(\varepsilon_i \geq -\beta x_i|x_i) \\ &= P(\varepsilon_i \leq \beta x_i|x_i) \text{ (by the symmetry of the normal distribution)} \\ &= F(\beta x_i) \end{aligned}$$

Equation 7: Standard normal distribution of the latent variable

Where F is the standard normal distribution thus making Equation 5 and Equation 6 have the same distribution as the probit model in Equation 7. Therefore, a maximum likelihood estimation is applied in determining the coefficients β (Bliss, 1935, 1964; Fisher, 1935). To do this, it is assumed that z_i and x_i are random, with the same probability distribution and mutually

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independent (independently and identically distributed (IDD)). The likelihood of an individual observation z_i and x_i is given by:

$$L(\beta: z_i x_i) = [F(\beta x_i)]^{z_i} [1 - F(\beta x_i)]^{1-z_i}$$

Equation 8: Maximum likelihood estimation

Where $L(\beta: z_i x_i)$ is determined by the value of z_i such that when $z_i = 1$, $1 - z_i = 0$ and so:

$$L(\beta: z_i x_i) = F(\beta x_i)$$

Equation 9: Maximum likelihood estimation when $z_i = 1$, $1 - z_i = 0$

On the other hand, when $z_i = 0$, $1 - z_i = 1$ and so:

$$L(\beta: z_i x_i) = 1 - F(\beta x_i)$$

Equation 10: Maximum likelihood estimation when $z_i = 0$, $1 - z_i = 1$

Thus, factoring the independent and identical distribution (IID) mentioned above, the likelihood of the sample is the same as that of the individual observation with z being a $N * 1$ vector of the left hand of the equations and X $N * K$ matrix of all the right-hand side factors and therefore defined as:

$$L(\beta: z, X) = \prod_{i=1}^N [F(\beta x_i)]^{z_i} [1 - F(\beta x_i)]^{1-z_i}$$

Equation 11: Maximum likelihood estimation under independent and identical distribution

Taking an equation defined as:

$$r_i = 2z_i - 1$$

Equation 12: Equation definition under the likelihood estimation

Such that:

$$r_i = \begin{matrix} 1 & \text{if } z_i=1 \\ -1 & \text{if } z_i=0 \end{matrix}$$

Then the likelihood in Equation 11 can be reduced to:

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$$L(\beta: z, X) = \prod_{i=1}^N F(\beta x_i r_i)$$

Equation 13: Reduced maximum likelihood estimation

While the log-likelihood defined as:

$$L(\beta: z, X) = \sum_{i=1}^N [z_i \ln(F(\beta x_i)) + (1 - z_i) \ln(1 - F(\beta x_i))]$$

Equation 14: Log-likelihood

And using r_i as defined in, it can be written as:

$$L(\beta: z, X) = \sum_{i=1}^N \ln(F(\beta x_i r_i))$$

Equation 15: Equation definition under log-likelihood

The estimation of the model is done via maximum likelihood estimation. Considering IID assumption and the presence of a $N * K$ matrix noted above defined as:

$$X = \begin{bmatrix} x_i \\ \vdots \\ x_N \end{bmatrix}$$

Equation 16: Maximum likelihood estimation under IID assumption matrix

The maximum likelihood estimation procedure uses an iterative procedure with an initial solution presumption $\widehat{\beta}_0$ that is defined as $\widehat{\beta}_0 = 0$. This iteration is repeated until the convergence is achieved such that the presumptions between $\widehat{\beta}_t$ and $\widehat{\beta}_{t-1}$ is negligible. Therefore, this iteration generates a system of presumptions such that:

$$\widehat{\beta}_t = \widehat{\beta}_t + (X^T W_{t-1} X)^{-1} X^T \lambda_{t-1}$$

Equation 17: System of presumptions

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Where W_{t-1} is a $N * N$ diagonal matrix and λ_{t-1} is a $N * 1$ vector. Then considering Equation 12 and signifying probability density function of the standard normal distribution as $f(t)$, then λ_{t-1} can be defined as:

$$\lambda_{t-1} = \frac{f(\widehat{\beta_{t-1} r_i x_i}) r_i}{F(\widehat{\beta_{t-1} r_i x_i})}$$

Equation 18: Definition of Equation 12 under probability density function of the distribution

And the $N * 1$ vector defined as:

$$\lambda_{t-1} = \begin{bmatrix} \lambda_{t-1} \\ \vdots \\ \lambda_{N,t-1} \end{bmatrix}$$

Equation 19: Vector definition under probability density function of the distribution

And the $N * N$ diagonal matrix defined as:

$$W_{t-1} = \begin{bmatrix} \lambda_{1,t-1}(\beta_{t-1} x_1 + \lambda_{1,t-1}) & 0 & \dots & 0 \\ 0 & \lambda_{2,t-1}(\beta_{t-1} x_2 + \lambda_{2,t-1}) & \dots & 0 \\ \vdots & \vdots & \ddots & 0 \\ 0 & 0 & \dots & \lambda_{N,t-1}(\beta_{t-1} x_N + \lambda_{N,t-1}) \end{bmatrix}$$

Equation 20: Diagonal matrix under probability density function of the distribution

Assuming that the last iteration is denoted by τ , then the maximum likelihood estimator is $\hat{\beta} = \widehat{\beta_\tau}$ and the related asymptotic covariance matrix where $W = W_\tau$ is:

$$\widehat{AVar}[\hat{\beta}] = \left[\frac{1}{N} X^\tau W X \right]^{-1}$$

Equation 21: Substitution of estimator $\hat{\beta}$

Equation 21 makes it possible for $\hat{\beta}$ to be estimated by means of a normal distribution with similar average to the real parameter and covariance matrix $[X^\tau W X]^{-1}$. However, it is notable that the coefficients do not represent the effect of an individual variable on irrigation, as such, the marginal effects are calculated and interpreted (Greene, 2003, pp. 668–669)

4.2.2.2. Application of the probit model in the study

In the specification, a probability equation defined as:

$$PR(I = 1|X) = \Phi X^i \beta$$

Equation 22: Probability equation

Where PR is the probability, I is denoting irrigation or irrigation arrangements, X are the smallholder farm household's socioeconomic characteristics, Φ is the cumulative distribution function of the standard normal distribution and.

Translating it into a latent variable model:

$$Y_i^* = \alpha + \beta X_i + \mu_i$$

Equation 23: Latent variable model

Where α is a constant and μ_i is the error term and $\mu \sim N(0,1)$.

However, Y_i^* is latent where only the two decisions in the model are observed such that:

$$Y_i = 1 \text{ if } \alpha + \beta X_i + \mu_i > 0$$

$$Y_i = 0 \text{ if } \alpha + \beta X_i + \mu_i \leq 0$$

Equation 24: Decision modelling

As such, the model specification for the study can be simplified as:

$$I_i(0,1) = \alpha + \beta_s X_s + \mu_i$$

Equation 25: Probit model specification

Where I_i indicates the irrigation or irrigation arrangement status of the farm household, μ_i is the randomized error term,, β_s are the parameters relating to the socioeconomic factors to be estimated and to be estimated and X_s are the socioeconomic factors comprising of access to fertilizer, access to hybrid seeds, age of the household head, age of the primary female decision maker, assets, distance to the market, education level of the household head, education level of the primary female decision maker, gender of the household head, household group membership, household size, knowledge of pumping technology, land owned, land rental price, primary female decision maker production decision, single adult household type and tropical livestock units.

4.2.3. Multinomial logit regression

This model is an extension of the logit model algorithm that solves simultaneously multiple outcome models. The model achieves this by calculating the likelihoods of categorical dependent variable with multiple possible outcome classes (Bhat, 1995; Böhning, 1992; McFadden, 1974; Train, 2009, pp. 34–75, 151–182).

4.2.3.1. Logic behind the multinomial logit regression model and its application to the study

The model's logic follows that of a discrete binary choice model extended to fil more than two choices. This model followed the work by the work of Greene (2008, pp. 843–847). As such, the model for the irrigation choice by the smallholder farm household is given by 3 choices which can be stated as: 0 = non-irrigating farm household, 0 = non-irrigating farm household, 0 = non-irrigating farm household

$$Prob(Y_i = j|w_i) = \frac{\exp(w_i' \alpha_j)}{\sum_{j=0}^3 \exp(w_i' \alpha_j)}, j = 0, 1, 2$$

Equation 26: Multinomial logit regression probability equation

Where Y_i is the probability of the household i of making $j + 1$ choice in irrigation based on the household's socioeconomic characteristics w , and α is a vector for parameters to be estimated. To solve for the indeterminacy of the model, α_0 was set to be equal to zero since the sum of probabilities is equal to one and thus only J parameter vectors is necessary to determine the probabilities of $J + 1$. The equation becomes:

$$Prob(Y_i = j|w_i) = P_{ij} = \frac{\exp(w_i' \alpha_j)}{1 + \sum_{k=1}^J \exp(w_i' \alpha_k)}, j = 0, 1 \dots, J, \quad \alpha_0 = 0$$

Equation 27: Multinomial logit regression probability equation when $\alpha_0 = 0$

Where the models J log-odds ratios is given by:

$$\ln \frac{P_{ij}}{P_{ik}} = w_i'(\alpha_j - \alpha_k) = w_i' \alpha_j \text{ if } k = 0$$

Equation 28: Multinomial logit regression probability equation J log-odds ratios

Note that, the α_j cannot be directly associated with the j th outcome. As such, marginal effects of the characteristics on the probabilities were computed as:

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$$\delta_{ij} = \frac{\partial P_{ij}}{\partial w_i} = P_{ij} \left[\alpha_j - \sum_{k=0}^J P_{ik} \alpha_k \right] = \partial P_{ij} [\alpha_j - \bar{\alpha}]$$

Equation 29: Multinomial logit regression probability equation marginal effects

Based on Equation 29, α gets into the marginal effect through probabilities and the weighted average in δ_{ij} . For estimation, the asymptotic covariance is set to zero (that is $\text{Asy. Cov} [\hat{\alpha}_0, \hat{\alpha}_j] = 0$ for $j = 0, \dots, J$). Therefore:

$$\text{Asy. Var}[\hat{\delta}_{ij}] = \sum_{l=0}^J \sum_{m=0}^J \left(\frac{\partial \delta_{ij}}{\partial \alpha'_l} \right) \text{Asy. Cov} [\hat{\alpha}'_l, \hat{\alpha}'_m] \left(\frac{\partial \delta'_{ij}}{\partial \alpha_m} \right),$$

$$\frac{\partial \delta_{ij}}{\partial \alpha_l} = [1(j=l) - P_{ij}] [P_{ij} \mathbf{I} + \delta_{ij} \mathbf{w}'_i] + P_{ij} [\delta_{ij} \mathbf{w}'_i]$$

Equation 30: Asymptotic covariance

The log-likelihood under conditions of no covariates and no constant term is given by:

$$\ln L_c = \sum_{j=0}^J n_j \ln \left(\frac{1}{J+1} \right)$$

Equation 31: Log-likelihood

The number of farm households who choose outcome j being represented by n_j . Taking p_j as the proportion of the sample that makes choice j , then the restricted log-likelihood where the vector only has a constant term is given as:

$$\ln L_0 = \sum_{j=0}^J n_j \ln \left(\frac{n_j}{n} \right) = \sum_{j=0}^J n_j \ln p_j$$

Equation 32: Restricted log-likelihood

The methods above were utilized to estimate the model that can be simplified as:

$$Ir_i(0,1) = \alpha + \beta_s X_s + \varepsilon_i$$

Equation 33: Multinomial logit model specification

Where Ir_i indicates the irrigation or irrigation arrangement status of the farm household, ε_i is the randomized error term, β_s are the parameters relating to the socioeconomic factors to be estimated and X_s are the socioeconomic factors comprising of access to fertilizer, access to hybrid seeds, age of the household head, age of the primary female decision maker, assets, distance to the market, education level of the household head, education level of the primary female decision maker, gender of the household head, household group membership, household size, knowledge of pumping technology, land owned, land rental price, primary female decision maker production decision, single adult household type and tropical livestock units.

4.2.4. Propensity score matching approach

As already established in the previous section, this study involves farmers who are participating in the different irrigation arrangements and those who don't. As such, this study is liable to some potential selection bias which must be addressed in the empirical estimation. In this section, the potential selection biases that the study envisions and the general nature of evaluation related biases are discussed. The section then discusses the use of the propensity score matching (PSM) method as the analytical procedures that were used to minimize and address these biases.

4.2.4.1. The counterfactual problem and selection bias

The primary issue about evaluation is to investigate whether the outcome in a population of interest was affected by participating in a particular programme or activity. However, with the evaluation coming after the programme or activity commences or at the end of it, the main challenge is the inability to get this outcome from the same unit. This is because the same unit cannot be a participant and a non-participant at the same time. This problem is called the counterfactual problem (Hujer & Caliendo, 2000; Shadish et al., 2002 pg. 5; Loi & Rodrigues, 2012).

In this research, irrigation is a basic and key variable of interest. As such its aim was to look at the effect of irrigation as well as irrigation arrangements on production diversity, income, women's empowerment and dietary diversity. So, assigning the notation Y will represent the outcome variable (production diversity, income, women's empowerment or dietary diversity) for household h , I is a dummy variable denoting irrigation ($I=1$) or not ($I=0$), then the ideal is to estimate the difference in the outcome variable for an irrigating household and a non-irrigating one given as:

$$\Delta_h = Y_{h I=1} - Y_{h I=0}$$

Equation 34: Ideal estimation equation for the outcome variable

Taking the average gives an average treatment effect denoted as:

$$ATE = E(Y_{h I=1} - Y_{h I=0})$$

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Equation 35: Average of the ideal estimation equation

However, Equation 35 gives the average effect of irrigation or irrigation arrangement for a random household in the population. However, this is not critical for policy as the households of interest would be the irrigating households (Heckman, 1997; Wooldridge, 2002, pg. 604). In order for the average treatment effect to portray the change in the irrigating households (referred to as the average treatment effect on the treated), then the irrigation aspect must be randomly assigned in the population. In reality, the irrigating farmers partly determine themselves whether they irrigate or not which is called self-selection (Wooldridge, 2002, pg. 606). Under such conditions, the outcome of interest on the irrigating households is defined by a conditional equation specified as:

$$ATE = E(Y_{hI=1} - Y_{hI=0} | I = 1)$$

Equation 36: Conditional equation

Expanding Equation 36 gives:

$$ATE = E(Y_{hI=1} | I = 1) - E(Y_{hI=0} | I = 1)$$

Equation 37: Expanded conditional equation

While the term $E(Y_{hI=1} | I = 1)$ can be estimated the term $E(Y_{hI=0} | I = 1)$ is impossible to observe as the household cannot be irrigating and non-irrigating at the same time. However, it is possible to observe the term $E(Y_{hI=0} | I = 0)$, which is the outcome of the non-irrigating household. If the term for the non-irrigating households in the equation is replaced, then the resultant equation will be:

$$ATE' = E(Y_{hI=1} | I = 1) - E(Y_{hI=0} | I = 0)$$

Equation 38: Expanded conditional equation with a replaced non-irrigating household

However, Equation 37 and Equation 38 are not equal. This difference in these two equations represents the selection bias brought about by the counterfactual between the irrigating households and non-irrigating households. However, as noted above, under random assignment, Equation 37 and Equation 38 would be equal. This can be simplified as:

$$ATE' = E(Y_{hI=0} | I = 0) = E(Y_{hI=1} | I = 1)$$

Equation 39: Expanded conditional equation under random assignment

Therefore, it means that the average treatment effect on the treated can then be estimated under the assumption that the outcome variable is independent of non-irrigating term by just

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taking the difference of the means while not restricting this to the interaction between the outcome variable and the irrigating household (Wooldridge, 2002, pg. 606). Then the Equation 36 can be written as:

$$ATE = E(Y_{hI=1} | I = 1) - E(Y_{hI=0} | I = 0)$$

Equation 40: Conditional equation under the given assumptions

This can be further simplified as:

$$ATE = E(Y_{hI=1} | I = 1) - E(Y_{hI=0} | I = 0) + E(Y_{hI=1} - Y_{hI=0} | I = 1)$$

Equation 41: Simplified conditional equation under the given assumptions

But given that $E(Y_{hI=1} - Y_{hI=0} | I = 1) = ATE'$, then Equation 41 becomes:

$$ATE = E(Y_{hI=1} | I = 1) - E(Y_{hI=0} | I = 0) + ATE'$$

Equation 42: Average treatment effect

But with the outcome of the non-irrigating households being mean independent of irrigation such that $(Y_{hI=0} | I = 0) = E(Y_{hI=0})$, then the first term of Equation 42 disappears and ATT becomes an unbiased estimator of ATE. However, this is such a strong assumption which is criticized in literature (Wooldridge, 2002, p. 606).

However, the estimation of both ATE and ATT can be estimated in conditions not assuming independence of the outcome variables and irrigation in this case. This is done by using observable characteristics for the irrigating and non-irrigating households under the framework by Rosenbaum & Rubin (1983) of ignorability of treatment. This means that conditional on the observable characteristics of households, the outcome variables and irrigation are independent. Under this assumption, then the average treatment effect (ATE) is the change in the entire population while the average treatment effect on the treated (ATT) is the difference in the irrigation households only (Wooldridge, 2002, pg. 608).

Under this assumption, then the ATT will be calculated as:

$$ATE_{se} = E(Y_{hI=1} | se, I = 1) - E(Y_{hI=0} | se, I = 0)$$

Equation 43: Average treatment effect on the treated

Where *se* and *ins* are the household socioeconomic characteristics. In this manner the second term $E(Y_{hI=0} | se, ins, I = 0)$ is observable and replaces the unobservable term $E(Y_{hI=0} | se, I = 1)$ since the irrigating and non-irrigating households are comparable bases in the socioeconomic factors. This measurement, average treatment effect on the treated, will be the principal interest

for this section of study for the outcomes since the interest is on the irrigating households and those in public irrigation scheme- and farmer-led irrigation- arrangements.

In order to match come up with comparable households based on the socioeconomic factors, this study uses the propensity score matching approach. This approach is discussed further in the following section. The propensity score matching technique is used to account for this selection bias that is caused by observable socioeconomic characteristics that make the irrigating and non-irrigating farmers distinct (Rosenbaum & Rubin, 1983).

4.2.4.2. Propensity score matching modelling

In this section, the framework is borrowed from the works of Becker & Ichino, 2002 and Rosenbaum & Rubin, 1983). A working definition borrowed from the above framework defines the propensity score matching in this the conditional probability of a household irrigating or being in a specific irrigation arrangement after considering the inherent socioeconomic household characteristics before irrigating. This is given as:

$$p(se, Ins) \equiv \Pr(I = 1|se) = E(I|X)$$

Equation 44: Propensity score matching estimation

Where *se* and *Ins* are the household socioeconomic characteristics and *I* is the variable denoting irrigation where *I*=1 if the household irrigates and *I*=0 if otherwise. To operationalize Equation 41, a probit equation is used consisting of a vector of socioeconomic (*se*) and institutional (*Ins*) characteristics of the households regressed against irrigation (*I*) which depicts the irrigation status and thus gives an equation specified as:

$$I_h = \alpha_h + \beta_{h,se}^I X_{h,se} + \mu_h^I$$

Equation 45: Propensity score matching estimation specification

Where I_h is the irrigation status of the household, α_h is a constant to be estimated, $\beta_{h,se}^I$ is the parameter to be estimated of the household's socioeconomic factors that affect irrigation and irrigation arrangements, $X_{h,se}$ is the household's socioeconomic factors and μ_h^I is a normally distributed error term. The socioeconomic factors used in the equation are age of the household head (years), age of the primary female decision maker (years), assets (USD), single adult household type, education level of the household head (years), education level of the primary female decision maker (years), household size, land owned (acres), tropical livestock units, non-farm income (USD), in-kind credit, household credit access, and household group membership.

To ensure that there is consistency in measuring the propensity scores, the variables above were used in determining the effect of irrigation on production diversity, income, women's empowerment and dietary diversity as well as in the disaggregated irrigation arrangements. In this manner the average treatment effect on the treated is calculated as:

$$\begin{aligned}
 ATE' &\equiv E\{Y_{h,I=1} - Y_{h,I=0} | I_h = 1\} \\
 &= E[E\{Y_{h,I=1} - Y_{h,I=0} | I_h = 1, p(se_h, Ins_h)\}] \\
 &= E[E\{Y_{h,I=1} | I_h = 1, p\} - E\{Y_{h,I=0} | I_h = 0, p(se_h, Ins_h)\} | I_h = 1]
 \end{aligned}$$

Equation 46: Average treatment effect on the treated for the outcome variables

Where the expectations on is for the outcomes of irrigating and non-irrigating households as well as the probability of having the household socioeconomic factors conditional on being an irrigating household. The above calculation is done under the conditions of balancing property of the socioeconomic variables plier to irrigation and unconfoundedness of the propensity scores (Becker & Ichino, 2002).

The matching technique used in this discussion is the nearest neighbor matching method where the non-irrigators with the closest propensity score are compared to the irrigators (Caliendo & Kopeinig, 2008). However in order to show the matching techniques the framework under the different matching methods (Becker & Ichino, 2002; Caliendo & Kopeinig, 2008), the results from radius, kernel and stratification matching methods are given for robustness check. Furthermore the matching estimation graphs under the different matching approaches (Leuven & Sianesi, 2003) is also given to further show the plausibility of the results.

The radius matching method uses a given propensity range and then compared individuals within this range thus overcoming the problem of having a comparison too far away for the comparison group and also allowing the use than one individual household in the comparison (Caliendo & Kopeinig, 2008; Dehejia & Wahba, 2002). The kernel matching method is a non-parametric matching estimator that in this case uses the weighted means of the non-irrigating households to construct the counterfactual outcome. The method has the advantage of reducing on the variance as it uses more information in the whole sample (Caliendo & Kopeinig, 2008). The stratification matching method in this case partitions the common support of the propensity score into strata (at least five to remove bias associated with one single covariate (Cochran & Chambers, 1965)) and calculates the average difference between the irrigators and non-irrigators in each strata (Aakvik, 2001; Caliendo & Kopeinig, 2008; Dehejia & Wahba, 2002; Rosenbaum & Rubin, 1983).

4.2.5. Three-stage least squares regression

As discussed earlier in this document, a major challenge in this study is that irrigation is a possible endogenous variable. Especially given the different irrigation arrangements that is novel in this research work, this study was cognizant that factors such as a household's resources, access to information, managerial skills, social networks, technical capabilities, motivation, risk attitude, time scheduling and transaction costs of poor infrastructure can make the irrigating households inherently different from non-irrigating households or adapt different irrigation arrangements. (Abdulai & Huffman, 2014; Adela & Aurbacher, 2018; Passarelli et al., 2018).

While the study acknowledges the ability to control some of these factors via variables such as level of education, group membership, leadership position in the society and farm ownership and characteristics, some of the unobservable characteristics cannot be controlled in this way. In this respect, a simultaneous equation model that incorporates the use of an instrumental variable approach was chosen to correct for these potential biases in estimating the impact pathways of irrigation and irrigation arrangements and its effect on nutrition outcomes.

Following the framework by Herforth and Harris (2014) and Domènech (2015) discussed earlier in the literature review chapter, the empirical model adapted three potential pathways that irrigation influences nutrition outcomes. These three pathways were production diversity, income and women's empowerment. With this in mind, the model structure involves five equations for each of these pathways, irrigation and a dietary diversity score. In order to get the structure of the model, an explanation on the working of the model is given in the next section.

4.2.5.1. The three-stage least squares (3SLS) estimation logic

The estimation of the three-stage least squares (3SLS) estimation method is based on the works by Zellner and Theil (1962). The 3SLS method is an addition of a system of equations to the two-stage least squares (2SLS) estimation approach. However, a major difference with the 2SLS is that the simultaneous equations in the 3SLS are not distinctly estimated for each structural equation but simultaneously estimated (also called systems method of estimation). In addition, this simultaneous estimation approach greatly improves the efficiency of the 3SLS by considering the specification of each of the coefficients and the restriction of each of the specified equations and unobserved disturbances across the equations specified in the three stages (Belsley, 1988; Rothenberg & Leenders, 1964; Zellner & Theil, 1962).

In the estimation, it is assumed that the disturbances in individual structural equation are uncorrelated and homoscedastic even if the ones across the three stages are correlated (also referred to as *contemporaneous correlation*). In doing this, the model adapts an instrumental variables estimation.

In the first stage, a 2SLS-like procedure estimates the residuals of the identified equation. Therefore, the endogenous variable is the dependent variable of this structural equation and it is regressed against the independent exogenous variables. The estimated values of these equations then act as the instruments in the second stage.

The second stage computes a valid and optimal instrument using the residuals estimated in the first stage. In other words, the values from the first stage are used to instrument the endogenous variables in the right-hand side of the structural equation. In addition, residuals from the first and second stage are used to construct the disturbance variance-covariance matrix.

In the last stage, the computed instrument is used to estimate the system of equations. But the use of instrumental variables is not sufficient in this case because this would be similar to the running of a 2SLS on each individual equation. Therefore, a Generalized Least Squares (GLS) is

applied transform the original variables using the disturbance variance-covariance matrix and therefore account for the correlations of the error terms of structural equations in the three stages. This method is thus a combination of both a generalized least squares and an instrumental variable approach to obtain the 3SLS estimator. In this way, this model is sometimes viewed as multiple equations generalized method of moments (GMM) (combining the observed data with information of the population to produce estimates for the unknown parameters in the model) with instrumental variables for all the equations (Hansen, 2010; Hayashi, 2000, pp. 276–279; Wooldridge, 2001).

In conclusion, the three steps are: producing instrumented values for the endogenous variables as predicted values of regressions of each of the endogenous variable on the exogenous variables, develop a covariance matrix of the equation and using a GLS estimation using the covariance matrix and the instrumented values. Therefore, the 3SLS is able to handle the concerns of endogeneity in the study, even if the endogenous variables are part of they are dependent variables in the other equations. Thus, in this case, the error term is not only correlated to endogenous variables but the error terms among the equations would be correlated as well. By the use of an instrumental variable approach to account for the correlation across the error terms in the equations, the 3SLS is able to have consistent estimates (Greene, 2003, pp. 405–407; Kmenta, 1997).

4.2.5.2. Application of the 3SLS in the study

The irrigation and irrigation arrangement equations are defined in the binary nature in that a household irrigates and in this case in one irrigation arrangement or depends on rainfed agriculture. This is regressed against the factors that influence the irrigation and the different irrigation arrangements. The irrigation equation was defined as:

$$I_h = \alpha_I + \beta_{hsc}^I X_{hsc} + \mu_h^I$$

Equation 47: 3SLS irrigation equation specification

Where I_h is the irrigation status of household h , α_I is a constant to be estimated, β_{hsc}^I is the parameter to be estimated of the household's socioeconomic factors that affect irrigation and irrigation arrangements, X_{hsc} is the household's socioeconomic factors and μ_h^I is the error term where $\mu_h^I \sim N(0,1)$. The socioeconomic factors used in the equation were access to fertilizer, access to hybrid seed, age of the household head, age of the primary female decision maker, assets, distance to the market, education level of the household head, education level of the primary female decision maker, gender of the household head, household group membership, household size, knowledge of pumping technology, land owned, and rental price, primary female decision maker production decision, single adult household type, and tropical livestock units. The Equation 47 above is included in the production diversity, income and women's empowerment equations. The rationale for this is explained in the discussion after the specification of these three equations.

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Production diversity score is defined as discussed in Chapter Four of this document and the given rationale for its specification, calculation and utilization is also documented therein. More elaborate justification as to why production diversity was included in this model is discussed in the conceptual framework on Chapter Three as regards how irrigation enables households to farm diverse and nutritious foods as well as smoothen seasonal food fluctuations. In this essence, the production diversity equation is defined as shown below:

$$PD_h = \alpha_{PD} + I_h + \beta_{hsc}^{PD} X_{hsc} + \mu_h^{I,PD}$$

Equation 48: Production diversity equation specification

Where PD_h is the household's production diversity score defined as stated in Chapter Four, α_{PD} is a constant to be estimated, I_h is the irrigation status and irrigation arrangement of the household as defined in Equation 47, β_{hsc}^{PD} is the parameter to be estimated of the household's socioeconomic factors that affect irrigation and irrigation arrangements, X_{hsc} is the household's socioeconomic factors and $\mu_h^{I,PD}$ is the normally distributed error term where $\mu \sim N(0,1)$. The socioeconomic factors used in the production diversity equation were age of the household head, age of the primary female decision maker, education level of the household head, education level of the primary female decision maker, household group membership, assets, land owned, primary female decision maker production decision, single adult household type and tropical livestock units.

Likewise, in the conceptual framework, it was postulated that irrigation increases the households' farm income and consequently the house is able to access more nutritious food from the market including more expensive nutritious foods such as proteins and off-season fruits and vegetables. However, since the relationship between the increase in farm income and improvement in household nutrition is not linear (SPRING, 2014a), this simultaneous equation modelling approach was utilized. Thus, the farm income equation was specified in the manner shown in Equation 49 as:

$$Finc_h = \alpha_{Finc} + I_h + \beta_{hsc}^{Finc} X_{hsc} + \mu_h^{I,PD,Finc}$$

Equation 49: Farm income equation specification

Where $Finc_h$ is the household's farm income, α_{Finc} is a constant to be estimated, I_h is the irrigation status and irrigation arrangement of the household indicating whether they irrigate or not or the irrigation arrangement, β_{hsc}^{Finc} is the parameter to be estimated of the household's socioeconomic factors that affect irrigation and irrigation arrangements, X_{hsc} is the household's socioeconomic factors and $\mu_h^{I,PD,Finc}$ is the error term with a mean of zero and a standard deviation of one. The socioeconomic factors used in this structural equation were access to fertilizer, access to hybrid seed, age of the household head, age of the primary female decision maker, distance to the market, education level of the household head, education level of the

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primary female decision maker, household size, land owned, land rental price, primary female decision maker production decision, production diversity and tropical livestock units.

The women's empowerment was measured and computed as discussed in Chapter Four using the Abbreviated women's empowerment in agriculture index (A-WEAI). The study puts forward that irrigation influences women's empowerment and in turn improves on the household's nutrition outcome. The discussion is delved deeper in the conceptual framework. The women's empowerment equation was specified as:

$$WE_h = \alpha_{WE} + I_h + \beta_{hsc}^{WE} X_{hsc} + \mu_h^{I,PD,Finc,WE}$$

Equation 50: Women's empowerment equation specification

Where WE_h is the A-WEAI of the primary woman decision maker, α_{WE} is a constant to be estimated, I_h is the irrigation status and irrigation arrangement of the household defined as above, β_{hsc}^{WE} is the parameter to be estimated of the household's socioeconomic factors that affect irrigation and irrigation arrangements, X_{hsc} is the household's socioeconomic factors and μ_h^{WE} is the error term. The socioeconomic factors used in the women's empowerment equation were access to extra land, access to fertilizer, access to hybrid seed, age of the household head, age of the primary female decision maker, distance to the market, education level of the household head, education level of the primary female decision maker, household size, land owned, land rental price, primary female decision maker production decision and tropical livestock units.

The final structural equation in this simultaneous equation model is the dietary diversity score. The score is measured using the minimum women dietary diversity (MDD-W) food-groupings due to its measure of nutrients intake as well as other factors given earlier in this chapter. This formed the principal equation of the simultaneous equation model. It encompasses all the above equations and it was estimated using three-stage least squares approach (Zellner & Theil, 1962). This equation consisted of the dependent variables in equations Equation 47, Equation 48 and Equation 49. However, Equation 47 on irrigation was excluded in this equation. As such, the dietary diversity (DD) equation which was a proxy of the nutrition outcome was specified as:

$$DD_h = \alpha_{DD} + PD_h + Finc_h + WE_h + I_h + \beta_{hsc}^{DD} X_{hsc} + \mu_h^{I,PD,Finc,WE,DD}$$

Equation 51: Dietary diversity equation specification

Where DD_h is the dietary diversity of the primary woman decision maker, α_{MDDW} is a constant to be estimated, PD_h is the production diversity score as defined in Equation 48, $Finc_h$ is the farm income as defined in Equation 49, WE_h is the women's empowerment as defined in Equation 50, β_{hsc}^{MDDW} is the parameter to be estimated of the household's socioeconomic factors that affect irrigation and irrigation arrangements, X_{hsc} is the household's socioeconomic factors and μ_h^{MDDW} is the error term. The socioeconomic factors used in this equation were age of the household

head, age of the primary female decision maker, distance to the market, education level of the household head, education level of the primary female decision maker, employed, household size and tropical livestock units.

In this three-stage least squares (3SLS) model, for irrigation to influence the dietary diversity, then it has to influence production diversity, farm income and women's empowerment. Additionally, production diversity, farm income and women's empowerment have to affect the dietary diversity. In this manner, use of instrumental variables helps in solving for any endogeneity in these five structural equations. Furthermore, by using a simultaneous equation approach, the model is able to leverage on the efficiency gains as the error terms will most possibly be correlated in these five structural equations as shown in the equations above (see the connotations on the error terms). By doing this, the 3SLS model handle all the exogenous variables as instruments for any variable in which endogeneity exists.

4.2.6. Tests for multicollinearity and heteroscedasticity

In order to ensure the validity of the statistical tests of significance, tests for multicollinearity and heteroscedasticity were also carried out. To check for the presence of multicollinearity among dummy variables, a variance-covariance estimation was carried out to check for the correlation between these variables and the independent variables. The closer the values are to absolute 1 (+1 or -1), the more correlated they are (R. Taylor, 1990) . However, none of the variables were close to absolute 1 and thus there was no reason to be concerned on the presence of strong multicollinearity.

The variance inflation factor (VIF) was applied to check for multicollinearity among continuous variables. The VIF was defined according to Gujarati (2002, pp. 351–358) as:

$$VIF(x_i) = \frac{1}{1 - R_i^2}$$

Equation 52: Variance inflation factor

Where $VIF(x_i)$ the variance inflation is factor for independent variable x_i and R_i^2 is the square of the multiple correlation coefficients attained by a regression of the regressing x_i on the other independent variables. When the VIF is above 10, it raises concerns of multicollinearity (Bowerman & O'connell, 1990). The values obtained for the VIF were below 10 which showed that there is no strong multicollinearity in the variables chosen.

Given that the study uses multiple analyses with different independent variables, different regressions for the constructions of the VIF were used. This included the analyses for the probit regression, multinomial logit regression, probit regression for the propensity score matching approach and the 3SLS regressions. The tests were also split according to the irrigation arrangements for a thorough check.

On the other hand, the Breusch-Pagan/Cook-Weisberg test was performed to check for the presence of heteroscedasticity. Given that the 3SLS regressions have the greatest number of variables embedded in the other regressions, it was used for this test. A full regression and also disaggregated in the irrigation arrangement was performed and the test done in accordance to the procedure defined by (Cameron & Trivedi, 2010, p. 97). The results for the tests for multicollinearity and heteroscedasticity are presented in Appendix 2.

4.3. Conclusion

Analyses at household level of linkages between agriculture and nutrition is scarce and graver still is that the linkage between irrigation and nutrition is vaguely understood. This research seeks to fill this gap in research and policy documentation. In order to do this, household level specific data is needed and thus the necessity of such an elaborate data collection tools and methodology.

Obtaining of such comprehensive data allows this study to apply further tools in statistical and econometric analysis to come up with plausible relationships and correlations. This made it possible for the study to come up with a causal relationship between irrigation and nutrition and show the pathways through which these relationships occur. In so doing, this study contributes to the gap in knowledge irrigation-nutrition causal effect and also the approaches about how such a study can be done. This is endeavored to be done through further econometric analysis that make the results theoretically and economically significant.

5. DESCRIPTIVE STATISTICS

5.1. Introduction

As discussed in Chapter Three, the premise underlying this study is that the nutrition outcomes of the farmers not only differ among irrigators and non-irrigators but also among the different irrigation arrangements. Following this premise, this section on descriptive statistics follows this kind of categorization.

It was therefore necessary to give a full view of how these categories are distributed in the sample. In doing so, the discussion gives the statistics of the pooled sample. Then a comparison of irrigators vis-à-vis non-irrigators is given. Further on the data is broken down further to the different irrigation arrangements i.e. public irrigation scheme irrigation arrangement and farmer-led irrigation arrangement. In order to give a better comparison and also as basis for further analysis as given in arguments from literature and field experience given in Chapters Two, Three and Four, the non-irrigators' statistics is included in the discussion on the irrigation arrangements.

The descriptive statistics start from the key main dependent variables to the selected independent variables. For a deeper understanding of the definition of the irrigation variables and key main independent variables, refer to Chapter Four. Thus, emphasis and attention of the reader is drawn to the flow in the presentation of the variables' descriptive statistics in this chapter as this forms the basis of the arrangement of the next chapters. As such, for ease of reference, the tables bearing all the information on the pooled sample, non-irrigators and irrigation arrangements are split for ease of reference but following each other.

5.2. Irrigation and irrigation arrangements

The analyses of the variables in this chapter and the following chapters are based upon the irrigation arrangements. In this respect, the households were first categorized as non-irrigators and irrigators. Further, the irrigators were categorized using the basis discussed in Chapters Two, Three and Four into the public irrigation scheme- and the farmer-led irrigation- arrangements. For comparison purposes, first the variables are compared based on the irrigating and non-irrigating households.

After this the irrigating households are disaggregated into the public irrigation scheme- and farmer-led irrigation- arrangements. However, for ease of comparison, in the summary table, the non-irrigating farm households' statistics are also given.

A total sample of 384 households were included in the study. Of the sample, 198 were non-irrigating households and 186 were irrigating households representing 51.56% and 48.44% respectively. Among the irrigators, 89 households were in the public irrigation scheme arrangement and 97 were in the farmer-led irrigation arrangements comprising about 23.18% and 25.26% of the sample respectively. The proportion of the distribution by irrigation and irrigation arrangements is given in Figure 22 and Figure 23 respectively.

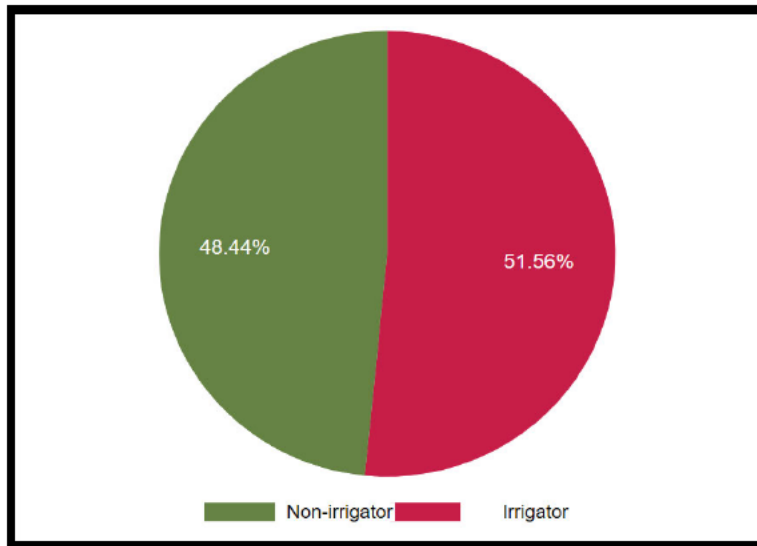


Figure 22: Distribution of irrigation in the sample

Source: Author based on survey data.

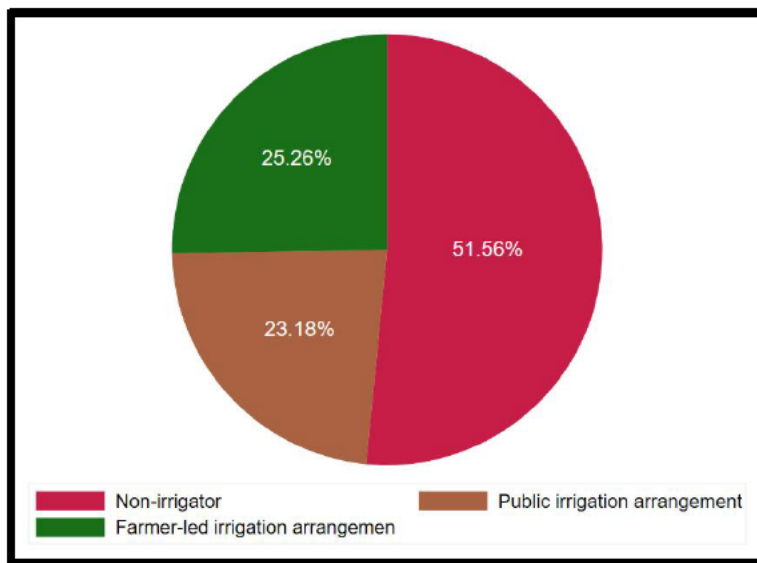


Figure 23: Distribution of irrigation arrangements in the sample

Source: Author based on survey data.

For the irrigating households in the public irrigation scheme arrangement, the source of water was unimodal in that they accessed water through canals. However, for the households in the farmer-led irrigation arrangement, the sources were varied. About 59% of the households in the farmer-led irrigation arrangement used water from rivers, 22% used canals and 9% from ground water. A small proportion of about 5% used water from ponds, 4% used harvested water and only about 1% of the households used boreholes.



Figure 24: A borehole-drip irrigated crop of speciality herbs

Source: Fieldwork photo

In the analysis it was found that the households in the farmer-led irrigation arrangement also used waters mainly from one source, with only 13 households in this arrangement using a combination of two and at most three sources given above. The information on the sources of water for irrigation for the households in the farmer-led irrigation arrangement is presented in Figure 25.

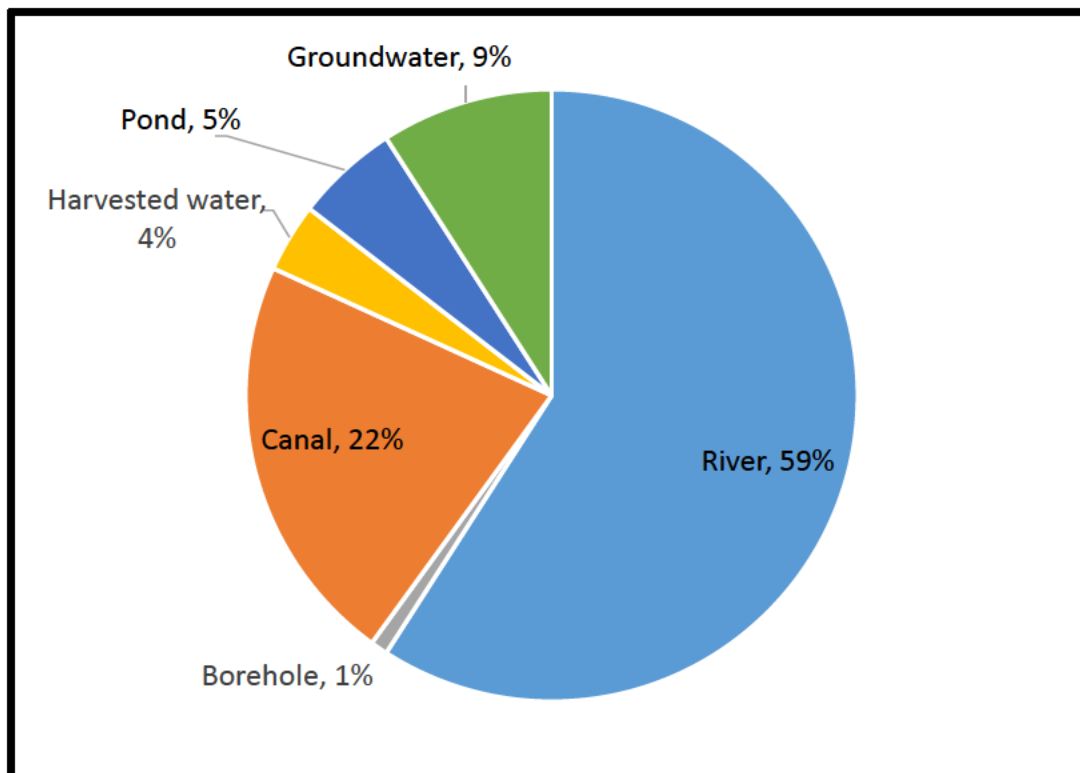


Figure 25: Sources of irrigation water for the farmers in the farmer-led irrigation arrangement

Source: Author based on survey data.

5.3. Main dependent variables

5.3.1. Household production diversity

The production diversity index showed that the sample did not have a diversified agricultural system with the mean index being 3.60. The non-irrigators had a more diversified agriculture with a mean of 3.88 as compared to the irrigators at 3.30 points. On disaggregating the irrigation arrangements, the farmer-led irrigation arrangement farm households had a higher production diversity at a mean of 3.62 as compared to the public irrigation scheme arrangement farm households at a mean of 2.94.

To demonstrate the ranges and median, refer to the box plot in Figure 26. The median production diversity for the pooled sample was 3. This echoes the low production diversity exhibited by the mean. The median production diversity for the non-irrigators was one point above the pooled sample's median at 4 while that of the irrigators was at 3. The farmer-led irrigation arrangement farmers' median was at 4 points while the public irrigation scheme arrangement farmers had a median of 3.

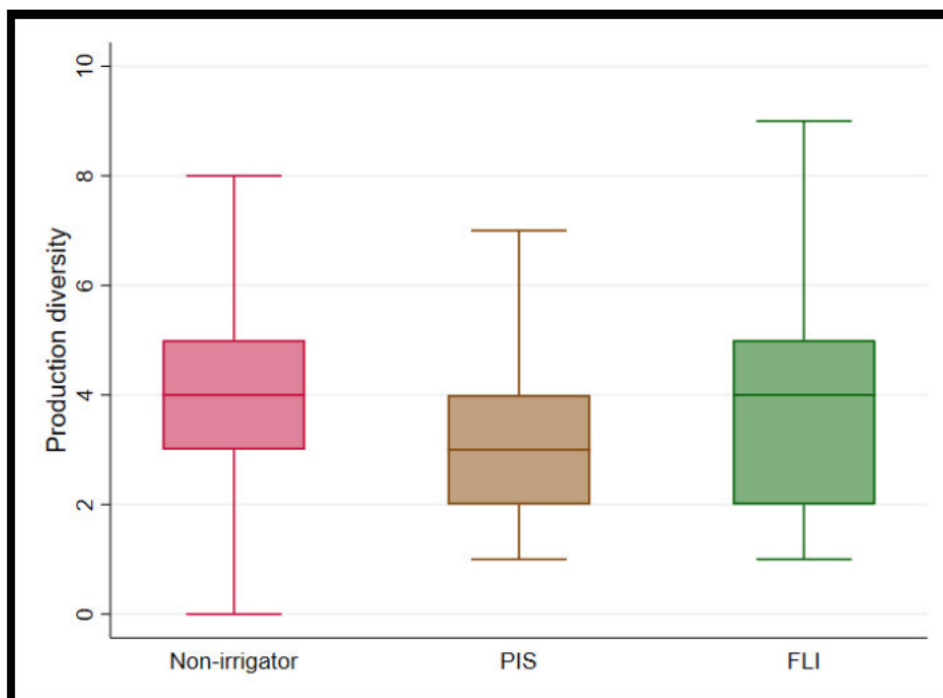


Figure 26: Box plot for the production diversity

Source: Author based on survey data.

These analyses are related to the type of agriculture carried out by these households. For the non-irrigators, the rainy season provides the only period for growing of crops and as such mixed cropping is common in an effort to grow as much complementary crops as possible. With this seasonal nature, the households are also able to manage to keep livestock in the farm which may also point to the availability of time and labor. On the other hand, with the labor requirement for

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irrigators being high, the opportunity cost of time in livestock keeping is higher over cropping engagements. In this regard, this also reduces the production diversity for the irrigators.

Likewise, irrigators also practice specialization in an effort to grow crops that are in demand and of high value. This is particularly so for the public irrigation scheme arrangement farm households that predominantly grow rice for commercial purposes and only use the fringes of the land for other crops as well as minimal rotation of the rice crop. However, for the farmer-led irrigation arrangement farmers, in order to maximize use of labor and irrigation related resources, there is the practice of intercropping at some stage of the crop production. For instance, it was noted that when tomatoes and French beans were in a late stage of harvest, the farmers would intercrop them with maize for selling mainly as off-season green-maize which fetches a higher price. This partly explains why the farmer-led irrigation arrangement farm households have a higher production diversity as compared to the public irrigation scheme arrangement farm households. The pictures in Figure 27, Figure 28 and Figure 29 give the different aspects discussed on production diversity.



Figure 27: Production diversity at a non-irrigators farm cropped with pumpkin, maize, beans, bananas, cassava and an avocado tree

Source: Fieldwork photo.



Figure 28: Production diversity at a farmer-led irrigation arrangement farm under French beans production showing maize cropped in at a later stage

Source: Fieldwork photo.



Figure 29: Production diversity at a public irrigation scheme arrangement farm showing rice production with the fringes having tomatoes and vegetables

Source: Fieldwork photo

5.3.2. Farm income

The average farm household income for the sample was USD 1,368.07 with the irrigators having a mean almost three times the non-irrigators' mean farm income. The irrigators' average farm income was USD 2,029.64 while that of the non-irrigators was USD 746.60. On disaggregation of the farm income, the farmer-led irrigation arrangement farm households had a higher farm income at USD 2,140 as compared to the public irrigation scheme arrangement farm households at USD 1,908.31.

Given also the large dispersion of the farm income, the analysis of the median and range across the irrigation arrangements was also analyzed. The median farm income for the sample was USD 441.07 with the median for the non-irrigators being USD 184.81 and the irrigators' median USD 890.05. The median for the public irrigation scheme arrangement farm households was higher at USD 977.77 as compared to the farmer-led irrigation arrangement farm households' median of USD 830.00. This low values of farm income did bring about concerns about the poverty levels in this area as measured through income.

In order to see the proportion under the rural poverty line, the total income of the households was calculated by adding the farm income with other non-farm incomes. The mean total income for the sample was USD 1,912.35 with the irrigating households have a pooled mean of USD 2,595.84 and non-irrigating households USD 1,270.28. The median for the irrigating households and the non-irrigating households was found to be USD 1287.12 and USD 468.76 respectively. The disaggregated total income across the different irrigation arrangement showed that the farmer-led irrigation arrangement farmers had an average total income of USD 2,809.43 and the public irrigation scheme arrangement farmers' average total income was USD 2,363.06. For the median across the irrigation arrangement was USD 1,261.52 and USD 1,384.88 for the farmer-led irrigation arrangement farm households and public irrigation scheme arrangement farm households respectively. The box plots for the farm income and the total income are shown in Figure 30.

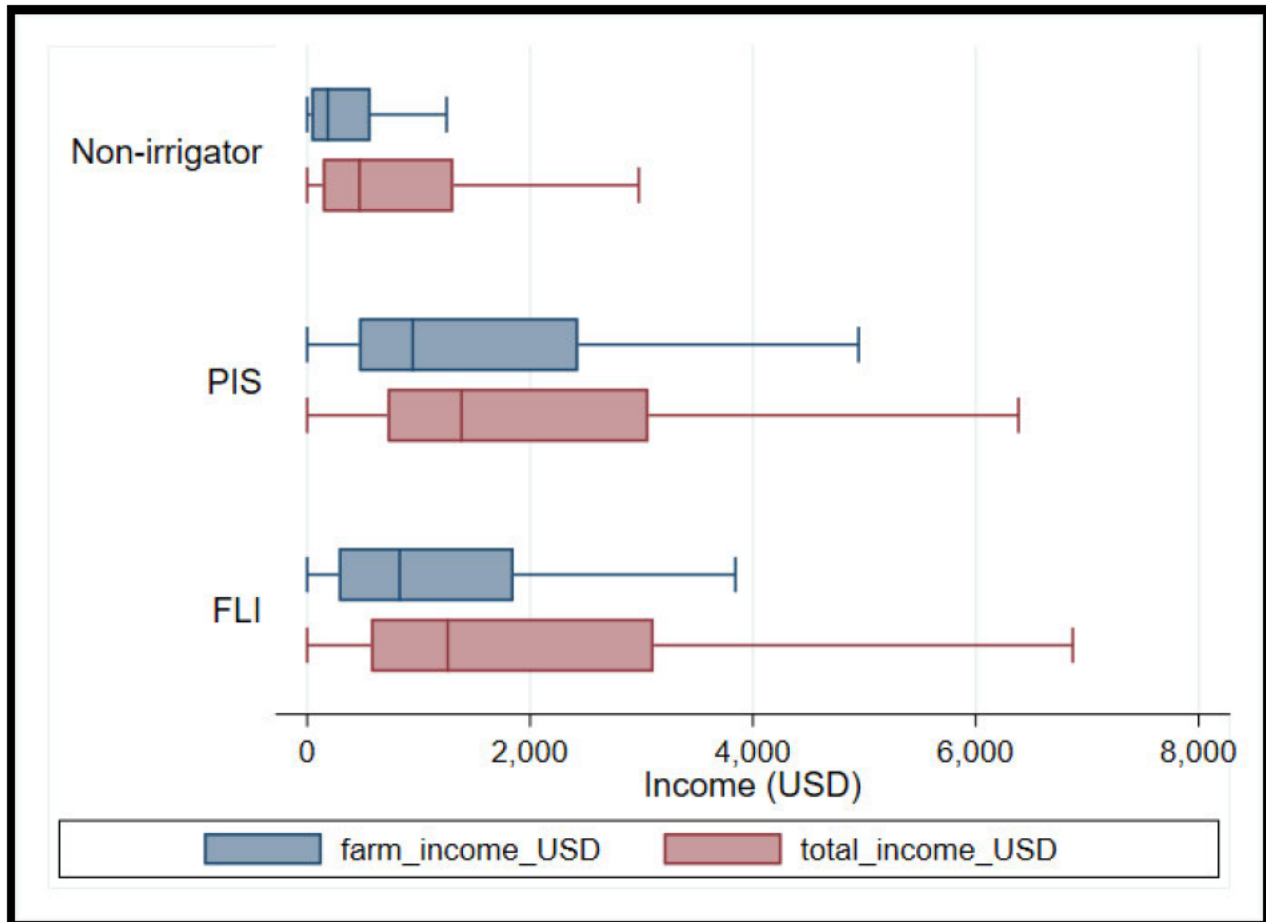


Figure 30: Box plots for farm income and total income with the sample farm income

Source: Author based on survey data.

The total income was then categorized in accordance to the country's poverty line. The official statistics based on the 2015/16 Kenya Integrated Household Budget Survey and used in the Comprehensive Poverty Report 2020 by the Kenyan National Bureau of Statistics (KNBS) (KNBS, 2020). The report sets the rural poverty line at KSH. 3,252 per month per person in adult equivalent terms. This was considered a good measure in that it takes into consideration not only the average expenditure needed to have the minimum recommended daily intake of 2,250 kilocalories, but also the minimum threshold for both food and non-food expenditures (World Bank, 2020).

With the rural poverty line given above, an annual poverty line was constructed and compared with the annual income for the households in the sample. The statistics showed that about 29% of the sampled households were below the monetary rural poverty line. Of this proportion below the poverty line, a higher proportion was made up of the non-irrigators who were approximately 77% of the sample with the farmer-led irrigation arrangement and public irrigation scheme arrangement farm households forming a proportion 13% and 10% respectively as shown in Figure 31. However, incidence in rural poverty of about 29% among the sampled household is lower than the country's prevalence of rural poverty which is about 40% for monetary poverty but this

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can be explained by the fact that the County as a whole has one of the lowest rural incidence of rural monetary poverty with actually the sample showing a higher prevalence than the 19.4% County prevalence in the Comprehensive Poverty Report 2020 (KNBS, 2020). With this study also looking at farm income as a potential pathway to nutrition, the following chapters dive deeper into the analysis of this variable as it relates to irrigation and irrigation arrangements.

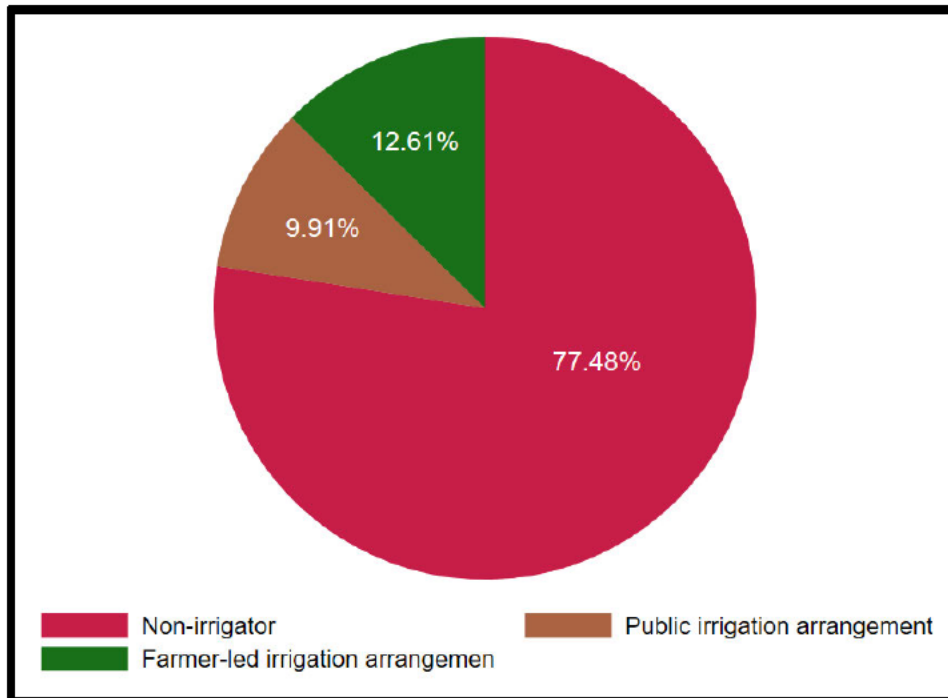


Figure 31: Proportion of households below the rural poverty line by irrigation arrangements
Source: Author based on survey data.

5.3.3. Women's empowerment

Measured on an index from 0 to 1 where the closer to one the more empowered a woman is, the mean for the sample was found to be 0.73. The difference between the non-irrigators and irrigators was just minimal with the non-irrigators having an index of 0.73 and the irrigators at 0.72. On disaggregation based on the irrigation arrangements showed that the women primary decision makers in the farmer-led irrigation arrangement farm households were more empowered at 0.74 as compared to an index of 0.71 for the public irrigation scheme arrangement farm households.

Exposing the same to a percentile analysis, it was found that the median of the pooled sample was 0.73 which was similar to the mean of the non-irrigators while the median for the irrigators was 0.72. The median of the farmer-led irrigation arrangement and public irrigation scheme arrangement farm households was the same at 0.73. However, while the range of the 25th and 75th percentiles for non-irrigators and the public irrigation scheme arrangement was wide, it was noted that the one for the farmer-led irrigation arrangement farm households was very close showing a less discrepancy in the measurement. This showed a more harmonized empowerment

among the farmer-led irrigation arrangement farm households. This analysis is shown in Figure 32.

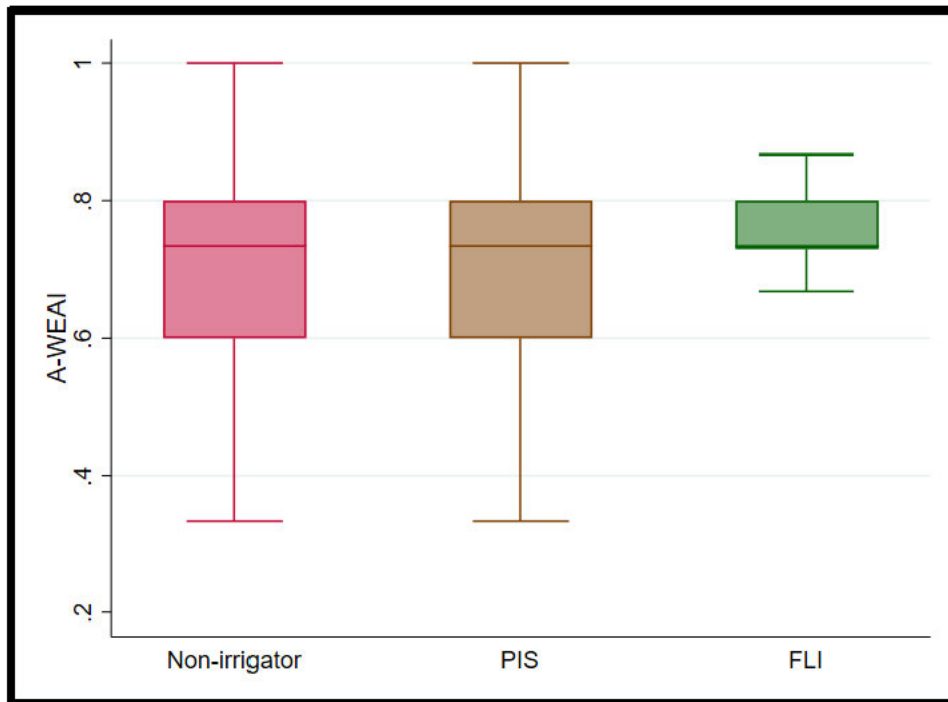


Figure 32: Box plots for women's empowerment

Source: Author based on survey data.

As a matter of clarity, the study also compared the intra-household empowerment in the sample by gender. The same measurement of the A-WEAI was applied in line with the instructional guide (H. Malapit et al., 2015). This gave a view of how the farm households differ in the empowerment measures between men and women. For the pooled sample and non-irrigators, there was a difference in the mean empowerment of the women and men with the women index being lower at 0.73 and the men at 0.75. On the other hand, for the irrigators in the public irrigation scheme arrangement farm households exhibited a difference in the empowerment between men and women with the women index being at 0.71 and the men index at 0.75. Contrary to the public irrigation scheme arrangement farm households, the farmer-led irrigation arrangement farm households had a similar level of empowerment at 0.74. This points to the farmer-led irrigation arrangement fostering a more equal intra-household decision making structure between the male and female decision makers. This information is presented in Figure 33.

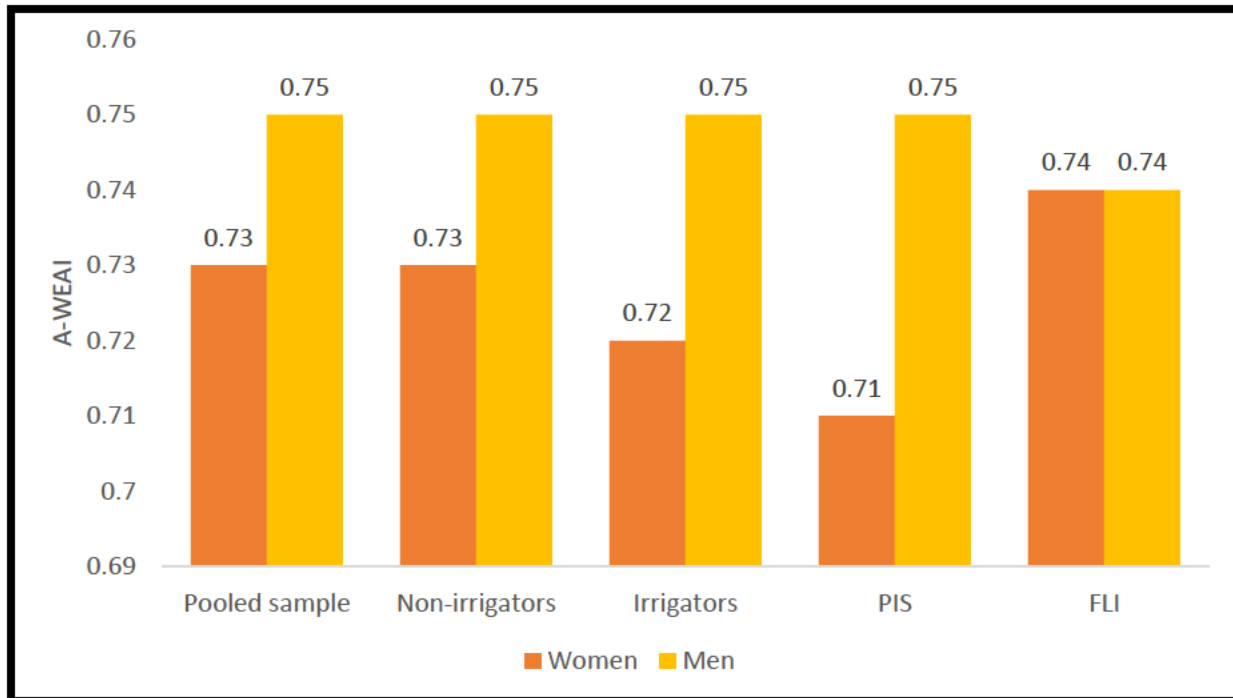


Figure 33: Analysis of the average empowerment by gender across the different irrigation arrangements

Source: Author based on survey data.

5.3.4. Dietary Diversity

As pointed out in Section 4.1.5.1. of Chapter Four, this variable is used as the proxy of the measurement of the nutrition outcome of the household. Though taken at individual level, the outcome is used to represent the case of dietary diversity for the individuals in the household. Therefore, this section gives a deeper analysis of the variable in respect to the measures of central tendencies as well as a comparison with the other three key mean variables (production diversity, farm income and women's empowerment). This is given in order to give a wider Birdseye view of the variable as a precursor to the analyses in the following chapters.

The mean dietary diversity for the pooled sample was 4.64 with a distribution range of 1 to 8. This mean it's quite low when compared to the nutritional threshold of 5 food groups (FAO,2021). This was evident in all the sub-samples in accordance to irrigation arrangements with the irrigators having a slightly larger mean of 4.83 as compared to 4.46 for the non-irrigators. Subsequently, the public irrigation scheme arrangement households had a mean of 4.72 and farmer-led irrigation arrangement households had the highest mean but still below the 5 food groups threshold at 4.93. A graph of the means given in Figure 34 shows that the means for the two irrigation arrangements is above the pooled sample mean while the non-irrigators' mean is below it. Though the distance is less than a unit between the irrigation arrangements, it will be interesting to see what statistical tests of significance draw from this distribution.

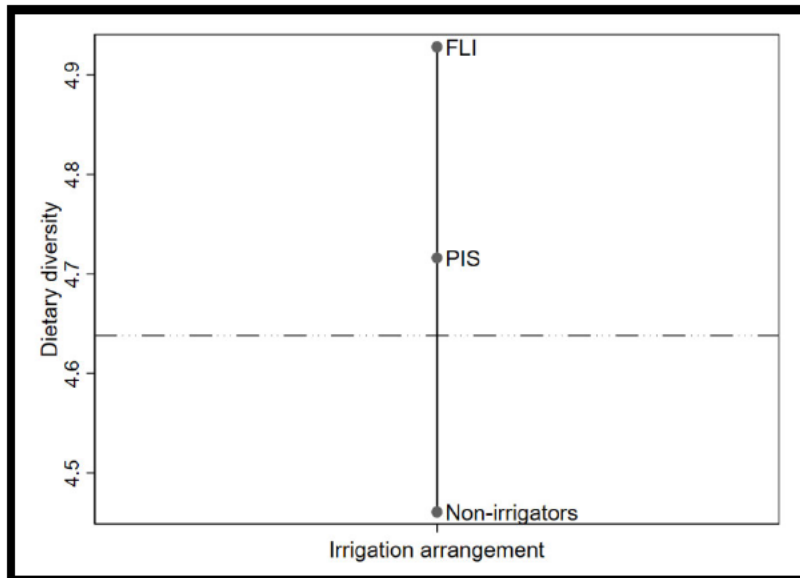


Figure 34: Graph of the means across the irrigation arrangements (dash and dot line represents the sample mean)

Source: Author based on survey data.

To check the analysis of the dietary diversity across the percentiles the box plots for the different irrigation arrangements is given in Figure 35. While the median for the pooled sample was 4.83, the median for the non-irrigators was lower at 4.46 while the median for the irrigators as well as for the public irrigation scheme arrangement farm households was the same at 4.83. The median for the farmer-led irrigation arrangement was at the recommended food group threshold of 5. This gives an indication that the farmer-led irrigation arrangement farmers may be able to access more diversified food. However further analysis on this is given in the following chapters.

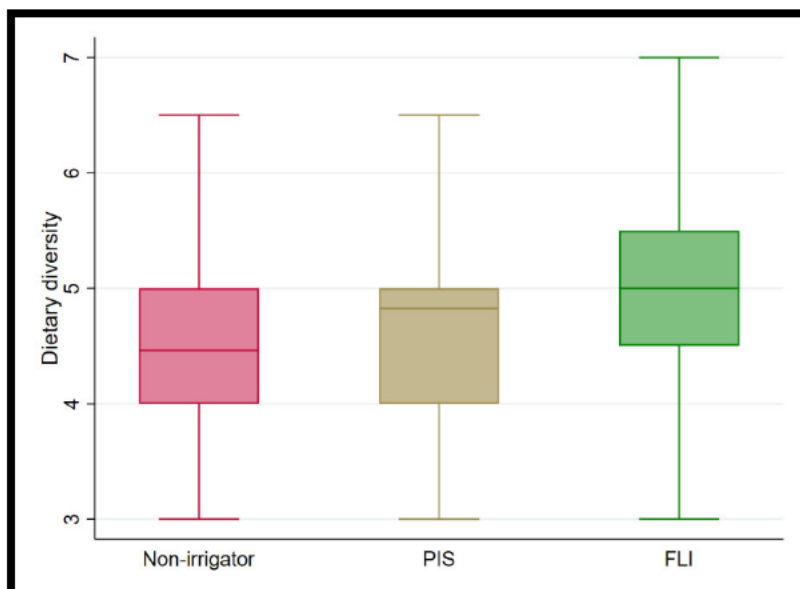


Figure 35: Dietary diversity across the irrigation arrangements

Source: Author based on survey data.

5.3.4.1. Comparison of the dietary diversity against production diversity, income and women's empowerment

Given that when data is more skewed or the range is large the median gives a better comparison, box plots for dietary diversity, production diversity, farm income and women's empowerment were used. For the production diversity, the comparison was rather synonymous given that the scale is the same. However, for the farm income, the natural logarithm was taken while for the women's empowerment, the values were multiplied by 10. This thus gave a similar comparison scale for all the variables in terms of distribution. This analysis is shown in Figure 36.

The box plots do not show any increment or decrement trend for the different variables or irrigation arrangements as it relates to the 25th 50th and 75th percentiles. For the production diversity showed a much larger range distribution than for the dietary diversity. There was also a dissimilarity as it relates to the median with the non-irrigators' having the lowest dietary diversity median but the highest production diversity median, the public irrigation scheme arrangement farm households having the lowest median production diversity.

In a similar manner, the dietary diversity and income medians also does not give any visual correlation based on the medians across the irrigation arrangements. In this aspect, it is noted that the public irrigation scheme arrangement farm households had the highest income with their log income 25th percentile almost above the non-irrigator's 75th percentile but not the highest dietary diversity among the irrigation arrangements. However, it is notable that in all the irrigation arrangements, the incomes' medians are higher than the dietary diversity medians.

The comparison of the dietary diversity and the women's empowerment medians also does not give any systematic stair-wise movement. Though the distribution of the percentiles between the non-irrigators and public irrigation scheme arrangement farm households is almost similar, the dietary diversity as seen earlier is not the same.

This thus begs the use of further methods to relate these variables. This will be done in the proceeding chapters where this study looked at each of these variables in depth. It then gives pathways through which production diversity, income and women's empowerment leads to higher dietary diversity.

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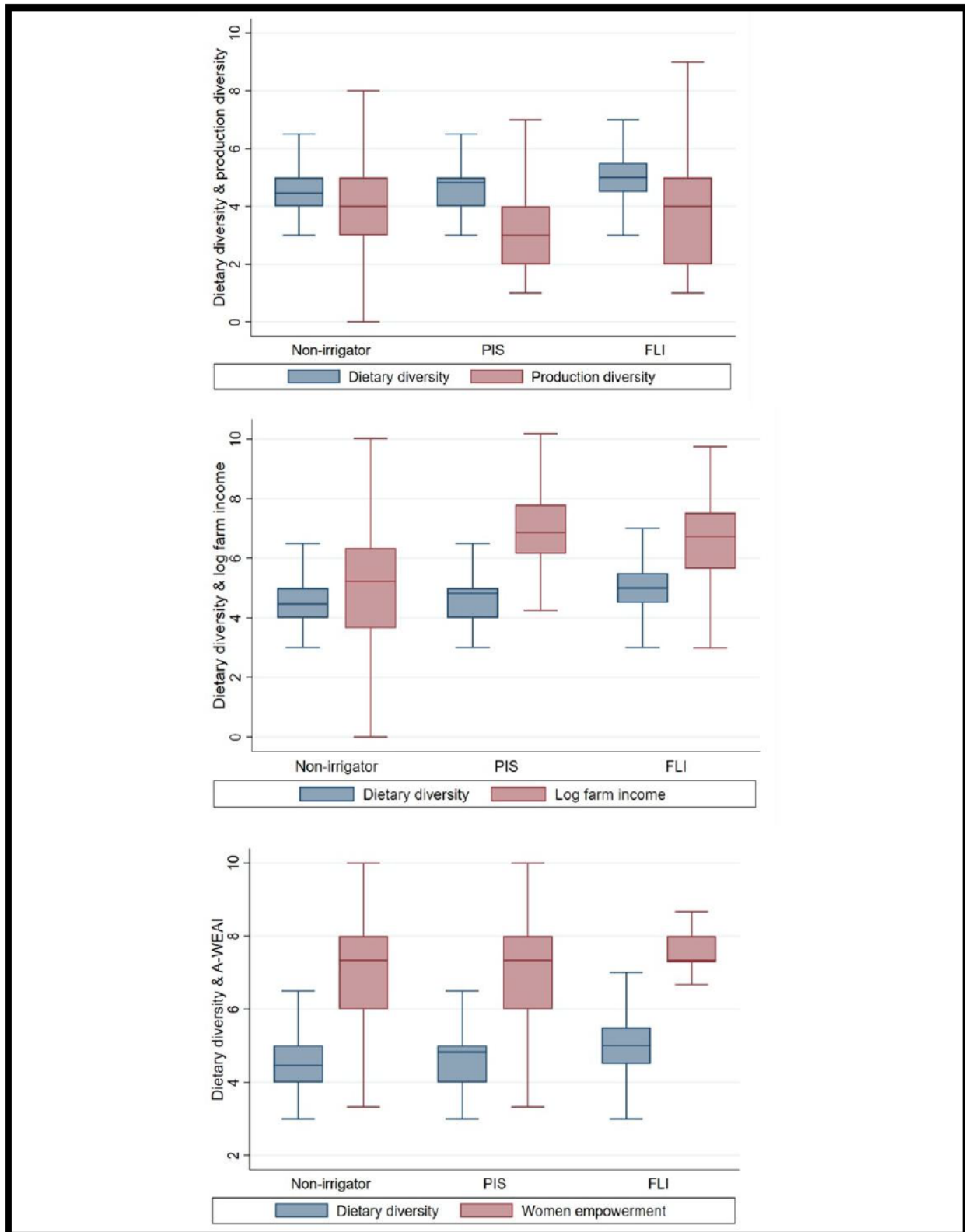


Figure 36: Comparison of the dietary diversity's percentiles against production diversity, income and women's empowerment by irrigation arrangement

Source: Author based on survey data.

5.4. Main independent variables

The statistics comprising of the mean, median, minimum and maximum for the independent variables are presented by irrigation and irrigation arrangements in Table 10 and Table 11 respectively. This presentation of the variables helps in getting the overall comparability of the independent variables. On the other hand, a deeper discussion and presentation of the individual variables is given in the subsections below.

5.4.1. Age of the household heads and the primary female decision makers

The sample consisted of a relatively middle-aged population with the mean age of the household heads being at about 52 years and that of the primary female decision makers being younger at about 48 years as presented in Figure 37. The irrigating farmers had younger households' heads and primary female decision makers with a mean age of about 48 years and 43 years respectively as compared with about 56 years and 52 years for the same measurements for the non-irrigators. Equally, the households' heads and primary female decision makers of the farmer-led irrigation arrangement were the youngest at 48 years and 42 years respectively in comparison to the public irrigation scheme arrangement farmers at about 49 years and 44 years respectively. In this manner, the farmers in the much riskier and entrepreneurial farmer-led irrigation arrangement are younger as compared to the other irrigation related farming arrangements.

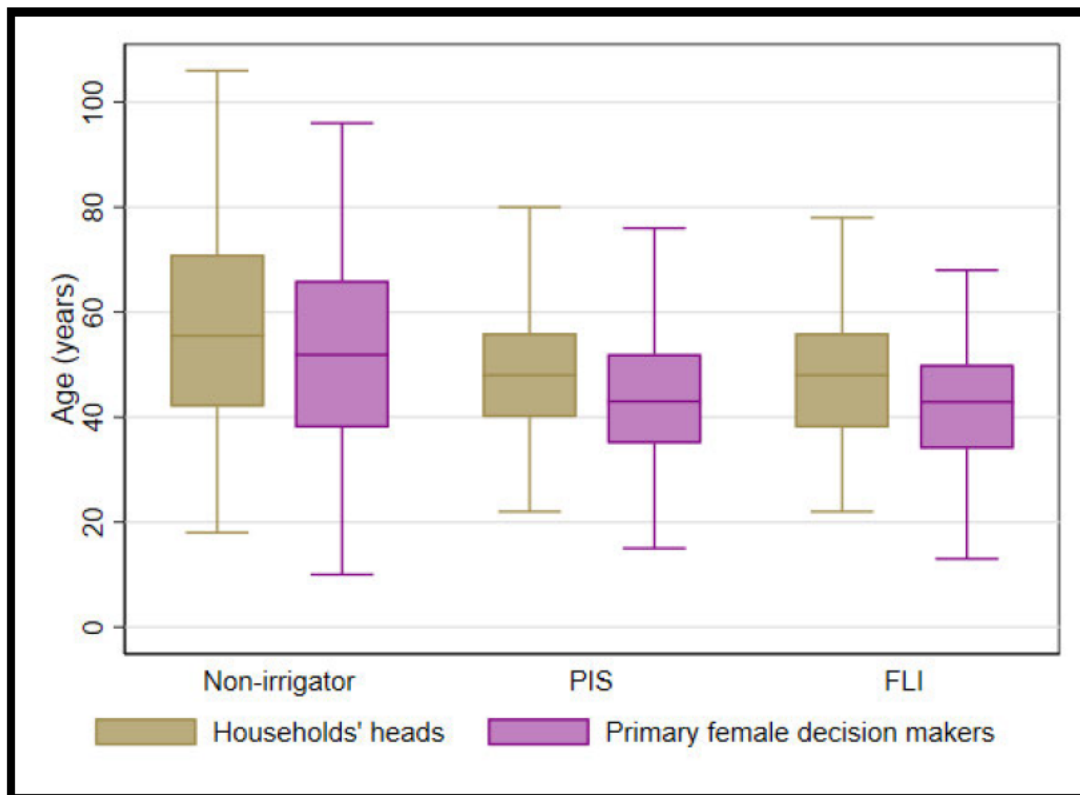


Figure 37: Age of the household heads and the primary female decision makers by irrigation arrangements

Source: Author based on survey data.

5.4.2. Education of the household heads and the primary female decision makers

The household's heads mean education years was about 8 years. This is equivalent to attaining the mandatory primary school level of education in Kenya. The irrigating households had a mean education of about 8.8 years. It was found that the household heads of the farmer-led irrigation arrangement farmers had the highest number of education years at a mean of 9.1 years as compared to the public irrigation scheme arrangement farmers at about 8.4 years. This is in comparison to the non-irrigators mean education years of about 7.3 years. The primary female decision makers pooled education level was lower in all the measurements at about 7.3 years for the pooled sample, 6.3 years for the non-irrigators, 8.3 for the farmer-led irrigation arrangement and 8.5 years for the public irrigation scheme arrangement farmers. This clearly shows that the irrigating farmers had a higher level of education years. In the same manner, the education level of the households' heads of the farmer-led irrigation arrangement farmers was quite high even while compared to their counterparts in public irrigation scheme arrangement. The box plots of the sample medians are represented in Figure 38.

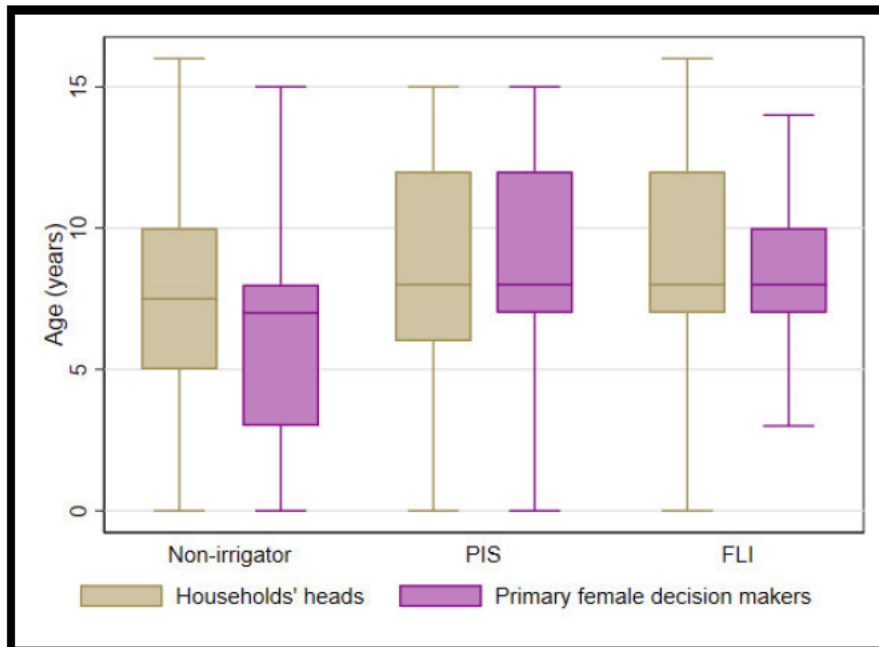


Figure 38: Education years of the household heads and the primary female decision makers by irrigation arrangements

Source: Author based on survey data.

5.4.3. Household composition by adults, size and gender

The study also looked at the composition of decision making at a household level. Two measurements were used in this measurement. One of it was as to whether the household had only one adult or not and the gender of the household head. The non-irrigators had a higher proportion of households with a single adult at about 62 percent as compared to the irrigators at about 38 percent. On the disaggregating the irrigation arrangements, the public irrigation

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scheme arrangement households had a proportion of single households of about 22 percent and the farmer-led irrigation arrangement households had about 15 percent.

The household size for the sampled households ranged between 1 and 8 members. The median household members of the pooled sample were 4 members per household which was the same median for the pooled irrigators, that is, the farmer-led irrigation arrangement farm households and the public irrigation scheme arrangement farm households. Only the non-irrigators median was different at 3 persons per household. In a scenario where household labor is essential, this shows that the non-irrigating households might have a disadvantage in this regard subject to other factors such as member involvement in farming, health situation and age of the members. The analysis of the medians of the household size is presented in Figure 39.

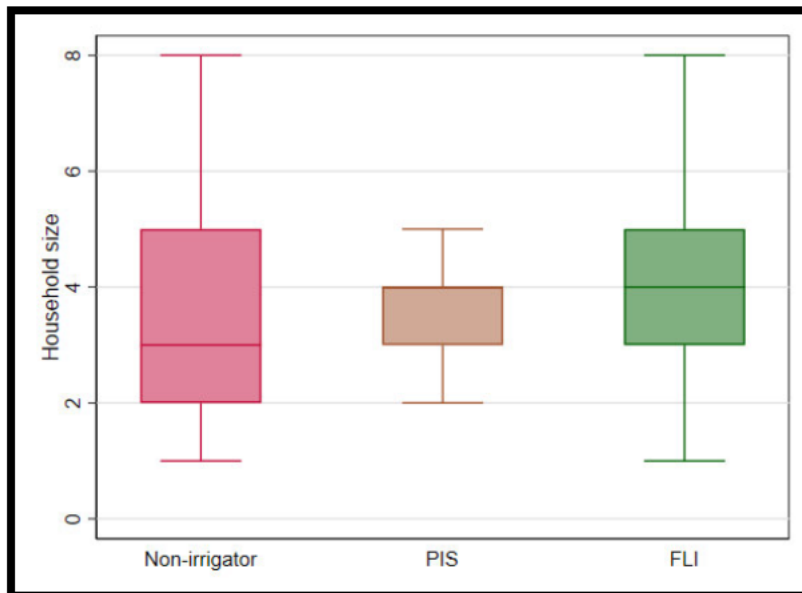


Figure 39: Household size across the irrigation arrangements
Source: Author based on survey data.

Contrariwise, the non-irrigators had the highest proportion of households whose head was of the female gender at about 64 percent. On the other hand, the proportion of households whose head was of the female gender for the irrigators was at about 36 percent. When disaggregated, it was found that the farmer-led irrigation arrangement farmers had the lowest proportion of households whose head was of the female gender was at about 12 percent. This was in comparison to about 24 percent for the public irrigation scheme arrangement farmers for the same variable.

5.4.4. Household assets holding and non-farm income

The average asset holding for the sampled households was at USD 1,443.48. The irrigators had almost three times the assets worth of the non-irrigators at USD 2,149.80 as compared to USD 779.79. The farmer-led irrigation arrangement farm households had a higher asset worth of about USD 2,670.62 compared to the public irrigation scheme arrangement farm households at

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a mean of USD 1,582.15. Given that the range of the asset holding at household level was quite wide, an analysis of the quantiles was also done and it is presented in Figure 40. The median for the whole sample was quite low at about USD 363.09. The median asset holding for the non-irrigating households was lower than the pooled median of the sample at approximately USD 262.78. The median asset holding for the farmer-led irrigation arrangement and public irrigation scheme arrangement farm households was found to be USD 2,670.62 and USD 1,582.15 respectively.

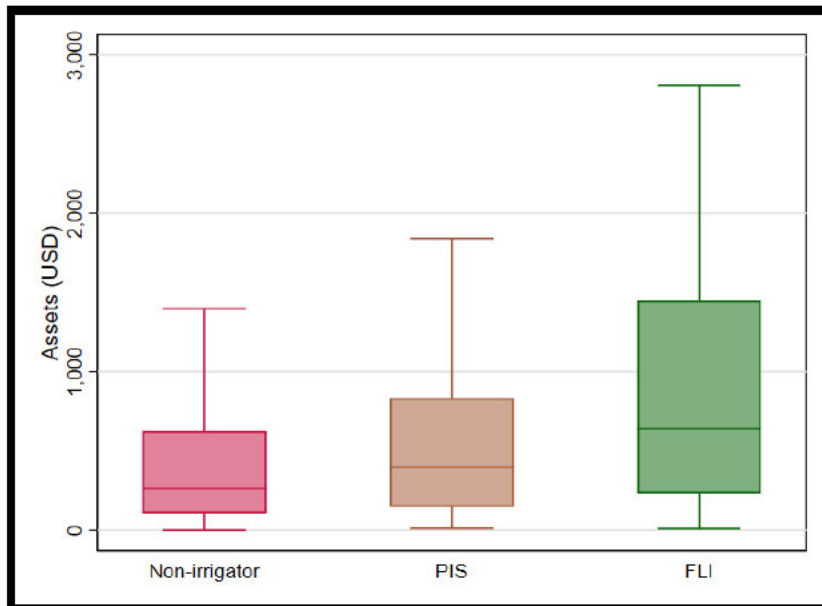


Figure 40: Household asset holding across the irrigation arrangements

Source: Author based on survey data.

The non-farm income of the pooled sample was also analyzed in a similar manner as the asset holding. The mean non-farm income of the pooled sample was found to be USD 544.28. The average non-farm income of both the irrigators and non-irrigators did not have a high range with the non-irrigators one at USD 523.68 and the irrigators at USD 566.20. The range between the mean non-farm income of the public irrigation scheme arrangement and farmer-led irrigation arrangement sampled households was wider. The mean non-farm income of the public irrigation scheme- and farmer-led irrigation- arrangement households was at USD 454.75 and USD 668.46 correspondingly.

To triangulate this by using the median as a measure of central tendency, it was found that the median non-farm income was quite low at USD 51.21. The median for the non-irrigators and irrigators was also at the same level of USD 51.21. The farmer-led irrigation arrangement and PSI households had a median non-farm income of USD 0.00 and USD 77.27 respectively. This is presented in Figure 41. This shows that the non-farm income from these households is quite minimal. This is plausible given that farming is the household's main economic activity and hence it leaves little time or other resources such as labor to be employed in income generating pursuits outside of the farming activities.

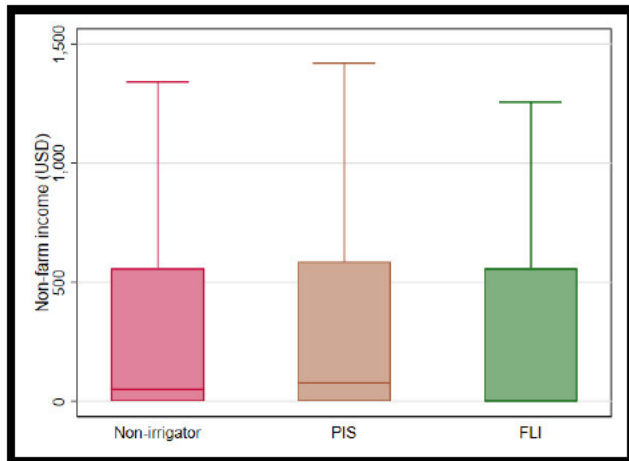


Figure 41: Non-farm income across the irrigation arrangements

Source: Author based on survey data.

5.4.5. Household livestock ownership

The range of the tropical livestock units showed that the ownership of livestock was majorly for small animals especially indigenous chicken and local breeds of goats as shown in Figure 42 below. This may reflect the land size constraints for keeping larger livestock especially the households in the public irrigation scheme arrangement who live in densely populated villages surrounded by rice paddies designed and allocated during the colonial period. From the focus group discussions, it was also noted that the ownership of small livestock especially domestic fowls was associated with women.

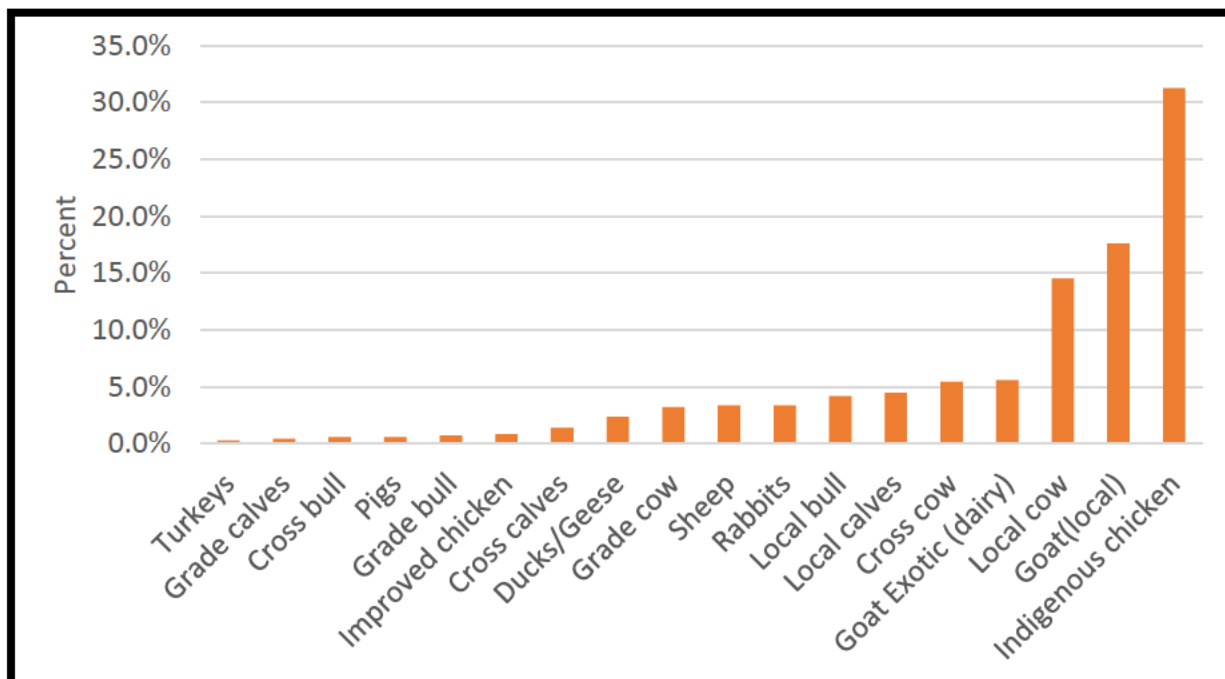


Figure 42: Type of livestock owned by the households

Source: Author based on survey data.

The livestock ownership in the sampled population was quite low with a mean of 0.69 tropical livestock units. The non-irrigators had higher units of livestock ownership at an average of 0.74 units as compared to 0.64 units for the irrigators. The farmer-led irrigation arrangement farmers had a mean tropical livestock unit of 0.72 units. The public irrigation scheme arrangement farm households had the lowest ownership of livestock at a mean of 0.55 tropical livestock units. A presentation of the box plots with this information is shown in Figure 43.

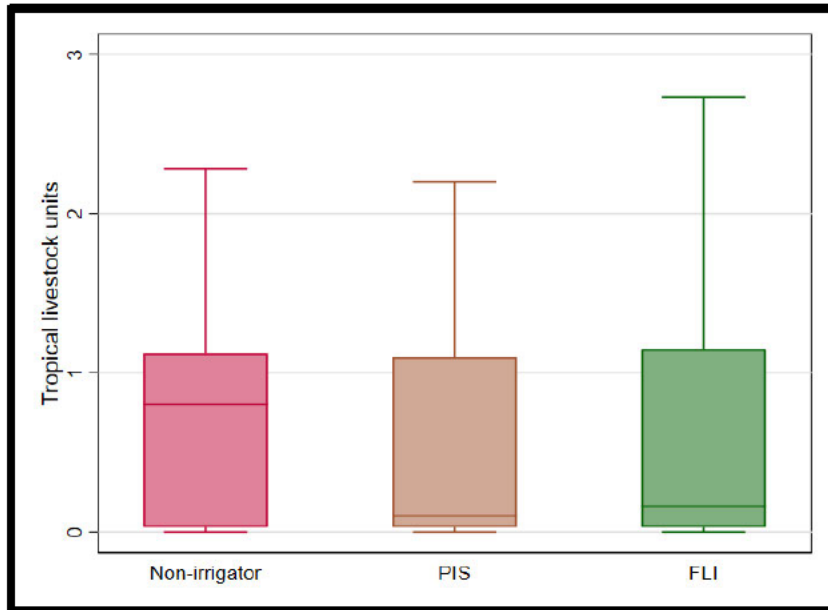


Figure 43: Household tropical livestock units by irrigation arrangement

Source: Author based on survey data.

The low ownership of livestock in the sample may be explained by the opportunity cost of applying labor in livestock keeping as opposed to crop production. Generally, the traditional African pastoral systems as well as the current livestock keeping such as dairy keeping is largely labor intensive (Kamuanga et al., 2008; Kibara & Kotosz, 2022). In this respect, the ownership of livestock would create a need to obtain more labor for which resources are scarce as shown earlier by the resource variables such as farm and non-farm incomes.

5.4.6. Household land access

The land title holding for the pooled sample was at about 49 percent with the non-irrigators having a proportion of 58 percent and the irrigators about 42 percent. Of the irrigators, the farmer-led irrigation arrangement farm households had about 24 percent of the households having land titles while only approximately 18 percent of the public irrigation scheme farm households had land titles. The low land title holding in public irrigation scheme arrangement farm households is because most of the farmers in the scheme were not given land titles even after the ownership moved from the defunct NIB (current NIA) to them (Kihoro et al., 2013). This was evident in the field with most of the farmers having a land allotment number instead of a land title deed. The land number was given during the allocation of land with each households

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being given 4 acres of land between 1954 and 1960 (Kabutha & Mutero, 2002; Kikuchi et al., 2021). The holding of title deed is an important aspect of credit access in Kenya, where land is mostly used as collateral and this has been a contentious issue in this area (Kabutha & Mutero, 2002; Kihoro et al., 2013; Makini et al., 2017). Further, the results point out to the irrigators' willingness to take up the risk of farming on land without permanent land tenure.

The sampled households' mean land ownership was found to be small and thus measured in terms of acres as opposed to hectares (1 hectare equals 2.47 acres). The land ownership in the sample was found to be an average of 1.56 acres. The mean ownership of land by the non-irrigating farm households, public irrigation scheme arrangement farm households and farmer-led irrigation arrangement farm households was 1.54 acres, 1.39 acres and 1.75 acres respectively. The box plot for this distribution of the medians is shown in Figure 44.

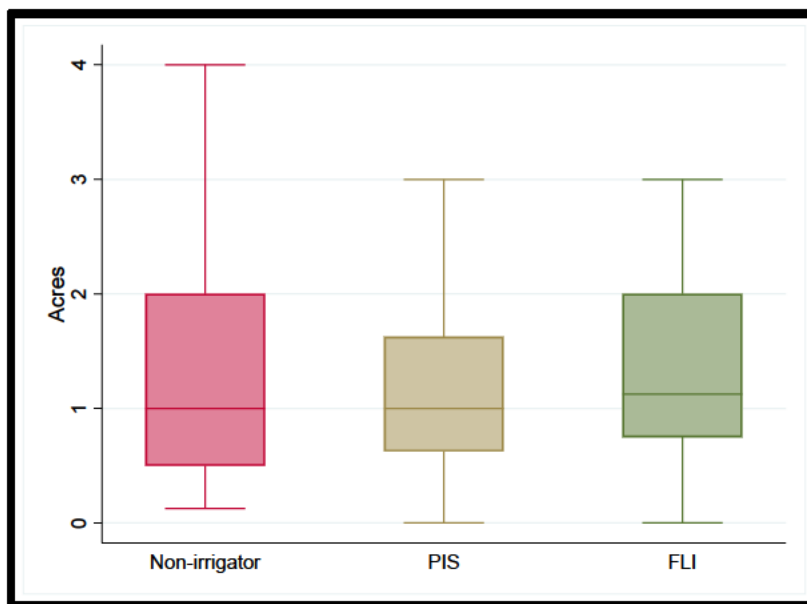


Figure 44: Land ownership

Source: Author based on survey data.

On the other hand, just as land ownership, the size of the land rented-in was small at an average of 0.33 acres and the non-irrigating households barely renting in land with a low mean of 0.09 acres. However, the irrigating households had a higher land renting acreage at 0.53 acres and 0.64 acres for the farmer-led irrigation arrangement and public irrigation scheme arrangement farm households respectively. Given the low land ownership as shown above, this is quite a significant amount of land rented in by the irrigating households as shown in Figure 45. This shows their affinity for more land to farm as opposed to those who are not irrigating. In line with this, the pricing of an acre of land was also investigated in this study.

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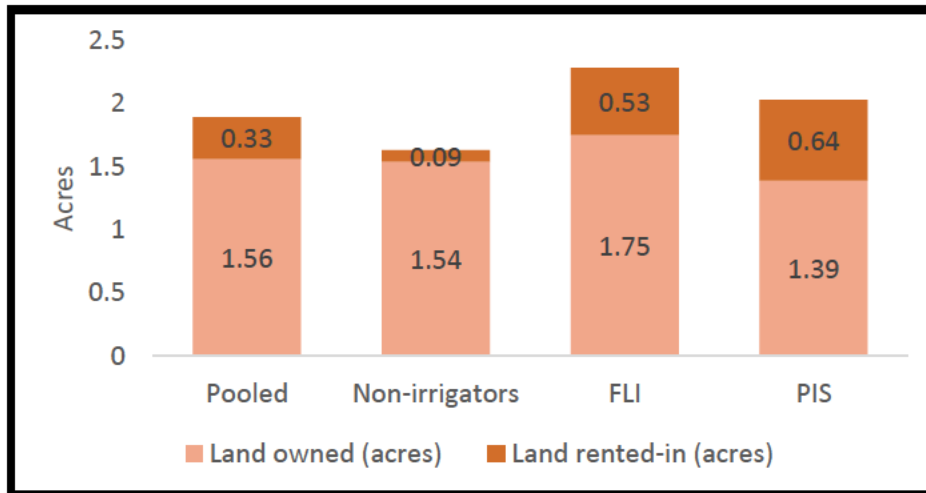


Figure 45: Land ownership and land rented-in

Source: Author based on survey data.

The distribution of the land rental rates for each of the irrigation arrangements is shown in Figure 46. As shown in the figure, the farm lands that are in the public irrigation scheme arrangement costed the highest to rent at a median of about USD 372.40. This can be attributed to the ease of water access in these areas and also the effect of demand for the land for commercial rice production. The land rental rates for the farmer-led irrigation arrangement areas were about a third of the rates for the public irrigation scheme arrangement areas at approximately USD 130.34. This can be attributed to the less attractive positioning of the lands in relation to water sources as opposed the public irrigation scheme arrangement counterparts. In addition, this may also reflect the price of the needed investments to produce in the land such as pipes, pumps and labor. The non-irrigated lands rental price was lowest at about USD 88.45.

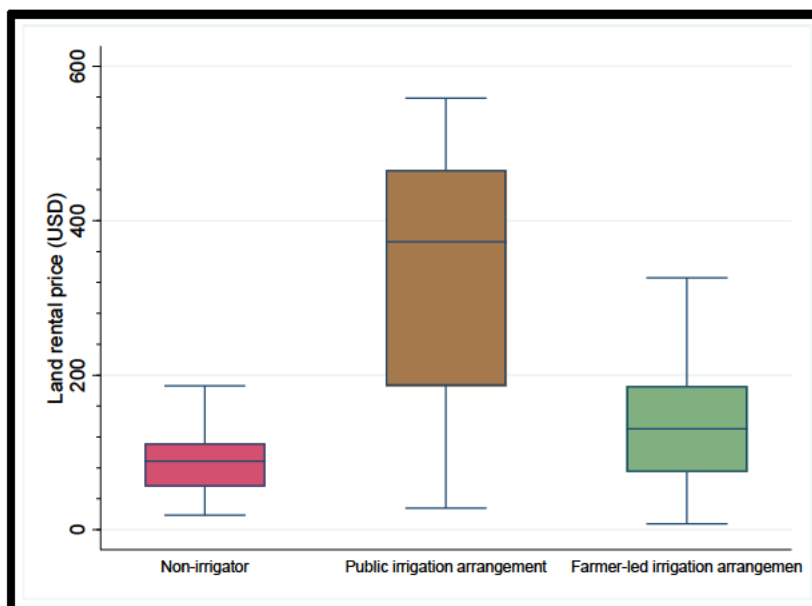


Figure 46: Land rental rates across the irrigation arrangements

Source: Author based on survey data.

5.4.7. Household access to extension services and inputs

The access to extension services was quite low in the sample with only about 17% of the households reporting ever receiving agricultural extension services in the reference period. The irrigators had a higher access of extension services at about 64% while the non-irrigators had a proportion of about 36%.

Unexpectedly, the farmers in the farmer-led irrigation arrangement had an even lower access to agricultural extension services than the non-irrigating households at approximately 26%. The farmers in the public scheme irrigation arrangement had the highest percentage of access to extension services at about 37%. This high proportion of extension services access among the public irrigation scheme arrangement farmers can be attributed to the focus of extension services by the Country Government and agricultural agencies on the rice growing farmers in the scheme with these service providers often taking advantage of the WUA's meetings (from FGDs and KIIs).

The access of fertilizer in the fields was very high among the respondents with about 93% of the sampled households having accessed the input. The access of fertilizer was 89% and 98% for the irrigators and non-irrigators respectively. On the other hand, just below half of the households accessed hybrid seeds, at about 47%. The irrigators were found to be using more hybrid seeds as compared to the non-irrigators at about 58% as compared to 37%. On the disaggregated irrigation arrangements, the proportion using fertilizer and hybrid seeds between the public irrigation scheme- and farmer-led irrigation- arrangement households were almost the same. This shows a high penetration of access of fertilizers and hybrid seeds. The aspects on fertilizer use can be attributed to the cropping culture of the area. Previous research show not only a frequent but an excessive use of chemical fertilizer especially on rice fields (Kihoro et al., 2013), and less use of hybrid seeds in rice farming (Kihoro et al., 2013) and other crops such as in tomato and green gram farming (Wamari et al., 2016).

5.4.8. Household credit access and group membership

The statistics showed a low access of in-kind credit with only about 2% of the sampled households using it. It was however noted that the irrigators were accessing this mode of credit at a higher proportion than the non-irrigators at 4% as compared to 1%. On disaggregating the different irrigation arrangements, about 7% of the public irrigation scheme arrangement farm households were found to be accessing in-kind credit arrangements as compared to about 1% of the farmer-led irrigation arrangement farm households.

Approximately 21% of the sampled households had access to credit. About 19% of the non-irrigating households and 23% of the non-irrigation households had accessed credit in the period of reference. The farmer-led irrigation arrangement farmers had a higher proportion of access to credit at about 27% as compared to the public irrigation scheme arrangement farm households at approximately 19%. To investigate further the access to credit at household level, the access to credit by the primary female decision maker was also investigated. It was thus found that about 15% of the primary female decision makers in the sampled households had access to credit.

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There was a minimal difference in credit access for the primary female decision makers between non-irrigators and irrigators at 15% and 14 % respectively. The credit access for the primary female decision makers for the farmer-led irrigation arrangement and public irrigation scheme arrangement farm households was 15% and 12% respectively. This shows a proportional difference especially among the irrigation arrangements with the primary female decision makers accessing less credit themselves.

There was a high level of group membership among the sampled households with approximately 78% of the households having a member of a group. The irrigating households had a higher proportion of households with group membership at about 83% as compared to 74% of the non-irrigating households. However, the group membership among households in the farmer-led irrigation arrangement and public irrigation scheme arrangement irrigation arrangements was almost alike at about 82% and 84% respectively.

Of the pooled sample, about 63% of the primary female decision makers were members of a group of which membership for the irrigators households was about 65% and non-irrigators was approximately 61%. The public irrigation scheme arrangement farm households had a higher proportion of primary female decision makers in groups at about 66% as compared to the farmer-led irrigation arrangement farm households at 63%. However, with these proportions above the 50% mark, it shows the high penetration of groups in which farm households are members not only for the households as a whole but also for the primary female decision makers.

5.4.9. Household distance to the nearest piped water and agricultural market

It was found that on average, households were 0.23 kilometers from the nearest piped water. The irrigators were closer to piped water with a mean distance of 0.16 kilometers as compared to the non-irrigators at 0.31 kilometers. Likewise, the public irrigation scheme arrangement farm households had a shorter distance to piped water at an average distance of 0.27 kilometers as compared to the farmer-led irrigation arrangement farm households at 0.36 kilometers. These statistics is plausible given the settlement arrangements discussed in Chapter Four, the households in the irrigation scheme enjoy the ease of pooling resources, lobbying and political and developmental goodwill that comes with clustered settlement. On the other hand, given the distance to water resources by the non-irrigators, concentrating on how water can be as close to the household as possible for water use is a priority unlike the farmers who can access irrigation waters.

The mean distance to the market for the sampled households was 3.6 kilometers with the non-irrigators having to cover a mean distance of 3.48 kilometers as compared to 3.73 kilometers for the irrigators. However, on disaggregating this on the irrigation arrangements, it was found that the public irrigation scheme arrangement farm households were closest to the market at a mean distance of 2.89 kilometers and the farmer-led irrigation arrangement farm households were furthest from the market at an average distance of 4.51 kilometers. As discussed above and also cited in Chapter Four, due to the clustering of the households in the settlement areas in the public irrigation scheme, these areas have developed into produce and supply markets. This can be seen

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in the map in Figure 47 that shows the locations of the markets with most of them inside the irrigation schemes owing to the scheme's settlement history.



Figure 47: Map of the area showing the location of the markets

Source: Google Earth, accessed on 27th September 2022 at 09:10 hours.

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Table 10: Descriptive statistics of variables by irrigation

Variables	Pooled sample (N = 384)				Non-irrigators (N = 198)				Irrigators (N =186)			
	Mean	Median	Min	Max	Mean	Median	Min	Max	Mean	Median	Min	Max
Key dependent variables												
Dietary diversity	4.64	4.83	1	8	4.46	4.46	1	7	4.83	4.83	3	8
Household production diversity	3.60	3.00	0	9	3.88	4.00	0	8	3.30	3.00	1	9
Farm income (USD)	1368	441.	0	2630	746.	184.	0	2240	2029	890.	0	2630
	.07	.07		1.09	.60	.81		0.15	.64	.05		1.09
Women's empowerment	0.73	0.73	0	1	0.73	0.73	0	1	0.72	0.73	0	1
Independent variables												
Age of the household head (years)	52.3	50.0	18	106	56.2	55.5	18	106	48.2	48.0	22	85
	4	0			2	0			1	0		
Age of the primary female decision maker (years)	47.5	46.0	10	96	51.8	51.8	10	96	42.9	42.9	13	80
	3	0			8	8			0	0		
Assets (USD)	1443	363.	0	7728	779.	262.	0	2200	2149	466.	9.	7728
	.48	.09		8.89	.97	.78		9.59	.80	.90	31	8.89
Gender of the household head (Female)	0.22	0.00	0	1	0.28	0.00	0	1	0.17	0.00	0	1
Single adult household type	0.22	0.00	0	1	0.27	0.00	0	1	0.17	0.00	0	1
Education level of the household head (years)	8.04	8.00	0	16	7.34	7.50	0	16	8.77	8.00	0	16
Education level of the primary female decision maker (years)	7.32	8.00	0	26	6.32	7.00	0	15	8.38	8.00	0	26
Household size	3.53	4.00	1	8	3.43	3.00	1	8	3.64	4.00	1	8
Land owned (acres)	1.56	1.00	0	18.13	1.54	1.00	0.1	18.13	1.58	1.00	0	10
							3					
Land rented-in (acres)	0.33	0.00	0	10	0.09	0.00	0	2	0.59	0.00	0	10
Land rental price (USD per acre)	171.	111.	7.	605.1	104.	88.4	18.	558.6	242.	186.	7.	605.1
	50	72	45	6	47	5	62	1	85	20	45	6
Tropical livestock units	0.69	0.13	0	3.4	0.74	0.80	0	3.26	0.64	0.13	0	3.4

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Variables	Pooled sample (N = 384)				Non-irrigators (N = 198)				Irrigators (N =186)			
	Mea n	Med ian	Mi n	Max	Me an	Med ian	Mi n	Max	Mea n	Med ian	Mi n	Max
Non-farm income (USD)	544. 28	51.2 1	0	1480 3.09	523. 68	51.2 1	0	6703. 29	566. 20	51.2 1	0	1480 3.09
Land title holding	0.49	0.00	0	1	0.56	1.00	0	1	0.42	0.00	0	1
Extension services	0.17	0.00	0	1	0.12	0.00	0	1	0.23	0.00	0	1
Primary female decision maker production decision	0.15	0.20	0	0.2	0.16	0.20	0	0.2	0.13	0.20	0	0.2
Access to fertilizer	0.93	1.00	0	1	0.89	1.00	0	1	0.98	1.00	0	1
Access to hybrid seed	0.47	0.00	0	1	0.37	0.00	0	1	0.58	1.00	0	1
In-kind credit	0.02	0.00	0	1	0.01	0.00	0	1	0.04	0.00	0	1
Household credit access	0.21	0.00	0	1	0.19	0.00	0	1	0.23	0.00	0	1
Primary female decision maker credit access	0.15	0.00	0	1	0.15	0.00	0	1	0.14	0.00	0	1
Household group membership	0.78	1.00	0	1	0.74	1.00	0	1	0.83	1.00	0	1
Primary female decision maker group membership	0.63	1.00	0	1	0.61	1.00	0	1	0.65	1.00	0	1
Distance to the nearest piped water (kilometers)	0.23	0.00	0	8	0.16	0.00	0	3	0.31	0.00	0	8
Distance to the market (Kilometers)	3.60	3.00	0	20	3.48	3.00	0	20	3.73	3.00	0. 15	20

Source: Fieldwork survey

5. DESCRIPTIVE STATISTICS

Table 11: Descriptive statistics of variables by irrigation arrangements

Variables	Non-irrigators (N = 198)				Farmer-led irrigation arrangement (N =97)				Public irrigation arrangement (N = 89)			
	Me an	Med ian	Mi n	Max	Mea n	Medi an	Min	Max	Mea n	Med ian	Mi n	Max
Key dependent variables												
Dietary diversity	4.46	4.46	1	7	4.93	5.00	3	8	4.72	4.83	3	7.5
Household production diversity	3.88	4.00	0	8	3.62	4.00	1	9	2.94	3.00	1	7
Farm income (USD)	746.60	184.81	0	2240.15	2140.97	830.00	0	17028.21	1908.31	947.77	0	2630.09
Women's empowerment	0.73	0.73	0	1	0.74	0.73	0.2	1	0.71	0.73	0	1
Independent variables												
Age of the household head (years)	56.22	55.50	18	106	47.45	48.00	22	78	49.03	48.00	22	85
Age of the primary female decision maker (years)	51.88	51.88	10	96	41.62	42.90	13	68	44.29	43.00	15	80
Assets (USD)	779.97	262.78	0	2200.959	2670.62	639.61	9.31	47790.71	1582.15	400.34	11.17	7728.89
Gender of the household head (Female)	0.28	0.00	0	1	0.10	0.00	0	1	0.24	0.00	0	1
Single adult household type	0.27	0.00	0	1	0.13	0.00	0	1	0.21	0.00	0	1
Education level of the household head (years)	7.34	7.50	0	16	9.09	8.00	0	16	8.43	8.00	0	15
Education level of the primary female decision maker (years)	6.32	7.00	0	15	8.25	8.00	0	26	8.52	8.00	0	15
Household size	3.43	3.00	1	8	3.69	4.00	1	8	3.58	4.00	1	8

5. DESCRIPTIVE STATISTICS

Variables	Non-irrigators (N = 198)				Farmer-led irrigation arrangement (N =97)				Public irrigation arrangement (N = 89)			
	Me an	Med ian	Mi n	Max	Mea n	Medi an	Min	Max	Mea n	Med ian	Mi n	Max
Land owned (acres)	1.54	1.00	0.13	18.13	1.75	1.13	0	6	1.39	1.00	0	10
Land rented-in (acres)	0.09	0.00	0	2	0.53	0.00	0	6	0.64	0.00	0	10
Land rental price (USD per acre)	104.47	88.45	18.62	558.61	162.24	130.34	7.45	605.16	330.69	372.40	27.93	558.61
Tropical livestock units	0.74	0.80	0	3.26	0.72	0.16	0	3.4	0.55	0.10	0	2.75
Non-farm income (USD)	523.68	51.21	0	6703.29	668.46	0.00	0	14803.09	454.75	77.27	0	3910.25
Land title holding	0.56	1.00	0	1	0.46	0.00	0	1	0.38	0.00	0	1
Extension services	0.12	0.00	0	1	0.19	0.00	0	1	0.28	0.00	0	1
Primary female decision maker production decision	0.16	0.20	0	0.2	0.14	0.20	0	0.2	0.12	0.20	0	0.2
Access to fertilizer	0.89	1.00	0	1	0.96	1.00	0	1	1.00	1.00	1	1
Access to hybrid seed	0.37	0.00	0	1	0.55	1.00	0	1	0.62	1.00	0	1
In-kind credit	0.01	0.00	0	1	0.01	0.00	0	1	0.07	0.00	0	1
Household credit access	0.19	0.00	0	1	0.27	0.00	0	1	0.19	0.00	0	1
Primary female decision maker credit access	0.15	0.00	0	1	0.15	0.00	0	1	0.12	0.00	0	1

5. DESCRIPTIVE STATISTICS

Variables	Non-irrigators (N = 198)				Farmer-led irrigation arrangement (N =97)				Public irrigation arrangement (N = 89)			
	Me an	Med ian	Mi n	Max	Mea n	Medi an	Min	Max	Mea n	Med ian	Mi n	Max
Household group membership	0.74	1.00	0	1	0.82	1.00	0	1	0.84	1.00	0	1
Primary female decision maker group membership	0.61	1.00	0	1	0.63	1.00	0	1	0.66	1.00	0	1
Distance to the nearest piped water (kilometers)	0.16	0.00	0	3	0.36	0.00	0	8	0.27	0.00	0	2
Distance to the market (Kilometers)	3.48	3.00	0	20	4.51	4.00	0.15	20	2.89	2.00	0.5	17

Source: Author based on survey data.

5.5. Conclusion

This chapter has given the descriptive statistics for the variables to be used in this study. This was aimed at giving the general landscape of the variables across the irrigation arrangements and not to give a statistically differentiated analysis of significance which was done in the following chapters. In this chapter, it has been established that from the descriptive statistics, it was not possible to make a conclusion on the relationship between dietary diversity and production diversity, income and women's empowerment. However, the analyses of the other independent variables across the irrigation arrangements have given quite eye-opening comparison on the difference in the socioeconomic setups of the households. This thus gives this study a good basis for the next analysis on the difference in the socioeconomic characteristics of households and how it influences irrigation and irrigation arrangements.

6. SMALLHOLDER FARMERS' HOUSEHOLD SOCIOECONOMIC FACTORS THAT INFLUENCE IRRIGATION AND IRRIGATION ARRANGEMENTS

6.1. Introduction

In literature, irrigation is most of the times treated as aggregated. Even when defined in different terms like small-scale irrigation (Bryan & Garner, 2022; Mangisoni, 2008; Passarelli et al., 2018) smallholder irrigation (Burney et al., 2010; Namara et al., 2011), smallholder irrigation systems (Hossain et al., 2005), or generally as irrigation (Von Braun et al., 1989). The analyses are centered on the premise that the irrigation practices are the same. However, in this study, it is claimed that this is not usually the case as premised in the hypotheses stated in Chapter Three of this dissertation.

Having presented the descriptive statistics in the last chapter, it is evident that there exist differences in the structure and composition of the socioeconomic factors of the households that practice irrigation and those that do not. In addition, there is clear differences in the household characteristics of those practicing the public irrigation scheme arrangement and the farmer-led irrigation arrangement. In this context, a key question ensues: which household factors have an effect on irrigation and irrigation arrangements? This chapter, answers this question.

However, the study is cognizant of the potential for bidirectional relationship between some socioeconomic factors and irrigation and irrigation arrangements. This is where some factors can influence a household's decision to irrigate, their choice of irrigation arrangement, and subsequently, the final outcome on nutrition. In this regard, the choice of the variables for the analyses provided in this study was a greatly informed by literature and the data structure. The choice of the variables is thus discussed in greater details in the conceptual framework section in Chapter Three and as to the postulated relationship to irrigation and irrigation arrangements. On the data structure, so as to reduce on biases related to endogeneity variables, only variables that individuals and collective households do not have control over were chosen. For instance, variables such as use of inputs were excluded rather including those related to access. In the ensuing analyses, further pre-econometric analyses are provided to show the relationship between the choice of variables and model validity.

In this chapter different econometric analyses were used to show the basis of the claim that household factors influence irrigation and irrigation arrangements. The first analysis compares the pooled irrigators with the non-irrigators thus providing a benchmark of comparison with the disaggregated analysis. In the second analysis, irrigation is disaggregated into the public irrigation scheme and farmer-led irrigation arrangements. To do this and ensure that the results are comparable, the choice of the regressors is maintained throughout all the regression analyses in this chapter. As such, the comparison between the two analyses is given to show that the factors that influence irrigation arrangements are dissimilar.

The analyses use the non-irrigators as the comparison group to show the influence of different socioeconomic factors in the households that determine these arrangements. In the first analysis, a binary probit analysis is used to show the factors that influence irrigation. This analysis was

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deemed important in that it gives the basis for comparison of the factors that influence irrigation as aggregated. In addition, it also aids the argument by comparing it with the results of the disaggregated analyses. In the second analysis, a multinomial logit analysis is applied to show the factors that influence the different irrigation arrangements. In this approach, the non-irrigators are used as the base outcome. The choice and justification for the model's base outcome are given in the model specification section in Chapter Four of this dissertation.

6.2. Results and discussion on the smallholder farmers' household socioeconomic factors that influence smallholder households towards irrigation

The regression statistics showed that the model is statistically significant. The likelihood ratio chi-square test had 17 degrees of freedom, which is equal to the number of regressors, in testing as to whether one of the predictors' regression coefficients is not equal to zero. In this respect, the probability of attaining the likelihood ratio statistic was found to be statistically significant at one percent level of confidence. As such, the null hypothesis that all of the regression coefficients in the model are equal to zero cannot be accepted. Therefore, it can be concluded that at least one of the regression coefficients is not equal to zero, which makes it reasonable to interpret the model. The regression results are presented in Table 12. The probit regression model analysis showed that the age and education level of the primary female decision maker, education level of the household head, land rental price, access to fertilizer and knowledge about water pumping technology influences irrigation.

An increase in the age of the primary female decision maker led to the decrease of a household irrigating. A unit increase in the age of the primary female decision maker was found to reduce the probability of the household irrigating by about 0.01. This therefore means that the households that had younger primary female decision makers were more likely to irrigate. This was against the hypothesized effect where age had been taken to be correlated to experience where the older one would be the more information one would have including of farming technologies such as irrigation. On the other hand, this conforms with the earlier postulation that the risk-taking attitude especially towards a new technology including irrigation reduces with age. This result is similar to the findings of Antwi-Agyei et al., (2021), Jaafar & Kharroubi, (2021) and Martey et al., (2023) who also found out that age influences irrigation technologies where older farmers are risk-averse towards it.

The regressions results showed that an increase in the education of the primary female decision maker increased the possibility of irrigating. In absolute terms, a unit increase in the years of education increased the possibility to irrigate by about 0.03. The extent of schooling a farmer has makes a significant difference in how much new information and technology they can use. Literacy also helps farmers read written sources, and also makes it easier for them to look for information from various sources (including digital ones) and use modern technology including irrigation technology. With about 59% rural women in Kenya involved in agriculture (World Bank, 2023a), increased access to education for women can have a positive influence on irrigation practices. In addition, higher education level among females is not only a source of power in

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accessing irrigation as found by Mwalyagile et al., (2025) in Tanzania, but also enhances autonomous decision making (Khare, 2021).

On the other hand, an increase in the education level of the household head reduces the probability of the household irrigating by about 0.003. This is plausible given that mostly, as found in the sample's descriptive statistics, household heads are usually men in this area's cultural context. However, research shows that most of the men of working age are usually engaged in off-farm activities including areas where irrigation practices take place (Cousins, 2013) leaving the women as the primary farmers (FAO, 2011). Therefore, there is a tendency of more learned male household heads applying the increase in information and knowledge away from agricultural activities (Brooks et al., 2013; Kang, 2010; Mwaura, 2017).

The higher the land rental rates, the higher the probability of irrigating in that a unit increase in the land rental price, increases the probability of irrigating by about 0.002. Land renting means incurring of a higher cost of production, as such the farmer would be inclined to put reasonable investment in the land to recoup the investment made on the land. This may explain the reason as to why the households renting-in land would invest in irrigation technologies. It is also notable that the land rental price for the irrigators was more than double the rental price for non-irrigators at USD 242.85 as compared to USD 104.47 for the non-irrigating farmers as discussed in Chapter Five on the descriptive statistics. The irrigators are willing to rent in land at higher cost which may also mean the need to make sure the land produces maximally across the season thus the need for irrigation.

In addition, the land rental rates may also be a proxy for reflects the suitability of the land to apply technologies such as irrigation. As such, land that is of a gently sloping gradient or near a water source would attract a higher rental price. This would then make this variable endogenous in that it would not only affect irrigation, but also irrigation affects it. With this being a potential problem to the analyses, the following chapters aim at using methods that can address this econometric and statistical challenge.

The access to inputs both fertilizers and hybrid seeds were found to increase the possibility of a household getting into irrigation. The results showed that households were most likely to be in irrigation if they accessed fertilizer by about 37% and about 13% more likely to be in irrigation if they accessed hybrid seeds. Inputs access in agriculture is highly associated with increase in production especially for commercial farming. In this regard, the use of hybrid seeds is common in irrigated crops such as tomatoes and French beans due to the commercial benefits. Therefore, in order to increase production and profits, the farmers who plant hybrid seeds of high value crops and use commercial fertilizers are more likely to invest in irrigation technologies to galvanize their investments against weather shocks increase the frequency and quantity of production and safeguard their investments. For instance, in the FGDs for the farmers in the farmer-led irrigation arrangement, the participants said that they sometimes intercrop crops at later stages and continue irrigating in order to fully utilize farm inputs like fertilizer applied on

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the main crops so they can get higher yields. This points out to influence of access to inputs on irrigation.



Figure 48: Sorting of harvested tomatoes with the background showing the crop
Source: Fieldwork photo

Having the knowledge of pump technologies was also found to influence the possibility of irrigating positively. If households had knowledge about pumping technology, they were likely to be irrigators by about 64%. The lack of knowledge on irrigation technologies is one of the challenges facing irrigation development in Kenya especially among smallholder farmers (Hornum & Bolwig, 2020, 2021) including those with access to extension services (B. M. Mati, 2008). However, it is worth noting that in this case, it does not mean knowledge in terms of information but rather experiential skills which is important in adoption of this technology given its complex nature (Hornum & Bolwig, 2021). Therefore, in this case, the farmers were asked if they had practical knowledge on the use of pumping technologies. Per se, the farmers in possession of this knowledge were more likely to adapt irrigation as opposed to those without it. This raises the question on what influences the other; does knowledge of pump technologies influence irrigation or irrigation influences knowledge of pump technologies. In this case, there is a case of potential interdependency between these two variables which is addressed in the ensuing chapters.

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Table 12: Probit regression on the factors of smallholder households' participation in irrigation [Equation 25]

Variables	Coefficients	Marginal effects (dy/dx)
Age of the household head (years)	0.003 (0.014)	0.001 (0.006)
Age of the primary female decision maker (years)	-0.026* (0.015)	-0.010 (0.006)
Education level of the household head (years)	-0.062* (0.033)	-0.025 (0.013)
Education level of the primary female decision maker (years)	0.077** (0.037)	0.031 (0.015)
Gender of the household head (Female) †	-0.172 (0.376)	-0.068 (0.148)
Single adult household type†	0.390 (0.392)	0.154 (0.152)
Household size	-0.070 (0.066)	-0.028 (0.026)
Assets (USD)	<0.000 (0.000)	<0.000 (0.000)
Land owned (acres)	-0.047 (0.050)	-0.019 (0.020)
Land rental price (per acre)	0.006*** (0.001)	0.002 (0.000)
Tropical livestock units	0.053 (0.124)	0.021 (0.050)
Household group membership†	0.255 (0.230)	0.101 (0.090)
Distance to the market (Kilometers)	-0.009 (0.030)	-0.004 (0.012)
Primary female decision maker production decision†	0.081 (0.328)	-0.070 (0.087)
Access to fertilizer†	1.112** (0.473)	0.375 (0.111)
Access to hybrid seeds†	0.326* (0.180)	0.129 (0.071)
Knowledge of pumping technology†	1.985*** (0.220)	0.639 (0.046)
Constant	-1.599** (0.730)	
Mean dependent variables	0.484	0.500
	SD dependent variables	

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Variables		Coefficients	Marginal effects (dy/dx)
Pseudo r-squared	0.495	Number of observations	384
Chi-square	263.289	Prob > chi2	0.000
Akaike crit. (AIC)	304.673	Bayesian crit. (BIC)	375.785

Note: Standard errors in parentheses. † dy/dx is for discrete change of dummy variable from 0 to 1. The notations and the meanings are as follows: *** p<.01, ** p<.05, and * p<.1

Source: Author based on survey data.

6.3. Results and discussion on the smallholder farmers' household socioeconomic factors that influence the possibility to be in the public irrigation scheme and farmer-led irrigation arrangements

The regression model was found to be statistically significant, as indicated by the regression statistics presented in Table 13. This was further confirmed by the likelihood ratio chi-square test, which had 34 degrees of freedom, which is the same number of regressors that were tested (each model had 17 degrees of freedom). This test was used to determine if one of the predictor's regression coefficients was not equal to zero. The analysis has led us to the conclusion that at least one of the regression coefficients in the model is not equal to zero. This suggests that the model is a valid representation of the data and that the predictor variables do have a statistically significant effect on the outcome. This means that the null hypothesis, which suggested that the regression coefficients were simultaneously equal to zero, was not accepted. This conclusion makes the model credible enough to be interpreted, as it shows that one or more of the regression coefficients is not equal to zero in that it has some predictive power, and can thus be used as a reliable tool for interpretation.

The age of the primary female decision maker influences households in the public irrigation scheme arrangement negatively. This means that as the primary female decision maker gets older, the likelihood of participating in the public irrigation scheme arrangement decreases. A unit change in the age of the primary female decision maker was found to reduce the probability of being in the public irrigation scheme arrangement by about 0.004. This was similar to the findings of the probit regression. The age of the primary decision maker is thus a critical factor in the entrance of farmers into both irrigation and public irrigation scheme arrangement. It is notable that as compared to the farmer-led irrigation arrangement, the public irrigation scheme arrangement is quite bureaucratic. This is in that it needs one to join a WUA, consistently attend the WUA's unit meetings and also participate in cleaning up of canals that supply water to the unit which is usually manually done. Such bureaucracies and additional manual work would tend to hinder the adoption of such an arrangement by older women.

The education of the household head was found to influence households in the public irrigation scheme arrangement negatively. A unit increase in the education level of the household head reduced the possibility of being in the public irrigation scheme arrangement by approximately

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0.01. This was in tandem with the earlier stated intuitive expectation. However it is essential to note that while education has a tendency to encourage technology adoption including in irrigation techniques, the kind of technology adopted by most educated smallholder farmers would draw them from this kind of irrigation arrangement that uses flood irrigation to more advanced irrigation technologies that are less labor intensive as also found out by Agarwal & Agrawal (2017). This explains the negative association between the household-heads' education and public irrigation scheme arrangement. In addition, as the household head gets more education, there is a tendency to draw the household away from agriculture (Brooks et al., 2013; Kang, 2010) or go towards agripreneurship (Mwaura, 2017). This finding is in contrast to the finding that education level of the primary female decision maker influences households towards public irrigation scheme arrangement. This is similar to the results for irrigation analysis presented earlier in this chapter. A unit increase in the education level of the primary female decision maker increases the possibility of being in the public irrigation scheme arrangement by approximately 0.02. This suggests that higher educated primary female decision makers are more likely to participate in the public irrigation scheme arrangement. However, it is notable that women farmers in Kenya (and much of SSA) do not have access to information and resources to adopt new practices (Manfre & Nordehn, 2013; Quisumbing & Pandolfelli, 2010) especially outside agriculture (Doss, 2018). Therefore, any additional knowledge through education by primary female household decision makers will most likely be applied in improving the farm enterprise including adoption of irrigation and specific irrigation arrangements.

The ability of the primary female decision maker making decisions about production was found to negatively influence the probability to be in the public irrigation scheme arrangement by 10.2%. This is in line with the anticipated outcome given the nature of landholding in the area from a historical background. With every farm household having been allocated 4 acres and a patriarchy patrimonial system existing in matters land ownership, women who have a decision on production would be more inclined to shift from this type of arrangement to one that they have a control over land ownership and use. In addition, in most cases in Kenya, decision making on irrigated agriculture and the accruing income is still being made by men (Njuki et al., 2014). This therefore further discourages women into venturing into this irrigation arrangement especially in such a situation where land use and ownership exacerbate the matter.

On the other hand, knowledge of pumping technology was found to positively influence households towards the adoption of the farmer-led irrigation arrangement by about 84.3%. While having knowledge of adoption of irrigation technology would increase the probability of one irrigating (Hornum & Bolwig, 2021), knowledge of pumping technology is of particular influence towards farmer-led irrigation arrangement. This could be because the farmers in this arrangement need to take initiative in the establishment of irrigated agriculture in their farms without infrastructural aid given to farmers in the public irrigation scheme arrangement. This thus may necessitate their knowledge of technologies that draw water from the source to their farms such as water pumps. As discussed earlier, the interdependency between knowledge of pumping technology and irrigation arrangements pose a problem of endogeneity to the econometric model. While this was not addressed in the models in this chapter, a profounder

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discussion of the methods and methodologies used to address this potential endogeneity between the dependent and independent variables is discussed in depth in Chapter Four as well as their application in the subsequent chapters.

Table 13: Multinomial logit regression results on the factors that determine smallholder households' participation in the public irrigation scheme and farmer-led irrigation arrangements [Equation 33]

Variables	Public irrigation scheme arrangement		Farmer-led irrigation arrangement	
	Coefficients	Marginal effects (dy/dx)	Coefficients	Marginal effects (dy/dx)
Age of the household head (years)	0.013 (0.028)	0.002 (0.042)	-0.009 (0.034)	-0.003 (0.005)
Age of the primary female decision maker (years)	-0.054* (0.031)	-0.004 (0.117)	-0.030 (0.037)	-0.003 (0.037)
Education level of the household head (years)	-0.130* (0.071)	-0.011 (0.289)	0.054 (0.075)	0.006 (0.083)
Education level of the primary female decision maker (years)	0.181** (0.076)	0.015 (0.403)	0.077 (0.080)	0.008 (0.116)
Gender of the household head (Female) †	0.539 (0.774)	0.076 (1.897)	-1.127 (0.915)	-0.140 (0.227)
Single adult household type†	0.444 (0.816)	0.028 (0.738)	0.672 (0.964)	0.098 (0.574)
Household size	-0.055 (0.141)	-0.003 (0.078)	-0.120 (0.167)	-0.016 (0.076)
Assets (USD)	<0.000 (0.000)	<0.000 (0.000)	<0.000 (0.000)	<0.000 (0.000)
Land owned (acres)	-0.170 (0.135)	-0.015 (0.391)	-0.044 (0.103)	0.003 (0.098)
Land rental price (per acre)	0.013*** (0.002)	0.001 (0.028)	0.008* ** (0.002)	0.001 (0.009)
Tropical livestock units	0.281 (0.261)	0.028 (0.752)	-0.151 (0.301)	-0.027 (0.085)
Household group membership†	0.786 (0.500)	0.064 (1.757)	-0.245 (0.589)	0.050 (0.274)
Distance to the market (Kilometers)	-0.008 (0.064)	<0.000 (0.006)	-0.035 (0.070)	0.005 (0.020)
Primary female decision maker production decision†	-0.875* (0.453)	-0.102 (2.496)	0.299 (0.534)	0.058 (0.301)

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Variables	Public irrigation scheme arrangement		Farmer-led irrigation arrangement	
	Coefficients	Marginal effects (dy/dx)	Coefficients	Marginal effects (dy/dx)
Access to fertilizer†	16.051 (491.432)	0.245 (0.041)	0.693 (0.968)	0.039 (0.099)
Access to hybrid seeds†	0.338 (0.379)	0.021 (0.550)	0.561 (0.460)	0.076 (0.388)
Knowledge of pumping technology†	0.763 (0.589)	-0.076 (2.232)	5.198* ** (0.562)	0.843 (0.473)
Constant	-17.784 (491.433)		- 2.027* * (1.650)	
Mean dependent variable	1.737	SD dependent variable		0.837
Pseudo r-squared	0.542	Number of observations		384
Chi-square	427.83 2	Prob > chi2		0.000
Akaike crit. (AIC)	433.63 7	Bayesian crit. (BIC)		575.860

Note: Standard errors are listed below the coefficients in parentheses. † dy/dx is for discrete change of dummy variable from 0 to 1. The notations and the meanings are as follows: *** p<.01, ** p<.05, and * p<.1

Source: Author based on survey data.

Of interest to note is that the land rental price was statistically significant in positively influencing irrigation, public irrigation scheme- and farmer-led irrigation- arrangement by a similar proportion of 0.001. The land rental price is an indicator of a quest for more land beyond what one has thus attracting an additional cost to the farmers production cost. Thus, the farmer who rents-in land is more likely to invest in irrigation in order to make the maximum use of the land without any interruptions that are associated with the seasonal farming cycles of rain-fed agriculture. Closely associated to this, the land rental price also indicates the different cost of accessing the land. Therefore, the higher the land rental rate, the more the investment the farmer is ready and willing to make to recoup the land rental price cost. This was seen in the descriptive statistics, where the land rental price is highest within the public irrigation scheme arrangement where the water availability is easier and cheaper (by investment) than the farmer-led irrigation arrangement. As such, this makes the farmer to invest in irrigation technology as a rational investment to ensure maximum returns on the land investment. However, at the same time, this may point to the potential of endogeneity in the model where the land rental price

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may influence irrigation and vice versa. This is a potential problem that we seek to address in the analyses encompassed in the subsequent chapters.

6.4. Conclusion

The analyses given in the two sections above gives a clear indication of how household factors affect both irrigation and irrigation arrangements. The factors that were found to affect irrigation and the factors that affect each of the irrigation arrangements were not only different but also different in the direction of effect for the same regressors.

The findings show that the factors that pertain to the primary female decision maker are integral in determining irrigation and irrigation arrangements. These factors related to the primary female decision maker were education level, age and ability to make production decisions. This gives key entry points for policy makers and implementers who want to undertake a gendered-approach to irrigation and irrigation arrangements.

The age of the primary female decision maker is a critical factor in influencing households to irrigate. In this regard, the results show that for policy makers and implementers, targeting households in whom the primary female decision makers are young. In a similar manner, ensuring that education is accessible to females is important to ensure that irrigation is adopted. Therefore, investments in education should be inclusive in ensuring that it is gender -sensitive and -inclusive to girls and women.

On the other hand, the primary female decision makers' ability to make production decisions influenced the public irrigation scheme arrangement negatively. There is therefore need to look into mechanisms that pertains to the households' in this arrangement as it pertains the primary female decision makers. This may include looking at the structure and institutional arrangement in the public irrigation scheme arrangement that deters women from adopting it when they have the power over production decisions. While we postulate that this may be due to land access (especially patriarchy inheritance) and labor demands associated with canal maintenance , there is need for further gendered-approach research on this irrigation arrangement.

Inputs access also plays a key role in a household's decision to adoption of irrigation technology. However, access to fertilizer and hybrid seeds was only significant in influencing households towards irrigation and insignificant for the two irrigation arrangements. Therefore, access to inputs, especially fertilizer and hybrid seeds, also play a critical factor in ensuring that households adopt agriculture. Cognizant of the fact that use of these two inputs is still low in Kenya (Mathenge et al., 2014; J. O. Ouma & De Groote, 2011; Sibiko & Qaim, 2020; Wainaina et al., 2016), targeting bottlenecks that hinder their access would also significantly increase irrigation uptake. However, this points out to the importance of approaching irrigation as a disaggregated undertaking since the same household factors have different implications depending on the irrigation arrangements.

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Land access also is a key factor to influencing whether irrigation is taken up or not. Moreso, the ability to access additional land that one can invest in.

Lastly, there is need for communities to be trained on irrigation technologies especially on irrigation pumps. In line with research findings on technology adoption, the lack of knowledge and skills is a constraint for adopting irrigation (Chikafa et al., 2023; Mwangi & Kariuki, 2015; Teferi et al., 2024). It is therefore necessary to ensure that irrigation technologies are not only available and accessible but also knowledge and skills on their use is transferred to the final users who are the farm households. However, this needs to be comprehensive hands-on skills that include repairs so as to ensure sustainable uptake of irrigation technologies and avoid abandonment (Adeoti et al., 2009). Figure 49 gives a summary of the factors from the probit and multinomial regressions discussed in this chapter.

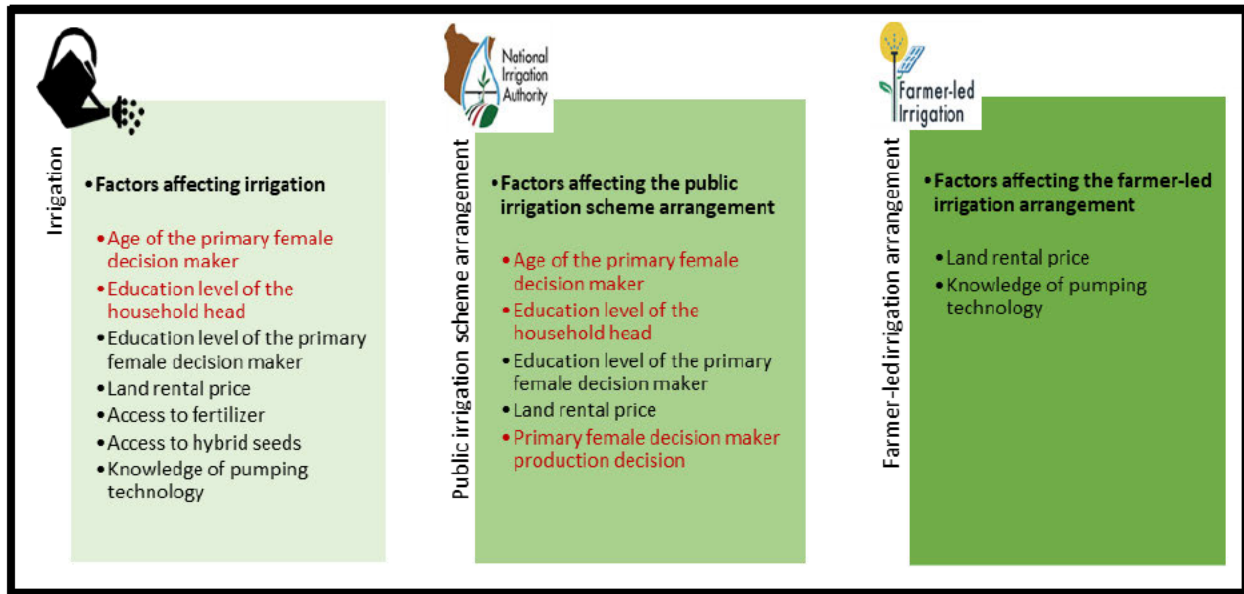


Figure 49: Summary of the factors that influence irrigation and public irrigation scheme- and farmer-led irrigation- arrangement (factors in red had a negative effect).

Source: Author based on survey data.

Therefore, the analyses do show that the household factors affect irrigation and irrigation arrangements differently. It also points out to the need of approaching irrigation as differentiated based on the different socio-technical set-up in which irrigation takes place which we refer to as irrigation arrangements in this study. As can be seen in the summary in Figure 49, when irrigation is approached as a unitary practice, it becomes difficult to get specific policy initiatives that targets specific farmers in the different social-technical set-ups. The amalgamation of such policy is bound to create dissonance of initiatives instead of synergy in irrigation. However, the two analyses do point out to the need for further analyses.

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As pointed out previously in this chapter, in the analyses, cognizance was taken that there might arise concerns on an inherent endogeneity of the factors, where there exist backward linkages between the household factors, irrigation and irrigation arrangements. However, in the choice of the variables used in the analysis, this was carefully considered in order to have exogenous variables (The discussions of the variables are intensely discussed in Chapter Four of this dissertation in a bid to make the measurements of the variables and their linkage to irrigation and irrigation arrangements understood by a reader not conversant with the area of study). In addition, the use of two different econometric models also gives further plausibility in the credibility of the results and affirms the premise on the differences in the irrigation arrangements. The analyses give the statistical and econometric basis to show that the different irrigation arrangements are influenced differently by the household socioeconomic factors by comparing the irrigation analysis and the irrigation arrangement analysis.

However, having established the effect of household factors on irrigation, the effect of these factors on the three suggested irrigation-nutrition pathways is needed. This chapter also points out to the need to take these household factors into consideration when running such analyses. These analyses form the basis of the next chapters of this dissertation.

Nevertheless, based on the possibility of endogeneity existing, this study undertook further analyses using methods that correct for any potential bias based on variable selection which is presented in the following two chapters of this dissertation. Methodologies that address endogeneity are employed as regards the two irrigation arrangements and the four main dependent variables discussed in Chapter Four i.e. production diversity, farm income, women's empowerment and dietary diversity. This is with the standpoint that there are household factors that are interrelated with these main dependent variables (thus correlated with the error term). In this respect and in a bid to keep the analyses comparable, the independent factors used for this analysis are also maintained in the application of a simultaneous equation model utilizing a three-stage least squares (3SLS) approach.

7. EFFECT OF IRRIGATION AND IRRIGATION ARRANGEMENTS ON PRODUCTION DIVERSITY, INCOME, WOMEN'S EMPOWERMENT AND DIETARY DIVERSITY

7.1. Introduction

As a build up to the irrigation-nutrition impact pathway, it was deemed necessary to analyze the effect of irrigation and irrigation arrangements on the four key dependent variables namely production diversity, income, women's empowerment and dietary diversity. To do this, the analyses in this chapter used the methodology and analytical framework discussed in Chapter Four on the "The counterfactual problem, selection bias and use of propensity score matching". However, in this chapter, the probit analyses were used for the purposes of matching only and hence this section does not go into the inferential statistics of the econometric analyses. This is in contrast to the inferential statistics for irrigation and irrigation arrangements discussed in detail in Chapter Six of this dissertation. However, the importance of having plausible econometric analyses is still valid. Therefore, the analysis and the algorithms that went into the construction of the propensity score matching are presented but only interpreting the statistics relating to the model plausibility and not the causativeness aspect between the independent and dependent variables. The analyses on the causal effects have been discussed in length in Chapter Six of this dissertation on "Smallholder Farmers' Household Socioeconomic Factors that Influence Irrigation and Irrigation Arrangements".

We draw the reader to note that this chapter has been extracted, peer-reviewed and published under the title "Analyzing the impact of irrigation on dietary diversity: A comparison between farmer-led and public irrigation in Kenya" in the interdisciplinary journal *Food Security* (Springer Nature Food Security – The Science, Sociology and Economics of Food Production and Access to Food) as Kiratu et al., (2025). Therefore, for the reader wanting to get a concise (but comprehensive) overview of this chapter, it is recommended that they refer to the above mentioned reference.

The chapter follows a flow that first compares the pooled irrigators with the non-irrigators then the disaggregated irrigation arrangements starting with the public irrigation scheme arrangement farm households and then the farmer-led irrigation arrangement farm households. To do this and ensure that the results are comparable, the matching variables as well as the techniques are maintained in all analyses. In addition several matching techniques suggested by Becker & Ichino (2002) and Leuven & Sianesi (2003) are used in order to give robust and credible results to inform and advice policy.

However, given that the irrigation arrangements form sub-sample analyses, the variables chosen for matching in this chapter differ from the ones in the analyses in Chapters Six and Eight. This is due to the methodological challenges related to sub-sampling of the analyses vis-à-vis getting good matches (refer to Chapter Four for an in-depth discussion on the application of the propensity score matching in this chapter). In this regard, maintaining the long list of regressors for the probit model in this chapter was not possible. Nevertheless, the chosen variables were

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maintained for the pooled irrigation, public irrigation scheme and farmer-led irrigation arrangements analyses.

Of interest in this study is the average treatment effect on the treated (ATT) which looks at the effect of irrigation on the irrigating households and not on the population (Heckman, 1997; Wooldridge, 2002). It is therefore noteworthy that the policy recommendations are drawn only from the ATT which gives the effect of irrigation or irrigation arrangement on the irrigating households (Heckman, 1997; Heckman & Vytlačil, 2001; Wooldridge, 2002).

7.2. Average treatment effects of irrigation and irrigation arrangements on production diversity, income, women's empowerment and dietary diversity

It was deemed of importance to examine the matching quality of the approaches used in the analyses. Given that the sampling of the comparisons in each of these sections is different, a presentation of the matching quality including the regressions, distribution of the propensity score and generation of the blocks is given before the presentation of the results. Of main interest is the confirmation of the balancing property of the non-irrigating and the irrigating on the different irrigation arrangement household characteristics and the common support of the propensity scores as a check of quality of matching as suggested in literature (Caliendo & Kopeinig, 2008).

7.3. Algorithm and probit model results for the calculation of the propensity scores

The probit model was used to calculate the propensity score. The results behind the probit model are shown in Table 14. The first model was for the pooled irrigating households and the non-irrigating households. This model comprised of 384 farm households and the model was found to be statistically significant with the probability of getting a LR test statistic showing that at least one of the coefficients in the model is not equal to zero. While the model showed that the age of the primary female decision maker (years), assets (USD), education level of the primary female decision maker (years), in-kind credit and household group membership to be statistically significant at 10% confidence level, this is not interpreted further for reasons mentioned earlier on in this chapter. The model was solely used for matching and further tests for analysis such as the marginal effects were not done.

In the second model, the variables and procedure of analysis was maintained as the one used for the analysis of the effect of irrigation on the key dependent variables given above. This was done to ensure the consistency and bolster comparability of the results. The analysis involved farmers only in the public irrigation scheme compared to the non-irrigators. Thus, this saw the sample of the households be truncated to 287 from 384 households. The probit model output showed that the model was statistically significant at 99% level of confidence. The model showed a modest representation of the variables affecting public irrigation scheme arrangement with a pseudo R^2 of about 11%. The model showed that the education level of the primary female decision maker (years) and tropical livestock units to be statistically significant at 10% confidence level and in-

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kind credit to be statistically significant at 5% confidence level. However, these results are not inferred further but only used for construction of propensity scores only. The results of this probit model are presented in the second column of Table 14.

The third model was for the farm households in the farmer-led irrigation arrangement. The model was also found to be significant with at 1% confidence level and consisted of a sample size of 295 households. The sample comprised of 97 farm households in the farmer-led irrigation arrangement and 198 non-irrigators. The pseudo R^2 showed that the model's goodness-of-fit covered only about 13% of the possible predictors. The model showed that the age of the primary female decision maker and assets was significant in influencing being in the farmer-led irrigation arrangement at 10% confidence level. This analysis was not analyzed further. These results are presented in the last column of Table 14.

Table 14: Probit regression on irrigating and non-irrigating households for the calculation of the propensity scores [Equation 45]

Variable	Coefficients and associated statistics		
	Pooled	Public irrigation scheme arrangement	Farmer-led irrigation arrangement
Age of the household head (years)	-0.002 (0.010)	-0.002 (0.012)	-0.002 (0.012)
Age of the primary female decision maker (years)	-0.018* (0.010)	-0.009 (0.012)	-0.024* (0.012)
Assets (USD)	<0.000* (0.000)	<0.000 (0.000)	<0.000* (0.000)
Single adult household type	-0.063 (0.207)	0.049 (0.241)	-0.139 (0.265)
Education level of the household head (years)	-0.002 (0.024)	-0.032 (0.030)	0.030 (0.030)
Education level of the primary female decision maker (years)	0.052* (0.026)	0.086** (0.032)	0.024 (0.030)
Household size	-0.034 (0.053)	0.004 (0.062)	-0.052 (0.066)
Land owned (acres)	0.033 (0.040)	0.005 (0.050)	0.052 (0.045)
Tropical livestock units	-0.078 (0.092)	-0.196* (0.117)	0.031 (0.110)
Non-farm income (USD)	<0.000 (0.000)	<0.000 (0.000)	<0.000 (0.000)
In-kind credit	1.053* (0.560)	1.554** (0.585)	0.302 (0.861)
Household credit access	0.031	-0.102	0.151

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Variable	Coefficients and associated statistics		
	Pooled	Public irrigation scheme arrangement	Farmer-led irrigation arrangement
	(0.172)	(0.219)	(0.202)
Household group membership	0.308*	0.309	0.283
	(0.171)	(0.208)	(0.211)
Constant	0.350	-0.490	0.131
	(0.473)	(0.594)	(0.551)
N	384	287	295
LR chi2(13)	57.96	40.29	50.42
Prob>chi2	0.0000	0.0001	0.0000
Log likelihood	-237.00	-157.56	-161.62
Pseudo R2	0.11	0.11	0.13

Note: Standard errors are listed below the coefficients in parentheses. The notations and the meanings are as follows: *** p<.01, ** p<.05, and * p<.1

Source: Author based on survey data.

For the pooled analysis (irrigating households and non-irrigating households), the region of common support is for the propensity scores was found to lie between 0.124 and 0.9998. The propensity scores had a mean of 0.492 with a standard deviation of 0.179. The median was also found to be 0.507 and the scores were positively skewed at 0.031. As it relates to the public irrigation scheme arrangement farm households, the lowest propensity score after the probit regression was 0.070 while the highest was 0.963. This range of the lowest and smallest propensity score represented the region of common support. The region of common support for the farmer-led irrigation arrangement was found to be between 0.082 and 0.987. The median was at 0.345 while the mean was a bit larger at 0.358. The statistics for the estimated propensity score in region of common support and the percentiles, mean, standard deviation, variance, skewness and kurtosis of the propensity scores is shown in Table 15.

These analyses showed that the pooled data had the widest range of common support, followed by the farmer-led irrigation arrangement analysis and the public irrigation scheme arrangement analysis had the narrowest range. This is understandable given the sampling sizes given on Table 14 and thus shows the possibility of getting more matching for the propensity scores.

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Table 15: Description of the estimated propensity score for irrigating and non-irrigating households in region of common support

Measure and statistics	Percentiles				Regions of common support		
	Pooled sample	Public irrigation scheme arrangement	Farmer-led irrigation arrangement		Pooled sample	public irrigation scheme arrangement	Farmer-led irrigation arrangement
1%	0.141	0.073	0.084	Smallest	0.112	0.070	0.082
5%	0.191	0.094	0.104		0.122	0.071	0.083
10%	0.231	0.135	0.131		0.135	0.073	0.084
25%	0.357	0.196	0.225		0.141	0.076	0.085
50%	0.507	0.298	0.345	Median	0.507	0.298	0.345
75%	0.603	0.422	0.462	Largest	0.947	0.870	0.780
90%	0.726	0.527	0.587		0.961	0.913	0.802
95%	0.774	0.603	0.660		0.983	0.921	0.960
99%	0.947	0.913	0.802		1.000	0.963	0.987
n	376	275	265				
Sum of weight	376	275	265				
Mean	0.492	0.321	0.358				
Std. Dev.	0.179	0.163	0.172				
Variance	0.032	0.027	0.030				
Skewness	0.031	1.073	0.573				
Kurtosis	2.640	4.787	3.364				

Source: Author based on survey data.

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For the comparison among groups especially using the stratification matching method, the blocks of propensity score become an important aspect of grouping. The blocks imply that the average propensity score within each block is not different thus allowing for comparison between the blocks for irrigating households and respective irrigation arrangements and non-irrigating households (Becker & Ichino, 2002). For all the analyses, five blocks were generated. In the pooled analysis the blocks were created among 376 farm households which comprised of 190 non-irrigating households and 186 irrigating households. For the analysis involving the public irrigation scheme- and farmer-led irrigation- arrangement farm households had the same number of households in the five blocks which consisted of 89 households and 186 non-irrigating households thus having a total of 275 households.

The blocks form a critical way of analyzing the effect of irrigation and irrigation arrangements since the mean of the propensity for the farm households in the same block is the same. The results for the inferior bounds for the blocks and distribution of the blocks are shown in Table 16.

Table 16: Inferior bounds and distribution of the blocks among irrigating and non-irrigating households

Irrigation arrangement	Inferior bounds	Irrigation		Total
		Non-irrigators	Irrigators	
Pooled	0.112	19	4	23
	0.200	67	23	90
	0.400	70	95	165
	0.600	33	50	83
	0.800	1	14	15
	Total	190	186	376
Public irrigation scheme arrangement	0.070	61	10	71
	0.200	88	36	124
	0.400	35	31	66
	0.600	1	8	9
	0.800	1	4	5
	Total	186	89	275
Farmer-led irrigation arrangement	0.070	61	10	71
	0.200	88	36	124
	0.400	35	31	66
	0.600	1	8	9
	0.800	1	4	5
	Total	186	89	275

Source: Fieldwork survey

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To better visualize the distribution of the propensity scores, bar graphs were generated and presented in Figure 50, Figure 51 and Figure 52 showing the distribution of the propensity scores and their associated common support.

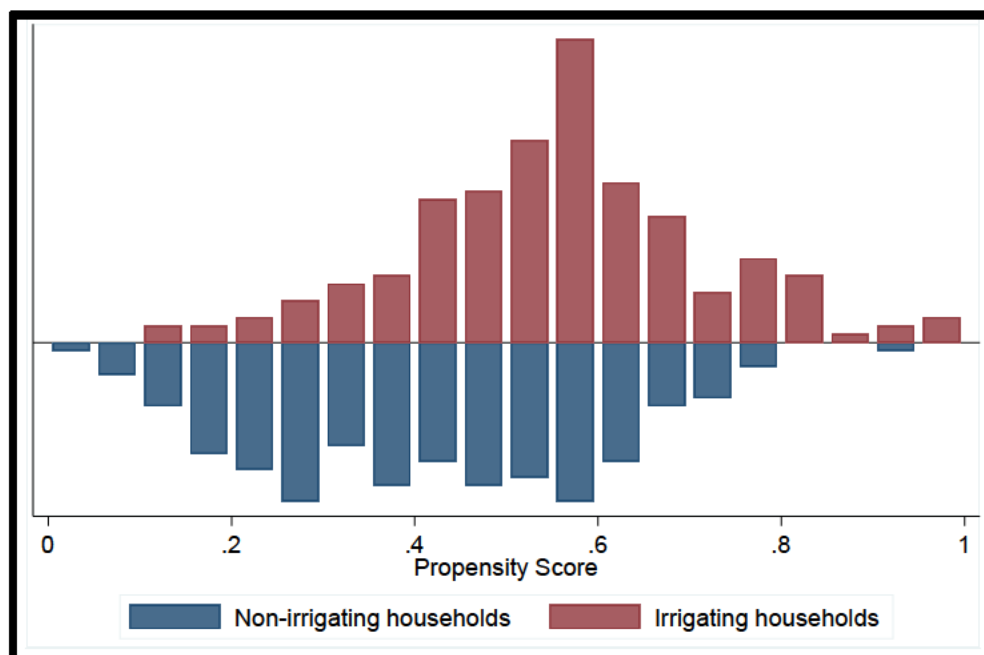


Figure 50: Irrigating and non-irrigating households' propensity score distribution and common support for propensity score estimation

Source: Author based on survey data.

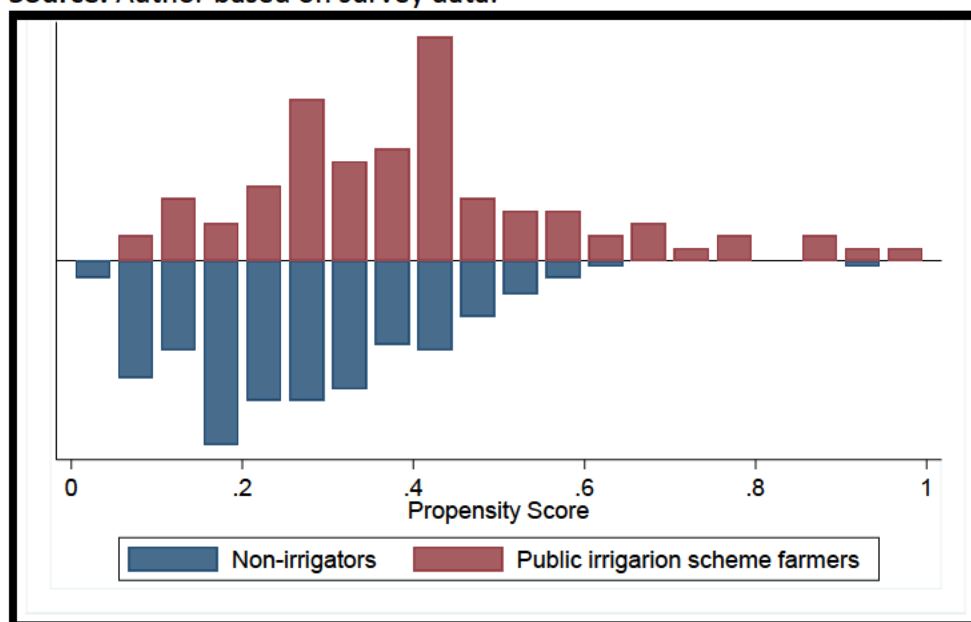


Figure 51: Public irrigation scheme arrangement and non-irrigating households' propensity score distribution and common support for propensity score estimation

Source: Author based on survey data.

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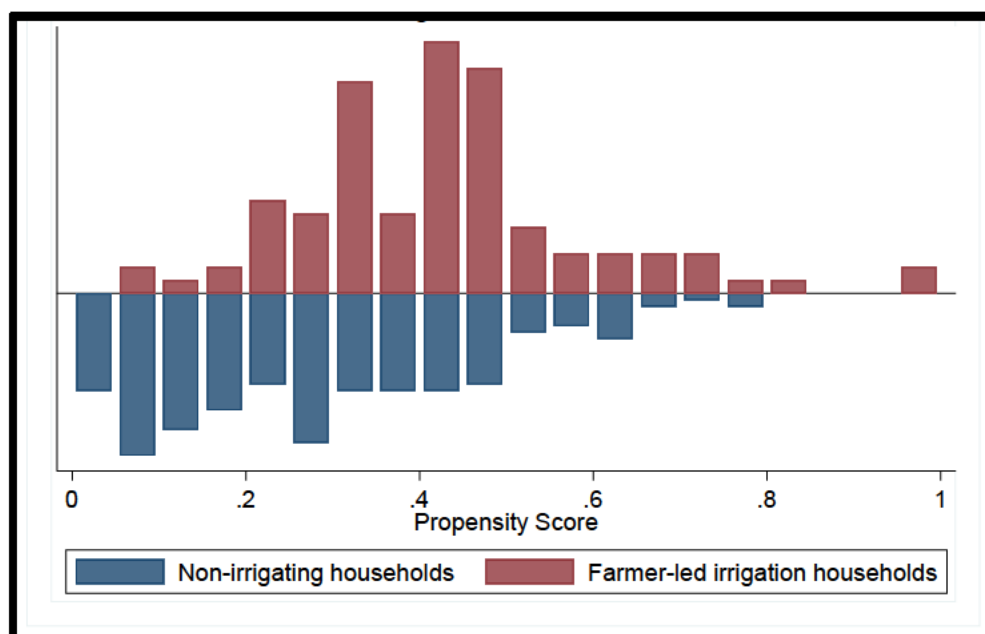


Figure 52: Farmer-led irrigation arrangement and non-irrigating households' propensity score distribution and common support for propensity score estimation

Source: Author based on survey data.

The analyses given above shows the algorithm behind creation of the propensity scores for the irrigating farm households, public irrigation scheme arrangement farm households and farmer-led irrigation arrangement farm households regressed against the non-irrigating farm households. This formed the basis for the investigation of the effect of irrigation and different irrigation arrangements on production diversity, income, women's empowerment and dietary diversity. Given the robust algorithm given here in this section, the matching was deemed strong and viable for further analysis involving different matching methods. These matching approaches are thus presented in the next section.

7.4. Results and discussion

The results of the PSM analysis and matching based on the nearest-neighbor matching method forms the basis of this discussion and are presented in Table 17. These are the mean values (Average treatment effect on the treated (ATT)) of the production diversity, farm income, women's empowerment and dietary diversity done using the approach suggested by Becker and Ichino (2002).

The results for the effect of irrigation showed that the ATT for the production diversity, and farm income were statistically different for irrigating and non-irrigating households at 90% level of confidence while for dietary diversity it was at 95% level of confidence. However, the women's empowerment was found not to be statistically different between the irrigators and non-irrigators as well as between the non-irrigators and the different irrigation arrangements.

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The results show that for the irrigating farm households, their production diversity at the farm reduced with irrigation by 0.392 points. The results of production diversity reducing due to irrigation was only significant for the pooled sample. This means that when irrigation is undertaken by a household, there is a tendency for the irrigating farm households to have a smaller number of crops and livestock as compared to the non-irrigating farmers. This may insinuate the tendency towards specialization at farm level for the irrigating farmers when it relates to growing crops and labor-saving strategies in keeping of less livestock. In addition, it is also of importance to note that the farm holding was also quite small with the mean land ownership for the sample being 1.56 acres (about 0.63 hectares) meaning that for commercial viability, the need to allocate a sizeable amount of land to a single crop becomes a paramount decision.

On the other hand, practices that increase the crop species such as intercropping are common among non-irrigating farmers. Intercropping is usually used as a strategy by non-irrigating farm households to reduce risk of crop failure and offer complementary crops in a bid to increase production in the rainy season (Abarike et al., 2025; Brooker et al., 2015; Chai et al., 2021; Nelson et al., 2021; Rusinamhodzi et al., 2012; Swinton & Dueson, 1988; Van Duivenbooden et al., 2000). However, for irrigating households, the use of irrigation water shields them from crop failure emanating from rainfall-dependent seasonality. This was noted in the FGD discussions where failure in rainfall was a major risk among non-irrigating farmers, but not so for the participants in the four irrigating FGDs. It is also notable that for the farm households in the public irrigation scheme arrangement the growing of rice is a strategic option given the high demand for the Basmati variety grown in the area. As such, the resultant cropping mode for this irrigation arrangement is monocropping rather than intercropping. Even though there is the use of fringe land for growing of other crops, from the results, it is concluded that this does not significantly affect their production diversity.

The insignificance results when irrigation is disaggregated can point out to the effect of reducing the sample given the weak level of significance (at 90% level of confidence), in that it is already it is a weak significance, which is further reduced for the smaller sub-samples. In addition, this is also a factor associated with the complex interrelations between specialization and land ownership that happens at farm level and aggregated areas like a region. Research done by Ward (2014) shows this complex relationship where it was found that while specialization happens at farm level, when there is a (comparative) larger amount of land, complete specialization does not happen. This was noted at the field where farmers with larger pieces of land would grow different irrigated crops to ensure that there is always a crop under production.

In addition, for the public irrigation scheme arrangement farmers' use of land on the margins of their fields also makes this result difficult to capture the crop differences at the disaggregated level for smaller sub-samples. For instance, as shown in Figure 53 and Figure 54, the growing of crops in the fringe land of the public irrigation scheme arrangement was difficult to capture as this is not only inadmissible, but with the crops being grown on a prohibited part of the field, they would not reveal it as a crop they grow. In a similar manner, as shown in Figure 55 farmers

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in the farmer-led irrigation arrangement plant crops along the rivers which they may not reveal as it isn't a crop in their fields. Therefore, these cropping patterns were captured more through observation and where possible inquisitive probing during the key informants' interviews. In particular, the key informants' interviews with officials of the Water Users' Association and the National Irrigation Authority officials, the practice of planting crops in and along the canals such as arrow roots, as demonstrated in the Figure 53 and Figure 54, is highly prohibited due to challenges this poses in impeding water flow thus necessitating frequent cleaning the canals. As such, this would explain the propensity of the farm households to conceal this practice if they engage in it. However, these results on production diversity are subjected to further analysis in the following chapter.



Figure 53: Growing of arrowroots along the canals in the public irrigation scheme arrangement
Source: Fieldwork photo.

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Figure 54: Growing of sorghum along the canals in the public irrigation scheme arrangement
Source: Fieldwork photo.



Figure 55: Growing of arrowroots along a river by farmers in the farmer-led irrigation arrangement
Source: Fieldwork photo.

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For farm income, the difference between non-irrigating farm households and pooled irrigating farm households was statistically significant at 90% level of confidence, for the public irrigation scheme arrangement farm households at 99% level of confidence and for the farmer-led irrigation arrangement farm households at 90% level of confidence. The coefficients for the three matching methods were positive. Thus, this showed that irrigation increases farm income for the pooled irrigating farm household by USD 1,006.40. Moreover, it was also found that being in the public irrigation scheme- and the farmer-led irrigation- arrangement increased the farm households' farm income by USD 1,385.97 and USD 961.15 respectively.

These results are consistent with the findings from the FGDs especially on the growing of high value crops. For instance, while maize is the staple food crop in the country it was interesting to find that the farm households in the farmer-led irrigation arrangement were growing green maize instead for sale for human consumption for the local market and/or for silage purposes (forages for ruminant livestock) as opposed to dry maize. This not only attracts a higher price (sale of the green maize as well as the maize stock especially during the crops off-season periods) but also shortens the cropping cycle so as to enable them to plant more crops in a year. In addition, the growing of high value crops such as French beans, tomatoes and fruits on high market demand such as bananas and papaws increases the earnings for the farmer-led irrigation arrangement households. On the other hand, in the FGDs, rice was a common crop among the households in the public irrigation scheme arrangement which attracts a high market price due to the high demand of the Basmati variety in the country.



Figure 56: A furrow irrigated maize crop for harvest as green maize

Source: Fieldwork photo

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These results were also coherent with other studies that has found a positive effect of irrigation on farm incomes in sub-Saharan Africa and specifically in Ghana (Adeoti et al., 2007), Malawi (Mangisoni, 2008) and Ethiopia (Passarelli et al., 2018). The reason for the positive effect of irrigation on farm income has been attributed to an increase in the growing of high-value crops (J. A. Burney & Naylor, 2012) and also an intensification in agricultural production that leads to higher yields ((Bryan et al., 2019b; J. A. Burney & Naylor, 2012; Passarelli et al., 2018). In addition, studies beyond the continent have also found positive effect of irrigation on farm income. For instance, Li et al., (2020) found a positive and statistically significant effect of irrigation on farm income in rural China by about 14%.

There was also no significant effect of irrigation on women’s empowerment; whether pooled or disaggregated. However, it is critical to note that the difference in women’s empowerment indicator of the farmer-led irrigation arrangement framers is higher than the public irrigation scheme arrangement farmers by 3 units. This is similar to the findings by Bryan & Mekonnen, (2023) that irrigation does not have a measurable impact on the empowerment of women. This was despite the observations made in the fieldwork such as the better access to water resources for women in the farmer-led irrigation arrangement where they grow and manage crops such as leafy vegetables on the fringe lands. In a similar manner, there was the use of lands along canals by women to grow crops such as arrow roots. However, it is notable that these benefits would be challenging to capture as it does not fall within the definitions of land owned. In this regard, this study would agree with the findings of Lefore et al., (2019), that while empowering women through irrigation is not impossible, there is need to recognize and make aware of the women’s limitations to unlock this potential. Cognizant of this state of affairs, this study takes the analysis of the women’s empowerment aspect to further analyses in the ensuing chapter.

The results also showed that there was a significant improvement in dietary diversity for the households practicing irrigation and in the different irrigation arrangements. It was found that irrigation increases the dietary diversity of farm households practicing irrigation by about 0.428 with this difference with non-irrigating households being significant at 95% level of confidence.

For the farm households in the public irrigation scheme- and farmer-led irrigation- arrangements the significance difference with the non-irrigating households was found to be significant at 95% level of confidence. The dietary diversity for the farmers in the public irrigation scheme arrangement showed an increase in dietary diversity of 0.329. On the other hand, the farmer-led irrigation arrangement had the highest effect on dietary diversity with the results showing an increase of 0.452. While this shows that there is a positive effect between irrigation and nutrition outcomes at household level, it also shows that the farmer-led irrigation arrangement has the greatest effect on dietary diversity. This can also point to the difference in the technology and institutions in the different irrigation arrangements and thus give a different outcome in the household outcome (J. A. Burney & Naylor, 2012). This result is also consistent with other studies that find that irrigation does increase nutrition outcomes at household level (Bryan et al., 2019b; Domenèch & Ringler, 2013; Mekonnen et al., 2019). These results are summarized in Table 17.

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Table 17: PSM results for the effects of irrigation on production diversity, income, women's empowerment and dietary diversity (nearest neighbor matching method) [Equation 46]

Variables and estimation outputs	Average treatment effect on the treated (ATT)		
	Pooled	Public irrigation scheme arrangement	Farmer-led irrigation arrangement
Production diversity	-0.392* (0.191)	-0.326(0.200)	-0.320 (0.247)
Farm income	1,006.396 (523.537)*	1,385.973*** (370.261)	961.149* (400.110)
Women's empowerment	-0.030 (0.025)	-0.032 (0.027)	-0.026(0.027)
Dietary diversity	0.428** (0.136)	0.329** (0.111)	0.452** (0.145)
n	384	287	295
Matches requested	1	1	1
Outcome model	matching	matching	matching
Min	1	1	1
Max	1	1	1

Note: Standard errors are showed in parentheses. The notations and the meanings are as follows: *** p<.01, ** p<.05, and * p<.1

Source: Author based on survey data.

7.5. Robustness checks on the Effect of Irrigation and Irrigation Arrangements on Production Diversity, Income, Women's Empowerment and Dietary Diversity

While the results given above used the nearest neighbor matching, for robustness purposes, further analyses based on radius matching, kernel matching and stratification matching methods were done (Becker & Ichino, 2002; Caliendo & Kopeinig, 2008) was done. The results are presented in Table 18.

The results showed that the difference between the means of production diversity, farm income and dietary diversity for the irrigating and non-irrigating households was significant for all the 3 matching methods. For production diversity, irrigation was found to be negatively influencing it by the 0.572, 0.481 and 0.427 using the radius, kernel and stratification matching methods respectively. The difference is larger than the 0.392 in the nearest neighbor matching approach but consistent in that it has a negative effect. On the other hand, the 3 matching methods also showed a positive increase in farm income for the irrigating households with the radius matching method showing a lesser increase while the other methods show a higher increase than the nearest neighbor matching approach. As a contrast, all the 3 matching methods gave a lesser effect of irrigation by magnitude as compared to the nearest neighbor matching approach albeit

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positive still. However, the direction of the effect was consistent with the findings of the earlier analysis using the nearest neighbor matching method. The difference in the women's empowerment was also found not to be significant using the 3 matching techniques.

For the public irrigation scheme arrangement farm households' analysis, all the 3 analyses did show that the irrigation arrangement does significantly affect production diversity of the farm households. This is in contrast to the analysis given through the nearest neighbor matching approach that was significant only at the aggregated level. This helps to elucidate further the results on the production diversity when the irrigation is aggregated that showed that irrigation does reduce production diversity. In this aspect it shows that the production diversity of the farm households in the public irrigation scheme arrangement was significantly lower than that of the non-irrigating households by -0.871, -0.652 and -0.597 when using the radius matching method, kernel matching method and stratification method respectively. It is notable that the negative effect is also in tandem with the results on the aggregated irrigation.

On the other hand, the results for the farm income of the public irrigation scheme arrangement farm households for the radius, kernel and stratification matching methods showed a positive effect in line with the results of the nearest neighbor matching approach. For the radius matching method farm income increased by USD 1,083.17 the kernel matching method showed an increase of USD 1,247.34 and the stratification method showed an increase of USD 1,302.25. These results are close to the USD 1,385.97 that was found earlier using the nearest neighbor method. The results on the effect of being in the public irrigation scheme arrangement on women's empowerment also is not significant. In addition, the effect of public irrigation scheme arrangement on the dietary diversity was found to be significantly greater by 0.217 for the radius matching method while the effect was not significant for the kernel matching method and stratification method.

The robustness results for the radius, kernel and stratification matching methods for the effect of being in the farmer-led irrigation arrangement on farm income and dietary diversity was found to be significantly different and positive in line with the results of the nearest neighbor matching approach analyses. There was an increase in farm income of USD 1,236.82 for the radius matching method, USD 1,084.708 for the kernel matching method and USD 1,022.795 for the stratification method. For the dietary diversity, the matching methods showed that it increased by 0.441, 0.448 and 0.392 radius matching method, kernel matching method and stratification method respectively. The effect of farm households being in the farmer-led irrigation arrangement on production diversity and women's empowerment was found not to be significant just as it was found in the earlier analysis done using the nearest neighbor matching approach. The results of these analyses using the radius matching methods, kernel matching methods and stratification methods is presented in Table 18.

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Table 18: PSM regression results for the effects of irrigation using radius, kernel and stratification matching methods (**Equation 46**)

	Outcome variable and matching method	Irrigation arrangement		ATT	t
		Irrigators (n)	Non-irrigators (n)		
Pooled	Production diversity				
	Radius Matching method	186	190	-0.572 (0.180)	-3.186
	Kernel Matching method	186	190	-0.481 (0.167)	-2.888
	Stratification method	186	190	-0.427 (0.157)	-2.722
	Farm income				
	Radius Matching method	186	190	992.358 (321.286)	3.089
	Kernel Matching method	186	190	1,048.765 (350.473)	2.992
	Stratification method	186	190	1,126.034 (336.612)	3.345
	Women's empowerment				
	Radius Matching method	186	190	-0.015 (0.018)	-0.851
	Kernel Matching method	186	190	-0.021 (0.018)	-1.130
	Stratification method	186	190	-0.027 (0.020)	-1.374
	Dietary diversity				
	Radius Matching method	186	190	0.325 (0.102)	3.184
	Kernel Matching method	186	190	0.334 (0.103)	3.250
	Stratification method	186	190	0.357 (0.108)	3.302
Public irrigation scheme arrangement	Production diversity				
	Radius Matching method	87	186	-0.871 (0.202)	-4.309
	Kernel Matching method	89	186	-0.652 (0.204)	-3.200

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Outcome variable and matching method		Irrigation arrangement		ATT	t
		Irrigators (n)	Non-irrigators (n)		
Stratification method		89	186	-0.597 (0.190)	-3.133
Farm income					
Radius Matching method		87	186	1083.174 (404.215)	2.680
Kernel Matching method		89	186	1247.343 (331.298)	3.765
Stratification method		89	186	1302.247 (370.873)	3.511
Women's empowerment					
Radius Matching method		87	186	-0.028 (0.024)	-1.172
Kernel Matching method		89	186	-0.034 (0.027)	-1.233
Stratification method		89	186	-0.023 (0.027)	-0.866
Dietary diversity					
Radius Matching method		87	186	0.217 (0.100)	2.165
Kernel Matching method		89	186	0.229 (0.123)	1.863
Stratification method		89	186	0.185 (0.109)	1.695
Farmer-led irrigation arrangement	Production diversity				
	Radius Matching method	95	168	-0.221 (0.205)	-1.079
	Kernel Matching method	97	168	-0.247 (0.208)	-1.190
	Stratification method	94	171	-0.315 (0.248)	-1.270
	Farm income				
	Radius Matching method	95	168	1,236.819 (439.676)	2.813
	Kernel Matching method	97	168	1084.708 (446.969)	2.427
	Stratification method	94	171	1022.795	2.138

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Outcome variable and matching method	Irrigation arrangement		ATT	t
	Irrigators (n)	Non-irrigators (n)		
			(478.318)	
Women's empowerment				
Radius Matching method	95	168	-0.002 (0.024)	-0.098
Kernel Matching method	97	168	-0.010 (0.020)	-0.503
Stratification method	94	171	<0.000 (0.021)	-0.017
Dietary diversity				
Radius Matching method	95	168	0.441 (0.118)	3.749
Kernel Matching method	97	168	0.448 (0.135)	3.327
Stratification method	94	171	0.392 (0.117)	3.341

Note: Standard errors are showed in parentheses

Source: Author based on survey data.

7.6. Conclusion

In order to make policy relevant recommendations, the analysis centered on the average treatment effect of not only the irrigating farmers but also the specific irrigation arrangements. This was in line with the hypothesis that apart from production diversity, farm income and women's empowerment being potential pathways to achieving nutrition outcomes at household level, irrigation and the different irrigation arrangements affect them differently. The analysis done on the effect of irrigation and irrigation arrangement show a clear effect of irrigation and irrigation arrangements on production diversity, farm income and dietary diversity. In addition, tests for robustness were also done to establish the credibility of the results.

These results in addition to the robustness matching methods conducted, provide a strong basis to conclude that irrigation does positively affect the irrigating households' farm income and nutrition outcomes at household level in the context of smallholder agriculture in Kenya. The positive effect on the farm income and dietary diversity is evident across all the irrigation arrangement. This points out to irrigation being a viable intervention for smallholder farmers to increase their farm incomes as well as improve on the households' nutrition outcomes.

Contrariwise, irrigation does negatively affect the production diversity of irrigating farm households. This can be attributed to the ability of the irrigating farm households specializing on

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crops whose market value is commensurate to the irrigation investment. This also was attributed to the mixed cropping techniques applied by the non-irrigating farmers in a bid to take advantage of the rainy season thus achieving higher seasonal crop variety.

While the findings on the effect of irrigation on women's empowerment, showed that there was no significant effect, the difference in the women's empowerment between the farmer-led irrigation arrangement and public irrigation scheme arrangement farmers called for further investigations and analyses. This would ideally be done by comparing these two irrigation arrangements with a sufficiently large sample that would give more precise results at the disaggregated irrigation level. As such, it is also noteworthy that while the women's empowerment was not found to be significantly affected by irrigation and irrigation arrangements, this does not negate the possibility of it being an impact pathway for nutrition.

Of interest also is that while the analyses fail to reject that farmer-led irrigation arrangement contributes more to dietary diversity than the public irrigation scheme arrangement, the alternative hypothesis that farmer-led irrigation arrangement contributes more to farm income than the public irrigation scheme arrangement cannot be accepted. This is since the results show that the effect on farm income for the farm households in the public irrigation scheme arrangement was higher than for the ones in the farmer-led irrigation arrangement.

Most importantly, the PSM results point to the study's need for further analysis. In this regard, while the PSM is effective in showing us the impact of the irrigation and irrigation arrangements on production diversity, farm income and dietary diversity, the method is limited in that it does not reveal the impact pathways. In this regard, while an impact effect is established, these results do not show in which way the households achieve the nutrition outcomes which is the main aim of this study.

In addition, the impact effect of the irrigation arrangements giving different outcomes for the production diversity and farm income points out to the potential of having different nutrition pathways. In addition, while the women's empowerment was not found to be significantly affected by irrigation and irrigation arrangements, this does not negate the possibility of it being an impact pathway for nutrition.

Therefore, these results act as a cue to the need for further analyses that considers production diversity, farm income and women's empowerment as potential impact pathways for nutrition outcomes. These analyses on this are provided in the next chapter of this dissertation.

8. ASSESSING SMALLHOLDER FARM HOUSEHOLDS' IRRIGATION-NUTRITION PATHWAYS UNDER DIFFERENT IRRIGATION ARRANGEMENTS

8.1. Introduction

In the previous chapters, this study has established that the household factors play a key role in not only determining irrigation, but also in determining the different irrigation arrangements that smallholder farm households undertake. A comparison of the probit and multinomial logit regressions showed that the household factors attributable to households, involved in irrigation and public irrigation scheme and farmer-led irrigation arrangements were different. However, while these two analyses were critical in showing the specific factors that affects these irrigation arrangements, they could not show the effect of irrigation and the two irrigation arrangements on the three irrigation-nutrition pathways (production diversity, farm income, women's empowerment) and nutrition outcome which we measure through the dietary diversity.

By the use of a quasi-experimental analyses and specifically the propensity score matching approach, it was possible to show as to whether the two irrigation arrangements have a different effect on production diversity, farm income, women's empowerment and dietary diversity. This was possible by using the same set of comparison group for the two irrigation arrangements as well as the same set of matching variables for the analyses. In these analyses, it has been shown also that irrigation and irrigation arrangements does affect production diversity, farm income and dietary diversity both in magnitude and direction of effect.

However, the momentous task of this study was to establish the pathways through which irrigating smallholder farm households in the farmer-led and public irrigation scheme arrangements can achieve their nutrition outcomes. This is under the premise that the two irrigation arrangements have different pathways through which they achieve their nutrition outcomes. This analysis is of paramount importance due to its policy implications. As previously argued, by this study disaggregating irrigation analysis, it becomes a frontrunner not only in Africa but also globally in the manner irrigation research is undertaken and the subsequent policy implications. This is the aim of this chapter.

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Even if the propensity score matching results showed that women's empowerment was not significantly affected by irrigation and irrigation arrangements, this does not necessarily mean that it is not a potential impact pathway to nutrition. In addition, the use of a matching approach has its limitations especially as it pertains the ability to identify the potential irrigation -nutrition impact pathways. Therefore, it was deemed necessary to include women's empowerment in this chapter's analyses.

The three-stage least squares (3SLS) estimation uses a different approach by the application of a system of simultaneous equations based on an instrumental variable approach. The analytical framework of this model is discussed in Chapter Four on "Specification for the three-stage least squares". The analysis follows the conceptual framework discussed in Chapter Three where the empirical model incorporates an irrigation equation into the three potential pathways of production diversity, farm income and women's empowerment and then incorporates these three equations into the dietary diversity equation. Therefore, for a pathway to be plausible, irrigation or the irrigation arrangement must first have a statistically significant effect on production diversity, farm income and/or women's empowerment and then have a subsequent statistically significant influence on dietary diversity.

The main premise of this chapter is that the different irrigation arrangements have different pathways through which they affect nutrition outcomes. With the previous probit and multinomial regressions showing that the factors that affect farmer-led irrigation arrangement and public irrigation scheme arrangement are different, and the propensity score matching approach giving different magnitudes and direction specifically for production diversity and farm income for the two arrangements, there was indications that the nutrition-pathways for the two arrangements would also be different. This is in line with the hypothesis that the pathways between at farmer-led irrigation arrangement and public irrigation scheme arrangement are different.

However, with this being a premise, it is imperative to provide proof. Therefore, to show the different nutrition-irrigation pathways are different by irrigation arrangements, an analysis of the aggregated irrigation is given in order to substantiate the pathways through which the aggregated analysis brings about nutrition outcomes. This helps in offering a comparison of how different the pathways are under disaggregated analyses. It is noteworthy that the specification of the base equation is similar to the specifications in the probit and multinomial logit regressions. This allows for comparability of the results thus improving the plausibility of the results throughout the study.

This chapter starts by presenting the case as to why the model is plausible for interpretation by giving a discussion on the tests done to verify its structure. Finally, the chapter delves into the main study focus of the thesis in investigating the pathways through which different irrigation arrangements impact on household nutrition. However, given that the effect of irrigation on nutrition is not direct, the effect of irrigation and irrigation arrangements on the pathways and

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its resultant effect on nutrition are also looked at. Therefore, a discussion on the effect of irrigation and irrigation arrangements on production diversity, farm income and women's empowerment while controlling for the households' socioeconomic factors is presented followed by the effect of the different irrigation pathways on the nutrition outcomes. The chapter ends with a summary of the findings.

We would like to point out that extracts from this chapter were presented as an oral presentation at the International Association of Agricultural Economists (IAAE) 2024 Conference and a conference paper published under the title "*Irrigation-nutrition linkages under farmer-led and public irrigation schemes in Kenya*" (Kiratu et al., 2024b). A journal paper on the same chapter is also under development.

8.2. Model validity

An overarching concern that this study has is the presence of endogeneity; a concern that has so far been handled specifically through the choice of variables used in the regressions and the matching approach. In choosing the variables that are included in the models, intricate knowledge of the variables in relation to the outcome model was considered through literature review, observation and even in the manner in which the variables were collected in the field. In addition, statistical methods are used in the form of a matching technique to handle the concern of endogeneity.

In the ensuing analyses, this endeavor is driven further by the application of simultaneous equations. Consisting of five systems of equations with the specifications being identical for irrigation and the two distinct irrigation arrangements. In addition, the base equation is specified in the same way as defined in the probit and multinomial logit regressions for plausibility and comparability purposes. The system of equations is applied as an instrument variable approach to address any endogeneity that may be present between irrigation and irrigation arrangements, dietary diversity, production diversity, farm income, women's empowerment and dietary diversity. However, this raises questions of how valid the instruments are.

While the choice of the variables may solve one of the underlying assumptions of simultaneous equation approach of pre-determinedness (that is exogeneity of the chosen variables; uncorrelated with the error term), the identifying restrictions that there is correlation to the endogenous variable needs to be determined (Anderson & Kunitomo, 1992; Wooldridge, 2013, p. 535). In order to do this, there is need to run tests for overidentification restriction.

The overidentification restrictions looks at whether the supposed endogenous regressors is less than the number of instruments used in the given equation. This checks whether the equation is just-identified. Thus, a just-identified model has enough instruments consequently making exogeneity of the instruments untestable (Wooldridge, 2013, pp. 537–538).

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While it is still debatable as to whether just-identified models makes the instruments valid as advocated by Hansen (1982), due to this inability to test this kind of models (Deaton, 2010), there is consensus that it does ensure that the instruments are coherent in identifying the same set of parameters (Parente & Silva, 2012). This is particularly important for this study since four main variables (production diversity, farm income, women's empowerment and irrigation/irrigation arrangements) have the potential of being endogenous to the households' nutrition outcome.

Therefore, two tests are applied to determine the effectiveness of the variables used in the simultaneous equation model. These tests were the Sargan–Hansen (Hansen, 1982; Sargan, 1958) and the Basmann (Basmann, 1960) tests of overidentification restrictions. To do this, a two-stage simultaneous equation was run where it was assumed that the four variables are endogenous to dietary diversity. The tests' null hypothesis is that the model is overidentified.

The results of these tests showed that the model was just-identified with both the Sargan–Hansen and Basmann tests p-values not being significant. As such, the null hypothesis that the irrigation, farmer-led irrigation arrangement and public irrigation scheme arrangement equations are overidentified cannot be accepted. This means that the number of identifying equations is not greater than the unknown parameters and thus the estimation of the equations will yield valid results. The summary of results of the Instrumental variables two-Stage least squares regression is presented in Appendix 2.

8.3. Results and discussion of three-stage least squares regression of dietary diversity, household production diversity, farm income, women's empowerment for irrigation and irrigation arrangements

The results of the regressions for the aggregated irrigation is presented in Table 19, for farmer-led irrigation arrangement in Table 20 and for public irrigation scheme arrangement in Table 21. The structure and parameter for all the analyses was maintained for comparability purposes. In addition, the structural equation for irrigation, farmer-led irrigation arrangement and public irrigation scheme arrangement used in Chapter Six was maintained for conformity, plausibility and robustness of the models. For the aggregated analysis, the number of observations was 384, for the farmer-led irrigation arrangement it was 295 and for the public irrigation scheme arrangement it was 287. All the models were found to be valid with the Wald Chi-Square tests showing that the predictors of the model are not simultaneously equal to zero. Therefore, the null hypothesis that all of the regression coefficients in the model are equal to zero was not accepted and thus it was reasonable to interpret the model.

8.3.1. Results and discussion for the production diversity equation

Livestock keeping positively affects production diversity. This was the case for the aggregated irrigation analysis as well as the disaggregated one. In all these analyses, the statistical

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significance was at 99% level of confidence. This illustrates the importance of integrating livestock keeping in farming practices for regardless of the irrigation arrangement.

Results also showed that for the public irrigation scheme arrangement, when the household had only a single adult, it led to higher production diversity. This was significant at 95% level of confidence. This could point out to the households' way of spreading the risk associated with mono-cropping. It also could point out at the households shift from commercial to subsistence farming by utilizing part of the land for growing food consumed in the household. Subsistence farming practices largely includes intercropping which is the growing of multiple crops in the same field (H. A. Smith & McSorley, 2000). Subsistence farmers adapt intercropping as a way of providing multiple food options for the household (Fifanou et al., 2011; Heywood et al., 2013, pp. 41, 151; Himmelstein et al., 2017; Jodha, 1980), risk mitigation (Clawson, 1985; Horwith, 1985; Jodha, 1980; McCord et al., 2015), expanding marketed products (Keleman et al., 2013) and increasing farm efficiency (Cong et al., 2015; Himmelstein et al., 2017; Hong et al., 2019; C. Li et al., 2020; Martin-Guay et al., 2018). This growing of multiple crops in the same field thus increases production diversity. This practice of intercropping is plausible for single adult households who face challenges of labor (subsistence farming is dependent on family labor).

In the farmer-led irrigation arrangement, the primary female decision maker making production decision increased production diversity. This effect of the primary female decision maker making production decision on dietary diversity was significant at 90% level of confidence. Giving women the ability to make production decision is a form of empowerment, which in this research has been associated more with farmer-led irrigation arrangement. Thus, it can be alluded that in so doing, the women in these households are able to increase the types of crops grown and livestock kept in the farm. Research shows that when empowered (including making decisions), women tend to increase production diversity including of more nutrient-dense foods such as vegetables and fruits (C. L. Anderson et al., 2021; Connors et al., 2023; De Pinto et al., 2020). Therefore, by giving the primary female decision maker the ability to decide what is produced, the households in the farmer-led irrigation arrangement benefit from a higher production diversity.

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Table 19: 3SLS results of a simultaneous system of dietary diversity, household production diversity, farm income, women's empowerment and irrigation for the pooled samples [Equation 47, Equation 48, Equation 49, Equation 50, and Equation 51]

Variables	Dietary diversity	Production diversity	Log of farm income (USD)	Women's empowerment	Irrigation
Production diversity	-0.047 (0.079)				
Log of farm income (USD)	0.090** (0.041)				
Women's empowerment	1.481*** (0.543)				
Household size	0.021 (0.033)		0.151** (0.074)	-0.008 (0.006)	-0.01 (0.013)
Employed†	-0.186 (0.12)				
Age of the household head (years)	-0.014** (0.007)	0.004 (0.011)	0.003 (0.015)	<0.000 (0.001)	0.001 (0.003)
Age of the primary female decision maker (years)	0.009 (0.007)	-0.010 (0.011)	0.001 (0.015)	0.002** (0.001)	-0.005* (0.003)
Tropical livestock units	0.255*** (0.095)	0.849*** (0.094)	0.257 (0.469)	-0.005 (0.011)	0.004 (0.024)
Education level of the household head (years)	-0.008 (0.016)	0.012 (0.024)	0.096*** (0.037)	0.001 (0.003)	-0.009 (0.006)
Education level of the primary female decision maker (years)	0.024 (0.017)	-0.017 (0.026)	-0.047 (0.047)	<0.000 (0.003)	0.015** (0.007)
Distance to the market (Kilometers)	0.027* (0.015)		-0.033 (0.037)	0.007** (0.003)	-0.005 (0.006)
Irrigation†		-0.859*** (0.204)	2.183*** (0.402)	0.134*** (0.034)	
Assets (USD)		<0.000 (0.000)			<0.000 (0.000)

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Variables	Dietary diversity	Production diversity	Log of farm income (USD)	Women's empowerment	Irrigation
Single adult household type†		0.400** (0.204)			
Primary female decision maker production decision†		0.085 (0.052)	-0.068 (0.431)	0.175*** (0.019)	-0.046 (0.043)
Land owned (acres)		0.110*** (0.042)	0.277*** (0.092)	-0.001 (0.005)	-0.010 (0.011)
Household group membership†		0.675*** (0.168)			0.147*** (0.042)
Production diversity			0.226 (0.637)		
Access to hybrid seed†			0.031 (0.518)	-0.005 (0.017)	0.103*** (0.036)
Access to fertilizer†			1.644*** (0.632)	0.063* (0.033)	0.099 (0.072)
Land rental price (per acre)			<0.000 (0.002)	<0.001*** (0.000)	0.002*** (0.000)
Access to extra land†				-0.014 (0.021)	
Knowledge of pumping technology†					0.518*** (0.041)
Single adult household type†					0.079 (0.069)
Gender of the household head (Female)†					-0.012 (0.068)
Constant	3.124*** (0.427)	2.651*** (0.495)	0.531 (1.854)	0.421*** (0.061)	0.050 (0.138)
Parameters	11	11	14	14	17
Equation root mean squared error	0.895	1.355	1.933	0.158	0.341

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Variables	Dietary diversity	Production diversity	Log of farm income (USD)	Women's empowerment	Irrigation
Equation R-squared	0.045	0.255	0.341	0.141	0.534
Chi-square	58.440	154.830	180.240	124.190	457.220
Chi-square p-value	0.000	0.000	0.000	0.000	0.000
Number of observations	384	384	384	384	384

Note: Standard errors are listed below the coefficients in parentheses. † Shows dummy variables. The notations and the meanings are as follows: *** p<.01, ** p<.05, and * p<.1

Source: Author based on survey data.

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Households with bigger land sizes had higher production diversity, which may point to the ability to grow more types of crops and keep livestock on the farm. The significance of land ownership was statistically significant at 99% level of confidence for the aggregated irrigation analysis and at 95% level of confidence for the farmer-led irrigation- and public irrigation scheme-arrangements. However, it is critical to notice that the land ownership across all the arrangements was very low. The mean land ownership for the pooled sample was 1.56 acres, while for the farmer-led irrigation arrangement and public irrigation scheme arrangement was 1.75 acres and 1.39 acres respectively. Therefore, it is imperative to note that even when the land ownership increases, the farms still remain small in size. The land rented-in can show this with the mean land rented-in for the sample being 0.33 acres while for the farmer-led irrigation- and public irrigation scheme- arrangement is 0.53 acres and 0.64 acres respectively as presented in Figure 45 in Chapter Five. While small farms have been associated with higher farm diversity (Ricciardi et al., 2021; Tacconi et al., 2022) however at very low levels of land ownership, this diversity is curtailed (Manjunatha et al., 2013; Ricciardi et al., 2021). Therefore, as the farm ownership increases, the diversity of the farms increases as the farmers have more land to farm different crops and keep livestock.

The aggregated irrigation analysis showed that a household member being a member of a community group influences production diversity positively. This was also evident in the farmer-led irrigation- and public irrigation scheme- arrangements. The statistical significance for the aggregated irrigation analysis and farmer-led irrigation arrangement was at 99% level of confidence. For the public irrigation scheme arrangement was at 95% level of confidence. Community groups act as points of information access and possible seed exchange among group members. Studies have shown that seed exchange is driven by social networks such as community groups especially those with similar agricultural production activities (Coomes et al., 2015; Giroux et al., 2023). This seed exchange among such social networks has been demonstrated to contribute to crop diversity (Labeyrie et al., 2016). In addition, with the farmers sharing identical water infrastructure, the advice and information ties would be stronger. Therefore, a farmer who is aware of a fellow farmer growing a crop or keeping livestock would easily ask in community group settings. Research shows that physical infrastructure as this fosters advice-seeking links (Giroux et al., 2023).

8.3.2. Results and discussion for the farm income equation

As regards farm income, the bigger the household size, the higher the farm income was. This was statistically significant at 95% and 99% level of confidence for the aggregated irrigation analysis and public irrigation scheme arrangement respectively. Paddy rice is the common crop farmed in the farmers in the public irrigation scheme arrangement and it is labor intensive (Ndiiri et al., 2013; Njagi & Mano, 2022). Given that household members in the case of smallholder farmers play a critical role in providing labor (Rapsomanikis, 2015), an increase in the number of members in a household translates to more agricultural activities like the cultivation of larger tracks of land (Baidoo et al., 2016) that in-turn may translates to higher farm income. In addition, research

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done in the area shows that family labor is extensively used in production as a key source of labor and a labor cost reduction strategy (Njeru et al., 2016). Therefore, this explains the positive effect of household size on farm income.

While the livestock ownership was not significant in influencing farm income for the aggregated and farmer-led irrigation arrangement analyses, it was significant in influencing farm income for the public irrigation scheme arrangement at 99% level of confidence. This was an interesting outcome given that the public irrigation scheme arrangement had the lowest tropical livestock units. However, it is critical to note that in the FDG, it was highlighted that livestock play a key role in the type of agricultural production practices by farmers in the public irrigation scheme arrangement, especially in providing labor for both farming and transport. With the area having low mechanization rates (Njagi & Mano, 2022), the use of animal drawn equipment such as ploughs is common especially in the soggy paddy rice farms. In addition, draft animals are commonly used to take products to the nearest road. This was especially a pronounced mode of transport from the FGD which they attributed to the animal-drawn transport's ability to maneuver through the often-dilapidated roads inside farms especially during the rainy season. In addition, labor from animals also complements tractors for other activities such as levelling and harrowing (Njagi & Mano, 2022).



Figure 57: Oxen-drawn carriages carrying tomato seedling for delivery to a farm and produce to Mwea market

Source: Fieldwork photo

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Figure 58: Donkey-drawn carriage

Source: Fieldwork photo



Figure 59: Oxen-drawn carriage

Source: Fieldwork photo

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Figure 60: Ox-drawn carriage carrying water from a canal

Source: Fieldwork photo

In addition, livestock especially small livestock like goats and chicken provide an additional income stream for the household especially in marketing their products or the livestock. This in turn leads to a higher farm income.

Households whose head had higher education had a positive effect on farm income. The statistical significance for this positive influence of the education of household head was at 99% level of confidence for the aggregated irrigation analysis and at 95% for both public irrigation scheme- and farmer-led irrigation- arrangement. The positive and significant effect of household-head's education level on farm income across the irrigation arrangements shows the critical component that education plays in smallholder farming. This is in line with other studies that have shown a positive relationship between the education of the household head and household income (De Janvry & Sadoulet, 2001; Panda, 2015).

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Table 20: 3SLS results of a simultaneous system of dietary diversity, household production diversity, farm income, women's empowerment and irrigation for the farmer-led irrigation arrangement [Equation 47, Equation 48, Equation 49, Equation 50, and Equation 51]

Variables	Dietary diversity	Production diversity	Log of farm income (USD)	Women's empowerment	Irrigation
Production diversity	0.036 (0.099)				
Log of farm income (USD)	0.153*** (0.051)				
Women's empowerment	1.092* (0.614)				
Household size	-0.008 (0.038)		0.119 (0.091)	-0.005 (0.006)	-0.017 (0.012)
Employed	-0.256* (0.143)				
Age of the household head (years)	-0.011 (0.008)	<0.000 (0.012)	0.008 (0.018)	-0.001 (0.001)	0.001 (0.002)
Age of the primary female decision maker (years)	0.008 (0.008)	<0.000 (0.012)	-0.005 (0.019)	0.003** (0.001)	-0.004* (0.002)
Tropical livestock units	0.083 (0.111)	0.826*** (0.106)	0.087 (0.429)	0.001 (0.012)	-0.032 (0.021)
Education level of the household head (years)	-0.028 (0.02)	0.014 (0.029)	0.098** (0.046)	0.001 (0.003)	-0.004 (0.006)
Education level of the primary female decision maker (years)	0.039* (0.02)	-0.023 (0.030)	-0.032 (0.054)	<0.000 (0.003)	0.005 (0.006)
Distance to the market (Kilometers)	0.022 (0.018)		-0.043 (0.04)	0.008*** (0.003)	-0.003 (0.005)
Farmer-led irrigation arrangement		-0.214 (0.219)	2.009*** (0.363)	0.049* (0.028)	

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Variables	Dietary diversity	Production diversity	Log of farm income (USD)	Women's empowerment	Irrigation
Assets (USD)		<0.000 (0.000)			<0.000 (0.000)
Single adult household type		0.333 (0.230)			
Primary female decision maker production decision		0.112* (0.059)	-0.122 (0.423)	0.167*** (0.022)	0.030 (0.04)
Land owned (acres)		0.103** (0.046)	0.218** (0.099)	-0.002 (0.005)	-0.008 (0.009)
Household group membership		0.720*** (0.185)			0.002 (0.038)
Production diversity			0.558 (0.538)		
Access to hybrid seed			0.246 (0.463)	0.016 (0.019)	0.021 (0.032)
Access to fertilizer			1.454** (0.591)	0.070** (0.032)	0.034 (0.057)
Land rental price (per acre)			<0.000 (0.002)	<0.000 (0.000)	<0.001** *
Access to extra land				-0.018 (0.025)	(0.000)
Knowledge of pumping technology					0.78*** (0.036)
Single adult household type					0.035 (0.062)
Gender of the household head (Female)					-0.075 (0.062)
Constant	2.984***	2.129***	-0.292	0.403***	0.174

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Variables	Dietary diversity	Production diversity	Log of farm income (USD)	Women's empowerment	Irrigation
	(0.482)	(0.541)	(1.667)	(0.065)	(0.116)
Parameters	11	11	14	14	17
Equation root mean squared error	0.910	1.345	2.063	0.151	0.257
Equation R-squared	0.049	0.263	0.305	0.195	0.701
Chi-square	44.740	111.850	132.730	79.190	691.650
Chi-square p-value	0.000	0.000	0.000	0.000	0.000
Number of observations	295	295	295	295	295

Note: Standard errors are listed below the coefficients in parentheses. † Shows dummy variables. The notations and the meanings are as follows: *** p<.01, ** p<.05, and * p<.1

Source: Author based on survey data.

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For the public irrigation scheme arrangement, contrary to the finding that as the education level of the household head increases farm income, when the education level of the primary female decision maker affected farm income negatively. The education level of the primary female decision maker was significant at 95% level of confidence. This meant that the more learned the primary female decision maker was, farm income decreases. This could be because of two possible reasons; withdrawal of labor and a shift in farming arrangement. One, studies have shown that education for women in agrarian systems offers them opportunities that are non-farm in nature (De Janvry & Sadoulet, 2001). Therefore, this would mean a shift of family labor from public irrigation scheme arrangement and thus a lowering of farm income (especially given that women form a large proportion of agricultural labor). Secondly, with education, comes women's empowerment (Kabeer, 1999; Mosedale, 2005; Unterhalter, 2012, pp. 35–110), thus enabling the women to shift from this irrigation arrangement that does not favor them especially as concerns land ownership as discussed earlier about the institutional structure of the public irrigation scheme arrangement. This would thus result in a reduction of the farm income earned at the household level. This points out to the need to look at the women empowerment as a stand-alone irrigation-nutrition pathway. In this regard, this aspect of women empowerment especially through the making of productive decision is better captured by the A-WEAI. This is discussed further down in the chapter,

The land rental price negatively influenced farm income for the public irrigation scheme arrangement at 99% level of confidence. An increase in land rental prices would increase the production costs in turn reducing farm profitability and affecting production. Given that land ownership for this irrigation arrangement is small as discussed earlier, the need to acquire more land for production would be a rational endeavor for the farmers. Therefore, for these farmers, an increase in the land rental prices would be an additional cost to the. On the other hand, for those who would rather rent out land, research shows that even when the rental prices are high, hiring out land decreases income (Geng et al., 2021). In addition, given that the plot sizes are small as discussed in Chapter Five, the rental prices normally decreases with plot size (Abay et al., 2021). Therefore, an increase in the rental prices raises the production cost, and reduces efficiency of farming in these smaller units, thus reducing farm income.

Land ownership influenced farm income positively despite the irrigation arrangement. For the aggregated irrigation analysis, the positive influence of land ownership on farm income was significant at 99% level of confidence. This positive influence was also evident on both public irrigation scheme- and farmer-led irrigation- arrangement with a significance level at 99% and 95% level of confidence respectively. This means that households that owned larger tracks of land were also disposed to have higher farm income. Land being a critical factor in production, its access in larger amounts is bound to have an effect on farm income and has also been shown to not only lead to higher profits but also production efficiency (Manjunatha et al., 2013). In addition, land ownership is positively associated with other factors of production such as credit access (Mbudzya et al., 2022), productivity (Mbudzya et al., 2022), possibility of mechanization (Kirui, 2019) and even climate change adaptation (Murken & Gornott, 2022) that have a direct

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influence on farm income. Therefore, this explains the positive linkage of land ownership and farm income.

Similarly, access to fertilizer had a significant increase farm income at 99% level of confidence for the aggregated irrigation analysis. This was also evident in the disaggregated analyses with the positive effect of access to fertilizer being significant at 95% level of confidence for both public irrigation scheme- and farmer-led irrigation- arrangements. This is congruent with other researches that have found that fertilizer forms a critical input that increases agricultural production and incomes (Adolwa et al., 2019; Belete et al., 1992; Habtemariam et al., 2019, 2019; Kiratu, 2014; Martey et al., 2019). This is a critical finding since access of fertilizer in Kenya is often a challenge from both the supply and demand side of the equation. This includes challenges such as weak institutions, poor infrastructure which makes supply expensive and difficult to reach the end markets, restricted credit access, high and volatile markets dependent on global markets trends, limited storage facilities and market information as well as limited skills and knowledge on input use (Chianu et al., 2008; Marennya & Barrett, 2009; Salami et al., 2010). This thus shows that making fertilizer accessible to irrigating farmers could have a positive effect on households' incomes.

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Table 21: 3SLS results of a simultaneous system of dietary diversity, production diversity, farm income, women's empowerment and irrigation for the public irrigation scheme arrangement [Equation 47, Equation 48, Equation 49, Equation 50, and Equation 51]

Variables	Dietary diversity	Production diversity	Log of farm income (USD)	Women's empowerment	irrigation
Production diversity	-0.152* (0.088)				
Log of farm income (USD)	0.012 (0.048)				
Women's empowerment	0.987* (0.569)				
Household size	0.038 (0.037)		0.268*** (0.096)	0.001 (0.019)	-0.005 (0.014)
Employed	-0.139 (0.139)				
Age of the household head (years)	-0.013* (0.007)	0.012 (0.011)	-0.002 (0.019)	-0.003 (0.004)	0.002 (0.003)
Age of the primary female decision maker (years)	0.012 (0.007)	-0.016 (0.011)	0.010 (0.020)	0.005 (0.004)	-0.004 (0.003)
Tropical livestock units	0.414*** (0.114)	0.818*** (0.106)	1.287** (0.549)	-0.027 (0.037)	0.016 (0.027)
Education level of the household head (years)	0.003 (0.019)	0.011 (0.027)	0.173*** (0.055)	0.013 (0.012)	-0.013* (0.007)
Education level of the primary female decision maker (years)	0.031 (0.021)	0.004 (0.030)	-0.144** (0.072)	-0.022* (0.014)	0.021*** (0.007)
Distance to the market (Kilometers)	0.032 (0.020)		0.049 (0.056)	0.016 (0.011)	-0.007 (0.007)
Public irrigation scheme arrangement		-1.460*** (0.245)	6.494*** (1.163)	1.102** (0.454)	
Assets (USD)		<0.000 (0.000)			<0.000 (0.000)

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Single adult household type	0.439**				
	(0.198)				
Primary female decision maker production decision	0.071	0.698	0.245***	-0.070	
	(0.056)	(0.520)	(0.066)	(0.046)	
Land owned (acres)	0.101**	0.439***	0.010	-0.010	
	(0.044)	(0.115)	(0.015)	(0.011)	
Household group membership	0.399**			0.136***	
	(0.174)			(0.034)	
Production diversity		-1.105			
		(0.734)			
Access to hybrid seed		-0.868	-0.102*	0.115***	
		(0.609)	(0.059)	(0.039)	
Access to fertilizer		1.412**	-0.077	0.076	
		(0.712)	(0.127)	(0.073)	
Land rental price (per acre)		-0.010***	-0.002**	0.002***	
		(0.003)	(0.001)	(0.000)	
Access to extra land			0.030		
			(0.123)		
Knowledge of pumping technology				0.065	
				(0.04)	
Single adult household type				0.069*	
				(0.037)	
Gender of the household head (Female)				-0.019	
				(0.032)	
Constant	3.689***	2.705***	4.226*	0.533***	-0.126
	(0.495)	(0.551)	(2.382)	(0.200)	(0.148)
Parameters	11	11	14	14	17
Equation root mean squared error	0.925	1.317	3.095	0.395	0.328
Equation R-squared	-0.043	0.276	-0.620	-4.197	0.498
Chi-square	36.480	144.810	122.420	137.680	307.500

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Chi-square p-value	0.000	0.000	0.000	0.000	0.000
Number of observations	287	287	287	287	287

Note: Standard errors are listed below the coefficients in parentheses. † Shows dummy variables. The notations and the meanings are as follows: *** p<.01, ** p<.05, and * p<.1

Source: Author based on survey data.

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8.3.3. Results and discussion for the women's empowerment equation

The age of the primary female decision maker positively affected women's empowerment for the aggregated irrigation and for the farmer-led irrigation arrangement with the statistical significance being at 95% level of confidence for both analyses. This then alludes that households where the primary female decision maker was older had women who were more empowered. Age has been found to be positively correlated to women's empowerment especially in the context of rural smallholder farm households (Haque et al., 2011; Nayak & Mahanta, 2012; Sell & Minot, 2018) with the notion being that women tend to get more decision making power with age (Hameed et al., 2014). This especially could be more possible for the farmer-led irrigation arrangement given that the farm household has more control on the type of enterprise to engage in and at what time. This offers an opportunity for household decision making in which the women can participate in especially as they age. Therefore, as the primary female decision maker ages, they have more decisions making powers in the household including on agricultural undertakings, income use and even input use (including labor). This concurs with a study done by Bryan and Mekonnen (2023) in Ghana that showed that for households involved in small-scale irrigation, women's empowerment increased with age especially as it relates to making decisions.

Being further from the market enhanced women's empowerment for in the aggregated irrigation analysis and for the farmer-led irrigation arrangement. The statistical significance for the distance to the market for the aggregated irrigation analysis and for the farmer-led irrigation arrangement was found to be at 95% and 99% level of confidence respectively. While this is against what was expected and also contrary to some studies have found that not being remote and remoteness is associated with women's disempowerment (e.g. Sell & Minot, 2018), it is good to be cognizant of the contextual difference of this study in terms of infrastructure, historical past and the data collection timing. This variable is usually highly contextual, with some analyses showing that the plot location as opposed to the homestead is the one that affects women's empowerment with the further the plot is from the homestead the more empowered the women in the household (Bryan & Mekonnen, 2023). In the case of Sell & Minot (2018), this measurement was based on the infrastructure of the area and the road connectedness of the area. As such, they used travel-time to the nearest paved road as a proxy of remoteness. In addition, it is also possible that (and considering the Covid-19 pandemic that closed markets) farm households further engaged less in cash crops that are usually men dominated into food crops. In this way, the women would have more control over the non-marketed products in the farm thus empowering them.

In addition, as opposed to the abovementioned citation, it is paramount to note that the area does have a vast network of roads (paved and all-weather roads) and as such the measurement of the distance was in actual distance of the homestead to the market. Secondly, as given in the literature review, with the colonial past of the area, the areas that developed into markets are often next to past colonial authority areas. This is shown in Chapter Four, Figure 47 on the map of the area showing the location of the markets. Thirdly, it is paramount to note that the collection of the data took place during the Covid-19 pandemic when interactions and congregation in places such as markets were either avoided or banned. As such, as people

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retreated to spending most of the times at home, I hypothesize that this may have resulted to most of the decisions being made at home (given that physical movement outside the home was minimized). This therefore made the women either aware or/and involved in the day-to-day decisions. Therefore, the further the household was from the market places, the more household decisions were made without any external input thus empowering women in these households. As argued before, this is particularly critical for the farmer-led irrigation arrangement where women are more involved and have more control especially on production than the public irrigation scheme arrangement.

For the case of the public irrigation scheme arrangement, the education level of the primary female decision maker influences women's empowerment negatively. The significance level of education level of the primary female decision maker was at 90% level of confidence. This meant that the more learned the primary female decision maker was, the more disempowered she would be. This is in contrast to the hypothesized priori influence. This may point out to the disenfranchisement of more learned women in an irrigation system that biasedly favors men especially on land rights which is a critical factor of agricultural production. As such, as the women get more enlightened through education and threatens the status quo, there may be a tendency of the existing institutional set-up of this irrigation arrangement, either by design or circumstantially, disempowers them. On the other hand, it may be that more learned women benefit more in getting out of this system of agriculture. This would be in concurrence with studies that show that sometimes in agricultural setups, advanced education profit women by leading them to non-farm gainful prospects (De Janvry & Sadoulet, 2001).

The ability of the primary female decision maker participating in production decision positively influenced women's empowerment at 99% level of confidence for the pooled analysis as well as for both the public irrigation scheme and farmer-led irrigation arrangements. This shows the critical part that decision making in production has on empowering women. Agricultural production is the main livelihood of the rural population and women form a majority of the labor force. Therefore, their participation on when and what is grown in the case of crops and what can be kept in the case of livestock is of paramount importance as pertains to their empowerment. This is also comparable to the finding of other studies that link female decision making with higher women's empowerment (Bushra & Wajiha, 2015; Chaudhry & Nosheen, 2009; Lépine & Strobl, 2013; Malhotra & Schuler, 2005). The positive relationship especially as regards the farmer-led irrigation shows the critical part that making decisions on women's empowerment be it in the right to use and govern household income, labor, means of production and/or expenses (C. L. Anderson et al., 2021; Diiro et al., 2018; Kehinde et al., 2021).

For the public irrigation scheme arrangement, access to hybrid seeds led to lower women's empowerment. The significance level for the effect of access to hybrid seeds on women's empowerment for the public irrigation scheme arrangement was at 90% level of confidence. Hybrid seeds are often used in cash crop or commercial farming that is habitually male dominated as opposed to food crops that are usually female dominated (Heyer, 2006; Mackenzie, 1998). This therefore explains the negative link between access to hybrid seeds and women's

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empowerment. As the households' accesses more hybrid seeds, there is a tendency for the agricultural activity to move towards commercial agriculture to which the female household members have less control over.

On the other hand, access to fertilizer led to higher women's empowerment for the aggregated irrigation and for the farmer-led irrigation. Access to fertilizer was statistically significant at 90% level of confidence for the pooled irrigation analysis and at 95% level of confidence for the farmer-led irrigation arrangement. The farmer-led irrigation arrangement focuses towards market-demand enterprises. Therefore, the female members of the households integrate in this kind of engagement with a common focus on commercial agriculture. As such, the women have more control of commercial undertaking in this kind of arrangement as illustrated by the descriptive statistics in Chapter Five. This includes the use of inputs such as fertilizer. In this way, this arrangement increases the ability of the women to access these inputs in its application on the crops as well as along the margins of the land or small gardens. Women access to inputs in sub-Saharan Africa is usually limited even when they have other production factors such as land, which affects their productivity (Bryan & Garner, 2022; Duflo, 2012; Mudege et al., 2015; Soetan, 1999). Consequently, access to inputs helps women in making their plots more productive (for both food and cash crops) which leads to higher control and access to household resources such as incomes (Duflo, 2012).

In addition, it was also found that there were also some positive spill-over effects of farmer-led irrigation arrangement to the women living in the community. Though beyond this study's scope, it was often observed that during labor-intensive periods like harvesting times, the farmer-led irrigation households often solicited labor from the community. It was therefore common to see women hired to work on the farms especially in the harvesting of crops such as French beans, sweet potatoes and tomatoes. This observation also concurred with the findings of Ofosu (2011) that farmer-led irrigation opens up income opportunities through labor for the communities. In addition, during roadside and FGDs discussions, another positive spillover effect was also noted in that this seasonal demand of labor raises the wages through which women in the community benefit. This also was found out by Wiggins & Lankford (2019) that farmer-led irrigation can generate labor demands and increases in rural wages that primarily benefit women.

Land rental price significantly and positively influenced women's empowerment in the aggregated irrigation analysis at 99% level of confidence. Nevertheless, on the disaggregated analyses, the land rental price negatively influenced women's empowerment for the public irrigation scheme arrangement at 95% level of confidence. With the land ownership in this public irrigation scheme arrangement disfavoring women, it is understandable as to why the limitation to access more land measured through the land rental price would disempower the women further. This therefore limits their ability to access a critical factor of production, which is land.

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Figure 61: Women engaged in the harvesting and packaging of French beans and sweet potatoes
Source: Fieldwork photo

8.3.4. Assessing smallholder farm households' irrigation-nutrition pathways under different irrigation arrangements

The results from the aggregated irrigation showed that irrigation significantly improved farm income and women's empowerment. These associations between irrigation farm income and women's empowerment were significant at 99% level of confidence. Sequentially, an improvement in the farm income and women's empowerment led to higher dietary diversity at the household level. The model showed the increase of dietary diversity due to farm income and women's empowerment was statistically significant at 95% level of confidence while for the

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women's empowerment it was at 99% level of confidence. On the other hand, irrigation influenced production diversity negatively. The statistical significance of the influence of irrigation on production diversity was at 99% level of confidence. This means that while irrigation increases farm income and women's empowerment, it reduces production diversity at household level. However, the influence of production diversity on dietary diversity was found not to be statistically significant. This suggests that farm income and women's empowerment are the only viable ways through which irrigation influences household nutrition outcomes.

However, the bulwark claim of this research is that different irrigation arrangements affect production diversity, farm income and women's empowerment differently. In addition, I make a claim that the different irrigation arrangements have different irrigation-nutrition pathways. Therefore, the above result is used as a comparison to show the basis as to why disaggregated analysis in irrigation is necessary.

The analysis showed that being in the farmer-led irrigation arrangement leads to an increase in farm income and women's empowerment at household level. The statistical significance for the farm income and women's empowerment was at 99% and 90% level of confidence respectively. The analysis showed that the farmer-led irrigation arrangement analysis, this arrangement does not have a significant influence on production diversity. In similar fashion, there was no statistical significance for the households in farmer-led irrigation arrangement on the effect of production diversity on dietary diversity. This means that production diversity is not a pathway through which farmer-led irrigation arrangement households can achieve nutrition outcomes.

The farmer-led irrigation arrangement analysis showed that an improvement in the farm income and women's empowerment led to higher dietary diversity at the household level. The model showed the increase of dietary diversity due to farm income and women's empowerment was statistically significant at 99% and 90% level of confidence respectively. Therefore, this shows that the farmer-led irrigation arrangement households' irrigation-nutrition pathways are farm income and women's empowerment.

As argued in the previous chapters, farmer-led irrigation arrangement leans towards marketed products. Therefore, this may be the reason as to why the production diversity is not a significant nutrition pathway. Research has shown that production diversity might actually lead to a negative effect due to loss of income gained through specialization (Sibhatu et al., 2015a). In this case, it can be argued that the households choose not to have a diversified production due to the gains in specializing in market demanded products. This is beneficial to the household through an increase in farm income which is a plausible irrigation-nutrition pathway. In addition in such households, market access plays a more vital role in their nutrition outcomes (they source food in the market) and thus reduces production diversity's impact on the nutrition of the household as also argued by Sibhatu et al., (2015).

The effect of public irrigation scheme arrangement on production diversity, farm income and women's empowerment were similar to the results of the aggregated irrigation. Public irrigation

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scheme arrangement had a positive effect on farm income and women's empowerment and a negative influence on production diversity. The statistical significance for the effect of public irrigation scheme arrangement on women's empowerment was at 95% level of confidence while for farm income and women's empowerment was at 99% level of confidence. Therefore, being in the public irrigation scheme arrangement has the possibility to improve farm income and women's empowerment at household level but reduce the household's production diversity. The reduction in production diversity in public irrigation scheme arrangement in turn does reduce dietary diversity. This negative effect of production diversity on dietary diversity was significant at 90% level of confidence.

The results also showed that the positive effect of public irrigation scheme arrangement on farm income does not translate to an effect on dietary diversity. On the contrary, the positive effect on women's empowerment leads to an improvement in dietary diversity at a significance level at 90% level of confidence. Therefore, women's empowerment is the only feasible irrigation-nutrition pathway through which public irrigation scheme arrangement improve their nutrition outcomes.

Furthermore, in the farmer-led irrigation arrangement analysis, the employment of a household member does reduce the dietary diversity of the household. This can be linked to the need for labor demand in farmer-led irrigation arrangement especially when rudimentary technologies that are labor intensive such as fallow method are used (Bjorneberg & Sojka, 2005; Friedman, 2023; Kloezen & Van Bentum, 1993). Therefore, employment draws away labor from the household that could be used in the farm. In addition, given that the results show that farm income and women's empowerment are the pathways through which the households in farmer-led irrigation arrangement achieve nutrition outcomes, then labor diverted to employment negatively affects the household's dietary diversity.

Similar to the aggregated analysis, the results showed that the age of the household head affects dietary diversity negatively for households in the public irrigation scheme arrangement. This means that as the age of the household member increases, the household's dietary diversity reduces. Similarly, after controlling for the effect of livestock ownership on production diversity, it was found that keeping livestock increases dietary diversity in the aggregated irrigation and public irrigation scheme arrangement analyses. However, livestock ownership in the farmer-led irrigation arrangement did not have a statistically significant effect on dietary diversity. The positive association between livestock ownership and dietary diversity is in concurrence with other research (Bhagowalia et al., 2012; Flax et al., 2023; Jodlowski et al., 2016; Otte et al., 2012). The lack of effect of livestock ownership on dietary diversity for the households in the farmer-led irrigation arrangement can be partly explained by the non-significance of dietary diversity on production diversity. In this case, livestock keeping would lead to higher production diversity that does not have any significant effect on dietary diversity for the farmer-led irrigation arrangement.

Moreover, in farmer-led irrigation arrangement analysis, after controlling for the effect of education level of the primary female decision maker on women's empowerment, it was found

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that it leads to a higher dietary diversity. This also is congruent to the pathway results as women's empowerment is a nutrition pathway for farmer-led irrigation arrangement households. This means that for farmer-led irrigation arrangement households, the more learned the primary female decision maker, the higher the women's empowerment and the higher the dietary diversity. Thus, the education level of the primary female decision maker has a direct effect on women's empowerment as well as dietary diversity for the farmers in the farmer-led irrigation arrangement.

In the aggregated analysis, the distance from the market influenced dietary diversity positively. This was after controlling for its effect on women's empowerment. On the other hand, the effect of the distance to the market on dietary diversity was not significant for the disaggregated analyses. The distance from the market was only significant in its effect on women's empowerment for the farmer-led irrigation arrangement analysis but this does not translate directly to an effect on dietary diversity but rather through women's empowerment. This further shows the importance of disaggregating irrigation analyses in order to ensure policy relevant recommendations.

8.4. Conclusion

The regression results showed that different irrigation arrangements achieve nutrition outcomes through different pathways and the factors that affects them are different. While in the aggregated results it shows that the three pathways of production diversity, farm income and women's empowerment were affected by irrigation, in finer details, the results show that the irrigating households can only achieve better nutritional outcomes through the farm income and women empowerment pathways. Therefore, as evidenced in the field, for the farm households utilizing irrigation, they are able to have an increase in their earnings from the farm enterprise emanating from increased yields (reliable cropping, optimal watering and increased frequency of cropping), the crops grown (high value crops), and the frequency of cropping. However, as highlighted earlier on, the disaggregated analysis shows that the pathways differ.

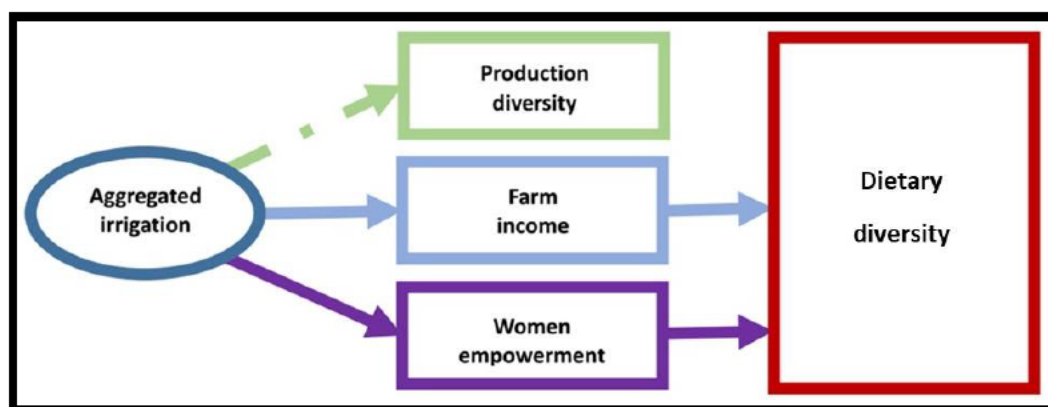


Figure 62: Irrigation-nutrition pathways for aggregated irrigation

Note: Continuous lines indicate a positive effect and a dotted line negative effect

Source: Author based on survey data.

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In the farmer-led irrigation arrangement analysis, production diversity was neither influenced by this irrigation arrangement nor influenced dietary diversity. In this irrigation arrangement, only farm income and women's diversity are plausible pathways through which the households attain a diversified diet.

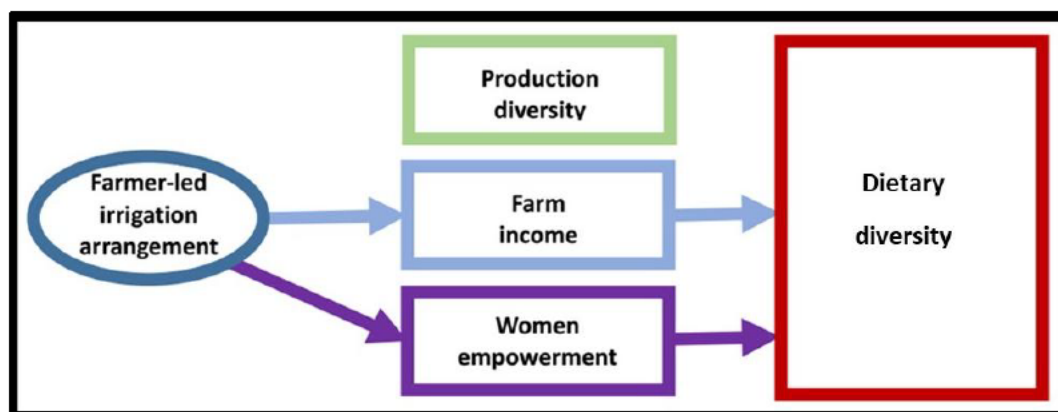


Figure 63: Irrigation-nutrition pathways for farmer-led irrigation arrangement

Note: Continuous lines indicate a positive effect and a dotted line negative effect

Source: Author based on survey data.

For the farm income pathways, it is observed that the households who practice farmer-led irrigation arrangement are able to have a higher income from the farming enterprise through several ways. One of the ways is through increased yields by reducing reliance on rainfall thus mitigating crop failure. They are also able to have multiple cropping seasons whereby they also overlap crops as seen in the planting of a maize crop in the at a later stage of a French bean crop as shown in Figure 64. In addition, the ability of the farm households to provide optimal water supply to the crops enhances the harvest derived from the crop.



Figure 64: A farmer-led irrigation French beans crop intercropped with maize

Source: Fieldwork photo

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Another way through which the farmer-led irrigation arrangement farm households achieve higher farm incomes is through the growing of high value crops. Water availability enables these households to grow high value crops that have a high market demand (local, urban and export markets) such as French beans, tomatoes, fruits and vegetables as shown in Figure 65 and Figure 66. These crops have a higher market price that bolsters their farm income. With most of these crops being sensitive to water availability, farmers in this arrangement are able to use irrigation to reduce this risk. Furthermore, irrigation also unlocks unproductive and low productivity lands into highly productive and intensive growing areas. This was especially visible in the utilization of dry areas and previously un- and/or under-utilized fringe lands. This observation is in concurrence with the findings of Khatri-Chhetri et al., (2017) that farmer-led irrigation enables prudent use of the limited smallholder farmers' resources. Thus, by maximumly using these resources, the farmers also increase the farms' productivity thus leading to higher farm incomes.



Figure 65: A farmer-led irrigation arrangement farmer specializing in the production of green leafy vegetables (in planting pits) and green maize

Source: Fieldwork photo

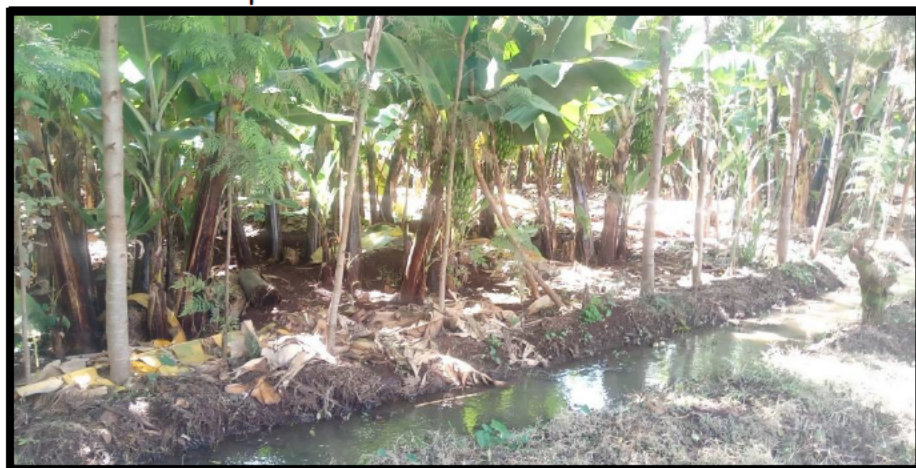


Figure 66: A farmer-led irrigation arrangement farmer specializing in the production of bananas with the irrigation water shown at the front

Source: Fieldwork photo

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On the other hand, the public irrigation scheme arrangement has the possibility to improve the households' farm income and women's empowerment at household level. The increase in farm income was mainly through the growing of high value Basmati rice and the ability to grow it multiple times through irrigation using such techniques as ratooning. However, only women's empowerment is a plausible pathway for the households in this arrangement to achieve better nutrition outcomes.

However, households practicing the public irrigation scheme arrangement led to lower production diversity and this in turn affected their dietary diversity negatively. In this regard, the production diversity was not a viable pathway through which households in public irrigation scheme arrangement positively influence their dietary diversity. This was mostly found to be because of monocropping of Basmati rice and also the use of the ratooning technique after harvest which propagates the crop for another season. Interestingly, the women in the public irrigation scheme arrangement FGDs were opposed to this rice ratooning practice. It was apparent that when there were distinct seasons, the women used to plant nutrition-rich coarse grain such as legumes (e.g. fresh peas and green beans) and pulses (cowpeas, pigeon peas, lentils, beans, green grams and dolichos) for the 3 to 4 months that the fields were unoccupied/uncropped. However, the practice of ratooning made the fields unavailable to them and mostly the proceeds from the Basmati rice was often controlled by the men. Therefore, there is need to look into gender-sensitive agricultural practices even as rice intensification measures are undertaken. In addition, there is scope for policy makers and implementers to look into ways of improving production diversity for households in public irrigation scheme arrangement so that they can achieve higher nutrition outcomes through this pathway and alleviate the negative effects found in this study.

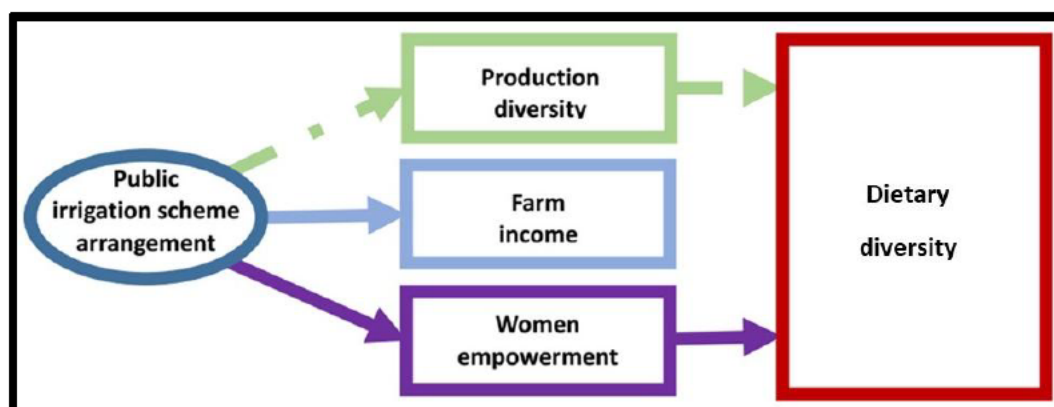


Figure 67: Irrigation-nutrition pathways for public irrigation scheme arrangement

Note: Continuous lines indicate a positive effect and a dotted line negative effect

Source: Author based on survey data.

As evidenced in the study, women's empowerment was a critical pathway through which households attained diversified diets. There were several ways observed in this study through which women in the households practicing the two irrigation arrangements were empowered. One of the ways that women were empowered in the households was through a reduction in the

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time, distance and energy burden related to fetching water. Water is a critical component of food and nutrition security especially due to its integral part in Water, Sanitation, and Hygiene (WASH) at the household level. Therefore, its availability improves the WASH aspect of the household. The infrastructural development of the public irrigation scheme through canals brings this vital resource near the household thus reducing the time spent by women (a culturally gender role in the area) in the household (especially the primary female decision maker) to draw water for household use. Likewise, in the farmer-led irrigation arrangement, the pumping or siphoning of water from a far water source to a plot near the farm reduces the distance, time and energy needed to access water. This was especially evident in the field where women would go draw water from the pipe during irrigation times.

For the women in the farmer-led irrigation arrangement, empowerment also came through the management of income from enterprises in the farm, especially the ones they traditionally control such as green leafy vegetables, sweet potatoes and arrow roots and some grains such as millet and sorghum. These were often grown in the fringe lands or intercropped with the main irrigated crops. In addition, the ability of the women to access these crops for household use e.g. green vegetables, saved income that would have been used in the market to purchase these foodstuffs. The growing of these women-controlled crops was also common in the fringe lands and canal linings for the farmers in the public irrigation scheme arrangement. Which would have a similar empowerment effect for the women in these households.

The availability of these crops for the women especially during the dry seasons also creates an opportunity for new sources of livelihood by selling the surplus especially vegetables to the neighbors and if sufficient, to the market. The growing of nutrient-dense vegetables also empowers the women in that it provides the necessary nutrients to the vulnerable members of the households such as children and lactating mothers.

For the farmers in the two irrigation arrangements, women are also empowered by being involved in more decision making at the household and also community level. By farmer-led irrigation arrangement requiring substantial investment by the household, the involvement of the primary female decision maker is not only important but a necessity in both from an investment perspective (given the substantial finances needed vis-à-vis the low incomes of the smallholder farmers) and also labor aspect (women form a considerable proportion of farm labor in the country and region). For the farmer-led irrigation arrangement, it was also found that farmers organized themselves into groups where women also got the opportunity to lead. In a similar manner, the participation of the household as a unit in the Water Users' Association (WUA) in the public irrigation scheme arrangement, ensures that time and again the primary female decision maker will represent the household unit in the meetings which sometimes include trainings thus making skills and information accessible to them. The involvement of women in the productive decisions (in growing crops on the fringe lands, intercropping or even as partners in the venture), credit information (through credit institutions that reach out through WUA and farmer groups' meetings) and asset holdings (e.g. pump and pumping infrastructure

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and associated investments such as a knapsack sprayers) for the two irrigation arrangements is also other avenues through which they are empowered.

The finding that public irrigation scheme arrangement leads to a reduction in production diversity and in turn a reduction in nutrition outcome shows a potential policy intervention area. However, it is important to look at these pathways as complimentary in nature and not as isolated. In this case, research also shows that women's empowerment has the capability to alleviate the negative nutrition effects that may accrue from low production diversity (H. J. Malapit et al., 2015). Therefore, this may be the case here for the public irrigation scheme arrangement analysis. The positive effect of women's empowerment mitigates the effect of low production diversity and leads to a positive nutrition outcome through the women's empowerment pathway. It would be beneficial then to look at how these pathways could complement each other.

In this regard, given the small land holding, the use of fringe lands in the rice fields could also help diversity production e.g. arrow roots in canals, sweet potatoes in the earthen canal molds and vegetables along the farm edges (see pictorials for examples). While the evidence of such crops on the irrigation molds or canals was captured qualitatively by observation and FGDs, and even in the dietary data it is important that this could have been easily captured in the plots data during the household interviews since it is neither owned, rented or cultivated land in its conventional meaning. Interestingly, from the FGDs this kind of farming was done by women. However, such crops are often cleared during canal maintenance which the women in the FGDs regarded as "destroyed crop".

While increase in income only translated to better nutrition outcomes for the households under farmer-led irrigation arrangement, it should not downplay also the significance of both irrigation arrangements increasing farm income. In an agro-based economy like Kenya, this plays a crucial role in improving the rural poverty. As shown in Chapter Five of this thesis, about 29% of the sampled households are under the rural poverty line as per the country's official statistics. In addition, the average total annual income for the sampled households being at USD 1,912.35 and a mean sample household size of 4 persons, this indicates that most of the households are within the band of extreme poverty of spending less USD 2.15 per person per day at 2017 purchasing power parity. Therefore, investments in technologies that would improve the incomes of this population such as irrigation is needful. This finding that irrigation does lead to increased income is also congruent with similar finding in Nigeria (J. A. Burney & Naylor, 2012), Malawi (Mangisoni, 2008), Ethiopia (Passarelli et al., 2018), Ghana (Balana et al., 2020; Okyere & Usman, 2021) and in sub-Saharan Africa in general (Xie et al., 2014; You et al., 2011).

In addition, in the farmer-led irrigation arrangement, it is evident that such increase in incomes of such households is also spent on food which is supported by other in research findings such as Banerjee & Duflo (2007) and Zezza et al., (2009). This particular finding is of great importance to sub-Saharan Africa that is experiencing a policy intensity towards irrigation due to climate related challenges under a backdrop of dismal performance of large-scale water infrastructure such as

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large publicly funded irrigation schemes (Higginbottom et al., 2021). Which has renewed an interest in farmer-led irrigation (de Bont et al., 2019; Woodhouse et al., 2017). This research therefore provides evidence on the limitedly researched farmer-led irrigation arrangement especially its impact on incomes and nutrition. It is thus concluded that increased farm incomes from engagement in the farmer-led irrigation arrangement does translate to better household nutrition as measured through dietary diversity.

Similarly, the finding that irrigation leads to better nutrition outcome through increased income has been evidenced in Benin where the increase in income was spent on food, healthcare and education (Alaofè et al., 2016) and in India especially when supplemented by better health and education (Bhagowalia et al., 2012). In Ghana, irrigation was also associated with better nutrition outcomes for children (Okyere & Usman, 2021) and in Ethiopia where irrigation increased the diversity of households' diets through increased incomes (Passarelli et al., 2018).

The feasibility of the women's empowerment in both irrigation arrangements shows the importance of this impact pathway in the attainment of a diversified diet at the household level. The finding concurs with previous research done that associates aspects of women's empowerment to improved diets (C. L. Anderson et al., 2021; Baye et al., 2021; Connors et al., 2023; M. Kassie et al., 2020; Komakech et al., 2022; V. L. Pandey et al., 2016; Sinharoy et al., 2018; Sraboni & Quisumbing, 2018; Vermes, 2021). There are particular reasons that could point as to why women's empowerment seems to transverse through all the irrigation arrangements as a means to achieve higher household nutrition outcomes. Given that women are the key caregivers and meal preparers in Kenya (Bukachi et al., 2022; Fingleton-Smith, 2018; M. Kassie et al., 2020; Okelo et al., 2022; Reiheld, 2014), given the power, their decisions will tend to influence the household nutrition.

Secondly, when in control of income and decisions on resource use, research has shown that women tend to spend a considerable amount of these resources on household welfare including food and healthcare and any other of their expenditures does not compromise on the households' nutrition needs (Bukachi et al., 2022). Lastly, women's empowerment also enhances the welfare of the women themselves in an ability to make sure that their wellbeing is taken care of. In this way, the household's benefits directly and indirectly in relation to her resource use, care, time load and availability (Lépine & Strobl, 2013).

The results of this research are particularly significant when taking consideration of the timing of the data collection period. The data collection was during the Covid-19 crisis period with the data collection spanning from 1st February 2020 to 28th February 2021. This was a time when households were experiencing a pandemic shock including a reduction on income and food price hikes (Kansiime et al., 2021; Nechifor et al., 2021; Shupler et al., 2021). It is therefore remarkable that irrigation would lead to increases in incomes and women's empowerment under such a predicament. Even more outstanding is that the positive effect of the irrigation arrangements on dietary diversity during a time that the economy was experiencing a shock, shows the robustness of these arrangements in contributing to households' nutrition outcomes.

9. CONCLUSION, POLICY RECOMMENDATIONS AND AREAS OF FURTHER RESEARCH

9.1. Introduction

As a culmination of this study, this chapter's main objective is to illustrate how the analyses and resultant findings inform policy and areas of further research. In order to have a seamless flow, the chapter follows the hypotheses for the study broken down into the specific variables of interest. After stating the hypotheses, a summary of the results centered on the variable of interest is given and how they are interpreted in light of the postulated effect. The policy implications of the results are then given as well as the suggested areas of future research.

9.2. Conclusions, policy recommendations and areas of further research

9.2.1. Socioeconomic factors

The first hypothesis was centered on the households' socioeconomic factors. The two specific hypotheses for this study were that the households' socioeconomic factors influence irrigation and the household's choice of irrigation arrangement. The descriptive statistics gave a general landscape of the variables across irrigation and irrigation arrangements (not to give a statistically differentiated analysis of significance), that showed how different the households factors are across the sampled households. The descriptive statistics showed that there is difference in the socioeconomic setups of the households both in irrigation and the two distinct irrigation arrangements. Therefore, the descriptive statistics results provided a good basis for the next analyses on the effect of households' socioeconomic factors how it influences irrigation and irrigation arrangements.

In the analyses in Chapter Six, a combination of a probit and multinomial logit regressions showed how household factors affect both irrigation and irrigation arrangements. The factors that were found to affect irrigation and the factors that affect each of the irrigation arrangements were not only different but also different in the direction of effect for the same socioeconomic factors. Unfortunately, there is scarce research directed on the effect of households' socioeconomic

factors in irrigation.

The factors that pertain to the primary female decision maker were found to be integral in determining irrigation arrangements. The education level of the primary female decision maker was a key determinant of being in the public irrigation scheme arrangement. The age of the primary female decision maker was also a significant determinant in influencing households from not being involved in the public irrigation scheme arrangement. This showed that the risk-taking attitude especially towards a new technology including this irrigation arrangement reduces with age. The results concurs with the findings of Antwi-Agyei et al., (2021), Jaafar & Kharroubi, (2021) and Martey et al., (2023) who also found that older farmers are risk-averse to irrigation technologies.

On the other hand, the primary female decision maker ability to make production decisions influenced the public irrigation scheme arrangement negatively. While this may seem to be contrary to research that shows that when women are able to make decision on production it can lead to higher adoption of irrigation systems (Bryan & Garner, 2022), understanding the institutional structure of the public irrigation system showed the reason for this finding. The public irrigation scheme has the propensity to disempower women through a lack of control of productive assets such as land (patriarchal hereditary system), heavy workloads in cleaning and maintaining the tertiary canals, and limiting their participation in its governance through the WUA (usually the registered member is the household head who is often a male, a factor that has been associated with low adoption of irrigation (Bryan & Garner, 2022; Bryan & Mekonnen, 2023; Imburgia, 2019; Lefore et al., 2019; Nation, 2010; Theis et al., 2018)). There is therefore need to look into mechanisms that pertains to the households' primary female decision makers in the context of the public irrigation scheme arrangement.

Knowledge of pumping technology was found to positively influence households towards the adoption of the farmer-led irrigation arrangement. As found by Hornum & Bolwig, (2021), having knowledge of adoption of irrigation technology increases the probability of one irrigating. The results show that knowledge of pumping technology is of particular influence towards farmer-led irrigation arrangement. This could be because the farmers in this arrangement need to take initiative in the establishment of irrigated agriculture in their farms that do not have the infrastructural support available farmers in the public irrigation scheme arrangement. This makes knowledge of technologies that draw water from the source to their farms such as water pumps a necessity especially given that they are mostly smallholder farmers who do not have access to necessary tools including access to such knowledge (Mati, 2023).

Additionally, access to inputs, especially fertilizer and hybrid seeds, also play a critical factor in ensuring that households adopt both irrigation arrangements. Cognizant of the fact that use of these two inputs is still low in Kenya (Mathenge et al., 2014; J. O. Ouma & De Groote, 2011; Sibiko & Qaim, 2020; Wainaina et al., 2016), targeting bottlenecks that hinder access would also significantly increase irrigation uptake. The analysis showed that the education level of the household head influenced households away from the public irrigation scheme arrangement,

while the land rented-in and the land rental prices was found to influence households towards irrigation and both irrigation arrangements.

This study thus contributes to a growing research area that shows the effect of household socioeconomic factors on irrigation such as the study by Abarike et al., (2025) that showed that the subsidiary part that women perform in irrigation is as a result of the socioeconomic related challenges that they encounter. Another study is by Kaini et al., (2020) who carried out research in an irrigation scheme and found that socioeconomic status and socio-cultural practices had an effect on the cropping intensity.

9.2.1.1. Policy recommendations; Household social economic factors matter!

Household social economic factors matter in determining the two irrigation arrangements.

Factors relating to women in the households such as education, decision making and even age needs to be taken into consideration when crafting policy interventions that want households to adopt any of the irrigation arrangements. In this regard, policy actions that empower women in the households especially as regards education, decision making and knowledge enhancement in irrigation technology is needed in order to encourage the adoption of irrigation arrangements.

Also, emanating from these analyses, there is a need to also reevaluate the institutional and structural set-up of the public irrigation scheme arrangement as there seems to be a tendency for the relatively empowered women to eschew it. With the public irrigations schemes currently spanning the larger area under irrigation in Kenya, it affects a huge number of women and therefore the need to intervene in order to highlight the areas that may be disenfranchising and/or disadvantaging women as regards either its operations or access.

Current research also shows that the farmer-led irrigation arrangement is a budding area of interest in Kenya (Kiratu et al., 2025; B. Mati, 2023) as well as in Africa (Lefore et al., 2019; Woodhouse et al., 2017). However, this study shows that the knowledge of pumping technology, and access to fertilizer and certified seeds play an integral part in its proliferation. This is in line with limited access to inputs having been shown as a barrier to scaling of farmer-led irrigation (Minh et al., 2024), this research showed how this directly affects this irrigation arrangement. In this regard, there is need for policy measures geared towards growth of farmer-led irrigation to also address the bottlenecks that exist as regards access to fertilizer and certified seeds as well as knowledge about pumping technologies.

9.2.1.2. Areas of further research

This research showed that the socioeconomic factors play a critical role in influencing the choice of irrigation arrangements. This is an area that has been inadequately studied especially as regards each of the irrigation arrangements studied herein. There is therefore need for researchers to study further the interception between household socioeconomic factors, public irrigation scheme and farmer-led irrigation arrangements.

9.2.2. Production diversity

In the second hypotheses concerning production diversity, it was postulated that irrigation and farmer-led irrigation arrangement increases production diversity at the household level which in-turn increases dietary diversity. The propensity score matching results showed that irrigation negatively affected production diversity of irrigating farm households but it was not affected by farmer-led irrigation arrangement. A more thorough analyses through the three least squares analyses, the results showed that when irrigation aggregated, it still negatively affected production diversity but had no significant effect on dietary diversity. Similar to the propensity score matching results, for the three least squares analysis, farmer-led irrigation arrangement neither had an effect on production diversity not on dietary diversity. This means that we fail to accept both null hypotheses on production diversity. Contrariwise, though not foreseen, under the three least squares analysis, production diversity was negatively affected by public irrigation scheme arrangement which also negatively affected the farm households' dietary diversity. This emphasizes the need to examine irrigation as disaggregated into different irrigation arrangements. This can be attributed to the specialization especially in rice production in dissimilarity to the mixed cropping techniques applied by the non-irrigating farmers in a bid to take advantage of the rainy season thus achieving seasonal higher crop variety.

9.2.2.1. Policy recommendations; Gains of specialization compromises gains on nutrition!

Gains of specialization in the public irrigation scheme arrangement compromises households' nutrition outcome! In a continent that a fifth of the population (over 300 million people) face hunger and whose population is projected to contribute to about 60% of the undernourished people (FAO et al., 2025), nutrition outcomes should be at the center of every agricultural intervention. In addition, with public irrigation scheme arrangement being the most widely spread and largest public investment irrigation arrangement in Africa (Giordano et al., 2019) as well as Kenya (National Irrigation Authority, 2024), this study's results call for an immediate policy intervention. The government needs to immediately intervene in alleviating the negative effects of not diversifying production on the dietary diversity of public irrigation scheme farmers. This includes production diversity fostering initiatives such as having a more diverse cropping schedule, use of fringe lands and bolstering animal keeping. The aim of these interventions should be to stop the negative effects on dietary diversity for households in this irrigation arrangement. Further, this policy intervention should also look into enhancing ways through which the farm households in the public irrigation scheme arrangement can achieve nutrition outcomes through the production diversity pathway.

9.2.2.2. Areas of further research

The results show a need to study as to whether the opportunity cost of forfeiting a diverse production system (both crops and livestock) balances out with the improvements in households' dietary diversity through other irrigation-nutrition pathways for the public irrigation scheme arrangement. This study also needs to be extended to the farmer-led irrigation arrangement to evaluate the means through which the production pathways can contribute to better health

outcomes at the household. There is a need for more research in looking ways through which the farm households in the two-irrigation arrangement can achieve nutrition outcomes through the production diversity pathway.

9.2.3. Farm income

The third hypotheses claimed that irrigation and farmer-led irrigation arrangement increases farm income which results to a higher dietary diversity in the household. The propensity score matching approach, its related robustness matching methods and the three stage least squares analyses provided a strong basis to conclude that irrigation does positively affect the irrigating households' farm income in the study area. Thus, the null hypotheses concerning farm income are accepted. The surprising but is that the positive effect on the farm income was significant across the two irrigation arrangements. This result reinforces the positive impact of irrigation on income found by of Kassie & Alemu (2021), Mangisoni (2008), Passarelli et al. (2018) and Zewdie et al. (2020).

While the aggregated analyses in the three stage least squares analysis showed that the increase in farm income also increases dietary diversity, the disaggregated analyses showed a different story. Thus, reiterating the need for analyses that considers the heterogeneity of these irrigation arrangements. The farm income increases in both irrigation arrangements; this increase only resulted in a more diverse diet among the households practicing the farmer-led irrigation arrangement. Therefore, this means that the positive effect in farm incomes among the public irrigation scheme arrangement households, does not translate to significant increase in the variety of food groups consumed therein.

While this finding also adds to the existing evidence that increased income from irrigation leads to better nutrition outcome i.e. from Benin where the increase in income was spent on food, healthcare and education (Alaofè et al., 2016), in India especially when supplemented by better health and education (Bhagowalia et al., 2012), in Ghana, irrigation was also associated with better nutrition outcomes for children (Okyere & Usman, 2021) and in Ethiopia where irrigation increased the diversity of households' diets through increased incomes (Passarelli et al., 2018), this study underpins the need for a disaggregated analyses. Therefore, the policy-correct position of this study is that the positive association between irrigation and income and its positive effect on dietary diversity can only be attributed to the farmer-led irrigation arrangement.

However, while increase in income only translated to better nutrition outcomes for the households under farmer-led irrigation arrangement, this does not downplay the significance of the public irrigation scheme arrangements increasing farm income. In an agro-based economy like Kenya, this plays a crucial role in improving the rural poverty. Therefore, investments in technologies that would improve the incomes of this population such as these irrigation arrangements are still necessary.

9.2.3.1. Policy recommendations; While public and farmer-led irrigation arrangements are plausible ways of increasing farm income, gains in income does not always translate to gains in nutrition outcomes!

This research has established that irrigation, regardless of irrigation arrangements, has a positive effect on farm incomes. This is particularly important for rural poverty alleviation policy interventions. The distinguishing of farm income particularly in this research shows that policy interventions that foster irrigation at farm level can be practicable and effective. With most of Kenya as well as sub-Saharan Africa farm holding being under two hectares, irrigation would be a tool to lift the rural populations above the poverty levels.

This study's results shows that farmer-led irrigation is a viable intervention for smallholder farmers to increase their farm incomes as well as improve on the households' nutrition outcomes. Given the low level of incomes in the area of study (well below the country's rural-poverty line), this is a key finding given the deficiency of studies delving into this irrigation arrangement in sub-Saharan Africa. Therefore, it is imperative for government to encourage, support and subsidize farmer-led irrigation initiatives as a way of not only increasing rural incomes but also improving on nutrition in these areas.

While the positive effect of irrigation on food and nutrition security has been found by other researchers (Alaofè et al., 2016; Baye et al., 2021; Belete et al., 1992; Benson, 2015; Bhagowalia et al., 2012; Biru et al., 2025; Bryan et al., 2019b; Domenèch & Ringler, 2013; Mekonnen et al., 2019, 2022; Nkonya et al., 2022; Passarelli et al., 2018; van der Hoek et al., 2002), this study shows the need in disaggregating such analyses based on the socio0technical set-ups (referred to irrigation arrangements as earlier discussed). While the farmer-led irrigation arrangement gains in farm income brought about a positive and significant rise in dietary diversity, this was not the case for the public irrigation scheme arrangement. Therefore, for the public irrigation scheme arrangement, there is a need to put in place measures to ensure that the positive gains in farm income translate into tangible improvements in dietary diversity.

In this regard, with markets being the primary means through which the farm income pathways impact on nutrition outcomes, this shows the need to buttress irrigation arrangement policy initiatives with market-correcting factors, nutrition education programs that nurtures behavioral change in the buying and consumption of food at the household level. In addition, also this shows the need for intervention for households in the public irrigation scheme arrangement as concerns the access, control, and use of farm income at the household level. With research showing that women-controlled income is often directed towards household welfare including food (Bukachi et al., 2022; Njuki et al., 2019; Soh Wenda et al., 2024), this might point to aspects of women disempowerment. It is hence essential to ensure that the women's empowerment in household practicing public irrigation scheme arrangement is enhanced.

9.2.3.2. Areas of further research

This also points out to the need of looking at the intersections between increases farm income and dietary diversity. Further research is necessary that looks at the aspects of farm income and dietary diversity especially among the different irrigation arrangements.

9.2.4. Women's empowerment

On the fourth premises, it was hypothesized that irrigation and farmer-led irrigation arrangement leads to women's empowerment which also improves the household's dietary diversity. The propensity score matching findings on the effect of irrigation and the two irrigations arrangements had no significant effect on women's empowerment. However, with the prior results at disaggregated level, the analyses on women's empowerment between the farmer-led irrigation- and public irrigation scheme- arrangement farmers called for further investigations and analyses. This is especially given that while the women's empowerment was not found to be significantly affected by irrigation and irrigation arrangements, this does not negate the possibility of it being an impact pathway for nutrition, which was the main aim of this study.

The three stage least squares analyses results showed that irrigation and both irrigation arrangements had a positive effect on women's empowerment which eventually led to a positive effect on dietary diversity. This therefore both led to the acceptance of the null hypotheses stated above and also was a surprise as it regards the effect of public irrigation scheme arrangement on dietary diversity.

As earlier discussed, the farmer-led irrigation arrangement as postulated earlier in the study was deemed to be more inclusive including towards omen which leads to their empowerment. Similar results by Duker et al., (2023) and Izzi et al., (2021) also found that farmer-led irrigation empowers women in that it is more inclusive to female farmers. However, the dominance of the women's empowerment pathways across all the analyses was as extraordinary as it was astounding. This shows the vital role that these irrigation arrangements play in women's empowerment and its resultant positive effect on household dietary diversity.

9.2.4.1. Policy recommendations; Farmer-led and public irrigation scheme arrangements for women's empowerment and dietary diversity!

This study presents a groundbreaking result in an understudied area; that the two irrigation arrangements not only make households equitable, but also enhances their nutrition outcome. For policy implications, this is a phenomenal combination especially for sub-Saharan Africa as it touches two key areas of interest for development policy practitioners.

In this regard, policy interventions geared towards women's empowerment and dietary diversity need to invest in public and farmer-led irrigation arrangements. As such, the need for policy.

Project and program implementers, need to ensure that aspects of women's empowerment and dietary diversity are addressed simultaneously in irrigation interventions.

9.2.4.2. Areas of further research

Women's empowerment as an irrigation-nutrition impact pathways is the most understudied of the pathways investigated in this study. Surprisingly, it proved to be the most impactful. Researchers are therefore urged to delve more (in depth and occurrence) into the study of this pathway so as to not only increase the accessibility and availability literature on the matter, but also inform policy formulation and implementation particularly under the renewed interest on irrigation in sub-Saharan Africa.

This research also shows the need for the application of multiple, diversified and robust quantitative methods in the study of the women's empowerment as an irrigation-nutrition pathway. One of the challenges in the study of irrigation and nutrition pathways has been methodological flaws especially relating to small samples (Domènech, 2015). In this regard, this study breaks through this glass-ceiling in providing a basis of how to apply econometric analyses while working with a relatively small sample and sub-samples in order to produce plausible results from which relevant policy can be derived. However, this is only a beginning and the need for similar analyses using both small localized as well as larger regionalized datasets cannot be overemphasized.

9.2.5. Dietary diversity

The fifth hypotheses stated that irrigation and the farmer-led irrigation had a greater positive effect on household dietary diversity. This was in line with the supposition that apart from dietary diversity being the desired outcome of the three potential pathways (production diversity, farm income and women's empowerment, irrigation and the different irrigation arrangements affect it differently. Following these two hypotheses, analyses based on the propensity score matching approach was done on the average treatment effect of not only the aggregated irrigating farmers but also the specific irrigation arrangements. The analyses showed a clear difference of the effect of irrigation and irrigation arrangements on dietary diversity. In addition, the magnitude as also shown by the tests for robustness showed that the farmer-led irrigation arrangement farm households had a more diverse diets as compared to the public irrigation scheme arrangement farmers. These results were confirmed by the three stage least square regression. We can therefore accept the null hypotheses as stated above.

Therefore, this research as in tandem with the findings of (Alaofè et al., 2016; Baye et al., 2021; Belete et al., 1992; Benson, 2015; Bhagowalia et al., 2012; Biru et al., 2025; Bryan et al., 2019b; Domènèch & Ringler, 2013; Mekonnen et al., 2019, 2022; Nkonya et al., 2022; Passarelli et al., 2018; van der Hoek et al., 2002), that of irrigation has a positive effect on food and nutrition security. Also it does confirm that farmer-led irrigation does lead to higher nutrition outcomes as put forward by Harmon et al., (2023) and Kiratu et al., (2025).

9.2.5.1. Policy recommendations; Farmer-led irrigation arrangement increases household dietary diversity!

These results show the sturdiness of the farmer-led irrigation arrangement in making a significant positive effect in the household's dietary diversity. Therefore, as a relatively new policy interest area, governments and policy implementers should be emboldened to invest in this farmer-led irrigation as a way of tackling nutrition insecurity especially in sub-Saharan Africa. This should be done by focusing on making the environment conducive for farmers to drive, establish and practice farmer-led irrigation. This includes incentivizing investments in pump technology and its related infrastructures through targeted initiatives like tax breaks on investments and subsidies on water extraction technologies.

9.2.5.2. Areas of further research

The available studies on the impact of farmer-led irrigation in sub-Saharan Africa is insufficient. In addition, the magnitude of the effect of this irrigation arrangement especially on nutrient-sensitive measures (e.g. MDD-W food-grouping) is also direly warranted. Therefore, future researches need to fill this near-void literary and policy space.

9.2.6. Dominant irrigation-nutrition impact pathways

In the last hypotheses, it was postulated that when aggregated, irrigation's dominant irrigation-nutrition pathways would be through production diversity, farm income and women's empowerment, while the pathways for the public irrigation scheme arrangement would be only the income pathway. It was hypothesized that the farmer-led irrigation arrangement would have production diversity, farm income and women's empowerment as its irrigation to nutrition pathways. Of these three null hypotheses none was accepted.

The three stage least squares analyses results demonstrated that different irrigation arrangements achieve nutrition outcomes through different pathways as opposed to an aggregates analysis. The aggregated analysis results indicated that the dominant irrigation-nutrition pathways were farm income and women's empowerment. The disaggregated analyses showed that the pathways differ as showed in Figure 68.

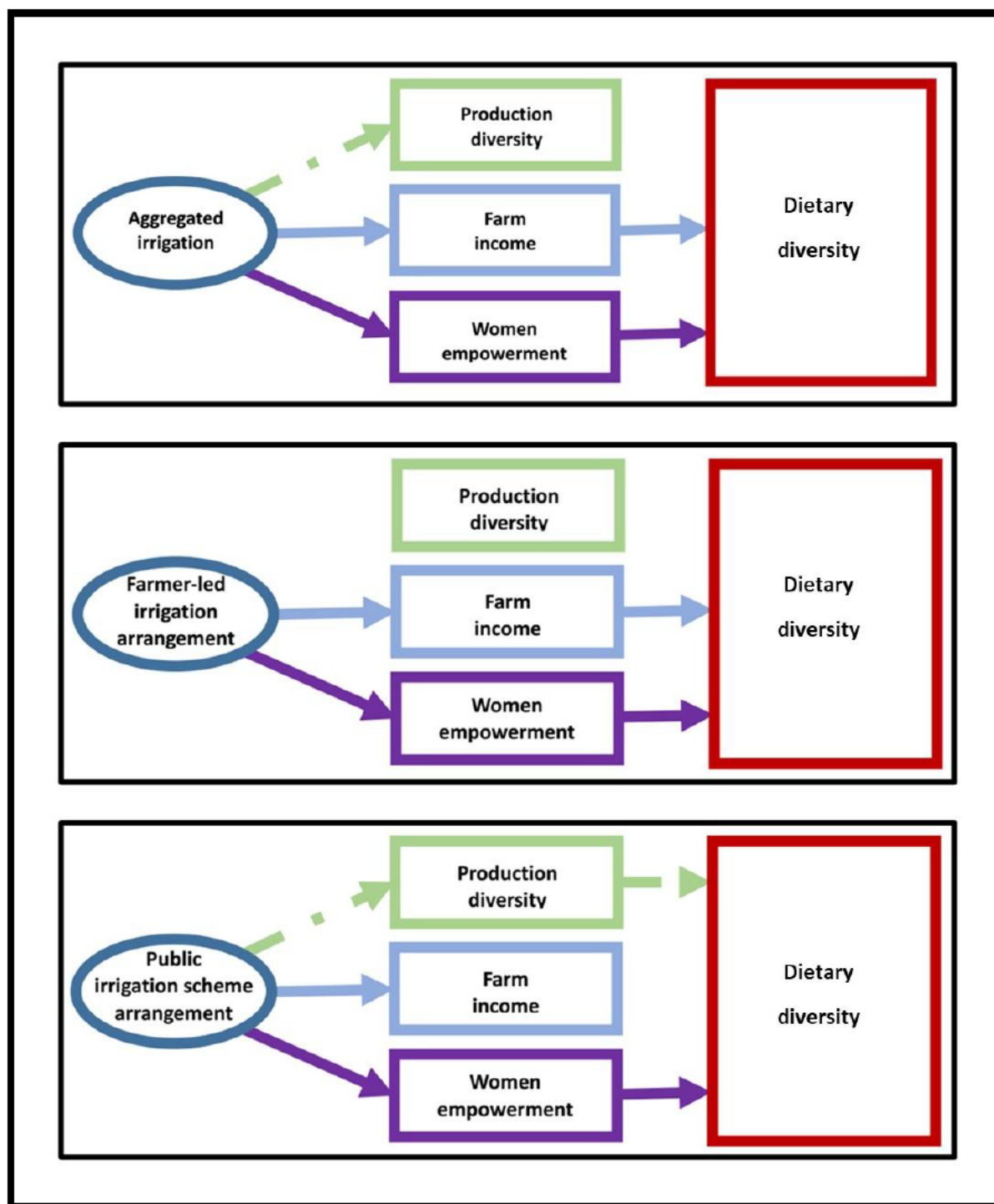


Figure 68: Dominant pathways under different disaggregated analyses

Source: Author based on survey data.

In the farmer-led irrigation arrangement analysis, production diversity was neither influenced by this irrigation arrangement nor influenced dietary diversity. In this irrigation arrangement, farm income and women's diversity were found to be plausible pathways for the households to higher dietary diversity. Therefore, this research bolsters the claim that the higher income gained from

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applying farmer-led irrigation is directed towards the consumption of nutritious food in the households. In addition, in the farmer-led irrigation arrangement, it is evident that such increase in incomes of such households is also spent on food which is supported by other evidences in research such as Banerjee & Duflo (2007) and Zezza et al., (2009). However, this research finding also contradicts the findings by Katic (2024) who found that farmer-led irrigation though having a positive effect on farmer incomes, it did not translate to better dietary diversity. However, it is important to note that unlike our research, Katic (2024) specifically looked at farmer-led groundwater-based irrigation and highlighted that the reason for this result included factors related to siltation soils, fertilizers, water-yields of wells and crop diversity.

Whereas the public irrigation scheme arrangement had a positive effect on farm income and women's empowerment at household level, only women's empowerment was a possible irrigation-nutrition impact pathway. On the other hand, households being in the in public irrigation scheme arrangement led to lower production diversity and this in turn affected their dietary diversity negatively. In this regard, the production diversity was not a plausible pathway through which households in public irrigation scheme arrangement can achieve a diversified diet. Contrariwise, the results it showed that the lack of a diversified production in this irrigation arrangement, reduces the diet diversification of the household.

Women's empowerment emerged as the dominant irrigation-nutrition impact pathway for both irrigation arrangements. The finding that women empowerment leads to better dietary diversity at household level is in line with the findings of Holland & Rammohan (2019) in Bangladesh, Bonis-Profumo et al. (2021) in Timor-Leste, Jemaneh & Shibeshi (2023) in Ethiopia, V. Pandey et al. (2021) in India and by Shang et al. (2025) that it increases dietary quality (an aspect captured in diet diversity as well), and use more of their expenditure on food in China. The finding also concurs with previous research done that associates aspects of women's empowerment to improved diets (C. L. Anderson et al., 2021; Baye et al., 2021; Connors et al., 2023; M. Kassie et al., 2020; Komakech et al., 2022; V. L. Pandey et al., 2016; Sinharoy et al., 2018; Sraboni & Quisumbing, 2018; Vermes, 2021)

The feasibility of the women's empowerment as an irrigation-nutrition pathway in both irrigation arrangements shows the importance of this pathway in relation to household nutrition. There are particular reasons that could point as to why women's empowerment seems to transverse through all the irrigation arrangements as a means to achieve higher household nutrition outcomes. One is that women are the key caregivers and meal preparers in Kenya (Bukachi et al., 2022; Fingleton-Smith, 2018; M. Kassie et al., 2020; Okelo et al., 2022; Reiheld, 2014) and therefore, their decisions will tend to influence the household nutrition. For instance, during the fieldwork there were instances where a chicken coop would be squeezed in between a cowshed as shown in Figure 69, and on asking the household head (male), the response was that it belonged to his wife. However, in probing the source of their eggs in the 24-hour dietary recall questions, the source was mostly from the women-kept chicken.



Figure 69: A chicken coop owned and managed by the primary female decision maker
Source: Author based on survey data.

Similarly, it was common to see women drawing water from canals (e.g. Figure 70) or when water was being pumped thus reducing their workload in terms of time (and energy) in fetching water for household use. Therefore, the time (and energy) saved can then be redirected into caregiving for the household including meal preparations, thus improving the households' nutrition outcomes.



Figure 70: Women drawing water for household use from the canal thus reducing their workload
Source: Author based on survey data.

Secondly, when in control of income and decisions on resource use and production, research has shown that women tend to spend a considerable amount of these resources on household welfare including food and healthcare and any other of their expenditures does not compromise on the household's nutrition needs (Bukachi et al., 2022; Njuki et al., 2019; Soh Wenda et al.,

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2024). For example, by the women intercropping a crop of sweet potatoes to a banana field (Figure 71), which not only provided a cover crop thus improving soil management but also provided food for the household and the sale of the surplus was an extra income to the household mostly under the control of the primary female household head and thus mostly directed more towards the household welfare.

Additionally, it was found that women were also commercializing traditional food crops such as arrow roots and sweet potatoes through irrigation (e.g. Figure 72) which increased the household's income and trickles down to better nutrition outcomes as evidenced by the results.

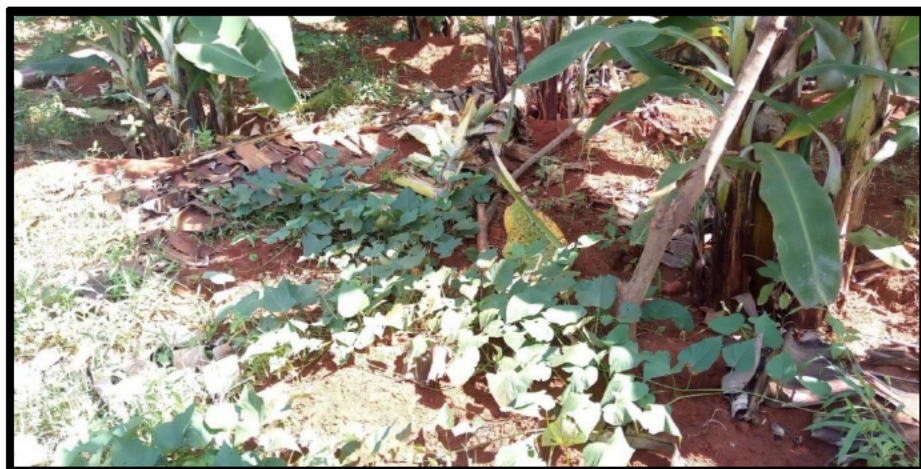


Figure 71: Sweet potatoes planted by the primary female decision maker in a farmer-led irrigation household's banana plot

Source: Author based on survey data.



Figure 72: A sweet potato harvest crop being packaged and prepared for the market by female agripreneurs

Source: Author based on survey data.

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Lastly, women's empowerment also enhances the welfare of the women themselves in an ability to make sure that their wellbeing is taken care of. In the case of being involved in community leadership especially of farmer groups (e.g. Figure 73) not only brings the much-needed expertise to the community but also enhances the woman's skills and ability to navigate leadership at the household level. In this way, the household's benefits directly and indirectly in relation to her resource use, care, time load and availability (Lépine & Strobl, 2013).



Figure 73: A farmer-led irrigation farmers' group leadership in which 5 out of the 6 leaders are female

Source: Author based on survey data.

It is imperative for one to take cognizance of the significance of these results in the context of the data collection period. The data collection was done at the height of the Covid-19 crisis period, with the reference period covering the 1st February 2020 to 28th February 2021 when its effects were being felt locally, regionally and globally. In this regard, this was a time when households were experiencing a pandemic shock which not only affected incomes but also led to food price hikes. It is therefore noteworthy that the irrigation arrangements led to increases in incomes and women's empowerment under such a predicament. Even more remarkable is that that the effect on the households' dietary diversity would be achieved during a time that the global, regional and national economies were experiencing a substantial pandemic shock that included drastic adjustments and restrictions such as limited movement and market activities, shows the robustness of the irrigation arrangements in improving household's nutrition outcomes.

9.2.6.1. Policy recommendations; Irrigation is not unilateral and its social-technical setup determines the irrigation-nutrition impact pathway(s)!

There is a need to take into consideration the household socioeconomic factors that lead to the choice of the specific irrigation arrangements when formulating appropriate policy actions. By doing this, future policies will be able to appropriately and correctly formulate specific interventions specifically designed for precise irrigation arrangements. Therefore, when irrigation is approached as a unitary practice, it becomes difficult to get specific policy initiatives

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that targets specific farmers in the different social-technical set-ups. An amalgamation of such policies is bound to create dissonance of initiatives instead of synergy.

Looking at the different dominant pathways across the irrigation arrangements, there arises a need for policy interventions to look into the possibility of enhancing production diversity as a feasible irrigation to nutrition pathway especially for households in the public irrigation scheme arrangement where a reduction in production diversity worsens the nutrition outcome. This may necessitate looking into these three potential pathways as complimentary in nature. Given that generally the public irrigation scheme arrangement also leads to an improvement in the dietary diversity of the household through the women's empowerment pathways, it may be that the positive effect of this pathway mitigates the effect of low production diversity and leads to a positive nutrition outcome. Policy interventions need to look at how these pathways could complement each other as the negative effect of the low production diversity is backtracking the gains in nutrition achieved through the women's empowerment pathway.

The finding that production diversity is not an irrigation-nutrition impact pathways (and especially a negative one for farm households in the public irrigation scheme arrangement points out to the possible negative gains in specialization at farm level. This can be attributed to the choice of market demand crops that are not common foods in the households e.g. baby corn and French beans (especially given the small land holdings). This may necessitate interventions that sensitize farmers (especially irrigating subsistence farm households) on the need to prioritize household food consumption over market-oriented production. This is particularly more important for farmers who grow only rice all-year round unlike former times when crops such as beans, vegetables and soya would be planted in-between the seasons. While two cropping seasons may be leading to the increase in farm income, the lack of this production diversity is negatively leading to lower dietary diversity at household level.

These last hypotheses cement the findings discussed earlier that increase in farm income may not translate to better nutrition outcomes at household level. This is particularly the case for farm households in the public irrigation scheme arrangement where the gains in income did not translate to better nutrition outcomes for the households. This further emphasizes the need to incorporate other interventions in the public irrigation scheme arrangement like nutritional education to redirect and influence spending of the increase in income on food expenditures. In this way, the households may be able to direct the gains in incomes to nutritional gains at household level. It also points to the need to ensure that irrigation initiatives targeting farm income ensure that the household-market linkages are inclined towards healthy food expenditures. This is particularly important since markets form an important link to household food and nutrition security in sub-Saharan Africa with most rural households being net consumers of food (Giller, 2020). Therefore, since market factors play an important role in the feasibility of farm income as an irrigation-nutrition pathway, ensuring that diversified nutritious foods are available for purchase becomes a key policy consideration for such interventions.

Another policy initiative that could promote nutrition outcomes would be to improve on the storage and processing facilities for rural farm households. The selling of farm produce

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immediately after harvest may be due to lack of facilities to store and process products especially perishable products such as nutrient-dense green leafy vegetables. Thus the income earned may be counterproductive as the farmers may end buying the same food later on at higher prices thus obtaining lower quantities, a phenomena common among poor rural farm households in sub-Saharan Africa (Burke et al., 2019; Leonardo et al., 2015; Stephens & Barrett, 2011). Therefore, there is a need to have a more holistic approach beyond irrigation enabling policy initiatives to infrastructural initiatives that improve storage facilities in rural areas.

The women's empowerment pathway emerged as a dominant irrigation-nutrition pathway for smallholder farm households. There is therefore a need for policy to redirect nutrition initiatives to include women's empowerment initiatives. This is especially in the domains of irrigation arrangements including how it makes women have the ability to make and be involved in agricultural production decisions, access and have decision-making power over productive resources, control income, be involved in leadership roles, have a healthier time allocation and lessen their workload.

Lastly, a key entry point for the Kenyan policy arena is the reviewing of the Irrigation Policy 2017 and the amendment of the Irrigation Act Cap. 347. As shown in this thesis, the current policy governing irrigation gives definitions that elbows-out and implies that irrigation development only occurs in scheme-like arrangements. This research shows that this is not the case in that farmer-led irrigation can drive impactful irrigation development. And while irrigation schemes provide a good condition for the development of farmer-led irrigation, by having a law that not only disregards this arrangement but that renders irrigation implemented outside the schemes or in the schemes by individual or farmer groups as an unrecognized irrigation development, the country hinders its development. There is thus need to revise the narrow framing of irrigation development in Kenya's irrigation policy and laws so that the country can both support and harness the opportunities arising from farmer-led irrigation development as an alternative form of expanded irrigation. Furthermore, recognizing the farmer-led irrigation arrangement in law will highlight the opportunities to other stakeholders thus fostering equity in the irrigation sector.

9.2.6.2. Areas of further research

As laid earlier on as a major claim to this study, there is a need to not have a unilateral view of irrigation but to consider the different socio-technical environment in which it takes place. All the way from the descriptive statistics, probit and multinomial logit regressions, propensity score matching results to the 3SLS regressions, a clear finding is that irrigation is not unilateral but rather segmented. The analyses do show that household factors affect irrigation and irrigation arrangements differently. Need to have disaggregated analyses at research level that take cognizance of the different irrigation arrangements are required. It also points out to the need of approaching irrigation as differentiated based on the different socio-technical set-up in which irrigation takes place. Additionally, though both farmer-led irrigation arrangement and public irrigation arrangement had a positive effect on the nutrition outcome, the pathways through which this occurs differ. This points out to the need for research to desist from viewing it as unilateral.

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This research also points out to the need for a gender-disaggregated approach when it comes to investigating household socioeconomic factors. In this regard, the results showed that the household socioeconomic factors that pertain to the primary female decision maker are integral in determining irrigation and irrigation arrangements. Factors such as education level, age, ability to make production decisions of the primary female decision maker were fundamental in determining irrigation arrangements. Unfortunately, research commonly centers on factors of the household heads of which in most patriarchal societies will be factors related to male members of the households. This has had an effect also on policy direction with most of the interventions centered on household heads e.g. farmer trainings or being generic in a gender-neutral manner or community nutrition training that doesn't focus at gendered roles and their specific effects on sociotechnical setups such as irrigation arrangements.

Even though women's empowerment is the dominant pathway through which both irrigation arrangements achieve their nutrition outcome, it is the least studied pathway especially quantitatively. Furthermore, when studied, it is often by the use of proxies such as female household heads and decision making and not in the totality of the aspects of women in agriculture as captured here in this research. There is therefore the need for comprehensive studies that incorporate all the aspects of empowerment of women in agriculture such as production aspects such as input in productive decisions, access and decisions on resources such as credit and assets, access and control over use of income, leadership including on community groups and allocation of and time as a measure of workload (H. Malapit et al., 2015; H. J. Malapit et al., 2017; H. J. L. Malapit et al., 2013). This will lead to more informed gender-sensitive policies that simultaneously addresses the women's empowerment requirements of the primary female decision makers in the households and tackle the pressing need to tackle nutrition insecurity in sub-Saharan Africa.

Finally and in a single breath, based on the analysis conducted, the household socioeconomic factors that were found to affect irrigation and the factors that affect each of the irrigation arrangements were not only different but also different in the direction of effect for the same regressors. It is recommended that policy should take cognizance of the household socioeconomic factors even as irrigation arrangements are promoted as a viable intervention for smallholder farmers to increase their farm incomes, women's empowerment as well as improve on the households' nutrition outcomes. Therefore, policies, programs and initiatives that encourage investments in irrigation and access to irrigation-related information and technologies should be a priority for the government and development agencies working in the country. Furthermore, there should be a focus on exploring other ways in which irrigating households achieve nutrition outcomes, such as through the markets, and further research should be conducted to investigate the differences in production, farm income, women's empowerment and nutrition outcomes between farmers in different irrigation arrangements rather than a unitary approach to irrigation. This research only acts as a frontrunner in this area of study and there is therefore a need for more research. Finally, there should be initiatives in place to promote initiatives that encourage mixed farming techniques (both crops and livestock) and other production diversity techniques, to ensure that irrigating smallholder farmers are able to take advantage of the water resources achieve higher farm variety.

A key policy entry point for this research is the push for the recognition of irrigation that is implemented outside the schemes or in the schemes by individual or farmer groups in Kenya's policy documents. Unfortunately, as indicated earlier in Table 2 in Chapter Two on the "Literature Review", none of the definitions in the current Irrigation Act Cap. 347 would fit in the definition of a farmer-led irrigation farmer. This elbows out farmer-led irrigation development thereby robbing both the country and the farmers the ability to make use of the opportunities arising from farmer-led irrigation development such as providing an alternative form of expanded irrigation. This also renders the farmer-led irrigation arrangement unrecognized in law, and thus continues to be ignored by the irrigation stakeholders thus fostering inequity in the sector especially given that most of these farmers would be smallholder farmers and mostly involving women who take advantage of the available unutilized or underutilized resources. This is among the most prominent Kenya's irrigation policy documents and one of the endeavors of this research. Therefore, a suggestion on the amendment of both the National Irrigation Policy 2017 and the Irrigation Act Cap. 347 is intended to be presented to the Ministry of Water, Sanitation and Irrigation once this thesis dissertation is successfully defended.

9.3. Limitation to the study

This research also recognizes some limitations especially when it comes to the evaluation of production diversity as an impact pathway. Farm households' dietary diversity changes throughout the year especially depending on agricultural seasons. More research using high frequency data is therefore needed to solve the problem of seasonality component of dietary diversity. Kenya has a poor storage infrastructure (De Groote et al., 2023; Gogo et al., 2017; Huss et al., 2021) which makes it impossible for farmers to even out supply across the seasons. Therefore, any production related nutrition benefits could not be taken into account due to seasonality fluctuations. Due to the storage limitations, the benefits of such crops in the households' diets are limited to the time within which they are produced since they are rarely stored beyond this period (apart from grains which are easier to store). Even if the multiple visits to households mitigated the effect of daily nutrition intakes, the data collection period limits the collection of seasonal variations. This is especially important since this study was focused on measurements that are inclined towards micronutrient measurements. As such, crops such as green leafy vegetables or seasonal fruits play a huge role in micronutrient supply but are difficult to store in the normal rural farm infrastructure in sub-Saharan Africa. Therefore, further studies that can overcome this limitation need to use more robust data collection methodologies such as a cross-seasonal diet diary.

On the data, it is particularly important to recognize that this research is based on cross-sectional data. Therefore, the causal relationships are estimations and not actual relationships based on longitudinal studies. In addition, this limits the generalizations of these results across spaces and may only reflect relationships in the local context or very similar contexts. This points out to the need for further longitudinal research on irrigation-nutrition pathways and their effect on smallholder farm households' nutrition outcomes.

SUMMARY

While great progress had been achieved under the Millennium Development Goals, owing to global crises such as the Covid-19 pandemic, climate change and ongoing wars, the global food and nutrition crisis is deteriorating and the number of undernourished people is bound to increase by the year 2030 which is a significant year in eradicating hunger and malnutrition under the Sustainable Development Goals. Conversely, despite its land and water resources, sub-Saharan Africa remains the region with the highest prevalence of undernourishment in the world in absolute terms. In this regard, irrigation has increasingly gained interest as a pivotal solution for the region due to its ability to increase agricultural output, galvanize production from weather and climatic risks and bring underutilized water-stressed lands into cultivation.

However, the debate about what kind of irrigation to implement in sub-Saharan Africa and its purposed effect has been a matter of discussion in the global and African policy arena given that irrigation has been in the past considered as a single input factor that disregards irrigation arrangements (i.e. socio-technical set-up in which irrigation takes place (referred herein as irrigation arrangements). Furthermore, the linkage between irrigation and nutrition is still vaguely understood and remain largely understudied. In this regard, postulating that production diversity, farm income and women empowerment as the three vital nutrition pathways, this study investigated the linkages between irrigation and nutrition in a manner that takes into account various socio-technical irrigation arrangements and their differential effects on dietary diversity.

Using complementary data collection techniques comprising of reconnaissance visits, key informant interviews, focus group discussions and a household survey, cross-sectional data was collected from smallholder farm households in farmer-led irrigation (FLI), public irrigation scheme (PIS) arrangements and non-irrigators in rural Kenya. To analyze the data, the study utilized descriptive statistics and econometric approaches comprising of probit model, multinomial logit regression (MNL), propensity score matching approach (PSM) and a three-stage least squares regression (3SLS).

The results from the descriptive statics, probit model and MNL showed that the household socioeconomic factors that affect irrigation and irrigation arrangements were not only different but also different in the direction of effect for the same regressors. The PSM analyses showed that the FLI and PIS arrangements have a positive effect on farm income and dietary diversity. Further analyses using the 3SLS showed that the FLI leads to a more diverse household diet through the farm income and women's empowerment pathways while the PIS households achieved it only through the women's empowerment pathway. On the contrary, PIS was found to reduce production diversity and lead to a decrease in dietary diversity through this pathway.

This study provided a strong basis to conclude that irrigation positively affects the irrigating households' farm income and nutrition outcomes at household level across both irrigation arrangements in the context of smallholder agriculture in the study area. In contrast, irrigation was found to negatively affect the production diversity for the farm households in the PIS as well as their dietary diversity while it was not significant for the FLI and neither influenced their dietary diversity. Conspicuously, the feasibility of the women's empowerment as an irrigation-nutrition pathway in both irrigation arrangements shows the importance of this pathway in improving the nutrition of irrigating households.

Therefore, policy should take cognizance of the irrigation arrangements when promoting irrigation as a viable intervention towards production diversity, farm income and women empowerment as well as a means of improving smallholder farm households' nutrition outcomes. Additionally, there is need to complementary intervene enabling factors that aide irrigating households achieve nutrition outcomes, such as through the markets for the farm income pathways and factors such as decision making, ownership of assets, credit access and decisions, control over use of income, leadership and workload for the women's empowerment pathways. As regards research and policy analysis, the differences in production, income, women's empowerment and nutrition outcomes between farmers in different irrigation arrangements needs to be investigated rather than a unitary approach to irrigation as well as a revision of the policy instruments in Kenya to recognize and support farmer-led irrigation arrangement.

KURZFASSUNG

Obwohl im Rahmen der Millenniums-Entwicklungsziele große Fortschritte erzielt wurden, verschärft sich aufgrund globaler Krisen wie der Covid-19-Pandemie, des Klimawandels und anhaltender Kriege die weltweite Nahrungsmittel- und Ernährungs Krise. Die Zahl der unterernährten Menschen wird bis zum Jahr 2030, einem für die Beseitigung von Hunger und Unterernährung im Rahmen der Ziele für nachhaltige Entwicklung bedeutenden Jahr, voraussichtlich weiter ansteigen. Dennoch bleibt Subsahara-Afrika trotz seiner Land- und Wasserressourcen die Region mit der weltweit höchsten Prävalenz von Unterernährung in absoluten Zahlen. Vor diesem Hintergrund hat die Bewässerung als zentrale Lösung für die Region zunehmend an Bedeutung gewonnen, da sie die landwirtschaftliche Produktion steigern, die Produktion vor Wetter- und Klimarisiken schützen und ungenutzte, wasserarme Flächen für den Anbau nutzbar machen kann.

Die Debatte darüber, welche Art der Bewässerung in Subsahara-Afrika umgesetzt werden soll und welche Auswirkungen dies haben wird, ist jedoch seit Langem Gegenstand von Diskussionen in der globalen und afrikanischen Politik. Dies liegt daran, dass Bewässerung in der Vergangenheit oft als ein einziger Input-Faktor betrachtet wurde, der die Bewässerungsvorkehrungen (d. h. die soziotechnischen Rahmenbedingungen, unter denen Bewässerung stattfindet – im Folgenden als „Bewässerungsvorkehrungen“ bezeichnet) außer Acht lässt. Darüber hinaus ist der Zusammenhang zwischen Bewässerung und Ernährung noch immer nur vage verstanden und weitgehend unerforscht. In diesem Zusammenhang untersuchte diese Studie die Zusammenhänge zwischen Bewässerung und Ernährung. Dabei berücksichtigte sie verschiedene soziotechnische Bewässerungsvorkehrungen und deren unterschiedliche Auswirkungen auf die Ernährungsvielfalt, unter der Annahme, dass Produktionsvielfalt, landwirtschaftliches Einkommen und die Stärkung der Rolle der Frau die drei wesentlichen Einflussfaktoren für die Ernährung sind.

Mithilfe ergänzender Datenerhebungsmethoden – darunter Erkundungsbesuche, Interviews mit wichtigen Informanten, Fokusgruppendifkussionen und eine Haushaltsbefragung – wurden Querschnittsdaten von Kleinbauernhaushalten in landwirtschaftlichen Bewässerungssystemen (FLI), öffentlichen Bewässerungssystemen (PIS) und Nichtbewässern im ländlichen Kenia erhoben. Zur Analyse der Daten wurden deskriptive Statistiken und ökonometrische Ansätze verwendet, darunter das Probit-Modell, die multinomiale Logit-Regression (MNL), der Propensity-Score-Matching-Ansatz (PSM) und eine dreistufige Regression der kleinsten Quadrate (3SLS).

Die Ergebnisse der deskriptiven Statistik, des Probit-Modells und der MNL-Analyse zeigten, dass die sozioökonomischen Faktoren der Haushalte, die die Wahl der Bewässerung und der Bewässerungsmethoden beeinflussen, nicht nur variierten, sondern sich auch hinsichtlich ihrer Wirkungsrichtung für dieselben Prädiktoren unterschieden. Die PSM-Analysen zeigten, dass die FLI- und PIS-Maßnahmen einen positiven Einfluss auf das landwirtschaftliche Einkommen und die Ernährungsvielfalt haben. Weitere Analysen unter Verwendung von 3SLS zeigten, dass der FLI über das landwirtschaftliche Einkommen und die Stärkung der Rolle der Frauen zu einer vielfältigeren Ernährung der Haushalte führt. PIS-Haushalte erreichten dies jedoch nur durch die Stärkung der Rolle der Frauen. Im Gegensatz dazu wurde festgestellt, dass PIS die Produktionsvielfalt verringert und über diesen Mechanismus zu einer Verringerung der Ernährungsvielfalt führt.

Diese Studie lieferte eine solide Grundlage für die Schlussfolgerung, dass sich die Bewässerung positiv auf das landwirtschaftliche Einkommen und die Ernährungssituation der bewässerten Haushalte auf Haushaltsebene in beiden Bewässerungssystemen im Kontext der kleinbäuerlichen Landwirtschaft im Untersuchungsgebiet auswirkt. Im Gegensatz dazu wurde festgestellt, dass sich die Bewässerung negativ auf die Produktionsvielfalt der landwirtschaftlichen Haushalte im PIS sowie auf deren Ernährungsvielfalt auswirkt, während dieser Effekt für das FLI nicht signifikant war. Auffällig ist, dass die Stärkung der Rolle der Frau als erfolgreicher Weg zur Verbesserung der Ernährung in beiden Bewässerungssystemen die zentrale Bedeutung dieses Pfades für die bewässernden Haushalte unterstreicht.

Daher sollte die Politik die Bewässerungsvorkehrungen berücksichtigen, wenn sie die Bewässerung als eine praktikable Maßnahme zur Diversifizierung der Produktion, zur Steigerung des landwirtschaftlichen Einkommens und zur Stärkung der Rolle der Frau sowie als Mittel zur Verbesserung der Ernährungssituation kleiner landwirtschaftlicher Haushalte fördert. Darüber hinaus besteht Bedarf an ergänzenden Maßnahmen, die Faktoren fördern, welche bewässerten Haushalten zu besseren Ernährungsergebnissen verhelfen – beispielsweise durch Märkte für landwirtschaftliche Einkommensquellen sowie durch die Förderung von Entscheidungsfindung, Eigentum an Vermögenswerten, Zugang zu Krediten, Kontrolle über die Verwendung von Einkommen, Führungsqualitäten und die Reduzierung der Arbeitsbelastung zur Stärkung der Rolle der Frau. Was die Forschung und Politikanalyse betrifft, so müssen die Unterschiede in Bezug auf Produktion, Einkommen, Stärkung der Rolle der Frau und Ernährung zwischen Landwirten in verschiedenen Bewässerungssystemen untersucht werden, anstatt einen einheitlichen Ansatz für die Bewässerung zu verfolgen. Außerdem müssen die politischen Instrumente in Kenia überarbeitet werden, um von Landwirten geführte Bewässerungssysteme anzuerkennen und zu unterstützen.

EXECUTIVE SUMMARY

Less than a decade to the year 2030 which is a significant year in eradicating hunger and malnutrition under the Sustainable Development Goals (SDGs), the global food and nutrition crisis is deteriorating (FAO et al., 2023; United Nations, 2015b). This is partly attributed to the effect of the Covid-19 pandemic as well as the global conflicts particularly the Ukraine war (FAO et al., 2023; Kornher & von Braun, 2023; F. Lin et al., 2023; Rahut et al., 2022). In addition, the global food and nutrition security is under threat from the ever increasing extreme weather and climate events and a looming reduction in agricultural production due to global warming (IPCC, 2023; W. Liu et al., 2023; D. Wang et al., 2023; Zhu et al., 2022).

Under these arrays of challenges facing the global populace, increasing production is a non-negotiable policy intervention. Irrigation has increasingly gained interest as a pivotal solution in increasing the world's agricultural output. This is due to irrigation's potential to increase agricultural output (De Wrachien et al., 2021; Mueller et al., 2012; Sauer et al., 2010; X. Wang et al., 2021; Wichelns & Oster, 2006), galvanize agricultural production from weather and climatic risks (Agathokleous et al., 2023; BenYishay et al., 2023; Rosa, Chiarelli, Sangiorgio, et al., 2020; L. Wang et al., 2022) and bring underutilized water-stressed lands into cultivation (Altchenko & Villholth, 2015; Shahid & Al-Shankiti, 2013; L. Wang et al., 2022).

However, even as the world's aims at increasing agricultural output, it is imperative that nutrition aspects take the center stage. Despite the increase in caloric supply in all the regions of the world for the last six decades, the global nutrition situation has continued to deteriorate. This neglect of nutrition aspects has led to a situation of manifold malnutrition comprising a goal to decrease stunting, wasting and micronutrient deficiency, under an increasing overweight and obesity, represent the current challenge to address (FAO et al., 2023; Haddad et al., 2016; Sukhdev et al., 2016).

Kenya as one of the economic powerhouses in the sub-Saharan region, faces a myriad of malnutrition challenges also. Latest data shows that over a quarter of her population is undernourished. However, this number varies greatly in the country with some arid areas experiencing a prevalence of moderate or severe food insecurity level of up to 70% (FAO et al., 2023). The prevalence of wasting and stunting in children under five years in 2022 was approximately 4.9% and 18.4% respectively and 28.7% of the women of reproductive age had anemia in 2019 (FAO, 2023, 2023; World Bank, 2023a). On the other hand, over-nutrition has been on the increase in the last decade. In 2022, the prevalence of overweight in children under five years was at 3.8% and the 2016 data showed that the prevalence of obesity in the adult population at 28.7% (FAO et al., 2023). This makes nutrition a key policy priority for the government of Kenya.

However, Kenya faces an immense agricultural production limitation in that only about 17% of its land area is suitable for rain-fed agriculture (Hornum & Bolwig, 2020; Njoka et al., 2016) with much of it already under production. In addition, climate change related effects (Gebre et al., 2023; Marigi, 2017) have made drought cycles more common of which culminated in one of the most severe drought in the last 40 years due to five consecutive failed rainy seasons in the 2022/2023 period (Devi, 2023; Leal Filho et al., 2023; Salm-Reifferscheidt, 2023). Irrigation thus is an essential technology for the country's food production and nutrition security. In this line,

the country's development blueprint, Kenya Vision 2030, designates the expansion of irrigation as a pivotal component in augmenting agricultural production and fortifying it against climatic shocks. Luckily, the country has a huge irrigation potential with only 19% of surface water and drainage irrigation developed (National Irrigation Authority, 2019).

The debate about what kind of irrigation has been a matter of debate in the global and African policy arena (Lankford, 2009; Woodhouse et al., 2017). This is also has been as a result of a dismal performance of irrigation investments in the 1970s and 1980s (Woodhouse et al., 2017). This has arisen the consideration of the different approaches to irrigation.

The different types of irrigations that arise due to these sociotechnical differences have been greatly overlooked in literature despite its evidence in affecting water management and related policies (Naz & Subramanian, 2010). The different sociotechnical settings of access and use of irrigation water is referred to as irrigation arrangements in this study. Given that a household's social relations are affected by the household socioeconomic factors, these socioeconomic factors were used to find out their contributions to these irrigation arrangements. Therefore, this study takes a viewpoint that the different socio-technical setup in which irrigation takes place affects both the nutrition pathways as well as the nutrition outcomes.

Unfortunately, while irrigation has for long been held as a critical factor to agricultural production, the linkage between irrigation and nutrition is still vaguely understood (Ringler et al., 2018). One of the reason is attributed to a global focus of agricultural intensification on grain production due to supply leaning value chain focus thus persistently overlooking nutrition aspects (Fan & Pandya-Lorch, 2012, p. 2; Hawkes & Ruel, 2012, pp. 75–76). This has led to a delink between agriculture and nutrition (Gillespie & van den Bold, 2017). This is the case in Kenya where a majority of irrigation developments are skewed towards the production of calorie-rich grains like rice and high-value horticultural crops, predominantly for export with only a small fraction allocated to vegetable production for local markets (Hornum & Bolwig, 2020; B. M. Mati, 2008). Consequently, irrigation has minimal to no impact on the country's nutrition security. Therefore, as the country endeavors to expand its irrigated agriculture, there is a pressing need to focus on how it can lead to improved nutrition outcomes (Muthayya et al., 2013; Ruel et al., 2018).

However, empirical evidence on the link between agriculture and nutrition remains scarce and when it is available it remains weak (Ruel et al., 2018; Webb & Kennedy, 2014). Similarly, the pathways through which irrigation impacts on nutrition outcomes are understudied, with only few rigorous studies available (Domènech, 2015; Hanjra & Williams, 2020). This underscores the need for a comprehensive investigation on the linkages between irrigation and nutrition in a manner that takes into account various socio-technical irrigation arrangements and their differential effects on nutrition outcomes.

This dissertation contributed to the bridging of this gap in knowledge by systematically investigating the complex pathways through which different irrigation arrangements influence the nutrition outcomes of smallholder farm households in rural Kenya. To do this, it was hypothesized that the different household socioeconomic factors affect the choice of irrigation arrangements. Sequentially, the households achieve their nutrition outcomes through different impact pathways and the socioeconomic factors affect these impact pathways differently. Lastly,

the different irrigation arrangements lead to a difference in the smallholder farm household's nutrition. To achieve this, three irrigation-nutrition pathways of production diversity, farm income, and women's empowerment are examined as potential intermediate outcomes of the different irrigation arrangements. After ascertaining the effect of irrigation arrangements on these outcomes, further analyses are carried out to investigate the effects of these outcomes under different irrigation arrangements on dietary diversity, which is used as a proxy for nutrition. In so doing, this study provides evidence-based insights that can inform policy and practice for enhancing both agricultural productivity and nutrition well-being in Kenya.

In this study, irrigation is taken as a form of agricultural production at the household level and seeks to show its linkages to nutrition outcomes. In doing so, the conceptual framework linking agriculture to nutrition was therefore taken as appropriate in that it gives the basis under which to ground the research. The conceptual framework developed by (Herforth & Harris, 2014a) is used in linking agriculture to nutrition outcomes. To do this the methodology by (Passarelli et al., 2018) was adapted where irrigation is a production innovation for the smallholder households to achieve their nutrition outcomes through the food production, agricultural income, and women's empowerment pathways as suggested by (Domenèch & Ringler, 2013). By taking irrigation as an agricultural innovation component, the distinguishing of irrigating and non-irrigating households and the different irrigation arrangements is thus made possible.

In this study, it is claimed that the socioeconomic factors in the farm households determines whether a farm household irrigates or not. Furthermore, these factors also influence the choice of the irrigation arrangement that the farm household will engage in, be it a farmer-led irrigation arrangement or a public irrigation scheme arrangement. It is then hypothesized that the different households in diverse irrigation arrangements have different pathways for which they achieve their nutrition outcome while taking into account the socioeconomic variances.

This research was done in the Mwea Irrigation Scheme which is Kenya's oldest public irrigation scheme. Due to the availability of the water primarily for the irrigation scheme, the area has also developed as an agricultural region with farmer-led irrigation being common in the area (Momanyi et al., 2019; Tomizuka et al., 2019). This existence of different irrigation arrangements (public and farmer-led), made the area ideal for the study.

Following the work by Cochran (2007) and Israel (1992) three critical factors were considered in calculating the sample size of this study; level of precision, confidence level and degree of variability. Therefore, with the three key criteria deemed important for the research, the study adopted the sampling formula by Cochran (1963) to get the appropriate sample size for the study. This then gave a total sample size of 384 smallholder farm households.

While the study does use many socioeconomic, institutional and farm characteristic variables, there are five main variable that are fundamental. These are dietary diversity, income, production diversity, abbreviated women's empowerment in agriculture index and irrigation.

Consisting of ten food groups, the Minimum Dietary Diversity for Women (MDD-W) is a stricter measure of dietary diversity designed to capture the micronutrient adequacy of women of productive age which is one main aspect of diet quality. The MDD-W targets women of reproductive age are targeted due to their requirement for more nutritious foods due to the

biological and physical susceptibility related to factors such as breastfeeding and pregnancy (Black et al., 2013; Torheim & Arimond, 2013). With the merits of the MDD-W indicator, it was deemed to be a better fit for the food-grouping a proxy for nutrition in this study as compared to the other dietary diversity classifications. However, this study opted to use the continuous measure of the score as opposed to the dichotomous measure (yes or no) of whether a woman of productive age (15 to 49 years) has taken at least five of the ten food groups. In this regard, we refer to this measure as simply dietary diversity so as to distinguish it from the dichotomous measure in the MDD-W.

By taking the farm-household-level perspective, both farm and non-farm income were considered. In calculating the farm income, farm sales comprising of crop sales, sale of livestock and livestock products was calculated from the farmers' responses. Production diversity is measured as the variety of crops, livestock and livestock products on the farm in the period of reference (12 months). To make the production index more robust and plausible, the study overcame the double counting a specie twice (e.g. cow and milk production) by using the same groupings as MDD-W given in the earlier section as well as only including products produced in the period (i.e. the ownership of a cow does not equal milk production unless there was milk production recorded in the reference period).

Adapted from the work by Dimitrievski et al., (2019), women's empowerment in this study means increasing the personal, political, social or economic strength of women. In this study, the Abbreviated Women's Empowerment in Agriculture Index (A-WEAI) is used as it fits the domain of the study (women in agriculture) and due to its ability to capture the different aspects of empowerment. The A-WEAI is a standardized measure of women's empowerment in five domains: agricultural production decisions; access to, and decision-making power over, productive resources; control over use of income; leadership roles within the community; and time allocation (H. J. Malapit et al., 2017). The first three domains on production, resources and income are related to economic empowerment, while leadership and time allocation relay to decision making and representation and equitable workload balance.

This research uses an econometric analysis that can be broken down into four econometric processes that follow the logical flow of this study's objectives. In the first analysis, a binary approach is used to look at the factors that affect irrigation arrangement. For this analysis, a probit regression was used. However, given that the study's main claim is that irrigation is disaggregated, a second analysis based on a multinomial logit regression is applied. The multinomial analysis allows for the simultaneous analysis of the irrigation arrangements while using the non-irrigators as the base outcome.

The study then embarks on looking at whether irrigation and irrigation arrangements have an effect on the production diversity, farm income, women's empowerment and the envisaged nutrition outcome (captured through dietary diversity). This is particularly important as it given the ability to quantify these effects thus providing key empirical evidence in research and policy. In order to achieve this, a propensity score matching approach is applied as the third analysis.

In the last analysis, the study applied a three stage least squares analysis to investigate the irrigation-nutrition impact pathways for irrigation and irrigation arrangements. In following this flow of econometric analysis, the study sought to answer overall the questions that may arise on

the why irrigation analysis should be approached as disaggregated based on the factors affecting them, the overall impact they have on the irrigation nutrition pathways, and the difference in the impact pathways.

In the probit and multinomial logit regressions, the analyses showed how household factors affect both irrigation and irrigation arrangements. The factors that were found to affect irrigation and the factors that affect each of the irrigation arrangements were not only different but also different in the direction of effect for the same regressors.

The education level of the household head influenced households away from the public irrigation scheme arrangement. The knowledge of pumping technology was a positive influencer of households irrigating and being in the farmer-led irrigation arrangement. The access of land beyond what a household owns influences households towards irrigation and both irrigation arrangements as reflected in the land rental price.

The factors that pertain to the primary female decision maker have also proven to be integral in determining irrigation and irrigation arrangements. The education level of the primary female decision maker is a key determinant of irrigation and public irrigation scheme arrangement. The age of the primary female decision maker was also a significant determinant in influencing households from not being involved in irrigation and the public irrigation scheme arrangement. On the other hand, the primary female decision maker ability to make production decisions influenced the public irrigation scheme arrangement negatively. There is therefore need to look into mechanisms that pertains to the households' primary female decision makers.

Inputs access also plays a key role in a household's decision to adoption of irrigation technology. However, access to fertilizer and hybrid seeds was only significant in influencing households towards irrigation and insignificant for the two irrigation arrangements. This points out to the importance of approaching irrigation as a disaggregated undertaking since same household factors have different implications depending on the irrigation arrangements.

Therefore, the analyses do show that the household factors affect irrigation and irrigation arrangements differently. It also points out to the need of approaching irrigation as differentiated based on the different socio-technical set-up in which irrigation takes place. As can be seen when irrigation is approached as a unitary practice, it becomes difficult to get specific policy initiatives that targets specific farmers in the different social-technical set-ups. The amalgamation of such policy is bound to create dissonance of initiatives instead of synergy in irrigation.

For the propensity score matching analyses, to make policy relevant recommendations, it centered on the average treatment effect of not only the irrigating farmers but also the specific irrigation arrangements. This was in line with the hypothesis that apart from production diversity, farm income and women's empowerment being potential pathways to achieving nutrition outcomes at household level, irrigation and the different irrigation arrangements affect them differently. The analysis done on the effect of irrigation and irrigation arrangement show a clear effect of irrigation and irrigation arrangements on production diversity, farm income and dietary diversity. In addition, tests for robustness were also done to establish the credibility of the results.

These results in addition to the robustness matching methods conducted, provide a strong basis to conclude that irrigation does positively affect the irrigating households' farm income and nutrition outcomes at household level in the context of smallholder agriculture in Kenya. The positive effect on the farm income and dietary diversity is evident across all the irrigation arrangement. This points out to irrigation being a viable intervention for smallholder farmers to increase their farm incomes as well as improve on the households' nutrition outcomes.

Contrariwise, irrigation does negatively affect the production diversity of irrigating farm households and also for the farm households in the public irrigation scheme arrangement. This can be attributed to the ability of the irrigating farm households specializing on crops whose market value is commensurate to the irrigation investment. This also was attributed to the mixed cropping techniques applied by the non-irrigating farmers in a bid to take advantage of the rainy season thus achieving seasonal higher crop variety. However, this also calls for a need for more research in looking into other ways into which the irrigating farm households achieved nutrition outcomes such as through the markets (especially given the higher farm income).

While the findings on the effect of irrigation on women's empowerment, showed that there was no significant effect, the difference in the women's empowerment between the farmer-led irrigation arrangement and public irrigation scheme arrangement farmers called for further investigations and analyses. This especially would ideally be done by comparing these two irrigation arrangements and with a sufficiently large sample that would give more precise results at the disaggregated irrigation level. As such, it is also noteworthy that while the women's empowerment was not found to be significantly affected by irrigation and irrigation arrangements, this does not negate the possibility of it being an impact pathway for nutrition.

The 3SLS regression results clearly shows that different irrigation arrangements achieve nutrition outcomes through different pathways and the factors that affects them are different. While in the aggregated results it shows that the three pathways of production diversity, farm income and women's empowerment were affected by irrigation, the disaggregated analysis shows that the pathways differ.

In the farmer-led irrigation arrangement analysis, production diversity neither influenced by this irrigation arrangement nor influence dietary diversity. In this irrigation arrangement, only farm income and women's diversity are plausible pathways for the households to higher dietary diversity.

On the other hand, while the public irrigation scheme arrangement has the possibility to improve farm income women's empowerment at household level, however only women's empowerment is a possible pathway for the households in this arrangement to achieve better nutrition outcomes. On the other hand, households in public irrigation scheme arrangement led to lower production diversity and this in turn affected their dietary diversity negatively. In this regard, the production diversity is still a viable pathway through which households in public irrigation scheme arrangement can influence their dietary diversity. As such, there is potential for households in public irrigation scheme arrangement can achieve higher nutrition outcomes through production diversity and women's empowerment if the production diversity is improved.

Though the finding that public irrigation scheme arrangement leads to a reduction in production diversity and in turn a reduction in nutrition outcome was not as previously hypothesized, the results show a potential policy intervention area. In addition, it is important to look at these pathways as complimentary in nature and not as isolated. In this case, research also shows that women's empowerment has the capability to alleviate the negative nutrition effects that may accrue from low production diversity (H. J. Malapit et al., 2015). Therefore, this may be the case here for the public irrigation scheme arrangement analysis. The positive effect of women's empowerment mitigates the effect of low production diversity and leads to a positive nutrition outcome through the women's empowerment pathway. It would be beneficial then to look at how these pathways could complement each other.

The significance of these results is particularly significant when taking consideration of the timing of the data collection period. The data collection was during the Covid-19 crisis period with the data collection spanning from 1st February 2020 to 28th February 2021. This was a time when households were experiencing a pandemic shock which included income shocks but also food price hikes (Kansiime et al., 2021; Nechifor et al., 2021; Shupler et al., 2021). It is therefore remarkable that irrigation would lead to increases in incomes and women's empowerment under such a predicament. Even notable that the effect of increase in farm income during a time that the economy was experiencing a shock, shows the robustness of increasing incomes on the household's nutrition outcomes.

All the way from the descriptive statistics, probit and multinomial logit regressions, propensity score matching results to the 3SLS regressions, a clear finding is that irrigation is not unilateral. This points out to the need for both research arenas and policy fora to desist from viewing it as such. A need to have disaggregated analyses at research level that takes cognizance of the different irrigation arrangements is needed. When irrigation is approached as a unitary practice, it becomes difficult to get specific policy initiatives that targets specific farmers in the different social-technical set-ups. The amalgamation of such policy is bound to create dissonance of initiatives instead of synergy in irrigation.

The research also points out to the need for a gender disaggregated approach when it comes to investigating household socioeconomic factors. In this regard, the results showed the household socioeconomic factors that pertain to the primary female decision maker are integral in determining irrigation and irrigation arrangements.

This research established that irrigation despite of irrigation arrangements have a positive effect on farm incomes. This is particularly important for rural poverty alleviation policy interventions. The distinguishing of farm income particularly in this research shows that policy interventions that foster irrigation at farm level can be practicable and effective. With most of Kenya as well as sub-Saharan Africa farm folding being under two hectares, irrigation would be a tool to lift the rural populations above the poverty levels.

However, this increase in farm income may not translate to better nutrition outcomes at household level. This is particularly the case for farm households in the public irrigation scheme arrangement. The gains in income do not lead to better nutrition outcomes for these households. This thus points out to the need for nutrition education when it comes to spending income on food expenditures. In this way, the households may be able to direct the gains in incomes to

nutrition gains at household level. It also points to the need to ensure that the household-market linkages are inclined towards healthy food expenditures. This is particularly important since markets form an important link to household food and nutrition security in sub-Saharan Africa with most rural households being net consumers of food.

On the other hand, production diversity reduces due to irrigation and especially for farm households in the public irrigation scheme arrangement and it is insignificant in the farmer-led irrigation arrangement households. This may point out to the gains in specialization at farm level leading to negative effects on the household's nutrition outcomes. This can be attributed to the choice of market demand crops that are not common foods in the households e.g. baby corn and French beans given the small land holdings. This may necessitate interventions that sensitize farmers on the need to prioritize household food consumption over market supply. However, despite the negative effect for households in public irrigation scheme arrangement, it also shows a potential to positively impact on nutrition outcomes if farm production is more diversified.

The women's empowerment pathway emerged as a dominant irrigation-nutrition pathway for smallholder farm households. Unfortunately, among the three pathways from irrigation to nutrition in this study, it is the least studied aspect especially quantitatively. When studied, it is often by the use of proxies such as female household heads and decision making and not in the totality of the aspects of women in agriculture as captured here in this research. There is therefore a need for policy to redirect nutrition initiatives to include women's empowerment initiatives. This is especially in the domains of agricultural production decisions, access to, and decision-making power over productive resources, control over use of income, leadership roles and time allocation.

In a single breath, based on the analysis conducted, it is recommended to promote irrigation as a viable intervention for smallholder farmers to increase their farm incomes as well as improve on the households' nutrition outcomes. Therefore, policies, programs and initiatives that encourage investments in irrigation and access to irrigation-related information and technologies should be a priority for the government and development agencies working in the country. Furthermore, there should be a focus on exploring other ways in which irrigating households achieve nutrition outcomes, such as through the markets, and further research should be conducted to investigate the differences in production, income, women's empowerment and nutrition outcomes between farmers in different irrigation arrangements rather than a unitary approach to irrigation. Finally, there should be initiatives in place to promote initiatives that encourage mixed farming techniques (both crops and livestock) and other production diversity techniques, to ensure that irrigating smallholder farmers are able to take advantage of the water resources achieve higher farm variety as well as a revision of the policy instruments in Kenya to recognize and support farmer-led irrigation arrangement.

ZUSAMMENFASSUNG

Bis zum Jahr 2030, einem für die Beseitigung von Hunger und Mangelernährung im Rahmen der Ziele für nachhaltige Entwicklung (ZNU) bedeutenden Datum, verschärft sich die weltweite Nahrungs- und Ernährungskrise (FAO, IFAD, UNICEF, WFP, WHO, 2023; Vereinte Nationen, 2015). Dies ist partiell auf die Folgewirkungen der Covid-19-Pandemie sowie auf globale Konflikte, insbesondere den Ukraine-Krieg, zurückzuführen (FAO, IFAD, UNICEF, WFP, WHO, 2023; Kornher & von Braun, 2023; F. Lin et al., 2023; Rahut et al., 2022). Zusätzlich wird die globale Nahrungs- und Ernährungssicherheit durch zunehmende extreme Wetter- und Klimaereignisse sowie eine drohende Reduzierung der landwirtschaftlichen Produktion infolge der globalen Erwärmung gefährdet (IPCC, 2023; W. Liu et al., 2023; D. Wang et al., 2023; Zhu et al., 2022).

Angesichts dieser Herausforderungen für die Weltbevölkerung ist eine Steigerung der landwirtschaftlichen Produktion eine nicht verhandelbare politische Intervention. Die Bewässerung gewinnt zunehmend als entscheidende Lösung zur Steigerung der weltweiten landwirtschaftlichen Produktion an Interesse. Dies basiert auf ihrem Potenzial, die Produktion zu erhöhen (De Wrachien et al., 2021; Mueller et al., 2012; X. Wang et al., 2021), die Landwirtschaft vor Wetter- und Klimarisiken zu schützen (Agathokleous et al., 2023; BenYishay et al., 2023; L. Wang et al., 2022) und ungenutzte, wasserarme Flächen in den Anbau einzubeziehen (Altchenko & Villholth, 2015; Shahid & Al-Shankiti, 2013).

Dennoch ist es zwingend erforderlich, dass inmitten der Bemühungen zur Produktionssteigerung ernährungsphysiologische Aspekte im Mittelpunkt stehen. Trotz der Zunahme der Kalorienzufuhr weltweit in den letzten sechs Jahrzehnten hat sich die globale Ernährungssituation weiter verschlechtert. Die Vernachlässigung ernährungsphysiologischer Belange hat zu einer Vielzahl von Mangelernährungsformen geführt, darunter Wachstumsverzögerung, Auszehrung und Mikronährstoffmangel, bei gleichzeitiger Zunahme von Übergewicht und Adipositas, was die aktuelle Herausforderung darstellt (FAO, IFAD, UNICEF, WFP, WHO, 2023; Haddad et al., 2016; Sukhdev et al., 2016).

Kenia, als eines der wirtschaftlichen Zugpferde Subsahara-Afrikas, steht ebenfalls vor zahlreichen Mangelernährungsherausforderungen. Neueste Daten belegen, dass über ein Viertel der Bevölkerung unterernährt ist. Diese Zahl variiert jedoch erheblich innerhalb des Landes, wobei einige aride Gebiete eine Prävalenz von mäßiger oder schwerer Ernährungsunsicherheit von bis zu 70 % aufweisen (FAO, IFAD, UNICEF, WFP, WHO, 2023). Die Prävalenz von Auszehrung und Wachstumsstörungen bei Kindern unter fünf Jahren betrug 2022 etwa 4,9 % bzw. 18,4 %, und 28,7 % der Frauen im gebärfähigen Alter litten 2019 an Anämie (FAO, 2023; Weltbank, 2023a). Gleichzeitig hat die Überernährung in den letzten zehn Jahren zugenommen: 2022 betrug die Prävalenz von Übergewicht bei Kindern unter fünf Jahren 3,8 %, und die Daten von 2016 zeigten, dass die Prävalenz von Fettleibigkeit in der erwachsenen Bevölkerung bei 28,7 % lag (FAO, IFAD, UNICEF, WFP, WHO, 2023). Dies macht die Ernährung zu einer wichtigen politischen Priorität für die Regierung Kenias.

Kenia sieht sich allerdings mit erheblichen landwirtschaftlichen Produktionsbeschränkungen konfrontiert, da nur etwa 17 % seiner Landfläche für Regenfeldbau geeignet ist (Hornum & Bolwig, 2020; Njoka et al., 2016), wobei ein Großteil dieser Fläche bereits bewirtschaftet wird. Darüber hinaus haben die Auswirkungen des Klimawandels (Gebre et al., 2023; Marigi, 2017)

Dürrezyklen häufiger gemacht, was in einer der schwersten Dürren der letzten 40 Jahre gipfelte, bedingt durch fünf aufeinanderfolgende erfolglose Regenzeiten im Zeitraum 2022/2023 (Devi, 2023; Leal Filho et al., 2023; Salm-Reifferscheidt, 2023). Bewässerung ist daher eine wesentliche Technologie für die Nahrungsmittelproduktion und Ernährungssicherheit des Landes. In diesem Sinne sieht der Entwicklungsplan des Landes, Kenia Vision 2030, die Ausweitung der Bewässerung als entscheidenden Bestandteil zur Steigerung der landwirtschaftlichen Produktion und zur Stärkung gegen klimatische Schocks vor. Glücklicherweise verfügt das Land über ein enormes Bewässerungspotenzial, wobei nur 19 % der Oberflächenwasser- und Drainagebewässerung erschlossen sind (National Irrigation Authority, 2019).

Die Debatte darüber, welche Art von Bewässerung in der globalen und afrikanischen politischen Arena angemessen ist (Lankford, 2009; Woodhouse et al., 2017), resultiert auch aus der dürftigen Leistung von Bewässerungsinvestitionen in den 1970er und 1980er Jahren (Woodhouse et al., 2017). Dies hat zu Überlegungen bezüglich unterschiedlicher Ansätze in der Bewässerung geführt.

Die verschiedenen Arten von Bewässerung, die aufgrund dieser sozio-technischen Unterschiede entstehen, wurden in der Literatur trotz ihres Nachweises für ihre Auswirkungen auf die Wasserwirtschaft und verwandte Politiken weitgehend übersehen (Naz & Subramanian, 2010). Die verschiedenen sozio-technischen Rahmenbedingungen für den Zugang und die Nutzung von Bewässerungswasser werden in dieser Studie als Bewässerungsarrangements bezeichnet. Da die sozialen Beziehungen eines Haushalts von seinen sozioökonomischen Faktoren beeinflusst werden, verwenden wir diese, um deren Beitrag zu den Bewässerungsarrangements zu ermitteln. Die Studie nimmt daher die Perspektive ein, dass die unterschiedlichen sozio-technischen Rahmenbedingungen der Bewässerung sowohl die ernährungsphysiologischen Pfade als auch die ernährungsphysiologischen Ergebnisse differenziell beeinflussen.

Leider ist die Verbindung zwischen Bewässerung und Ernährung trotz der langen Anerkennung der Bewässerung als entscheidender Faktor für die landwirtschaftliche Produktion immer noch nur vage verstanden (Ringler et al., 2018). Einer der Gründe liegt im globalen Fokus der landwirtschaftlichen Intensivierung auf die Getreideproduktion aufgrund einer wertschöpfungskettenorientierten Angebotsstrategie, die ernährungsrelevante Aspekte hartnäckig ignoriert (Fan & Pandya-Lorch, 2012, S. 2; Hawkes & Ruel, 2012, S. 75–76). Dies hat zu einer Trennung zwischen Landwirtschaft und Ernährung geführt (Gillespie & van den Bold, 2017). In Kenia äußert sich dies darin, dass die Mehrheit der Bewässerungsprojekte auf die Produktion kalorienreicher Getreidesorten wie Reis und hochwertiger Exportgemüsekulturen ausgerichtet ist, wobei nur ein kleiner Teil für den Gemüseanbau lokaler Märkte vorgesehen ist (Hornum & Bolwig, 2020; Mati, 2008). Infolgedessen hat die Bewässerung minimalen bis keinen Einfluss auf die ernährungsspezifische Sicherheit des Landes. Bei den Bemühungen Kenias, seine Bewässerungswirtschaft auszubauen, besteht daher ein dringender Bedarf, sich darauf zu konzentrieren, wie dies zu verbesserten ernährungsbezogenen Ergebnissen führen kann (Muthayya et al., 2013; Ruel et al., 2018).

Es liegen jedoch leider nur wenige empirische Belege für die Verbindung zwischen Landwirtschaft und Ernährung vor, und falls vorhanden, sind diese schwach (Ruel et al., 2018; Webb & Kennedy, 2014). Ebenso sind die Wege, über die Bewässerung die ernährungsbezogenen Ergebnisse

beeinflusst, understudiert, mit nur wenigen rigorosen Studien (Domènech, 2015; Hanjra & Williams, 2020). Dies unterstreicht die Notwendigkeit einer umfassenden Untersuchung der Verbindungen zwischen Bewässerung und Ernährung, die verschiedene sozio-technische Bewässerungsarrangements sowie deren differentielle Auswirkungen auf ernährungsbezogene Ergebnisse berücksichtigt.

Diese Dissertation trägt dazu bei, diese Wissenslücke zu schließen, indem sie systematisch die komplexen Wege untersucht, durch die verschiedene Bewässerungsarrangements die ernährungsbezogenen Ergebnisse von Kleinbauernhaushalten im ländlichen Kenia beeinflussen. Dabei wird die Hypothese aufgestellt, dass unterschiedliche sozioökonomische Faktoren der Haushalte die Wahl der Bewässerungsarrangements beeinflussen. In der Folge erreichen die Haushalte ihre ernährungsbezogenen Ergebnisse durch unterschiedliche Einflusswege, und die sozioökonomischen Faktoren beeinflussen diese Wege unterschiedlich. Schließlich führen die verschiedenen Bewässerungsarrangements zu Unterschieden in der Ernährung der Kleinbauernhaushalte. Um dies zu operationalisieren, werden drei Bewässerungs-Ernährungspfade – Produktvielfalt, landwirtschaftliches Einkommen und Ermächtigung der Frauen – als potenzielle Zwischenergebnisse der verschiedenen Bewässerungsarrangements untersucht. Nachdem nun der Einfluss der Bewässerungsformen auf diese Ergebnisse ermittelt wurde, werden weitere Analysen durchgeführt, um zu untersuchen, wie sich diese Ergebnisse unter verschiedenen Bewässerungsformen auf die Ernährungsvielfalt – die als Indikator für die Ernährung dient – auswirken. Auf diese Weise liefert die Studie auf evidenzbasierter Grundlage Erkenntnisse, die die Politik und Praxis zur Verbesserung sowohl der landwirtschaftlichen Produktivität als auch des ernährungsspezifischen Wohlbefindens in Kenia informieren können.

In dieser Studie wird Bewässerung als eine Form der landwirtschaftlichen Produktion auf Haushaltsebene betrachtet und versucht, ihre Verbindungen zu ernährungsbezogenen Ergebnissen aufzuzeigen. Hierbei wurde das konzeptuelle Rahmenwerk zur Verbindung von Landwirtschaft und Ernährung als geeignet erachtet, die Forschung zu fundieren. Das von Herforth & Harris (2014) entwickelte Rahmenwerk wird genutzt, um Landwirtschaft mit ernährungsbezogenen Ergebnissen zu verknüpfen. Hierzu wird die Methodik von Passarelli et al. (2018) angepasst, indem Bewässerung als landwirtschaftliche Innovation für Kleinbauernhaushalte betrachtet wird, um deren ernährungsbezogene Ergebnisse über die Pfade der Lebensmittelproduktion, des landwirtschaftlichen Einkommens und der Ermächtigung der Frauen zu erreichen, wie von Domenech & Ringler (2013) vorgeschlagen. Die Betrachtung der Bewässerung als Bestandteil landwirtschaftlicher Innovation ermöglicht die Unterscheidung zwischen bewässerten und nicht bewässerten Haushalten sowie den verschiedenen Bewässerungsarrangements.

Die vorliegende Studie argumentiert, dass die sozioökonomischen Faktoren in den Bauernhaushalten die Entscheidung über eine Bewässerungsteilnahme determinieren. Darüber hinaus beeinflussen diese Faktoren auch die Wahl des Bewässerungsarrangements, an dem sich der Bauernhaushalt beteiligen wird, sei es ein von Landwirten geführtes Bewässerungsarrangement oder ein Bewässerungsschema der öffentlichen Hand. Es wird dann die Hypothese aufgestellt, dass die verschiedenen Haushalte in verschiedenen Bewässerungsarrangements unterschiedliche Pfade zur Erreichung ihrer ernährungsbezogenen Ergebnisse aufweisen, wobei die sozioökonomischen Varianzen berücksichtigt werden.

Diese Forschung wurde im Mwea-Bewässerungsschema durchgeführt, dem ältesten öffentlichen Bewässerungsschema Kenias. Aufgrund der Wasserverfügbarkeit, hauptsächlich durch das Bewässerungsschema, hat sich die Gegend auch als landwirtschaftliche Region entwickelt, wobei die von den Landwirten geführte Bewässerung in der Gegend häufig vorkommt (Momanyi et al., 2019; Tomizuka et al., 2019). Die Koexistenz verschiedener Bewässerungsarrangements (öffentliche und von Landwirten geführte) machte die Gegend ideal für die Studie.

Nach den Arbeiten von Cochran (2007) und Israel (1992) wurden bei der Berechnung der Stichprobengröße dieser Studie drei kritische Faktoren berücksichtigt: Genauigkeitsgrad, Konfidenzniveau und Grad der Variabilität. Die Studie hat daher die Stichprobenformel von Cochran (1963) übernommen, um die geeignete Stichprobengröße zu erhalten, welche eine Gesamtstichprobengröße von 384 Kleinbauernhaushalten ergab.

Obwohl die Studie zahlreiche sozioökonomische, institutionelle und wirtschaftsbezogene Merkmale heranzieht, sind fünf Schlüsselvariablen von grundlegender Bedeutung: Ernährungsvielfalt, Einkommen, Produktvielfalt, der abgekürzte Agricultural Women's Empowerment Index (A-WEAI) und Bewässerung. Der MDD-W, der aus zehn Lebensmittelgruppen besteht, ist ein strengerer Maßstab für die Ernährungsvielfalt, der darauf abzielt, die Mikronährstoffversorgung von Frauen im gebärfähigen Alter zu erfassen, was ein zentraler Aspekt der Ernährungsqualität ist. Da Frauen im gebärfähigen Alter aufgrund biologischer und körperlicher Anfälligkeiten (wie Stillen und Schwangerschaft) einen erhöhten Bedarf an nährstoffreicheren Lebensmitteln haben, wurde der MDD-W für diese Studie als geeigneter angesehen als andere Klassifikationen der Ernährungsvielfalt (Black et al., 2013; Torheim & Arimond, 2013). Während die Einteilung der Lebensmittelgruppen dem MDD-W-Rahmenwerk folgte, wurde die dichotome Messgröße (ja oder nein), mit der angegeben wird, ob eine Person mindestens fünf der zehn Lebensmittelgruppen zu sich genommen hat, jedoch nicht übernommen. Stattdessen verwendete die Studie die kontinuierliche Skala, weshalb die Messgröße in dieser Studie einfach als „Ernährungsvielfalt“ bezeichnet wird.

Durch die Einnahme der Perspektive des landwirtschaftlichen Haushalts werden sowohl landwirtschaftliches als auch nichtlandwirtschaftliches Einkommen berücksichtigt. Bei der Berechnung des landwirtschaftlichen Einkommens wurde der Verkauf von landwirtschaftlichen Produkten, einschließlich Getreideverkauf, Verkauf von Vieh und Viehprodukten, aus den Antworten der Landwirte ermittelt. Die Produktvielfalt wird als die Vielfalt der Kulturen, des Viehs und der Viehprodukte auf dem Bauernhof im Bezugszeitraum (12 Monate) gemessen. Um den Produktindex robuster und plausibler zu gestalten, wurde die doppelte Zählung einer Art zweimal (z. B. Rinder- und Milchproduktion) vermieden, indem dieselben Gruppierungen wie die MDD-W verwendet wurden und nur Produkte berücksichtigt wurden, die im Bezugszeitraum tatsächlich hergestellt wurden (d. h. der Besitz einer Kuh bedeutet nicht automatisch Milchproduktion, es sei denn, diese wurde im Bezugszeitraum erfasst).

Adaptiert von der Arbeit von Dimitrievski et al. (2019) bedeutet Frauenförderung in dieser Studie die Steigerung der persönlichen, politischen, sozialen oder wirtschaftlichen Stärke von Frauen. In dieser Studie wird der gekürzte Index für Frauenförderung in der Landwirtschaft (A-WEAI) verwendet, da er sich für das Untersuchungsfeld (Frauen in der Landwirtschaft) eignet und verschiedene Aspekte der Stärkung erfassen kann. Der A-WEAI ist eine standardisierte Messung

der Frauenförderung in fünf Bereichen: Entscheidungen zur landwirtschaftlichen Produktion; Zugang zu und Entscheidungsbefugnis über produktive Ressourcen; Kontrolle über die Verwendung von Einkommen; Führungsrollen in der Gemeinschaft; und Zeitallokation (H. J. Malapit et al., 2017). Die ersten drei Bereiche (Produktion, Ressourcen, Einkommen) stehen im Zusammenhang mit der wirtschaftlichen Stärkung, während Führung und Zeitallokation sich auf Entscheidungsfindung, Vertretung und ausgewogene Arbeitslast beziehen.

Diese Forschung bedient sich einer ökonometrischen Analyse, die in vier Prozesse unterteilt ist, die dem logischen Fluss der Studienziele folgen. In der ersten Analyse wird ein binärer Ansatz zur Untersuchung der Faktoren verwendet, welche die Bewässerungsanordnung beeinflussen. Hierfür kam eine Probit-Regression zum Einsatz. Da die Hauptbehauptung der Studie jedoch die Disaggregation der Bewässerung ist, wird eine zweite Analyse basierend auf einer multinomialen Logit-Regression (MNL) durchgeführt. Die MNL ermöglicht die gleichzeitige Analyse der Bewässerungsarrangements unter Verwendung der Nicht-Bewässerer als Basisergebnis.

Anschließend untersucht die Studie, ob Bewässerung und Bewässerungsarrangements Auswirkungen auf die Produktionsvielfalt, das Farmeinkommen, die Frauenförderung und das angestrebte Ernährungsergebnis (über die Ernährungsvielfalt) haben. Dies ist besonders wichtig, da es die Möglichkeit bietet, diese Effekte zu quantifizieren und somit wichtige empirische Belege für Forschung und Politik bereitzustellen. Um dies zu erreichen, wird als dritte Analyse ein Propensity Score Matching-Ansatz (PSM) angewendet.

In der letzten Analyse wandte die Studie eine Dreistufige Kleinste-Quadrate-Analyse (3SLS) an, um die Bewässerungs-Ernährungs-Impaktwege für Bewässerung und Bewässerungsarrangements zu untersuchen. Indem die Studie diesem Fluss der ökonometrischen Analyse folgt, versucht sie insgesamt, die Fragen zu beantworten, die hinsichtlich des *Warums* der disaggregierten Bewässerungsanalyse, des *Gesamteinflusses* auf die Bewässerungsernährungswege und des *Unterschieds* in den Einflusswegen aufkommen könnten.

In den Probit- und MNL-Regressionen zeigten die Analysen, wie Haushaltsfaktoren sowohl die Bewässerung als auch die Bewässerungsanordnungen beeinflussen. Die Faktoren, die sich auf die Bewässerung auswirken, und diejenigen, die jede der Bewässerungsanordnungen beeinflussen, waren nicht nur unterschiedlich, sondern wiesen auch eine unterschiedliche Wirkungsrichtung für dieselben Regressoren auf.

Der Bildungsstand des Haushaltsvorstands beeinflusste Haushalte negativ in Bezug auf die Anordnung des öffentlichen Bewässerungssystems (PIS). Das Wissen über Pumpentechnologie war ein positiver Einflussfaktor für die Bewässerung und für die Anordnung der landwirtschaftlich geführten Bewässerung (FLI). Der Zugang zu Land über das hinaus, was ein Haushalt besitzt (reflektiert im Landmietpreis), beeinflusste Haushalte positiv in Richtung Bewässerung und beide Bewässerungsanordnungen.

Die Faktoren, welche die primäre weibliche Entscheidungsträgerin betreffen, erwiesen sich ebenfalls als entscheidend für die Bestimmung der Bewässerung und der Bewässerungsanordnungen. Der Bildungsstand der primären weiblichen Entscheidungsträgerin ist ein Schlüsselfaktor für die Bewässerung und das PIS-Arrangement. Das Alter der primären weiblichen Entscheidungsträgerin war ebenfalls ein wesentlicher Bestimmungsfaktor, der

Haushalte von der Beteiligung an der Bewässerung und dem PIS-Arrangement abhielt. Andererseits beeinflusste die Fähigkeit der primären weiblichen Entscheidungsträgerin, Produktionsentscheidungen zu treffen, das PIS-Arrangement negativ. Daher besteht Bedarf an Mechanismen, die auf die primären weiblichen Entscheidungsträgerinnen der Haushalte abzielen.

Der Zugang zu Inputs spielt ebenfalls eine entscheidende Rolle bei der Entscheidung eines Haushalts zur Einführung von Bewässerungstechnologie. Der Zugang zu Dünger und Hybrid-Saatgut war jedoch nur für die Beeinflussung von Haushalten in Richtung Bewässerung signifikant und nicht signifikant für die beiden Bewässerungsanordnungen. Dies weist auf die Notwendigkeit hin, die Bewässerung als disaggregierte Maßnahme anzugehen, da dieselben Haushaltsfaktoren je nach Bewässerungsanordnung unterschiedliche Auswirkungen haben.

Die Analysen belegen somit, dass die Haushaltsfaktoren Bewässerung und Bewässerungsanordnungen unterschiedlich beeinflussen. Sie weisen auch darauf hin, dass die Bewässerung differenziert betrachtet werden muss, basierend auf den unterschiedlichen sozio-technischen Gegebenheiten, in denen sie stattfindet. Wenn Bewässerung als einheitliche Praxis betrachtet wird, wird es schwierig, spezifische politische Initiativen zu konzipieren, die sich an bestimmte Landwirte in den verschiedenen sozialtechnischen Konfigurationen richten. Die Zusammenführung solcher Politikinitiativen schafft voraussichtlich Dissonanz anstelle von Synergie in der Bewässerung.

Bei den PSM-Analysen konzentrierte sich die Entwicklung politikrelevanter Empfehlungen auf den durchschnittlichen Behandlungseffekt nicht nur unter Bewässerungslandwirten, sondern auch über spezifische Bewässerungsformen hinweg. Dies geschah im Einklang mit unserer Hypothese, dass neben Produktionsvielfalt, landwirtschaftlichem Einkommen und der Stärkung der Rolle der Frau als potenzielle Wege zur Erreichung ernährungsbezogener Ergebnisse auf Haushaltsebene auch die Bewässerung und die verschiedenen Bewässerungsformen diese Ergebnisse auf unterschiedliche Weise beeinflussen. Die Analyse der Auswirkungen von Bewässerung und Bewässerungsformen zeigt einen deutlichen Einfluss von Bewässerung und Bewässerungsformen auf die Produktionsvielfalt, das landwirtschaftliche Einkommen und die Ernährungsvielfalt. Darüber hinaus wurden Robustheitstests durchgeführt, um die Glaubwürdigkeit der Ergebnisse zu überprüfen.

Diese Ergebnisse sowie die durchgeführten robusten Matching-Methoden bieten eine solide Grundlage für die Schlussfolgerung, dass Bewässerung die Einkommen der bewässernden Haushalte und die ernährungsphysiologischen Ergebnisse auf Haushaltsebene im Kontext der Kleinbauernlandwirtschaft in Kenia positiv beeinflusst. Der positive Effekt auf das Farmeinkommen und die diätetische Vielfalt ist bei allen Bewässerungsanordnungen deutlich, was darauf hindeutet, dass Bewässerung eine lebensfähige Intervention für Kleinbauern ist, um ihre Einkommen zu steigern und gleichzeitig die ernährungsphysiologischen Ergebnisse der Haushalte zu verbessern.

Im Gegensatz dazu beeinflusst Bewässerung die Produktionsvielfalt der bewässernden Landwirtschaftshaushalte und insbesondere der Haushalte im PIS-Arrangement negativ. Dies kann auf die Spezialisierung der bewässernden Landwirtschaftshaushalte auf Kulturen zurückzuführen sein, deren Marktwert dem Bewässerungsinvestment entspricht. Dies ist auch

auf die Mischfruchttechniken der nicht bewässernden Landwirte zurückzuführen, die die Vorteile der Regenzeit nutzen und so saisonal eine höhere Vielfalt an Nutzpflanzen erreichen. Dies erfordert jedoch weitere Forschung, um andere Möglichkeiten zu untersuchen, wie bewässernde Landwirtschaftshaushalte ernährungsphysiologische Ergebnisse erzielen, wie zum Beispiel über die Märkte (insbesondere angesichts des höheren Farmeinkommens).

Während die Ergebnisse zur Wirkung der Bewässerung auf die Frauenförderung keinen signifikanten Gesamteffekt zeigten, erforderte der Unterschied in der Frauenförderung zwischen den FLI- und PIS-Landwirten weitere Untersuchungen und Analysen. Dies sollte idealerweise durch den Vergleich dieser beiden Bewässerungsanordnungen und mit einer ausreichend großen Stichprobe erfolgen, die präzisere Ergebnisse auf disaggregierter Bewässerungsebene liefert. Daher ist es auch wichtig zu beachten, dass, obwohl die Frauenförderung durch Bewässerung und Bewässerungsanordnungen nicht signifikant beeinflusst wurde, dies die Möglichkeit eines Auswirkungspfads für die Ernährung nicht ausschließt.

Die 3SLS-Regressionsergebnisse belegen eindeutig, dass unterschiedliche Bewässerungsanordnungen ernährungsphysiologische Ergebnisse durch unterschiedliche Wege erreichen und die Faktoren, die sie beeinflussen, unterschiedlich sind. Während in den aggregierten Ergebnissen gezeigt wird, dass die drei Pfade (Produktionsvielfalt, Farmeinkommen und Frauenförderung) von Bewässerung beeinflusst wurden, zeigen die disaggregierten Analysen, dass sich die Wege unterscheiden.

In der FLI-Analyse wird die Produktionsvielfalt weder durch dieses Bewässerungsarrangement beeinflusst, noch beeinflusst sie die Ernährungsvielfalt. In diesem Arrangement sind nur das Farmeinkommen und die Frauenförderung plausible Wege für die Haushalte zu einer höheren Ernährungsvielfalt.

Andererseits besteht für das PIS-Arrangement die Möglichkeit, das Farmeinkommen und die Ermächtigung der Frauen auf Haushaltsebene zu verbessern; jedoch ist nur die Ermächtigung der Frauen ein möglicher Weg für die Haushalte in dieser Anordnung, bessere ernährungstechnische Ergebnisse zu erzielen. Zudem führten Haushalte im PIS-Arrangement zu einer geringeren Produktionsvielfalt, was wiederum ihre Ernährungsvielfalt negativ beeinflusste. In diesem Kontext ist die Produktionsvielfalt nach wie vor ein gangbarer Weg, über den Haushalte im PIS-Arrangement ihre Ernährungsvielfalt beeinflussen können. Insofern besteht das Potenzial, dass Haushalte im PIS-Arrangement durch verbesserte Produktionsvielfalt und Frauenförderung bessere ernährungstechnische Ergebnisse erzielen können.

Obwohl die Feststellung, dass das PIS-Arrangement zu einer Verringerung der Produktionsvielfalt und damit zu einer Verringerung der ernährungstechnischen Ergebnisse führt, nicht wie zuvor vermutet wurde, zeigen die Ergebnisse einen möglichen Politikinterventionsbereich. Darüber hinaus ist es wichtig, diese Wege als komplementär und nicht als isoliert zu betrachten. In diesem Fall zeigt die Forschung auch, dass die Ermächtigung der Frauen in der Lage ist, die negativen ernährungstechnischen Auswirkungen zu lindern, die aus einer geringen Produktionsvielfalt resultieren können (H. J. Malapit et al., 2015). Dies könnte hier für die PIS-Analyse der Fall sein: Die positive Wirkung der Frauenförderung mildert die Auswirkungen der geringen Produktionsvielfalt und führt über den Weg der Frauenförderung zu einem positiven

ernährungstechnischen Ergebnis. Es wäre daher vorteilhaft, zu untersuchen, wie diese Wege sich gegenseitig ergänzen könnten.

Die Bedeutung dieser Ergebnisse ist besonders signifikant, wenn man den Zeitpunkt der Datensammlung in Betracht zieht. Die Datensammlung erfolgte während der Covid-19-Krise, wobei der Datenerhebungszeitraum vom 1. Februar 2020 bis 28. Februar 2021 reichte. Dies war eine Zeit, in der die Haushalte einen Pandemieschock erlebten, der Einkommensschocks und Lebensmittelpreiserhöhungen umfasste (Kansiime et al., 2021; Nechifor et al., 2021; Shupler et al., 2021). Es ist daher bemerkenswert, dass Bewässerung unter solchen Umständen zu Einkommenssteigerungen und zur Ermächtigung der Frauen führen würde. Ebenso bemerkenswert ist der Effekt der Zunahme des Farmeinkommens in einer Zeit, in der die Wirtschaft einen Schock erlebte, was die Robustheit von Einkommenssteigerungen für die ernährungstechnischen Ergebnisse der Haushalte zeigt.

Von den deskriptiven Statistiken über Probit- und MNL-Regressionen bis hin zu den 3SLS-Regressionen ergibt sich ein klares Ergebnis, dass Bewässerung nicht einseitig ist. Dies weist auf die Notwendigkeit hin, sowohl in der Forschung als auch in der Politik von einer solchen Sichtweise abzugehen. Auf Forschungsebene besteht die Notwendigkeit, disaggregierte Analysen durchzuführen, die die unterschiedlichen Bewässerungsanordnungen berücksichtigen. Wenn Bewässerung als eine einheitliche Praxis betrachtet wird, wird es schwierig, spezifische politische Initiativen zu konzipieren, die sich an bestimmte Bauern in verschiedenen sozio-technischen Setups richten. Die Zusammenführung einer solchen Politik könnte Unstimmigkeiten der Initiativen anstelle von Synergien in der Bewässerung schaffen.

Die Forschung weist auch auf die Notwendigkeit eines geschlechtsspezifisch disaggregierten Ansatzes bei der Untersuchung sozioökonomischer Faktoren von Haushalten hin. In diesem Zusammenhang zeigten die Ergebnisse, dass die sozioökonomischen Faktoren der primären weiblichen Entscheidungsträgerin entscheidend für die Bestimmung von Bewässerung und Bewässerungsanordnungen sind.

Diese Forschung hat ergeben, dass Bewässerung trotz unterschiedlicher Bewässerungsanordnungen eine positive Wirkung auf die Farmeinkommen hat. Dies ist besonders wichtig für politische Maßnahmen zur Armutsbekämpfung auf dem Land. Die Unterscheidung des Farmeinkommens in dieser Forschung zeigt, dass Politikmaßnahmen, die Bewässerung auf Farmebene fördern, praktikabel und effektiv sein können. Da sich der Großteil Kenias sowie der landwirtschaftlich genutzten Flächen in Subsahara-Afrika unter zwei Hektar befindet, könnte Bewässerung ein Instrument sein, um die ländlichen Bevölkerungen über das Armutsniveau zu heben.

Diese Steigerung des Farmeinkommens führt jedoch möglicherweise nicht automatisch zu besseren ernährungstechnischen Ergebnissen auf Haushaltsebene. Dies ist insbesondere der Fall für Bauernhaushalte im PIS-Arrangement, wo die Einkommensgewinne nicht zu besseren ernährungstechnischen Ergebnissen für diese Haushalte führen. Dies weist auf die Notwendigkeit hin, hinsichtlich der Ausgaben für Lebensmittel eine ernährungsbewusste Erziehung vorzunehmen. Auf diese Weise könnten die Haushalte die Einkommensgewinne in ernährungstechnische Gewinne auf Haushaltsebene umleiten. Es weist auch darauf hin, dass die Verbindungen zwischen Haushalt und Markt auf gesunde Lebensmittelkosten ausgerichtet sein

sollten. Dies ist besonders wichtig, da Märkte eine wichtige Verbindung zur Ernährungssicherheit von Haushalten in Subsahara-Afrika darstellen, wobei die meisten ländlichen Haushalte Nettoverbraucher von Lebensmitteln sind.

Andererseits nimmt die Produktionsvielfalt durch Bewässerung ab, insbesondere bei Bauernhaushalten im PIS-Arrangement, und ist bei den FLI-Haushalten unbedeutend. Dies könnte auf die Vorteile der Spezialisierung auf Farmebene zurückzuführen sein, die negative Auswirkungen auf die ernährungstechnischen Ergebnisse des Haushalts haben. Dies kann auf die Auswahl von Marktnachfragekulturen (z.B. Babymais und grüne Bohnen bei kleinen Landbesitztümern) zurückzuführen sein, die keine gängigen Lebensmittel in den Haushalten sind. Dies könnte Interventionen erfordern, die Landwirte darauf aufmerksam machen, die Priorität auf die Ernährung des Haushalts vor dem Marktzugang zu legen. Trotz der negativen Auswirkungen auf Haushalte im PIS-Arrangement zeigt dies auch ein Potenzial, ernährungstechnische Ergebnisse positiv zu beeinflussen, wenn die Farmproduktion vielfältiger ist.

Der Weg der Ermächtigung der Frauen erwies sich als dominierender Bewässerungs-Nährstoffweg für Bauernhaushalte. Leider ist dies unter den drei Wegen von der Bewässerung zur Ernährung in dieser Studie der am wenigsten untersuchte Aspekt, insbesondere quantitativ. Wenn er untersucht wird, erfolgt dies oft durch die Verwendung von Proxyvariablen (wie weibliche Haushaltsvorstände und Entscheidungsfindung) und nicht in der Gesamtheit der Aspekte von Frauen in der Landwirtschaft, wie sie hier in dieser Forschung erfasst wurden. Daher besteht die Notwendigkeit, Initiativen zur Förderung der Ernährung umzuleiten, um Initiativen zur Ermächtigung von Frauen einzubeziehen. Dies betrifft insbesondere die Bereiche landwirtschaftliche Produktionsentscheidungen, Zugang zu produktiven Ressourcen, Kontrolle über die Verwendung von Einkommen, Führungspositionen und Zeiteinteilung.

Aufgrund der durchgeführten Analyse wird empfohlen, die Bewässerung als praktikable Maßnahme für Kleinbauern zu fördern, um deren landwirtschaftliche Einkommen zu steigern und die Ernährungssituation der Haushalte zu verbessern. Daher sollten politische Maßnahmen, Programme und Initiativen, die Investitionen in Bewässerung und den Zugang zu bewässerungsbezogenen Informationen und Technologien fördern, für die Regierung und die in diesem Land tätigen Entwicklungsorganisationen Priorität haben. Darüber hinaus sollte der Schwerpunkt auf der Erforschung anderer Möglichkeiten liegen, wie bewässernde Haushalte Ernährungsergebnisse erzielen können (beispielsweise über die Märkte), und es sollten weitere Untersuchungen durchgeführt werden, um die Unterschiede in Bezug auf Produktion, Einkommen, Stärkung der Rolle der Frau und Ernährungsergebnisse zwischen Landwirten in verschiedenen Bewässerungssystemen zu untersuchen.

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APPENDICES

Appendix 1: Tests for multicollinearity and heteroscedasticity

Probit and multinomial logit regression

Table A1: Aggregated irrigation analysis linear regression for Irrigation and irrigation arrangements for tests for multicollinearity

Variable	Coefficient	
	Probit	Multinomial logit
Tropical livestock units	0.030 (0.030)	0.048 (0.054)
Land owned (acres)	0.007 (0.013)	0.028 (0.024)
Land rental price (per acre)	0.001*** (0.000)	0.001*** (0.000)
Household size	-0.014 (0.015)	-0.018 (0.028)
Age of the household head (years)	<0.000 (0.003)	-0.001 (0.006)
Age of the primary female decision maker (years)	-0.006** (0.003)	-0.011* (0.006)
Education level of the household head (years)	-0.005 (0.008)	0.004 (0.014)
Education level of the primary female decision maker (years)	0.017** (0.008)	0.015 (0.015)
Distance to the market (Kilometers)	0.012 (0.007)	0.031** (0.013)
Assets (USD)	<0.000 (0.000)	<0.000** (0.000)
Constant	0.407*** (0.140)	1.817*** (0.269)
Mean dependent variable	0.484	1.737
R-squared	0.297	0.17
F-test	15.729	7.658
Akaike crit. (AIC)	443.922	902.552
SD dependent variable	0.500	0.837
Number of observations	384	384
Prob > F	0.000	0.000
Bayesian crit. (BIC)	487.379	946.009

Note: Standard errors are listed below the coefficients in parentheses. The notations and the meanings are as follows: *** p<.01, ** p<.05, and * p<.1

Source: Fieldwork survey

Table A2: Aggregated irrigation analysis variance inflation factor for irrigation and irrigation arrangements for tests for multicollinearity

Variable	VIF	1/VIF
Tropical livestock units	5.53	0.181
Land owned (acres)	5.27	0.19
Land rental price (per acre)	2.03	0.492
Household size	1.73	0.577
Age of the household head (years)	1.15	0.866
Age of the primary female decision maker (years)	1.12	0.892
Education level of the household head (years)	1.11	0.903
Education level of the primary female decision maker (years)	1.09	0.916
Distance to the market (Kilometers)	1.08	0.923
Assets (USD)	1.04	0.958
Mean VIF	2.12	

Source: Fieldwork survey

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Table A3: Aggregated irrigation analysis matrix of correlations for irrigation and irrigation arrangements for tests for multicollinearity

Variables	Primary female decision maker production decision	Access to fertilizer	Access to hybrid seed	Knowledge of pumping technology	Single adult household type	Household group membership	Gender of the household head (Female)
Primary female decision maker production decision	1.000						
Access to fertilizer	-0.021	1.000					
Access to hybrid seed	-0.164	0.130	1.000				
Knowledge of pumping technology	-0.100	0.075	0.053	1.000			
Single adult household type	-0.049	-	-0.114	-0.122	1.000		
Household group membership	0.143	0.161	-0.011	0.115	-0.040	1.000	
Gender of the household head (Female)	0.139	-	-0.082	-0.153	0.737	-0.037	1.000

Source: Fieldwork survey

Farmer-led irrigation arrangement

Table A4: Farmer-led irrigation arrangement analysis linear regression for Irrigation and irrigation arrangements for tests for multicollinearity

Variable	Coefficient	
	Probit	Multinomial logit
Tropical livestock units	0.023 (0.034)	0.046 (0.068)
Land owned (acres)	0.011 (0.015)	0.022 (0.030)
Land rental price (per acre)	0.001*** (0.000)	0.002*** (0.001)
Household size	-0.012 (0.017)	-0.024 (0.035)
Age of the household head (years)	<0.000 (0.004)	0.001 (0.007)
Age of the primary female decision maker (years)	-0.007* (0.004)	-0.014* (0.007)
Education level of the household head (years)	0.003 (0.009)	0.006 (0.018)
Education level of the primary female decision maker (years)	0.010 (0.009)	0.021 (0.019)
Distance to the market (Kilometers)	0.014* (0.008)	0.028* (0.017)
Assets (USD)	<0.000** (0.000)	<0.000** (0.000)
Constant	0.347** (0.167)	1.694*** (0.334)
Mean dependent variable	0.329	1.658
R-squared	0.196	0.196
F-test	6.930	6.93

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Variable	Coefficient	
	Probit	Multinomial logit
Akaike crit. (AIC)	349.022	757.979
SD dependent variable	0.471	0.941
Number of observations	295	295
Prob > F	0.000	0.000
Bayesian crit. (BIC)	389.579	798.536

Note: Standard errors are listed below the coefficients in parentheses. The notations and the meanings are as follows: *** p<.01, ** p<.05, and * p<.1

Source: Fieldwork survey

Table A5: Farmer-led irrigation arrangement variance inflation factor for irrigation and irrigation arrangements for tests for multicollinearity

Variable	VIF	1/VIF
Tropical livestock units	5.98	0.167
Land owned (acres)	5.68	0.176
Land rental price (per acre)	2.1	0.477
Household size	1.82	0.548
Age of the household head (years)	1.17	0.856
Age of the primary female decision maker (years)	1.17	0.857
Education level of the household head (years)	1.11	0.899
Education level of the primary female decision maker (years)	1.1	0.905
Distance to the market (Kilometers)	1.08	0.926
Assets (USD)	1.07	0.939
Mean VIF	2.23	

Source: Fieldwork survey

Table A6: Farmer-led irrigation arrangement matrix of correlations for irrigation and irrigation arrangements for tests for multicollinearity

Variables	Primary female decision maker production decision	Access to fertilizer	Access to hybrid seed	Knowledge of pumping technology	Single adult household type	Household group membership	Gender of the household head (Female)
Primary female decision maker production decision	1.000						
Access to fertilizer	0.003	1.000					
Access to hybrid seed	-0.121	0.123	1.000				
Knowledge of pumping technology	-0.180	0.120	0.141	1.000			
Single adult household type	-0.117	0.120	-0.118	-0.140	1.000		

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Variables	Primary female decision maker production decision	Access to fertilizer	Access to hybrid seed	Knowledge of pumping technology	Single adult household type	Household group membership	Gender of the household head (Female)
Household group membership	0.178	0.167	-0.009	0.138	-0.011	1.000	
Gender of the household head (Female)	0.112	-0.181	-0.112	-0.170	0.735	-0.054	1.000

Source: Fieldwork survey

Public irrigation scheme arrangement

Table A7: Public irrigation scheme arrangement analysis linear regression for Irrigation and irrigation arrangements for tests for multicollinearity

Variable	Coefficient	
	Probit	Multinomial logit
Tropical livestock units	0.020 (0.028)	0.020 (0.028)
Land owned (acres)	-0.008 (0.012)	-0.008 (0.012)
Land rental price (per acre)	0.002*** (0.000)	0.002*** (0.000)
Household size	-0.009 (0.014)	-0.009 (0.014)
Age of the household head (years)	0.001 (0.003)	0.001 (0.003)
Age of the primary female decision maker (years)	-0.003 (0.003)	-0.003 (0.003)
Education level of the household head (years)	-0.016** (0.007)	-0.016** (0.007)
Education level of the primary female decision maker (years)	0.024*** (0.008)	0.024*** (0.008)
Distance to the market (Kilometers)	-0.003 (0.008)	-0.003 (0.008)
Assets (USD)	<0.000 (0.000)	<0.000 (0.000)
Constant	0.072 (0.141)	1.072*** (0.141)
Mean dependent variable	0.310	1.310
R-squared	0.472	0.472
F-test	24.667	24.667
Akaike crit. (AIC)	210.633	210.633
SD dependent variable	0.463	0.463
Number of observations	287	287
Prob > F	0.000	0.000
Bayesian crit. (BIC)	250.887	250.887

Note: Standard errors are listed below the coefficients in parentheses. The notations and the meanings are as follows: *** p<.01, ** p<.05, and * p<.1

Source: Fieldwork survey

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Table A8: Public irrigation scheme arrangement variance inflation factor for irrigation and irrigation arrangements for tests for multicollinearity

Variable	VIF	1/VIF
Tropical livestock units	5.39	0.186
Land owned (acres)	5	0.2
Land rental price (per acre)	2.3	0.435
Household size	1.9	0.525
Age of the household head (years)	1.17	0.858
Age of the primary female decision maker (years)	1.12	0.893
Education level of the household head (years)	1.12	0.896
Education level of the primary female decision maker (years)	1.11	0.897
Distance to the market (Kilometers)	1.1	0.913
Assets (USD)	1.07	0.931
Mean VIF	2.13	

Source: Fieldwork survey

Table A9: Public irrigation scheme arrangement matrix of correlations for irrigation and irrigation arrangements for tests for multicollinearity

Variables	Primary female decision maker production decision	Access to fertilizer	Access to hybrid seed	Knowledge of pumping technology	Single adult household type	Household group membership	Gender of the household head (Female)
Primary female decision maker production decision	1.000						
Access to fertilizer	-0.044	1.000					
Access to hybrid seed	-0.119	0.153	1.000				
Knowledge of pumping technology	-0.056	0.081	-0.091	1.000			
Single adult household type	-0.041	-0.075	-0.115	-0.039	1.000		
Household group membership	0.090	0.185	0.007	0.154	-0.008	1.000	
Gender of the household head (Female)	0.161	-0.124	-0.062	-0.017	0.746	-0.029	1.000

Source: Fieldwork survey

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Propensity score matching

Table A10: Aggregated irrigation analysis linear regression for production diversity, farm income, women's empowerment and dietary diversity for tests for multicollinearity

Variable	Coefficient			
	Production diversity	Farm income	Women's empowerment	Dietary diversity
Age of the household head (years)	-0.002 (0.01)	-22.568 (19.571)	<0.000 (0.001)	-0.011* (0.007)
Age of the primary female decision maker (years)	0.004 (0.01)	-12.109 (19.536)	0.002 (0.001)	0.007 (0.007)
Assets (USD)	<0.000* (0.000)	0.010 (0.024)	<0.000 (0.000)	<0.000 (0.000)
Education level of the household head (years)	0.006 (0.025)	71.244 (47.249)	-0.002 (0.003)	<0.000 (0.016)
Education level of the primary female decision maker (years)	-0.027 (0.027)	-50.856 (50.301)	0.005 (0.003)	0.033** (0.017)
Household size	0.074 (0.05)	-4.487 (95.184)	-0.003 (0.006)	0.027 (0.032)
Land owned (acres)	0.098** (0.043)	578.812*** (81.766)	<0.000 (0.005)	-0.003 (0.027)
Tropical livestock units	0.872*** (0.097)	104.554 (182.473)	0.012 (0.012)	0.275*** (0.061)
Non-farm income (USD)	<0.000 (0.000)	0.130 (0.111)	<0.000 (0.000)	<0.000 (0.000)
Constant	2.701*** (0.469)	1880.09** (886.307)	0.621*** (0.057)	4.399*** (0.298)

Note: Standard errors are listed below the coefficients in parentheses. The notations and the meanings are as follows: *** p<.01, ** p<.05, and * p<.1

Source: Fieldwork survey

Table A11: Aggregated irrigation analysis variance inflation factor for production diversity, farm income, women's empowerment and dietary diversity for tests for multicollinearity

Variable	Production diversity / Farm income / Women's empowerment / Dietary diversity	
	VIF	1/VIF
Age of the household head (years)	5.3	0.189
Age of the primary female decision maker (years)	5.13	0.195
Assets (USD)	2.03	0.493
Education level of the household head (years)	1.75	0.573
Education level of the primary female decision maker (years)	1.17	0.854
Household size	1.12	0.897
Land owned (acres)	1.08	0.925
Tropical livestock units	1.08	0.93
Non-farm income (USD)	1.05	0.949
Mean VIF	2.19	

Source: Fieldwork survey

Matrix of correlations

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Table A12: Aggregated irrigation analysis matrix of correlations for production diversity, farm income, women's empowerment and dietary diversity for tests for multicollinearity

Variables	Irrigation	Single adult household type	In-kind credit	Household credit access	Household group membership
Irrigation	1.000				
Single adult household type	-0.115	1.000			
In-kind credit	0.114	-0.078	1.000		
Household credit access	0.055	-0.073	0.060	1.000	
Household group membership	0.117	-0.040	0.077	0.223	1.000

Source: Fieldwork survey

Farmer-led irrigation arrangement

Table A13: Farmer-led irrigation arrangement linear regression for production diversity, farm income, women's empowerment and dietary diversity for tests for multicollinearity

Variable	Coefficient			
	Production diversity	Farm income	Women's empowerment	Dietary diversity
Age of the household head (years)	-0.004 (0.012)	-27.399 (21.476)	0.001 (0.001)	-0.008 (0.008)
Age of the primary female decision maker (years)	0.007 (0.012)	-7.719 (21.453)	0.001 (0.001)	0.004 (0.008)
Assets (USD)	<0.000 (0.000)	0.013 (0.033)	<0.000* (0.000)	<0.000 (0.000)
Education level of the household head (years)	0.002 (0.029)	109.95** (53.997)	-0.001 (0.004)	-0.008 (0.019)
Education level of the primary female decision maker (years)	-0.016 (0.031)	-96.63* (56.032)	0.004 (0.004)	0.043** (0.02)
Household size	0.115** (0.057)	46.156 (104.823)	0.001 (0.007)	0.021 (0.038)
Land owned (acres)	0.113** (0.048)	452.386*** (87.568)	-0.002 (0.006)	0.003 (0.031)
Tropical livestock units	0.848*** (0.11)	1.419 (201.454)	0.007 (0.013)	0.217*** (0.072)
Non-farm income (USD)	<0.000 (0.000)	0.141 (0.112)	<0.000 (0.000)	<0.000 (0.000)
Constant	2.613*** (0.521)	1851.305* (953.841)	0.599*** (0.063)	4.351*** (0.342)

Note: Standard errors are listed below the coefficients in parentheses. The notations and the meanings are as follows: *** p<.01, ** p<.05, and * p<.1

Source: Fieldwork survey

Table A14: Farmer-led irrigation arrangement variance inflation factor for production diversity, farm income, women's empowerment and dietary diversity for tests for multicollinearity

Variable	Production diversity / Farm income / Women's empowerment / Dietary diversity	
	VIF	1/VIF
Age of the household head (years)	5.63	0.178

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Variable	Production diversity / Farm income / Women's empowerment / Dietary diversity	
	VIF	1/VIF
Age of the primary female decision maker (years)	5.43	0.184
Assets (USD)	2.08	0.48
Education level of the household head (years)	1.83	0.548
Education level of the primary female decision maker (years)	1.19	0.841
Household size	1.16	0.865
Land owned (acres)	1.1	0.907
Tropical livestock units	1.07	0.932
Non-farm income (USD)	1.06	0.945
Mean VIF	2.28	

Source: Fieldwork survey

Table A15: Farmer-led irrigation arrangement matrix of correlations for production diversity, farm income, women's empowerment and dietary diversity for tests for multicollinearity

Variables	Farmer-led irrigation arrangement	Single adult household type	In-kind credit	Household credit access	Household group membership
Farmer-led irrigation arrangement	1.000				
Single adult household type	-0.151	1.000			
In-kind credit	0.030	-0.044	1.000		
Household credit access	0.093	-0.081	0.058	1.000	
Household group membership	0.097	-0.011	0.046	0.249	1.000

Source: Fieldwork survey

Public irrigation scheme arrangement

Table A16: Public irrigation scheme arrangement linear regression for production diversity, farm income, women's empowerment and dietary diversity for tests for multicollinearity

Variable	Coefficient			
	Production diversity	Farm income	Women's empowerment	Dietary diversity
Age of the household head (years)	0.006 (0.011)	-14.497 (19.114)	<0.000 (0.001)	-0.011 (0.007)
Age of the primary female decision maker (years)	-0.004 (0.011)	-17.342 (19.477)	0.001 (0.001)	0.01 (0.007)
Assets (USD)	<0.000 (0.000)	0.015 (0.031)	<0.000 (0.000)	<0.000 (0.000)
Education level of the household head (years)	0.019 (0.028)	60.24 (49.782)	-0.003 (0.004)	-0.004 (0.018)
Education level of the primary female decision maker (years)	-0.036 (0.031)	-39.606 (54.106)	0.005 (0.004)	0.04** (0.020)
Household size	0.039 (0.056)	4.200 (97.978)	-0.004 (0.007)	0.02 (0.036)
Land owned (acres)	0.092*	459.794***	<0.000	-0.032

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Variable	Coefficient			
	Production diversity	Farm income	Women's empowerment	Dietary diversity
	(0.047)	(82.269)	(0.006)	(0.03)
Tropical livestock units	0.893***	230.032	0.01	0.295***
	(0.11)	(192.418)	(0.014)	(0.070)
Non-farm income (USD)	<0.000	0.083	<0.000	<0.000
	(0.000)	(0.159)	(0.000)	(0.000)
Constant	2.728***	1648.368*	0.661***	4.155***
	(0.538)	(943.252)	(0.069)	(0.345)

Note: Standard errors are listed below the coefficients in parentheses. The notations and the meanings are as follows: *** p<.01, ** p<.05, and * p<.1

Source: Fieldwork survey

Table A17: Public irrigation scheme arrangement variance inflation factor for production diversity, farm income, women's empowerment and dietary diversity for tests for multicollinearity

Variable	Production diversity / Farm income / Women's empowerment / Dietary diversity	
	VIF	1/VIF
Age of the household head (years)	5.12	0.195
Age of the primary female decision maker (years)	4.8	0.208
Assets (USD)	2.29	0.436
Education level of the household head (years)	1.94	0.516
Education level of the primary female decision maker (years)	1.19	0.842
Household size	1.19	0.843
Land owned (acres)	1.16	0.865
Tropical livestock units	1.11	0.902
Non-farm income (USD)	1.08	0.927
Mean VIF	2.21	

Source: Fieldwork survey

Table A18: Public irrigation scheme arrangement matrix of correlations for production diversity, farm income, women's empowerment and dietary diversity for tests for multicollinearity

Variables	Public irrigation scheme arrangement	Single adult household type	In-kind credit	Household credit access	Household group membership
Public irrigation scheme arrangement	1.000				
Single adult household type	-0.058	1.000			
In-kind credit	0.187	-0.091	1.000		
Household credit access	0.005	-0.073	0.039	1.000	
Household group membership	0.116	-0.008	0.086	0.221	1.000

Source: Fieldwork survey

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Table A19: Aggregated irrigation dietary diversity analysis linear regression for tests for multicollinearity

Variable	Coefficient
Production diversity	0.076** (0.034)
Log of farm income (USD)	0.054** (0.021)
Women's empowerment	0.22 (0.267)
Household size	0.008 (0.031)
Age of the household head (years)	-0.013** (0.007)
Age of the primary female decision maker (years)	0.009 (0.007)
Tropical livestock units	0.189*** (0.067)
Education level of the household head (years)	-0.008 (0.016)
Education level of the primary female decision maker (years)	0.033** (0.017)
Distance to the market (Kilometers)	0.032** (0.015)
Assets (USD)	<0.000 (0.000)
Land owned (acres)	-0.031 (0.028)
Land rental price (per acre)	<0.000(0.000)
Constant	3.736*** (0.362)
Mean dependent variable	4.638
R-squared	0.130
F-test	4.250
Akaike crit. (AIC)	997.260
SD dependent var	0.918
Number of observations	384
Prob > F	0.000
Bayesian crit. (BIC)	1052.569

Note: Standard errors are listed below the coefficients in parentheses. The notations and the meanings are as follows: *** p<.01, ** p<.05, and * p<.1

Source: Fieldwork survey

Table A20: Aggregated irrigation dietary diversity variance inflation factor for tests for multicollinearity

Variable	VIF	1/VIF
Production diversity	5.580	0.179
Log of farm income (USD)	5.270	0.190
Women's empowerment	2.050	0.488
Household size	1.760	0.570
Age of the household head (years)	1.470	0.682
Age of the primary female decision maker (years)	1.330	0.752
Tropical livestock units	1.310	0.760
Education level of the household head (years)	1.300	0.769
Education level of the primary female decision maker (years)	1.210	0.829
Distance to the market (Kilometers)	1.180	0.850
Assets (USD)	1.090	0.917
Land owned (acres)	1.050	0.949
Land rental price (per acre)	1.050	0.955
Mean VIF	1.970	

Source: Fieldwork survey

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Table A21: Aggregated irrigation dietary diversity matrix of correlations for tests for multicollinearity

Variables	Irrigation	Employed	Single adult household type	Household group membership	Access to hybrid seed	Access to fertilizer	Primary female decision maker production decision	Access to extra land	Knowledge of pumping technology	Gender of the household head (Female)
Irrigation	1.000									
Employed	-0.056	1.000								
Single adult household type	-0.115	0.031	1.000							
Household group membership	0.117	0.003	-0.040	1.000						
Access to hybrid seed	0.212	0.012	-0.114	-0.011	1.000					
Access to fertilizer	0.178	0.009	-0.106	0.161	0.130	1.000				
Primary female decision maker production decision	-0.196	0.000	-0.049	0.143	-0.164	-0.021	1.000			
Access to extra land	0.357	0.043	-0.172	0.034	0.069	0.105	-0.014	1.000		
Knowledge of pumping technology	0.490	0.049	-0.122	0.115	0.053	0.075	-0.100	0.173	1.000	
Gender of the household head (Female)	-0.133	0.028	0.737	-0.037	-0.082	-0.154	0.139	-0.146	-0.153	1.000

Source: Fieldwork survey

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Farmer-led irrigation arrangement

Table A22: Farmer-led irrigation arrangement dietary diversity analysis linear regression for tests for multicollinearity

Variable	Coefficient
Production diversity	0.086** (0.039)
Log of farm income (USD)	0.054** (0.024)
Women's empowerment	0.435 (0.319)
Household size	-0.004 (0.037)
Age of the household head (years)	-0.01 (0.008)
Age of the primary female decision maker (years)	0.007 (0.008)
Tropical livestock units	0.123 (0.078)
Education level of the household head (years)	-0.017 (0.019)
Education level of the primary female decision maker (years)	0.042** (0.02)
Distance to the market (Kilometers)	0.028 (0.017)
Assets (USD)	<0.000 (0.000)
Land owned (acres)	-0.029 (0.032)
Land rental price (per acre)	<0.000 (0.001)
Constant	3.577*** (0.413)
Mean dependent variable	4.615
R-squared	0.121
F-test	2.987
Akaike crit. (AIC)	786.437
SD dependent variable	0.935
Number of observations	295
Prob > F	0.000
Bayesian crit. (BIC)	838.055

Note: Standard errors are listed below the coefficients in parentheses. The notations and the meanings are as follows: *** p<.01, ** p<.05, and * p<.1

Source: Fieldwork survey

Table A23: Farmer-led irrigation arrangement dietary diversity variance inflation factor for tests for multicollinearity

Variable	VIF	1/VIF
Production diversity	6.050	0.165
Log of farm income (USD)	5.690	0.176
Women's empowerment	2.110	0.474
Household size	1.850	0.540
Age of the household head (years)	1.400	0.712
Age of the primary female decision maker (years)	1.350	0.741
Tropical livestock units	1.310	0.762
Education level of the household head (years)	1.270	0.789
Education level of the primary female decision maker (years)	1.200	0.837
Distance to the market (Kilometers)	1.120	0.893
Assets (USD)	1.120	0.894

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Variable	VIF	1/VIF
Land owned (acres)	1.100	0.906
Land rental price (per acre)	1.060	0.940
Mean VIF	2.050	

Source: Fieldwork survey

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Table A24: Farmer-led irrigation arrangement dietary diversity matrix of correlations for tests for multicollinearity

Variables	Farmer-led irrigation	Employed	Single adult household type	Household group membership	Access to hybrid seed	Access to fertilizer	Primary female decision maker production decision	Access to extra land	Knowledge of pumping technology	Gender of the household head (Female)
Farmer-led irrigation arrangement	1.000									
Employed	-0.066	1.000								
Single adult household type	-0.151	0.018	1.000							
Household group membership	0.097	0.015	-0.011	1.000						
Access to hybrid seed	0.169	0.025	-0.118	-0.009	1.000					
Access to fertilizer	0.116	0.013	-0.120	0.167	0.123	1.000				
Primary female decision maker production decision	-0.154	0.072	-0.117	0.178	-0.121	0.003	1.000			
Access to extra land	0.362	0.087	-0.245	0.032	0.056	0.094	0.004	1.000		
Knowledge of pumping technology	0.817	0.062	-0.140	0.138	0.141	0.120	-0.180	0.281	1.000	
Gender of the household head (Female)	-0.198	0.021	0.735	-0.054	-0.112	-0.181	0.112	-0.201	-0.170	1.000

Source: Fieldwork survey

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Public irrigation scheme arrangement

Table A25: Public irrigation scheme arrangement dietary diversity analysis linear regression for tests for multicollinearity

Variable	Coefficient
Production diversity	0.125*** (0.041)
Log of farm income (USD)	0.038 (0.025)
Women's empowerment	-0.087 (0.299)
Household size	0.01 (0.035)
Age of the household head (years)	-0.015** (0.007)
Age of the primary female decision maker (years)	0.014** (0.007)
Tropical livestock units	0.187** (0.077)
Education level of the household head (years)	-0.009 (0.018)
Education level of the primary female decision maker (years)	0.04** (0.02)
Distance to the market (Kilometers)	0.039* (0.02)
Assets (USD)	<0.000 (0.000)
Land owned (acres)	-0.062)** (0.03)
Land rental price (per acre)	<0.000 (0.000)
Constant	3.531*** (0.42)
Mean dependent var	4.540
R-squared	0.154
F-test	3.809
Akaike crit. (AIC)	737.960
SD dependent var	0.908
Number of observations	287
Prob > F	0.000
Bayesian crit. (BIC)	789.193

Note: Standard errors are listed below the coefficients in parentheses. The notations and the meanings are as follows: *** p<.01, ** p<.05, and * p<.1

Source: Fieldwork survey

Table A26: Public irrigation scheme arrangement dietary diversity variance inflation factor for tests for multicollinearity

Variable	VIF	1/VIF
Production diversity	5.420	0.185
Log of farm income (USD)	5.010	0.200
Women's empowerment	2.340	0.427
Household size	1.920	0.521
Age of the household head (years)	1.600	0.626
Age of the primary female decision maker (years)	1.460	0.684
Tropical livestock units	1.400	0.715
Education level of the household head (years)	1.350	0.739
Education level of the primary female decision maker (years)	1.190	0.840
Distance to the market (Kilometers)	1.180	0.846
Assets (USD)	1.110	0.905

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Variable	VIF	1/VIF
Land owned (acres)	1.090	0.920
Land rental price (per acre)	1.050	0.948
Mean VIF	2.010	

Source: Fieldwork survey

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Table A27: Public irrigation scheme arrangement dietary diversity matrix of correlations for tests for multicollinearity

Variables	Public irrigation scheme arrangement	Employed	Single adult household type	Household group membership	Access to hybrid seed	Access to fertilizer	Primary female decision maker production decision	Access to extra land	Knowledge of pumping technology	Gender of the household head (Female)
Public irrigation scheme arrangement	1.000									
Employed	-0.036	1.000								
Single adult household type	-0.058	0.017	1.000							
Household group membership	0.116	0.016	-0.008	1.000						
Access to hybrid seed	0.232	0.023	-0.115	0.007	1.000					
Access to fertilizer	0.193	0.031	-0.075	0.185	0.153	1.000				
Primary female decision maker production decision	-0.227	0.013	-0.041	0.090	-0.119	-0.044	1.000			
Access to extra land	0.363	0.005	-0.098	0.035	0.097	0.074	-0.008	1.000		
Knowledge of pumping technology	0.043	0.184	-0.039	0.154	-0.091	0.081	-0.056	0.033	1.000	
Gender of the household head (Female)	-0.044	0.010	0.746	-0.029	-0.062	-0.124	0.161	-0.092	-0.017	1.000

Source: Fieldwork survey

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Table A28: Breusch-Pagan / Cook-Weisberg test for heteroscedasticity for the 3SLS regression

Variables	Coefficients		
	Aggregated irrigation	Farmer-led irrigation arrangement	Public irrigation scheme arrangement
Production diversity	0.077**(0.037)	0.076*(0.042)	0.133*** (0.045)
Log of farm income (USD)	0.025(0.023)	0.024(0.026)	0.02(0.027)
Women's empowerment	-0.068(0.32)	0.219(0.385)	-0.369(0.372)
Household size	0.006(0.035)	-0.01(0.04)	0.002(0.038)
Employed	-0.199(0.123)	-0.272*(0.148)	-0.156(0.143)
Age of the household head (years)	-0.014**(0.007)	-0.01(0.008)	-0.018**(0.008)
Age of the primary female decision maker (years)	0.015**(0.007)	0.012(0.008)	0.019**(0.008)
Tropical livestock units	0.169**(0.067)	0.107(0.078)	0.169**(0.079)
Education level of the household head (years)	-0.006(0.016)	-0.017(0.02)	-0.003(0.019)
Education level of the primary female decision maker (years)	0.027(0.017)	0.039*(0.02)	0.032(0.02)
Distance to the market (Kilometers)	0.028*(0.016)	0.021(0.018)	0.042**(0.021)
Public irrigation scheme arrangement	0.245*(0.139)	0.04(0.209)	0.286*(0.168)
Assets (USD)	<0.000 (0.000)	<0.000 (0.000)	<0.000 (0.000)
Single adult household type	0.049(0.185)	0.062(0.222)	-0.114(0.209)
Land owned (acres)	-0.026(0.028)	-0.024(0.032)	-0.059*(0.031)
Household group membership	0.046(0.121)	0.05(0.143)	0.145(0.141)
Access to hybrid seed	0.098(0.098)	0.045(0.116)	0.107(0.114)
Access to fertilizer	0.227(0.192)	0.223(0.2)	0.016(0.211)
Primary female decision maker production decision	0.193(0.124)	0.195(0.153)	0.128(0.152)
Land rental price (per acre)	<0.000 (0.000)	<0.000 (0.001)	<0.000 (0.000)
Access to extra land	0.035(0.115)	0.135(0.147)	-0.027(0.143)
Knowledge of pumping technology	0.15(0.129)	0.383*(0.203)	0.212(0.21)
Gender of the household head (Female)	-0.142(0.179)	-0.167(0.214)	-0.01(0.204)
Constant	3.431*** (0.387)	3.246*** (0.44)	3.525*** (0.455)
Mean dependent variables	4.638	4.615	4.540
R-squared	0.174	0.181	0.182
F-test	3.297	2.598	2.541

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Variables	Coefficients		
	Aggregated irrigation	Farmer-led irrigation arrangement	Public irrigation scheme arrangement
Akaike crit. (AIC)	997.303	785.832	748.213
SD dependent variables	0.918	0.935	0.908
Number of observations	384	295	287
Prob > F	0.000	0.000	0.000
Bayesian crit. (BIC)	1092.118	874.319	836.041
Breusch-Pagan / Cook-Weisberg test for heteroskedasticity	chi2(1) Prob > chi2	0.09 0.841	0.10 0.755

Note: Standard errors are listed below the coefficients in parentheses. The notations and the meanings are as follows: *** p<.01, ** p<.05, and * p<.1

Source: Fieldwork survey

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Appendix 2: Tests for overidentification restriction

Instrumental variables (2SLS) regression for the irrigation, farmer-led irrigation arrangement and public irrigation scheme arrangement equations

Variables	Coefficients		
	Aggregated irrigation	Farmer-led irrigation arrangement	Public irrigation scheme arrangement
Production diversity	0.108 (0.090)	0.139 (0.101)	-0.005 (0.144)
Log of farm income (USD)	-0.012 (0.067)	-0.004 (0.073)	-0.001 (0.098)
Women's empowerment	0.734 (0.548)	0.820 (0.600)	0.796 (0.582)
Irrigation/Irrigation arrangement†	0.467** (0.234)	0.583*** (0.208)	0.229 (0.452)
Household size	0.028 (0.033)	0.011 (0.038)	0.036 (0.039)
Employed†	-0.165 (0.124)	-0.208 (0.145)	-0.137 (0.165)
Age of the household head (years)	-0.013** (0.006)	-0.009 (0.007)	-0.014* (0.007)
Age of the primary female decision maker (years)	0.011* (0.007)	0.009 (0.008)	0.013* (0.008)
Tropical livestock units	0.186** (0.094)	0.096 (0.107)	0.299** (0.118)
Education level of the household head (years)	<0.000 (0.017)	-0.013 (0.020)	0.002 (0.020)
Education level of the primary female decision maker (years)	0.025 (0.017)	0.037* (0.019)	0.032 (0.020)
Distance to the market (Kilometers)	0.026* (0.015)	0.018 (0.017)	0.032 (0.021)
Constant	3.235*** (0.420)	3.073*** (0.467)	3.361*** (0.521)
Mean dependent variable	4.638	4.615	4.540
R-squared	0.138	0.136	0.092
Chi-square	60.843	52.434	36.763
SD dependent variable	0.918	0.935	0.908
Number of observations	384	295	287
Prob > chi2	0.000	0.000	0.000
Sargan (score) chi2(7)	5.879	3.926	4.780
Sargan (score) chi2 p-value	0.554	0.788	0.687
Basman chi2(7)	5.659	3.709	4.522
Basman chi2 p-value	0.580	0.813	0.718

Note: Standard errors are listed below the coefficients in parentheses. The notations and the meanings are as follows: *** p<.01, ** p<.05, and * p<.1

Source: Author based on survey data.

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Aggregated irrigation

Instrumental variables (2SLS) regression		Number of obs	=	384
		Wald chi2(12)	=	60.84
		Prob > chi2	=	0.0000
		R-squared	=	0.1377
		Root MSE	=	.85098

MDDW_hh	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
production_diversity	.1079643	.0899517	1.20	0.230	-.0683378	.2842664
lnfarm_income_USD_plus_K	-.0117331	.0668027	-0.18	0.861	-.1426639	.1191978
female_AWEAI	.7338532	.5483501	1.34	0.181	-.3408933	1.8086
irrigation	.4669385	.2337045	2.00	0.046	.008886	.924991
hhsize	.028484	.0325472	0.88	0.381	-.0353073	.0922753
Employed	-.1649046	.1235279	-1.33	0.182	-.4070148	.0772057
age_1	-.0133499	.0064011	-2.09	0.037	-.0258957	-.0008041
age_primary_woman	.0114641	.0066193	1.73	0.083	-.0015096	.0244378
LSU	.1857836	.0936376	1.98	0.047	.0022574	.3693099
hhhead_education_years	4.06e-06	.0166938	0.00	1.000	-.0327153	.0327234
education_primary_woman	.0246097	.016774	1.47	0.142	-.0082668	.0574861
mktkm	.0261624	.0151097	1.73	0.083	-.003452	.0557769
_cons	3.234945	.4203292	7.70	0.000	2.411115	4.058775

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Instrumented:  production_diversity lnfarm_income_USD_plus_K female_AWEAI irrigation
Instruments:   hhsize Employed age_1 age_primary_woman LSU hhhead_education_years
               education_primary_woman mktkm assetUSD hhtype_single_adult landown
               hh_group_membership hybrid_seed fertilizer female_production_dec_dummy
               lrryUSD extra_land usedpump hhhead_gender

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Tests of overidentifying restrictions:

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Sargan (score) chi2(7) = 5.87876 (p = 0.5540)
Basmann chi2(7)      = 5.65921 (p = 0.5801)

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Farmer-led irrigation arrangement

Instrumental variables (2SLS) regression		Number of obs	=	295
		Wald chi2(12)	=	52.43
		Prob > chi2	=	0.0000
		R-squared	=	0.1363
		Root MSE	=	.86764

MDDW_hh	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
production_diversity	.1393515	.1009802	1.38	0.168	-.058566	.3372689
lnfarm_income_USD_plus_K	-.0044362	.0731446	-0.06	0.952	-.1477969	.1389246
female_AWEAI	.8198748	.5998041	1.37	0.172	-.3557195	1.995469
FLI_irrigators	.5827308	.2084562	2.80	0.005	.1741641	.9912974
hhsz	.0113753	.0375537	0.30	0.762	-.0622285	.0849792
Employed	-.2079798	.1448952	-1.44	0.151	-.4919691	.0760096
age_1	-.0094704	.0074893	-1.26	0.206	-.0241492	.0052084
age_primary_woman	.0093772	.0076594	1.22	0.221	-.005635	.0243895
LSU	.0958788	.1070508	0.90	0.370	-.113937	.3056946
hhhead_education_years	-.013415	.0200307	-0.67	0.503	-.0526745	.0258444
education_primary_woman	.0373384	.0192692	1.94	0.053	-.0004286	.0751055
mktkm	.0176065	.0172708	1.02	0.308	-.0162436	.0514566
_cons	3.072906	.4673291	6.58	0.000	2.156958	3.988854

Instrumented: production_diversity lnfarm_income_USD_plus_K female_AWEAI FLI_irrigators
Instruments: hhsz Employed age_1 age_primary_woman LSU hhhead_education_years
education_primary_woman mktkm assetUSD hhtype_single_adult landown
hh_group_membership hybrid_seed fertilizer female_production_dec_dummy
lrryUSD extra_land usedpump hhhead_gender

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Tests of overidentifying restrictions:

Sargan (score) chi2(7) = 3.92613 (p = 0.7882)
Basmann chi2(7) = 3.70932 (p = 0.8126)

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Public irrigation scheme arrangement

Instrumental variables (2SLS) regression		Number of obs	=	287
		Wald chi2(12)	=	36.76
		Prob > chi2	=	0.0002
		R-squared	=	0.0916
		Root MSE	=	.86348

MDDW_hh	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
production_diversity	-.0052662	.1436778	-0.04	0.971	-.2868696	.2763371
lnfarm_income_USD_plus_K	-.0013102	.0982715	-0.01	0.989	-.1939187	.1912984
female_AWEAI	.7961257	.5821692	1.37	0.171	-.3449049	1.937156
public_irrigators	.2290385	.4524362	0.51	0.613	-.6577202	1.115797
hhsize	.0362065	.0385229	0.94	0.347	-.0392969	.1117099
Employed	-.1370242	.1651849	-0.83	0.407	-.4607806	.1867322
age_1	-.0139122	.0071005	-1.96	0.050	-.027829	4.53e-06
age_primary_woman	.0134009	.0075358	1.78	0.075	-.0013691	.0281708
LSU	.2993727	.1179943	2.54	0.011	.068108	.5306374
hhhead_education_years	.0021193	.019821	0.11	0.915	-.0367291	.0409678
education_primary_woman	.0315007	.0201851	1.56	0.119	-.0080613	.0710627
mktkm	.0317178	.0209017	1.52	0.129	-.0092488	.0726844
_cons	3.360573	.5206499	6.45	0.000	2.340118	4.381028

Instrumented: production_diversity lnfarm_income_USD_plus_K female_AWEAI
public_irrigators

Instruments: hhsize Employed age_1 age_primary_woman LSU hhhead_education_years
education_primary_woman mktkm assetUSD hhtype_single_adult landown
hh_group_membership hybrid_seed fertilizer female_production_dec_dummy
lrryUSD extra_land usedpump hhhead_gender

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Tests of overidentifying restrictions:

Sargan (score) chi2(7) = 4.78009 (p = 0.6868)
Basmann chi2(7) = 4.5223 (p = 0.7180)

Appendix 3: Focus group discussion guide

Focus Group Discussions

Participants: Male and female farmers (planning to have them separately) carrying out general cropping activities. Purposively selected based on information obtained from key informants.

Number of participants: Eight-Ten persons per focus group

How the data will be collected: Voice recorder will be used for the discussions

Number of focus groups: Two focus groups (one male and the other female) per irrigation arrangement.

Purpose of focus groups: Purposively to gather both qualitative data on the institutional set up (formal or informal), social aspects of the members, crop production and food security perceptions to act as an insight to the quantitative study and also in sample selection and questionnaire design.

Crop production

1. Which crops do you grow?

Comment: please probe, by asking "anything else?" DO NOT NAME EXAMPLES!

- a. Please name all the crops including food and cash crops
2. What share is sold or used for home-consumption?
 - a. If it is sold, where is it sold?
 - i. Why do you sell it there?
 - ii. Which kind of road connects you to the place of sale?
 - iii. Do you pay fees to the place of sale?
 1. How much?
 - iv. Who is responsible for the money from the sale?

3. Which ones are the food crops, cash crops, both food and cash crops?
4. Of the crops, which is the main crop?
5. Follow-up question: Is there a crop that is more important to you?
6. In which seasons do you grow these crops?
7. Why do you grow these crops?
8. Which crops do you usually grow together in the same plot of land?

Comment: please probe, by asking "any other crops mixed together"

- a. Can you give reasons why you usually grow these crops together?
9. Which of these crops do you consume at home?
10. Which of these crops do you sell?

Livestock production

1. Which livestock do you keep?

Comment: please probe, by asking "anything else?" DO NOT NAME EXAMPLES!

Urge them to please name all the crops including food and cash crops

2. Which ones do you keep for sale and which ones for consumption?
 - a. What share is sold or used for home-consumption?
 - b. If it is sold, where is it sold?
 - i. Why do you sell it there?
 - ii. Which kind of road connects you to the place of sale?
 - iii. Do you pay fees to the place of sale?
 1. How much?
 - iv. Who is responsible for the money from the sale?
3. Of the livestock kept, which is your main one?
 - a. *Follow-up question:* Is there a livestock that is more important to you?
4. Why do you keep these animals?
 - a. *Follow-up question:* Which of these animals do you consume at home?
 - b. *Follow-up question:* Which of these animals do you sell?

Irrigation and irrigation arrangement

1. Do you irrigate any of the crops?
Hint: if not, skip to the next section

Irrigators

1. Which crops do you irrigate?

APPENDICES

2. Who is responsible for irrigating the crops?
3. How do you irrigate?
 - a. Where do you get the water for irrigation?
 - b. What technology is used to irrigate?
Hint: Both water extraction and distribution
 - c. What are the costs involved in irrigation?
4. Are you in an irrigation group/society/water user association?
 - a. How many are you in the group/society/water user association?
 - b. Is the group/society/water user association registered?
5. How does the group/society/water user association operate?
 - a. Do you pay membership fees?
 - b. Is there any payment done to the group/society/water user association?
 - c. How are leaders elected in the group/society/water user association?
 - d. Is there a constitution/regulation/rule for the group/society/water user association?
 - i. How are these changes done?
 - e. Who can be members of the group/society/water user association?
 - i. Are there some specific criteria?
 - f. How are conflicts solved?
6. Do you have access to the water for irrigation any time, any day?
 - a. *Follow-up question:* Are there times when you do not have access for the water for irrigation?
7. Is there water stress in particular times of the year?
 - a. Has this changed over the years?
 - b. How do you or the community work to address this?
 - i. Is there an agreement on this?
 1. How did the arrangement come about?
8. Is irrigation helpful to you?
 - a. Does it help you have food at home?
 - i. If so how?
Hint: Avoid asking if it is for home consumption or sale in the market. Let the farmers come up with how it is helpful. Look out for pathways
9. Are there organizations that help out or give advice on irrigation in the area?
 - a. If so, who?
10. Is it possible to get credit to facilitate irrigation?
 - a. If so, where?
 - b. What are the set conditions for one to access the credit?
11. Does irrigation increase the labour requirement?
 - a. If so, how?
 - b. Is it worth it?

Non-irrigators

1. Why don't you irrigate the land?
2. What are the hindrances to you irrigating the land?
3. What are the advantages of irrigating the land?
4. What are the disadvantages of irrigating the land?
Hint: Do not combine question 3 and
5. Do you think not irrigating land it puts one at a worse position than people who irrigate?
Hint: ask this as the last question
 - a. If so, how?
Hint: Look out for more food, sell crops on the market (place of sale, price of sale, quality of sale), reliable production etc.
6. Are there organizations that help out or give advice on irrigation in the area?
 - c. If so, who?
7. Is it possible to get credit to facilitate irrigation?
 - d. If so, where?

APPENDICES

- e. What are the set conditions for one to access the credit?

Land access

1. Do you have ownership to the land you do agriculture on?
 - a. Who owns the land?
 - b. What are the rights to the land?
2. Did you lease in any land in the last one year?
 - a. What was the cost/arrangement of leasing?
Hint: money/share-cropping, contract...
 - b. What did you grow on the leased land?
 - i. Was it used for home consumption or for sale?
 - ii. Who controlled the proceeds from the sale?
3. Did you lease out land in the last one year?
 - a. What was the cost/arrangement of leasing?
Hint: money/share-cropping, contract...

Non-farm activities

1. Do you carry out any non-farm activities?
 - What are those activities?
- Comment: please probe for more, by asking "what else do you do when not in the farm?"*
2. In which months do you perform these activities?
 - a. *Follow-up question:* Why do you do these activities in this month?
 3. Do you earn from these activities?
 4. What do you do mainly with the earnings earned?

APPENDICES

Appendix 4: Household questionnaire

“Dear Sir/Madam. We are part of a team led by Nixon Murathi Kiratu who are studying aspects to do with irrigation and nutrition linkages in rural Kenya. Your willingness to participate in this survey is voluntary and highly appreciated. Your responses will be **completely confidential** and **anonymous** and will be merged with responses of other 384 farmers and analysed together in anonymized codes. Should you feel that you do not want to participate in this exercise, you have the freedom and right to do so and there will not be any penalties or consequences to that. If you have given your voluntary consent to participate in this interview, may we begin? Thank you for your kind co-operation. Should you have any further questions, the enumerator can also share contact information of Nixon Murathi Kiratu at your request.”

HOUSEHOLD ID

1	Household ID		8	County		12	First visit date	
2	Enumerator ID		9	Sub-County			Result: 1=Interview completed 2= Interview partly completed 3= Specify	
3	Date of interview		9	Division		14	Enumerator Name	
4	Start Time (24 Hr)		10	Village		13	Second visit date	
5	End time (24 Hr)		11	GPS Coordinates			Result: 1=Interview completed 2= Interview partly completed 3= Specify	
6	HH head Full Name					15	Enumerator Name	
7	Cell phone number							

DEMOGRAPHIC CHARACTERISTICS OF HOUSEHOLD MEMBERS (ad)

ID	Name	In which year was this person born?	Age (2020-ad01)	What is the sex of?	Relationship to current head	Marital status	Is..... currently attending school?	What is the highest level of education completed?	What year did come to reside here?	How many months in the period 2020 has this person been living at home?	Has this person been chronically ill for any consecutive month period in the last 12 months and unable to perform hh duties?	Household farm labour contribution
					Code ad03	Code ad04	1 = Yes 0 = No	Code ad06			1= Yes 0=No	Code ad10
memID	name	ad01	age	ad02	ad03	ad04	ad05	ad06	ad07	ad08	ad9	ad10

APPENDICES

<u>Relationship to head (ad03)</u>	<u>Marital Status (ad04)</u>	<u>Education levels (ad06)</u>			<u>Farm labour contribution (ad10)</u>	
1= head 8= son/daughter-in- law	1 = single	-99=don't	6=std 6	13=form 5	19=univ 1	1=Part-time
2= spouse 9= grandchild	2 = monogamously	-9=None 7=std 7		14=form 6	20=univ 2	2=Fulltime
3= own child 10=other relative	3 = polygamously married	0=nursery	8=std 8	15= college	21=univ 3	3=Does not work on farm
4= step child 11=unrelated	4 = divorced	1=std 1 9= form1		16= college	22=univ 4	
5= parent 12=brother/sister-in-	5 = widowed	2=std 2 10 = form		17= college	23=univ 5 &	
6= brother/sister 13=parent-in-law	6 = separated	3=std 3 11=form 3		18= college	above	
7= nephew/niece 14=worker	7 = other, specify_	4=std 4 12=form 4				
15=Other specify		5=std 5				

LAND HOLDING IN ACRES (period between 1st January 2020 and 31st December 2020)

How much land do you own in acres? _____

How much of your total land is under homestead? _____

Do you have a title deed for your land? _____ Yes=1 (all land), No=0 (no land), 2=partly, 3=under parent 4= under grandparent

Land category	Short rain season (2020)			Long rain season (2020)		
	Cultivated	Fallow		Cultivated	Fallow	
1. Own land (A)						
2. Rented in (B)						
3. Rented out (C)						
4. Total irrigated land						

What is the average cost of renting land per acre (KSh/per year)? _____

APPENDICES

CODES FOR NON-LABOUR PURCHASED INPUT USE MODULE						
Codes A			Codes B		Codes C	
Maize	Tea	Tree Tomato	1.	Kilogram	Grams	Seeds
Rice	Onion	Strawberry	Improved	Litre	Pick up	Bushes
Sorghum	Kales	Spring Onion	0. Local	90 Kg bag	Trees	45kg bag
Millet	Coffee	Desmodium		50 Kg bag	Green paper	Bottle top
Cassava	Napier grass	Spinach		25 Kg bag	bag	Seedlings
KK 15 Beans	Avocado	Arrow Roots		Gorogoro	Lines	Tonne
Other Field beans	Spider Plant	Green Peas		Debe	Packet (250g)	500 ML glass
Bananas	Vine Spinache	Pysallis		Wheelbarrow	Crates	25 grams
Cabbage	Pumpkin	Coriander		Ox-cart	Bundle	Cobs
Cowpea	Trees	Capsicum		Bunch (bananas)	Handful	Poles
Groundnut	Mangoes	Pepper		Piece/number	Cuttings	Crop failure/
Soybean	Guava	Grass		Not yet harvested (for	Vines	(MLND)
Sweet potatoes	Wheat	Butternut		perennials only)	Head load	Black paper bag
Orange Fleshed Sweet	Paw	Lemon		Stools	Lorry	
Potatoes (OFSP)	Tomatoes	Beetroot		Glas"		77Other
Black night shade	Loquat	Cucumber		Suckers		(specify)_____
Sugarcane	Green grams	Water melon		Bucket		
Pineapple		Tree Seedlings		ML		
Jute Mallow (Omutere)		Raspberry		Spoonful		
Amaranthas leaves		Gooseberry		5 kg bag		
(Emboga)		Pyrethrum		10 kg Bag		
Pumpkin leaves		Other_____		250 ML		
Sukuma wiki (Kales)		Other_____		Yellow paper bag		
Carrots		Other_____				
Passion Fruit						
Irish potato						
Bean leaves						

1	2	3	12	5	6	7	8	9	10	11
---	---	---	----	---	---	---	---	---	----	----

[illegible]

APPENDICES

CODES FOR CROP UTILIZATION MODULE			
Codes A Maize Rice Sorghum Millet Cassava Other Field beans Bananas Cabbage Cowpea Groundnut Soybean Sweet potatoes Orange Fleshed Sweet Potatoes (OFSP) Black night shade Sugarcane Pineapple Jute Mallow (Omutere) Amaranthas leaves (Emboga) Pumpkin leaves Sukuma wiki (Kales) Carrots Passion Fruit Irish potato Bean leaves Tea Onion Kales Coffee Napier grass Avocado Spider Plant Vine Spinache Pumpkin Trees	Tree Tomato Strawberry Spring Onion Desmodium Spinach Arrow Roots Green Peas Pysallis Coriander Capsicum Pepper Grass Butternut Lemon Beetroot Cucumber Water melon Tree Seedlings Raspberry Gooseberry Pyrethrum Other _____ Other _____ Other _____	Codes C Kilogram Litre 90 Kg bag 50 Kg bag 25 Kg bag Gorogoro Debe Wheelbarrow Ox-cart Bunch (bananas) Piece/number Not yet harvested (for perennials only) Stools Glas" Suckers Bucket Ml Spoonful 5 kg bag 10 kg Bag 250 Ml Yellow paper bag Grams Pick up Trees Green paper bag Lines Packet (250g) Crates Bundle Handful Cuttings Vines Head load	Seeds Bushes 45kg bag Bottle top Seedlings Tonne 500 Ml glass 25 grams Cobs Poles Crop failure/ (MLND) Black paper bag 77Other (specify) _____ Codes D 1. Farm gate 2. Village market 3. Main market 4. Collection center 77. Other (specify) _____ Codes E Own bicycle Boda-boda Hired truck PSV Donkey/oxen Walking Own truck Taxi Other (sp.) 99. NA

APPENDICES

Mangoes Avocado Guava Wheat Pawpaw Tomatoes Loquat Green grams		Lorry	Code F Male household head Female household head, Female spouse, Joint decision, Other hh member Other non-hh member Other (specify)_____
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APPENDICES

CROP UTILIZATION (period between 1st January 2020 and 31st December 2020)

1	2	3	4	5	6	7	8	9	10	11	12	13	14
Crop Code A (Aggregated crop)	Total Crop Output (Enter the total crop output from the plots)	Consumption	Saved as seed	Gift, tithe, donations, paid as wages	Stored	Quantity sold	Price	Point of most sales	Travel time to the point of sale (minutes)	Mode of transport	Who mostly decides on revenue use?	Who mostly decides technology use e.g. variety	Who mostly decides how much of the total output is consumed by the household?
Short rain													
Long rain													
Perennial crop													
Fruit trees													

APPENDICES

IRRIGATION

Season	Field no. [COPY FROM MODULE "LAND USE"]	Is the plot irrigated? 1=Yes 0=No (If "No," >> Next Plot)	If plot is irrigated, source of water for irrigation? 1=River 2=Lake 3=Dam 4=Pond 5=Groundwater 6=Harvested water 7=Other (specify)	If plot is irrigated using groundwater, was well drilled or hand-dug? 1=Drilled 2=Hand-dug	If plot is irrigated using groundwater, what is the depth of the well? 1=< 7 meters 2=8- 50 meters 3=>50 meters	Type of irrigation method 1=Furrow 2=Flooding 3=Sprinkler 4=Drip 5=Furrow 6=Level 7=basin 8=Bay/border strip 9=Bucket/hose/watering can 10=Other (specify)	What is the method of obtaining water? 1=Gravity 2=Hand/foot pump 3=Hand Bucket/hose 4=Diesel/petrol pump 5=Electric pump 6=Tractor pump 7=Other (specify)	How often do you irrigate? (# of times per CODE) 1=Days/week 2=Week 3=Two weeks 4=Month 5=Season 6=Year 7=Other, specify	At what time of the day do you irrigate? 1=Morning 2=Noon 3=Afternoon 4=Evening 5=Night 6=No specific time of the day 7=Other, specify	How well is this plot irrigated? Water is available: 1=Always when needed 2=Usually 3=Sometimes 4=Rarely 5=Never	What is the average length of time for which you irrigate per session? (# of long per CODE) 1=Minutes 2=Hours 3=Other, specify	Do you pay for water access? 1=Yes 0=No	If yes, which organization do you pay to?	How much do you pay? (# of times per CODE) 1= Week 2= Month 3 =Season 4 =Year	Amount	Period	
								No.			No.						

APPENDICES

Irrigation Pumps

If a pump is used (if answer above is, diesel/petrol pump, electric pump, tractor pump or any other pump specified by respondent)

Pump	Type 1=Hand/foot pump 2=Diesel pump 3=Electric pump 4=Solar pump 5=Tractor pump 6=Other (specify)	What plot is this pump used on? [COPY PLOT NUMBER from Irrigation part above]	Who owns the pump? 1=Household ownership 2=Jointly owned with other household's/farm entities 3=Farmer association 4=Water user association 5=Private company 6=Other farmer 7=Other (specify)	Year pump was purchased (if you own it)	What was the price of the pump when purchased?	Cost of fuel or electricity per production season paid by farmer	Repair cost per production season paid by farmer	Flow rate or horse power of the pump [enter either flow rate or horse power, if known]	Do you pay to use the pump? 1=Yes 0=No>> next question	If yes for question (9), how much (# per period per season?) 1=Day 2=Week 3=Two weeks 4=Month 5=Season 6=Year 7=Planting 8=Other, specify (Ksh)				
	CODE	FIELD NUMBER	CODE	YEAR	(Ksh)	Last long rain season	Last short rain season	Last long rain season	Last short rain season	Liter/ Second	Horse power	CODE	Last long rain season	Last short rain season
Pump 1														
Pump 2														

APPENDICES

LIVESTOCK PRODUCTION AND MARKETING

For the last **12 months (period between 1st January 2020 and 31st December 2020)**, please give details of revenue and cost of livestock production?

(Please include all animals on the farm last year also those that were later sold or died) If no livestock is owned skip to next module)

	1	2a	2b	3a	3b	4a	4b	5a	5b	6	7	8	9	10	11	12	13
	Animal species	Stock at the beginning of the period (01 Jan 2020)		Changes over the years				Stock at the end of 31 Dec 2020		Cash expenditures between 01/2020 and 12/2020 Value in KSh				Who decides sale?	Who decides revenue use?	Who decides technology use e.g. breed	Who mostly decides how much of the total output is consumed by the household?
		(If 0, skip to the next)		Home consumption		Sales											
		Unit	KSh	Units	KSh	Units	KSh	Units	KSh	Veterinary treatment	Feed	Hired labor	Others	B	B	B	B
1	Dairy cows/calves																
2	Cow/calves																
3	Goat																
4	Sheep																
5	Kuroiler/chicks																
6	Other chicken/chicks																
7	Donkeys																
8	Pigs																
9	Rabbits																
10	Ducks																
77																	

APPENDICES

For the last **12 months (01. Jan 2020 to 31. Dec 2020)**, please give details of production and revenue of the following livestock products?

	1 Animal product/services	2 Quantity produced		3 Quantity sold		4 Quantity Consumed		5 Price per unit	6 Who decides sale?	7 Who decides revenue use?
		Qty	Unit	Qty	Unit	Qty	Unit			
			A		A		A			
1	Milk									
6	Kuroiler Eggs									
2	Other Eggs									
7	Kuroiler Manure									
3	Manure									
4	Honey									
5	Hide									
77	Others specify_____									

Code A: 1=Kilogram, 2=Litre, 3=90 Kg bag, 4=50 Kg bag, 5=25 Kg bag, 6=Gorogoro, 7=Debe, 8=Wheelbarrow, 9=Ox-cart, 10=Bunch (bananas), 11=Piece/number, 77=Other (specify)_____

Code B: 1=Male household head, 2=Female household head, 3=Female spouse, 4=Joint decision, 5=Other hh member, 6=Other non-hh member, 77=Other (specify)_____

CREDIT

ACCESS TO CREDIT

CASH CREDIT

Did any household member try to get any cash credit during the 2020 crop year? 1=Yes 0=No	If yes, what was the intended purpose: 1=Agricultural purposes 2=Non-agricultural purposes 3=Both	Did you receive the cash credit that you tried to obtain? 1=Yes 2=No	If yes, how much cash credit in TOTAL did you receive (Ksh)	For the two main sources of cash credit, what was the source and the amount that you received from each? 1= neighbor 2=farmer group 3=SACCO/Cooperative society 4=commercial bank 5=relative/friend 6=NGO 7=Mobile loan (Mshwari/Fuliza/Equiloan/KCB Mpesa etc.) 8= Chama/table banking/group 9=local shopkeeper	How was the cash credit used? 1=Agricultural purposes 2=Nonagricultural purposes 3=Both	Who makes the decision to borrow from SOURCE 1 most of the time? 1=Self 2=Spouse	Who makes the decision to borrow from SOURCE 2 most of the time? 1=Self 2=Spouse	Who makes the decision about what to do with the money borrowed from SOURCE 1 most of the time?	Who makes the decision about what to do with the money borrowed from SOURCE 2 most of the time?	If you tried to get cash credit but did not get what was the reason for not getting? 1=no collateral
---	--	--	---	--	--	--	--	---	---	---

APPENDICES

If No, go to next module		If No, go to CRD1 1)		10=other, specify 11=employer 12=HELB 13=shylock 14=Church					3=Other hh member 4=Other non-hh member 5=not applicable	3=Other hh member 4=Other non-hh member 5=not applicable	1=Self 2=Spouse 3=Other hh member 4=Other non-hh member 5=not applicable	1=Self 2=Spouse 3=Other hh member 4=Other non-hh member 5=not applicable	2=had outstanding loan 3= don't know 4= did not have an account 5= lender lacked cash 6= not processed yet 7=other, specify
				SOURCE 1	AMOUNT 1	SOURCE 2	AMOUNT 2						
CRD1	CRD2	CRD3	CRD4	CRD51	CRD52	CRD53	CRD54	CRD6	CRD7	CRD8	CRD9	CRD10	CRD11

APPENDICES

IN KIND CREDIT

Did any household member try to get any credit in kind during the 2020/21 crop year? 1=Yes 2=No If No, go to the next module	If yes, what was the intended purpose? 1=Agricultural purposes 2=Non-agricultural purposes 3=Both	Did you receive the credit in kind that you tried to obtain? 1= Yes 2=No If No, go to next module	In what form was the credit in kind received? 1= Agricultural inputs 2=Household consumption 3=Both	Who makes the decision to borrow in kind most of the time? 1=Self 2=Spouse 3=Other hh member 4=Other non-hh member 5=not applicable	Who makes the decision about what to do with the item borrowed most of the time? 1=Self 2=Spouse 3=Other hh member 4=Other non-hh member 5=not applicable
CRD12	CRD13	CRD14	CRD15	CRD16	CRD17

Use of credit used for non-agricultural purposes

Main use of the credit 1= school fees 2 =medical 3 =business 4 =household 5=buy land	 6=build a house 7=other, specify 8=house improvement consumption 9=funeral expense 10=transport equipment	How is/was the credit repaid? 1=Crop revenue 2=Livestock revenue 3=Off farm income 4=Both livestock and crop revenue 5=other (specify_) 6=Not paid
CRD18		CRD22

APPENDICES

Fertilizer Subsidy and Availability

1a. Did you receive any fertilizer subsidy over the last three years? (1=Yes 2=No -> skip to 1c) **SUBSIDY_____** 1b. Please fill the table if the household received any fertilizer subsidy

(Enumerator Instruction: payment for partial subsidy and the market price should be recorded for the same unit as specified in Sbunit)

Year you received	Source of the subsidised fertilizer 1=Government NAAIAP 2=Government Other 3=NGO 4=Other (specify) _____	Quantity received	Unit 2 =kg 3 =litre 13=gram 8 =10 kg bag 7 =25 kg bag 9 =gorogoro 11=50 kg bag	Kgs of fertilizer received	What form of subsidy was it 1=Partial 2=Full
subsidyr	fsorc	sqnty	sbunit	sbkg	sform

1c. Have there been any periods during the last 3 years that you have tried to get fertilizer and have not been able to at the normal location?

(1=Yes 2= No -> go to 1e) **FERTGET_____**

1d. What were the reasons as to why you were unable to get the fertilizer at the normal source

Reason 1: _____

Reason 2: _____

LABOUR INPUTS (01. Jan 2020 to 31 Dec 2020 planting seasons, record days worked by plot)

Plot code	Plot manager (F=0, M=1; Joint=3)	Ask all activities E.g. Ploughing, harrowing, planting, thinning, applying fertilizer and /or manure, pesticide application (1 st and 2 nd), weeding (1 st and 2 nd , harvesting, threshing, shelling, bagging, bird-chasing	Days worked					
		Activity	Family labour			Hired labour		
			Total days	Males	Females	Total days	Males	Females
Short Rains								
Long Rains								

APPENDICES

1a. What is the average daily wage rate for men and women in this village? Men _____ KSh/day Women _____ KSh/per day

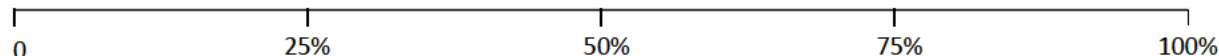
1.b. The hired labour works for how many hours per day? _____

1c. The family labour works how many hours per day? _____

TIME ALLOCATION AND DECISION MAKING

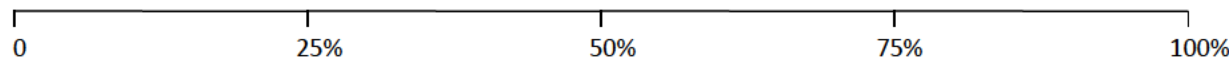
Enumerator Instructions: Introduce this section as follows: "As a farmer you may be involved in several activities such as farming, livestock, business activities and salaried activities." Show the respondent the lines and let him/her mark for you the points.

1a What Proportion of time did the Household Head allocate to farming activities (crop/livestock) in the last one year? TIMEHD _____



1b What Proportion of time did the spouse allocate to farming activities (crop/livestock) in the last one year? TIMESP _____

(no spouse use code -9)



1c Ask the exact hours for each of the activities listed below, the essence is to be as specific as possible and break down the activities as you go. Fill 0 if the activity is not applicable.

"I'm interested in everything you do (i.e. resting, eating, personal care, work inside and outside the home, caring for children, cooking, shopping, socializing, etc.), even if it doesn't take you much time."

Activity	Working/School Day (Monday to Friday)	Saturday	Sunday
Sleeping and resting			
Eating and drinking			
Personal care			
School (also homework)			
Work as employed			
Own business work			
Farming/livestock/fishing			
Shopping/getting service (incl health services)			
Weaving, sewing, textile care			
Cooking			
Domestic work (incl fetching wood and water)			
Care for children/adults/elderly			
Travelling and commuting			
Watching TV/listening to radio/reading			
Exercising			
Social activities and hobbies			
Religious activities			
Other, specify...			

APPENDICES

1d Indicate in the table below who in the household is the main decision maker on production marketing and income of the following enterprises in this Household

Enterprise	Participate in enterprise 1=yes 2=no	Irrigated/Irrigation water used? 1=yes 2=no	Who is the main decision maker on...				Prodec, makdec, irridec, useinc codes:
			Production	Marketing	Irrigation	Use of income generated	
enterp	partentr		prodec	makdec	irridec	useinc	
Food crops							1=head
Cash crops							2=spouse
Fruits							3=male children
Vegetables							4=female children
Other crops							5=head and spouse
Large Livestock							6=head, spouse & children
Small livestock							7=household non-members
							8=other (specify) _____
							9=brother
							10=daughter-in-law

LAND MARKETS

1 Did this household purchase or sell land in the **past 10 years** (since 2010)? (1=yes 2=no **if no, skip Q10b**): **LANDPS** _____

1a. Did you buy or sell land?

1=Bought/purchased 2=sold 3=Both

1.c If Yes, what was the reason for selling or purchase?

Purchase:

Selling:

1d. Please indicate the type of land transactions that the household was engaged in the table below.

Bought or sold the plot 1=purchased 2=sold	Size in acres	Is the land purchased/sold near a water source? 1=Yes 0=No	What is the water source for the purchased/sold land? 1=River 2=Canal 3=Dam 4=Water-pan 5=Pond 6=Groundwater 7=Harvested water 8=Other (specify	Was the water source there before or after purchase/selling? 1=Before 2=After	Is the land purchased/sold irrigated?
transc	acres	purcsold	watersource	orwater	purchsoldirri

APPENDICES

Bought or sold the plot 1=purchased 2=sold	Size in acres	Is the land purchased/sold near a water source? 1=Yes 0=No	What is the water source for the purchased/sold land? 1=River 2=Canal 3=Dam 4=Water-pan 5=Pond 6=Groundwater 7=Harvested water 8=Other (specify	Was the water source there before or after purchase/selling? 1=Before 2=After	Is the land purchased/sold irrigated?
transc	acres	purcsoldwatersource		orwater	purchsoldirri

1e. What is the land rental rate for one acre of good quality agricultural land for one year in this area? (Ksh per acre): **LRRY** ____

EXTENSION AND GROUP PARTICIPATION

1a. Did you **actively seek advice** on crop or livestock in **2020**? (1=Yes) (2=No **go to 1c**) **SEEKADV** ____

1b. If **Yes**, who did you **approach** for the advice? **ADVISOR1** ____ **ADVISOR2** ____

(1=public extension agent 2=private extension agent 3=neighbour/farmer 4= ASK Shows 5=traders/input dealers 6=radio /television 7=family/friend 8=newspaper/magazines 9=farmer organizations/cooperatives 10=field days/demonstrations 11= NGO agent 12=research organizations 13= other, specify____)

1c. If **No**, why didn't you seek advice? (**Give up to 2 reasons**) **SEEKNOT1** ____ **SEEKNOT2** ____

(1=long distance 2=expensive 3=time consuming 4=extension agents not available 5=don't need extension service 6=other, specify__7=not interested 8=was ill)

1d. Are you paying for **extension services**? (1=Yes **go to 1f**) 2=No) **PAYSERV** ____

1e. If **extension services** in general were to be availed at a fee, would you be **willing to pay**? (1=Yes) (2=No **go to 1g**) **AVAILFEE** ____ 1f.

How much would you be willing to compensate an extension worker who comes to train you for **three hours** on a **new technology** that you **urgently need** for the following:

Type of technology	Service	Individual	If indiv=14, ask how much	With other people	If others =14, ask how much	Group of 20 Members	If grp20 =14, ask how much	14= Above 320, specify the amount
	serv	indiv	othindiv	others	othoth	grp20	othgrp20	13 = KSh 320 12 = KSh 280 11 = KSh 240 10 = KSh 200 9 = KSh 180 8 = KSh 160
Irrigation	1							
Water efficiency	2							
Marketing	3							
Food and nutrition	4							

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Cash crop production	5							7 = KSh 140
Food crop production	6							6 = KSh 120
Livestock production	7							5 = KSh 100 Start at this level (go up or down depending on response)
								4 = KSh 80
								3 = KS 60
								2 = KSh 40
								1 = KSh 20
								0= Cannot pay for this specific service

1g. If not willing to pay for extension services, why?

WHYFEE _

(1=can't afford 2= it is a government role 3=free services available 4=bad past experience 5=don't need extension service 6=other, specify__)

BUSINESS AND INFORMAL LABOUR ACTIVITIES

We would like to know about all the off-farm income earning activities, including share dividends, your household was involved in, **except salaried employment pensions and remittances**. Please list the names of all persons from the demography table who indicated they had engaged in a business or informal labour activity, then enter their corresponding person code From the list below, please list all the informal income earning activities for which this person had primary responsibility at any time during the past 12 months (Feb 2020- Feb 2021) (include jua kali and farm kibaruas). **(Probe for charcoal burning, fishing and own tree selling)**

HH Member ID	Sector	Agricultural Related 1=Formal sector 2=Informal sector	Agricultural Related 1=Agricultural 2=Non-Agricultural related	Please classify each month's net earnings as:												Low earnings month			Average earnings month			High earnings month			Total business income
				0=none 1=low 2=average 3=high												#			#			#			
MemID	Sector	Agrirel		Jan	Feb	March	April	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	low	lgross	lcost	med	agross	acost	high	hgross	hcost	totbus

APPENDICES

SALARIED WAGE EMPLOYMENT/PERMANENT EMPLOYMENT ACTIVITIES

We would now like to talk about all **salaried employment** that anyone in this household engaged in during the past 12 months from **Jan 2020 to Dec 2020** including **pensions and remittances**. For remittances remember to separate into local and from abroad, depending on source. Include only income remitted back to

Person name Please list the names of all persons from the demography table who indicated they had engaged in salaried employment activities , then enter their correspondin g person code	Sector 1=Formal 2=Informal sector	Agricultural Related 1=Agricultural 2=Non- Agricultural related	What is this person's average monthl y wage? KSh	For how many months from Jan 2020 to Dec 2020 did this person earn this same monthly wage? Months	Total salar y for the year	Did any person receive remittance s in the last year? 1=Yes 0=No	If so, who received the remittance (s) 1=Male household head 2=Female household head, 3=Female spouse, 4=Both spouses, 5=Other hh member 6=Other non-hh member 7=Other (specify)_____	What is this person's average monthly receipt of remittances ? KSh	For how many months from Jan 2020 to Dec 2020 did this person receive remittances ? Months	Total remittance s for the year	What is the main sources of the remittances? 1=Son/Daught er 2=Other relative 3=friend 4=Well wisher 5=Other specify	If the household received remittance, what was the main mode of delivery? 1=Hand delivery 2=Bus 3=Western union 4=Posta pay 5=Money gram 6=Mobile money (Mpesa, Zap) 7=Commerci al bank 8=Telegraphi c money Order 9=Postal Order 10=Courier 12=Other, specify
MemID	Sector	Agrirel	mnwage	monthwage	totalsal	remit	remitID	Mnremit	remitwage	totremit		

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ACCESS TO RURAL SAVINGS/BANK ACCOUNTS

Does any member of the household have a savings/bank account? 1 = Yes 0 = No	Person with the account (Member number from the demog file) 0=joint account	Where is the savings account 1= Post bank 2 =SACCO 3=Commercial Bank 4=MFI 5=Groups (ROSCAs) 6=Village bank 7=Phone banking 8 = other, specify_		Which year did you open the account 99=don't know	Km to Banking point
	memID	saves		acopen	kmbank

Dietary Recall for YESTERDAY (2) (24hr DR)

Record Day _____

Respondent MEMID: _____

For administering to any female individual above 15 years and below 49 years. Includes all foods eaten by the individual of interest consumed inside or outside the home, irrespective of where they were prepared.

Now we would like to know, which food and drinks and how much of it did you (alone not your household) consumed yesterday? Please indicate which food item, procession and where did you get it from? Write down all the foods and drinks mentioned. When composite dishes are mentioned, ask for the list of ingredients. When the respondents has finished, probe for the meals and snacks not mentioned.

3	4	5	6	7	8	9	10	11	12
Main Dish	Quantity	Unit	How was the dish prepared	Ingredients	Quantity	Unit	Source of Ingredients 1=Own production 2=Purchased 3=Gift 77=Other, Specify	No of People ate from the Main Dish	Where was the food consumed? 1 Home 2 Hotel 3 Friend 4 Work 5 Market
		1=Small cup							
		2=Teaspoon							
		3=Tablespoon							
		4=Grams							
		5=Liter							
		6=Pinch							
		7=MI							
		8=Pint (500ml)							
		9=Serving spoon							
		10=Piece							
		11=Cup							
		12=Glass							
		13=Bundle							
		14=Kg							
		15=Slice							
		16=Cobs							
17=Plates									

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		18=Bowl 19=Handful 20=Gorogoro/2Kg Tin				18=Bowl 19=Handful 20=Gorogoro/2Kg Tin			
Breakfast									
Snack									
Lunch									
Snack									
Dinner									
Snack									

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ENUMERATOR: ASK THE PERSON RESPONSIBLE FOR HOUSEHOLD FOOD PREPARATION

HOUSEHOLD FOOD INSECURITY ACCESS SCALE (HFIAS)

PART A: FOR EACH OF THE FOLLOWING QUESTIONS, PLEASE CONSIDER WHAT HAS HAPPENED IN THE PAST 30 DAYS

1. During the last 30 days, did you worry that your household would not have enough food? 0 = Never 1 = Rarely (one or two times) 2 = Sometimes (3 to 10 times) 3 = Often (more than 10 times)	
2. Were you or any household member not able to eat the kinds of foods you preferred because of a lack of resources? 0 = Never 1 = Rarely (one or two times) 2 = Sometimes (3 to 10 times) 3 = Often (more than 10 times)	
3. Did you or any household member eat just a few kinds of food day after day due to a lack of resources? 0 = Never 1 = Rarely (one or two times) 2 = Sometimes (3 to 10 times) 3 = Often (more than 10 times)	
4. Did you or any household member eat food that you preferred not to eat because of a lack of resources to obtain other types of food? 0 = Never 1 = Rarely (one or two times) 2 = Sometimes (3 to 10 times) 3 = Often (more than 10 times)	
5. Did you or any household member eat a smaller meal than you felt you needed because there was not enough food? 0 = Never 1 = Rarely (one or two times) 2 = Sometimes (3 to 10 times) 3 = Often (more than 10 times)	
6. Did you or any other household member eat fewer meals in a day because there was not enough food? 0 = Never 1 = Rarely (one or two times) 2 = Sometimes (3 to 10 times) 3 = Often (more than 10 times)	
7. Was there ever no food at all in your household because there were no resources to get more? 0 = Never 1 = Rarely (one or two times) 2 = Sometimes (3 to 10 times) 3 = Often (more than 10 times)	
8. Did you or any household member go to sleep at night hungry because there was not enough food? 0 = Never 1 = Rarely (one or two times) 2 = Sometimes (3 to 10 times) 3 = Often (more than 10 times)	
9. Did you or any household member go a whole day without eating anything because there was not enough food? 0 = Never 1 = Rarely (one or two times) 2 = Sometimes (3 to 10 times) 3 = Often (more than 10 times)	

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How many meals, including breakfast are taken per day?			Do all household members eat roughly the same diet?		Who and how many in the household usually eat a more diverse variety of foods, a less diverse variety of foods, (including food consumed outside the house)?											
NUMBER			YES ► 16 NO		MORE DIVERSE LESS DIVERSE 0 NOT APPLICABLE											
...in the household?	...among children (6-24 months)? LEAVE BLANK IF NO CHILDREN	...among children (25-59 months)? LEAVE BLANK IF NO CHILDREN			Men	Women	Children 6-24 months									
10	11	12	13	14	15	16	17									
18	19	20						21								
How long does your food store usually last after the long rains harvest? Months	How long does your food store usually last after the short rain harvest? Months	Did you experience shortage of food in [MONTH] of 2020? 1=Yes 2=No						What were the main causes of food shortages? 1=Drought/poor rains 2=Crop pest damage 3=Small land size 4=Lack of farm inputs 5=Food in the market was very expensive 6=Not able to reach the market due to high transportation costs/poor roads 7=No food in the market 8=Floods/water logging/hailstorm 9=No money 10=poor health conditions 11Theft 12=Fire 13 other, specify [LIST UP TO 3 IN ORDER OF IMPORTANCE]								
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	1st	2nd	3rd

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CLIMATE CHANGE

Do you feel that there have been any changes between now and 10 years ago with regards to with regards to the amount of rain or rainfall pattern?

1=Yes, 2=No, 3=Don't Know

Please explain how the amount of rain and rainfall pattern changed

Which measures are you using to adapt to rainfall pattern change?

Do you feel that there have been any changes between now and 10 years ago with regards to temperature?

1=Yes, 2=No, 3=Don't Know

Please explain how the temperature changed?

Which measures are you using to adapt to rainfall pattern change?

CELL PHONE USAGE

1a. Is there a member of this household who owns a mobile phone?

1=Yes, 0=No

1b. If yes, who?

1=Male household head, 2=Female household head, 3=Female spouse, 4=Both spouses, 5=Other hh member

1b. If No, from **whom do you access a mobile phone?**

1=neighbour 2= relative 3=Other, specify_____

1d Please fill the table if the household has access to a mobile phone in the household.

Type of use of mobile phone	Use of mobile phone in the past year (1=yes, 2=no)	
	Household head	Spouse
	cellHH	Cellspouse
Staying in contact with family and friends		
To gather information about farm produce prices		
To locate buyers for your farm products		
To assist in running your own non-farm business		
To access credit (Fuliza, Mshwari, Equiloan, KCB-Mpesa)		
To send or receive money		
To get extension information from the provider		
Other uses (please list)		
Gather information about farm input prices		

APPENDICES

HOUSEHOLD ASSETS (PROMPT for each item as listed below)

At present, how much/many of the following does this household **own** that are **usable/repairable**?

(Enumerator Instructions: For value per unit, ask for the current purchase price of the asset as is or the current market value of the asset as it is.)

Agricultural asset		Quantity	Value per Unit (Ksh)	If Value/Unit not known Ask for Total Value	Total value of assets (Ksh)	Agricultural asset		Quantity	Value per Unit (Ksh)	If Value/Unit not known Ask for Total Value	Total value of assets (Ksh)
asset		qty	value	totval	assetval	asset		qty	value	totval	assetval
	Animal traction plough						Motorcycle				
	Battery						Ox plough				
	Beehive						Oxen				
	Bicycle						Panga				
	Biogas digester						Pestle and mortar				
	Boom sprayer						Piggery houses				
	Borehole						Planter				
	Cane crusher						Ploughs for tractor				
	Car						Pool table				
	Cart						Posho mill				
	Cattle dip						Poultry houses				
	Cereals sieve						Power saw				
	Chuff cutter						Radio				
	Combine harvester						Ridger/weeder				
	Cow shed (s)						Sewing/knitting machine				
	Dam						Sheller				
	Donkey						Solar panel				
	Donkey/ox cart						Spade/shovel				
	Electronics						Sprayer pump				
	Farm house(s)						Stores				
	Feed troughs						Television				
	Fish pond						Tractor				
	Fixed land line						Tractor trailer				
	Food store						Trailer				
	Furniture						Truck				
	Gas cooker						Tv				
	Generator						Vehicle(s)				
	Grinder						Water pump				

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	Harrow/tiller						Water tank				
	Houses (residential)						Water trough				
	Irrigation equipment						Weighing machine				
	Jaggery unit						Well				
	Jembe						Wheel barrow				
	Milk buckets						Wheelchair				
	Milking equipment						Zero-grazing units				
	Milking shed						Other(specify)				
	Mobile phone										

INFRASTRUCTURE

(Enumerator Instruction: Distance should be recorded in kilometers (Km))

What is the distance from your homestead to the nearest fertilizer seller (km) ?	fertskm	_____
How much does it cost to transport a 50 kilo bag of fertilizer from the nearest seller to homestead (Ksh)?	fertrans	_____
With what type of transport from seller to homestead? (1=car, 2=bus, 3=matatu, 4=bicycle, 5=donkey /oxcart, 6=Other specify, 7=boat, 8=donkey, 9=lorry, 10=motorcycle, 11=tractor, 12=wheelbarrow)	trantype	_____
What is the distance from your homestead to the nearest seller of hybrid seed (maize, rice, French beans) (km)?	certseed	_____
h) What is the distance from your homestead to extension advice (km) ?	dextn	_____
i) What is the distance from your homestead to veterinary help (km) ?	dvet	_____
j) What is the distance to the nearest A.I service provider (km)?	aikm	_____
k) What is the distance from your homestead to the nearest market place for farm produce (km) ?	mktkm	_____
l) What is the distance from your homestead to a motorable road (km) ?	dmtroad	_____
m) What is the distance from your homestead to a tarmac road (km) ?	dtmroad	_____
n) Is the nearest tarmac road better, worse or the same as in the last election (2017)? (1=better 2=worse 3=the same 4=not sure)	ctmroad	_____
o) What is the distance to the nearest pipied water source (km) ?	dph2o	_____
p) What is the distance to the nearest health centre (km) ?	dhlctr	_____
q) What is the distance to the nearest electricity supply (km) ?	delect	_____
r) What is the distance from your homestead to the nearest livestock market place (km) ? (-9=don't know)	animkt	_____
s) Do you/your spouse own a mobile phone? (km)	dtelep	_____
t) How much does it cost to transport one 90/100 kilo bag to the nearest market place (Ksh)?	mztrans	_____

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u) With what type of transport from your homestead to the nearest market place ? (1=car, 2=bus, 3=matatu, 4=bicycle, 5=donkey /oxcart 6=Other specify _____ 7=boat 8=donkey 9=lorry 10=motorcycle 11=tractor 12=wheelbarrow)	mztratyp	_____
v) What is the distance to the nearest town or headquarters ? (km)	distown	_____

FOOD SECURITY

1a. In the **last 12 months**, for how many months has the household relied **entirely on Relief food**? **RELIEF** _____

1b. What **coping mechanism** do you (your household) revert to **during famine or food scarcity**?

COPING1 _____

(0=never 1=food relief 2=rely on relatives/friends 3=skip some meals in a day 4=skip meals for entire day 5=take reduced meals 6=eat meals that are less preferred 7=consume wild food 8=consume immature crops 9=consume taboo/toxic foods 10=consume seed stocks 11=send household members to eat elsewhere 12=beg or engage in degrading jobs 13=withdraw children from school 14=allow children to eat more than adults 15=abandonment of children, elderly and the sickly 16=purchase food on credit 17=migration out of the area 18=sell livestock 19=dispose assets 20=other, specify _____)

1c. In the **last 12 months**, have you participated in a cash transfer program, either for senior citizens, orphans, or food security? **TRANSF** _____

(1 =Yes 2=No)

1d If 27c=yes, what was the amount and frequency (number of times) of transfer? **AMTTR1**_____ **TRAFREQ**_____

STORAGE FACILITIES FOR STAPLES

1a. Do you have a store for **grains**? (1=Yes 2=No (Go to Q29a)) **GSTORE**_____

1b. What type of store and capacity do you have? **STORET1**_____

STORET2_____

CAPACIT1_____ **CAPACIT2**_____

SUNIT1_____ **SUNIT2**_____

Store type codes:(1=Improved store 2=Traditional store 3=Room in the main house 4=Room in other houses) **Unit**

codes : (1=90kg bag 11=50kg bag 10=tons)

1c. Did you use any of your stores to store grains during the **2020** cropping year? (1=Yes 2=No (Go to next module)) **STORED**_____

1d. If **yes to 1c**, indicate the **grains** you stored, the duration (**no. of months**) of storage and any storage losses that you incurred?

Unit codes:	Type of store 1=Improved 2=Traditional 3=Room in main house 4=Room in other houses	Type of Grain stored (Use crop codes)	Quantity stored Quantity Unit	Month in which grain was stored.	Month most of the grain was out of store. (1=Jan..12=Dec -13=most still in store)	Quantity lost in storage (in stunit)	Main cause for storage losses	Cause for storage losses
1=90 kg bag 2=kgs 7=25kg bag 8=10kg bag 9=gorogoro (2kg tin) 10=tones 11=50 kg bag 12=debe (18kg tin)	store	grain	qstore stunit	mthin	mthout	qloss	stolos	1=storage pests 2=rotting 3=sprouting 4=theft 5=other (specify)

APPENDICES

OBSERVE AND ASK ABOUT THE FOLLOWING:

- 1a.** What is the **roofing** material of the **main house**? **ROOF** _____
 (1=grass /makuti 2=iron sheet 3=tiles 4=other, specify__5=tent-canvas)
- 1b.** What is the **wall** material of the **main house**? **WALL** _____
 (1=mud 2=bricks/stones 3=iron sheet 4=wood 5=plaster 6=other, specify__5=tent-canvas)
- 1c.** What is the **floor** material of the **main house**? **FLOOR** _____
 (1= earth 2=cement 3=wood 4=tiles 5=other, specify__)
- 1d.** What is the mode of ownership of the **main house**? **HSEOWN** _____
 (1= owned 2= rented 3= owned by relative 4=other, specify__)
- 1e.** What type of **toilet** do you use? **TOILET** _____
 (1= pit latrine 2= bush 3= flush toilet 4= other, specify__)
- 1f.** What is the **main** source of water for domestic use during the **wet-season**? **MAINWET** _____
 (1=pond 2=dam /sand dam 3=lake 4=stream/river 5=unprotected spring 6=protected spring 7=well 8=borehole
 9=piped into compound 10=piped outside compound 11=water tankers12=roof catchments 13=water hawkers-cart /boda-boda 14=
 other, specify____)
- 1g.** What is the **main** source of water for domestic use during the **dry-season**? **MAINDRY** _____
 (1=Pond 2=dam /sand dam 3=lake 4=stream/river 5=unprotected spring 6=protected spring 7=well 8=borehole
 9=piped into compound 10=piped outside compound 11=water tankers12=roof catchments 13=water hawkers-cart /boda-boda 14=
 other, specify____)
- 1h.** What is your **main cooking fuel**? **COOKFUEL** _____
 (1=electricity 2=paraffin 3=firewood 4=gas 5=charcoal 6=solar power 7=other, specify__)
- 1i.** What is your **main type of lighting**? **LITFUEL** _____
 (1=electricity 2=pressure lamp 3=tin lamp 4=fuel wood 5=lantern 6=solar power 7=other, specify__)
- 1j.** Is your family **better off, worse off, or about the same** as most households in this area? **COMPARE** _____
 (1=better off 2=worse off 3=about the same)

Thank You!