The impact of smallholder irrigation and water security on household welfare: The case of Tugela Ferry irrigation scheme in KwaZulu-Natal, South Africa

By

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Submitted in fulfilment of the requirements of the degree

Master of Science in Agriculture (Agricultural Economics)

in the

Discipline of Agricultural Economics

School of Agricultural, Earth and Environmental Sciences

College of Agriculture, Engineering and Science

University of KwaZulu-Natal

Pietermaritzburg

April 2013

Dedication

To my family, you are the best. I love you all!

Declaration

I, **Sinyolo Sikhulumile,** declare that;

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As candidate's main supervisor, I, **M. Mudhara,** agree to the submission of this thesis;

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As candidate's co-supervisor, I, **E.Z. Wale,** agree to the submission of this thesis;

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Acknowledgements

First and foremost, I am deeply grateful to the Lord God Almighty for His love and grace over my life. As always, I am so secure in your arms oh God! I am also deeply grateful to every one of the many people who were involved in the successful completion of this thesis. My particular indebtedness goes to my supervisors, Dr Maxwell Mudhara and Dr Edilegnaw Wale, whose guidance was considerably invaluable all the way. My heart-felt thanks also go to Sne, Liza, Makhosi, Jabu and Samke for their help in collecting data. This thesis would not be complete without special mention of my friends; Nondu, Voe, Fezile and Mbali, for their different roles in the translation of the questionnaire to Zulu and editing the final document. Further thanks are extended to the Canon Collins Trust scholarship for financial assistance throughout the tenure of the study, and to the Water Research Commission (WRC) project K5/2176 entitled "Empowerment of woman in rural areas through water use security and agricultural skills training for gender equity and poverty reduction in KwaZulu-Natal and North West Province", which initiated, managed and funded the field work. Finally, I am grateful to my family for their support throughout my studies.

Abstract

Smallholder irrigation has been promoted across the developing world as a means of poverty reduction and rural development. The potential of smallholder irrigated agriculture in alleviating rural poverty has led the South African government to prioritise and invest in irrigation establishment, rehabilitation and revitalisation. However, the extent to which smallholder irrigation has been able to reduce poverty in the rural areas of South Africa is not well understood. This study, therefore, aimed to contribute to smallholder irrigation literature in two ways. The first objective of this study was to conduct an in-depth impact evaluation of the Tugela Ferry smallholder irrigation scheme on household welfare using the treatment effect and propensity score matching (PSM) methods. Secondly, the study sought to investigate the determinants of household water security, and how the level of water security subsequently affects the farmers' household welfare. A stratified random sampling technique was used to obtain a sample of 186 irrigators and 70 non-irrigators in the Tugela Ferry area. Descriptive analysis highlighted that although the demographic characteristics of the farmers were not significantly different, the irrigators were characterized by better welfare indicators compared to non-irrigators. The Foster Greer Thorbecke (FGT) poverty indices also indicated that poverty incidence was more pronounced among non-irrigators than among irrigators. The results from the econometric models indicated that irrigation access plays an important role in the welfare of rural households, with irrigators consuming about R2,000 per adult equivalent per year more than the non-irrigators. While irrigation access is important, this study concluded that the poverty reduction effectiveness of smallholder irrigation can further be enhanced by ensuring that the irrigators are water secure. Factors such as age, off-farm income, duration of scheme membership, occurrence of conflicts, method of pumping water, location in the scheme and access to agricultural training influenced household water security. The study recommends that investments in smallholder irrigation should continue for poverty reduction, and that priority should be in ensuring water security not just irrigation participation. The study also recommends the introduction of small motorised pumps among the gravity-reliant irrigators and farmer training on water conservation techniques to improve the farmers' water security in the smallholder irrigation schemes. Although the study highlighted how perceptions of irrigators could be used to generate the water security index, the water security concept needs further investigation.

List of acronyms

ATE	Average Treatment Effect
ATT	Average Treatment effect on the Treated
DWA	Department of Water Affairs*
DWAF	Department of Water Affairs and Forestry*
FAO	Food and Agriculture Organization of the United Nations
FGT	Foster Greer Thorbecke
HDI	Historically Disadvantaged Individual
IB	Irrigation Board
IMT	Irrigation Management Transfer
MDGs	Millennium Development Goals
OLS	Ordinary Least Squares
PCA	Principal Component Analysis
PSM	Propensity Score Matching
SA	South Africa
WB	World Bank
WUA	Water User Association

*Department of Water Affairs (DWA) was formerly known as the Department of Water Affairs and Forestry (DWAF) before 2010.

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CHAPTER 1 INTRODUCTION

1.1 Background to the problem

Most of the poor people in developing countries depend directly or indirectly on smallholder agriculture for their livelihoods, and 75% of the poor live in rural areas (World Bank, 2008). Smallholder agriculture, therefore, is a relevant and potentially viable vehicle for reducing poverty and ensuring household food security in these rural areas (Altman *et al.*, 2009). Since poverty is more prevalent among rural dwellers, several authors agree that reaching the Millennium Development Goal (MDG) of halving poverty and hunger by 2015 requires high priority to smallholder agriculture (Smith, 2004; Matshe, 2009; Tshuma, 2012). However, despite its potential, smallholder agriculture's poverty reduction results in Africa have been disappointing (Lipton *et al*., 2003). Even though that rainfall is highly variable and insufficient in many cases, agricultural production in Africa is almost entirely rain-fed (You *et al.*, 2010). Lipton *et al.* (2003) argued that Africa has experienced significantly less reduction in poverty compared to other regions due to, among other factors, its less proportion of cultivated area under irrigation.

A general consensus is that irrigation remains a feasible and key strategy for improved smallholder agricultural production and/or productivity, household food security and rural poverty reduction in the developing countries (Kumar, 2003; Lipton *et al.*, 2003; Hussain and Hanjra, 2004; Gebregziabher *et al.*, 2009; Bacha *et al.*, 2011). In fact, Carruthers *et al.* (1997), cited in Hussain *et al*. (2006), argued that irrigation development is the most effective tool for rural poverty reduction compared to any other public development, particularly in arid and semi-arid climates. Although irrigation development is costly, and may have negative environmental and health consequences such as increased water logging, salinisation and water-borne diseases, it is an important factor in increasing crop productivity and improving overall agricultural performance (Hussain and Wijerathna, 2004). While access to irrigation decreases crop losses, it also increases the area under cultivation and crop intensity (Namara *et al.*, 2010). Moreover, it leads to poverty reduction by expanding opportunities for higher and more stable incomes, and by increasing prospects for multiple cropping and crop diversification (Hussain and Wijerathna, 2004).

Irrigation farming is imperative in South Africa as rain-fed crop production is inherently risky due to unreliable rainfall and frequent droughts (Cousins, 2012). South Africa is generally dry, with over 60% of the country receiving less than 500 mm of rain per annum on average, and with only 10% receiving more than 750 mm (World Bank 1994, cited in Cousins, 2012). The importance of irrigation farming in South Africa is underscored by the fact that the irrigated 8% of land under crop production contributes almost 30% of total agricultural production (Backeberg, 2006; NDA, 2007; Hope *et al.*, 2008). Smallholder irrigation accounts for about 0.1 million hectares (about 8%) of total irrigated land in South Africa (Tlou *et al.*, 2006; NDA, 2007; Van Averbeke *et al.*, 2011).

Although smallholder irrigation accounts for a small area of irrigated area in South Africa, it is important in South Africa for several reasons. Its importance arises primarily from its location in the rural areas, where poverty and food insecurity are concentrated (Perret, 2002; Sishuta, 2005; Vink and van Rooyen, 2009). South Africa is food secure at national level, while it is food insecure at the household level (Hart, 2009a; Backeberg and Sanewe, 2010). Therefore, the major area of concern in South Africa is to ensure availability of food at household level for the poor and food insecure households (Backeberg and Sanewe, 2010). Van Averbeke *et al.* (2011) highlighted the potential that smallholder irrigated farming has to significantly improve the welfare of participating homesteads in these densely populated rural areas. Furthermore, Van Averbeke *et al.* (2011) noted that smallholder irrigation can create employment in these underdeveloped rural areas, both directly and indirectly through forward and backward linkages.

In South Africa, the smallholder irrigation sector is also important because a large number of rural people benefit directly and indirectly (Speelman, 2009). The number of smallholder irrigators ranges between 200,000 and 250,000 participants (Backeberg, 2006; Van Averbeke, 2008). Assuming an average household size of 5 members (Machethe *et al.*, 2004), this translates to over a million rural people directly benefiting, at least partially, from smallholder irrigation. Therefore, as highlighted by Aliber and Hart (2009), the large number of rural households involved in smallholder irrigation necessitates prioritisation and government support. Accordingly, the South African government has prioritised and invested in the development of smallholder irrigation schemes as a rural development and poverty reduction strategy (Denison and Manona, 2007a; Van Averbeke *et al.*, 2011).

Smallholder irrigation schemes establishment, rehabilitation and revitalisation in South Africa were made possible through the investment of large public resources (Denison and Manona, 2007a). Shah *et al.* (2002) valued the public investments in smallholder irrigation at R2 billion (R40,000/ha). In fact, smallholder irrigation schemes continue to be a major budget item on many developmental and district municipality financial plans (Denison and Manona, 2007a). However, many researchers argue that, despite these public investments, smallholder irrigation schemes have failed to meet the rural development and poverty reduction objectives in South Africa (Bembridge, 2000; Perret, 2002; Hope *et al.*, 2008; Speelman, 2009; Yokwe, 2009; Fanadzo, 2012; Van Averbeke, 2012). According to Bembridge (2000), the performance and welfare impact of smallholder irrigation schemes has been poor, and fall far short of the expectations of many stakeholders. This is despite that smallholder irrigation has been successful in other developing countries, particularly in Asia (Hussain and Hanjra, 2004).

Several reasons have been presented in the literature for the failure of smallholder irrigation in South Africa. Tlou *et al.* (2006) highlighted that infrastructure deficiencies as a result of inappropriate planning and design of the irrigation schemes are a cause of this failure. However, most studies have identified institutional issues as the major challenge in smallholder irrigation in South Africa (Machete *et al*., 2004; Van Averbeke *et al*., 2011; Fanadzo, 2012). According to Van Averbeke *et al.* (2011), human (capacity) and social (institutional) resource problems are at the centre of the poor performance of smallholder irrigation schemes in South Africa. Fanadzo (2012) agreed that weak institutional and organizational arrangements are the major factors leading to the failure of most smallholder irrigation schemes. Moreover, Kemerink *et al.* (2011) highlighted that the failure of the smallholder schemes is due to the fact that the individual characteristics or heterogeneity of the irrigators have received little attention.

While too much attention has been placed on the physical (hydrology or engineering) aspects of irrigation at the schemes level, the social and distributive issues have largely been ignored in South Africa (Fanadzo, 2012). This neglect has left many farmers in irrigation schemes water insecure. As noted by Zeiton (2011), water insecurity is, in many cases, primarily social, with water security of some individuals being associated with insecurity of others. Adopted from Grey and Sadoff (2007) and Muller *et al*. (2009), household water security is defined in this study as access by the household to sufficient and reliable water to meet the agricultural needs throughout the year; the ability of the household to pay for the water and water-related services; and the household's ability to assert their right or entitlement to the water against other parties.

An irrigator's access to irrigation, although a necessary condition, is not sufficient for achieving water security and improved household welfare. Water security is important in enhancing the effectiveness of access to irrigation in poverty reduction and improving household food security. Findings from Hope *et al.* (2008), for instance, indicated that participating in smallholder irrigation results in expected income and food security benefits only to those farmers with secure irrigation access. Therefore, the understanding of how water security should be created and conferred to individual irrigators is an area in which research is urgently required (Hodgson, 2004). Hodgson (2004) argued that without sufficient water security in irrigation schemes, the irrigation management transfer (IMT) programmes, where the government cedes the operation of irrigation schemes to the farmers, would be unsuccessful over the long-term as farmers would stop farming as soon as government support is withdrawn.

1.2 Study motivation

The need for empirical evidence on the poverty reducing impacts of government programs cannot be overemphasised (Ravallion, 2008). However, despite a number of reports and studies on smallholder irrigation in South Africa, limited research has been devoted to the systematic and quantitative assessment of the poverty reduction impact of smallholder irrigation projects. Most of the previous studies on the impact of smallholder irrigation schemes in South Africa (Hope *et al*., 2008; Fanadzo *et al*., 2010; Van Averbeke, 2012) have been descriptive in nature and have not included any in-depth quantitative evaluations which controls for other confounding factors. Van Averbeke (2012), for example, used observations of cropping intensity as a performance and/or impact indicator, while Hope *et al*. (2008) relied on gross margin analysis. Although these evaluations are important and part of the measurements of poverty impacts of smallholder irrigation, they are not complete as they do not evaluate direct irrigation impact on household welfare.

Other economic evaluations and analyses in the South African smallholder irrigation literature have focused on water use efficiency, willingness to pay, valuation of water and financial viability of these smallholder irrigation projects (Kamara *et al.*, 2002; Speelman, 2009; Yokwe, 2009; Speelman *et al.*, 2010). As noted by Van Averbeke *et al*. (2010) and Van Averbeke (2012), information on the incomes and/or expenditures of plot holders and on the contributions of irrigation farming to household incomes is limited in South Africa. As such, the poverty reduction impact of smallholder irrigation remains relatively not well understood in South Africa. It can, therefore, be argued that much of the discussions about the role and/or failure of smallholder irrigation projects and policies in South Africa are based on limited empirical evidence. Yet, effective discussions and policies should be based on empirical evidence. Project impact evaluations provide foundations for evidence-based policies (Cobb-Clark and Crossley, 2003).

Despite a number of irrigation impact studies elsewhere (e.g., Namara *et al*., 2008; Bacha *et al*., 2010; Kuwornu and Owusu, 2012), there still remains a need for quantitative impact evaluations of South Africa's specific irrigation schemes. This is because irrigation schemes are not homogenous between (and even within) countries but are case specific due to factors such as objective, natural resource base, technology, scheme and plot size, farmer profile and marketing opportunities (Bembridge, 2000; Denison and Manona, 2007a; Dillon, 2008; Van Averbeke, 2008). This study, therefore, aimed to undertake an in-depth impact evaluation of the Tugela Ferry irrigation scheme and provide empirical evidence of the role of smallholder irrigation schemes on household welfare in South Africa.

Unlike previous studies, this study went beyond just evaluating the impact of irrigation participation, but its other objective was to assess the extent to which variations in the water security level of irrigation participants influence household welfare. Previous irrigation impact evaluation studies have assumed that irrigation participation results in the same level of water security among the individual irrigators. This assumption is hard to defend, as heterogeneity among the irrigators plays a role in determining the household water security level, given irrigation access. Little scientific knowledge exists on key determinants of water security and how it enhances the anti-poverty impacts of irrigation. Against this background, this study sought to investigate how the physical, socio-economic and institutional factors interact to influence the level of water security of an individual farmer, and how this water security level subsequently affects the farmer's household welfare. Because Mnkeni *et al.* (2010) reported that water distribution inequities were one of the major problems in the Tugela Ferry smallholder irrigation scheme, the scheme was deemed appropriate to achieve the study objectives.

In summary, the study's main goal was to answer the following two important questions empirically: To what extent do smallholder irrigation schemes improve household welfare? To what extent do variations in water security in an irrigation scheme influence household welfare? Information about how irrigating households vary by water security status, and the extent to which this relates to socio-economic and institutional variables, is central to questions such as how to target the poor and disadvantaged in the irrigation schemes. This knowledge is critical as it could assist in effective institutional design of new schemes and also recommend priorities when planning the revitalisation of existing schemes and the designing of successful IMTs. The research questions of the study were addressed by achieving the objectives listed in the next section.

1.3 Study objectives

Generally, the study's objective was to evaluate the impact of smallholder irrigation and water security on rural household welfare. Specifically, the study's objectives were to:

a) Evaluate the impact of the smallholder irrigation on rural household consumption expenditure;
b) Investigate the factors that determine an irrigator's water security level and;
c) Evaluate the impact of water security on rural household consumption expenditure.

PCA was used to generate the water security index while OLS was used to estimate the determinants of water security.

1.4 Organisation of the study

The thesis is organised into six chapters. The first chapter has motivated the research problem and the objectives of the study. The second chapter presents the literature on the role of smallholder irrigation in poverty reduction. The major focus of the literature review is the South African experience, though relevant global experiences are also discussed. The third chapter introduces the study area, the analytical framework and the empirical models used. The fourth chapter presents the first set of results, which focuses on the evaluation of the impact of the Tugela Ferry irrigation scheme on household welfare. The second set of results is presented in chapter five. This chapter focuses on generating the water security index and estimating the determinants of water security. The impact of water security on rural household welfare is also examined in this chapter. The conclusions drawn and policy recommendations made are presented in the final chapter.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

Smallholder irrigation plays an important role in the fight against rural poverty in developing countries. Accordingly, the South African government has invested substantially in smallholder irrigation. This chapter presents an overview of smallholder irrigation in South Africa, and synthesises the linkages among irrigation access, water security and household welfare. Factors that influence the poverty-reduction impacts of smallholder irrigation are also discussed. Furthermore, evidence from other developing countries in Sub-Saharan Africa and beyond is presented. Before this, however, the next section describes the main concepts used in this study.

2.2 Concepts and definitions

Concepts such as poverty, food security and water security have been defined and measured in different ways by different researchers. This section discusses these concepts drawing from the literature.

2.2.1 Poverty

Poverty is failure to meet basic human needs (World Bank, 2005). There is, however, a great variation in the manner in which poverty is defined and measured in developing countries (Hussain *et al.*, 2006; Namara *et al.*, 2008; Bacha *et al.*, 2011; Howe *et al.*, 2012; Tshuma, 2012). Although poverty has historically been described mainly as the inadequacies of income, consumption and wealth, the multiple dimensions of poverty and their complex interactions are now widely recognized (Hussain and Wijerathna, 2004; Hussain *et al.*, 2006; Namara *et al.*, 2008; Tshuma, 2012). Namara *et al.* (2008:98) identified poverty dimensions as "isolation, deprivation of political and social rights, a lack of empowerment to make or influence choices, inadequate assets, poor health and mobility, poor access to services and infrastructure, and vulnerability to livelihood failure."

Poverty is divided into two categories: absolute poverty and relative poverty. Absolute poverty denotes the failure to purchase the minimal quantity of basic goods and services required for human survival (Frye, 2005). In other words, absolute poverty refers to subsistence below minimum, socially acceptable living conditions, usually established based on nutritional requirements and other essential goods (Frye, 2005). Relative poverty, in contrast, is defined as when individuals, families and groups in the population "lack the resources to obtain the types of diet, participate in the activities and have the living conditions and amenities which are customary or at least widely encouraged or approved, in the societies to which they belong" (Townsend, 1979 cited in Frye, 2005:4). The relative poverty concept argues that an individual is poor when he/she is very much worse off than other people in their society (Tshuma, 2012). Thus, one's poverty status is measured against other people within the same society.

The preferred indicators of poverty and living standards have traditionally been reported using income or consumption expenditure (Achia *et al.*, 2010). Poverty is generally measured using income in developed countries while consumption expenditure is a preferred poverty measure in developing countries (World Bank, 2005; Achia *et al.*, 2010). By comparison, expenditure measures are much more reliable and easier to collect than income, especially in most rural settings (Filmer and Pritchett, 2001). The limitation of the income or consumption approach is the extensive data collection required, which is time-consuming and costly (Vyass and Kumaranayake, 2006). Given the resource constraints to measuring household income or expenditure in developing country settings, other methods of developing poverty indices have been used. Several authors have suggested the asset-based approach as an alternative method of measuring poverty (Filmer and Pritchett, 2001; Vyass and Kumaranayake, 2006; Achia *et al.*, 2010; Howe *et al.*, 2012).

The asset-based approach involves data collection of variables that capture living standards, such as household ownership of durable assets (e.g. car) and infrastructure and housing characteristics (e.g. source of water, sanitation facility) (Vyass and Kumaranayake, 2006). However, there is no agreement on the use of the asset-based approach (Vyass and Kumaranayake, 2006; Namara *et al.*, 2008). One weakness of the asset-based poverty measures is that they are more reflective of longer-run household wealth or living standards, but fail to take account of short-run or temporary interruptions, or shocks to the household (Filmer and Pritchett, 2001). Another weakness of the asset-based poverty measures is that conceptually, wealth is a stock, not a flow concept. If a household is depleting its asset base and another building its asset base, but these two have the same level of asset at a given moment in time, asset-based approach will put these two households at the same poverty level. However, the poverty status of these households should be different.

2.2.2 Food security

Food security is one dimension of poverty, and it does not capture all the dimensions of poverty (Hendriks, 2005; Tshuma, 2012). They are highly correlated though. Food security is limited only to having the right type of food in correct qualities and quantities (Tshuma, 2012). Food security is defined as when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life (FAO, 2001). This widely accepted definition points to the following dimensions or pillars of food security: food availability, food access, utilization and stability (FAO, 2006).

Food availability refers to the availability of sufficient quantities of food of appropriate quality, supplied through domestic production or imports (including food aid) (FAO, 2006). Food access, on the other hand, refers to access by individuals to adequate resources for acquiring appropriate foods for a nutritious diet. They should be able to access the food they prefer in a socially acceptable way (Hart, 2009b). The third pillar of utilization refers to use of food through adequate diet, clean water, sanitation and health care to reach a state of nutritional well-being where all physiological needs are met (FAO, 2006). People must be able to select, store, prepare, distribute and eat food in ways that ensure adequate nutritional absorption for all members of the household (Hart, 2009b).

The last pillar of food security, stability, points to the fact that to be food secure, a population, household or individual must have access to adequate food at all times. They should not risk losing access to food as a consequence of sudden shocks (e.g., an economic or climatic crisis) or cyclical events (e.g., seasonal food insecurity) (FAO, 2006). The concept of stability can therefore refer to both the availability and access dimensions of food security (FAO, 2006; Hart, 2009b). A distinction is frequently made between transitory and permanent food insecurity (Pinstrup-Anderson, 2009). Transitory food insecurity describes periodic food insecurity such as seasonal food insecurity, while permanent food insecurity describes a long-term lack of access to sufficient food (Pinstrup-Anderson, 2009).

According to Hendriks (2005), measuring food security is complex, extensive and expensive, and is often limited by data and/or resource availability. Hendriks (2005) summarized the studies in South Africa that have measured food security using different methods. Some studies have used household perceptions of food insecurity as an indicator of food insecurity, others have used the food security index while others income or expenditure. The income or expenditure approach is the single most important determinant of a household's ability to meet food security needs (Hendriks, 2005). Several studies that discuss the concept of food security and the different ways of measuring it have been done in South Africa (Hendriks, 2005; Altman *et al.*, 2009; Pinstrup-Anderson, 2009; Hart, 2009a; Hart, 2009b; Aliber, 2009).

2.2.3 Water security

Water security is an emerging concept, and there is no universal definition. Instead, there are multiple definitions which are often competing and evolving (GWP, 2000; Grey and Sadoff, 2007; Schultz and Uhlenbrook, 2007; Norman *et al.*, 2010). The GWP (2000:12), for instance, defined water security as meaning that "every person has access to enough safe water at affordable cost to lead a clean, healthy and productive life, while ensuring that the natural environment is protected and enhanced." Although this definition brings out some components of water security such as the water availability, affordability, and environmental dimensions, its limitation is that it focuses on water availability and affordability for mainly household consumption use.

Grey and Sadoff (2007:548), on other hand, defined water security as "the availability of an acceptable quantity and quality of water for health, livelihoods, ecosystems and production, coupled with an acceptable level of water-related risks to people, environments and economies." In simple terms, water security involves harnessing the productivity of water while limiting its negative impact (Grey and Sadoff, 2007). Grey and Sadoff (2007)'s definition is more comprehensive, as it indicates the importance of ensuring secure water access for livelihoods and productive uses, not just consumptive use. The weakness of this definition, however, is that it applies at the national level and fails to address the requirements at local or household level for achieving water security for irrigating households (Muller *et al.*, 2009).

The water security concept is related to concepts such as food security in that there is need to ensure that the population has access to sufficient water to meet all its needs (productive or consumptive). However, the difference is that unlike in food security, it is not only the absence of water that causes insecurity, but its presence as well. The destructive element of water in its natural, unmanaged state e.g., floods, also causes water insecurity (Grey and Sadoff, 2007). Due to the close relation between the food security and water security concepts, Muller *et al*. (2009) suggested that they both should be considered in a similar manner. Muller *et al*. (2009) argued that, as it is widely recognized that food security needs to be considered at both household and national level, water security should also be considered in a similar way, particularly in the rural context.

This, however, has not been the case so far. In fact, the common feature of the different definitions cited above is that they relate to water security as it applies mainly at national level. The emphasis is on the availability of water in a country, and the investments needed to ensure that water reaches the population of that country in appropriate quantities and qualities. An attempt to adapt Grey and Sadoff (2007)'s definition to apply at the irrigation scheme level is presented in Muller *et al*. (2009), who highlighted that water security at irrigation scheme level is achieved when the social and productive potential of water has been harnessed adequately to the benefit of all the irrigators, and its destructive potential is sufficiently contained. This definition albeit being relevant to this study, does not present itself to ease of measurement. In order to operationalise the definition for this study, some elements were modified and/or added.

Firstly, all the definitions emphasise the need to ensure reliable water availability to achieve water security, thus this aspect was maintained. Secondly, the ability of the household to access the water is critical. Access here implies the household's ability to afford the water, and also the rights or entitlement to the water. It is acknowledged that water security of different farmers may not be the same due to their geographic location in the irrigation scheme, gender, and other socio-economic factors. The rights of the individual farmers and their ability to exercise those rights are very pivotal in ensuring their water security. Water security, according to Cremers *et al.* (2005), implies that an irrigator is able to materialize water use rights now and in the future, and to avoiding, or controlling the risks of, unsustainable water management. However, this level of water use rights may not be attainable in rural areas as it implies formal rights. Water use rights in the rural areas are mainly informal, and are governed by customary law (Boelens *et al.*, 2007). This study focussed on the question of whether a particular farmer is able to seek some form of recourse if they do not receive water they are entitled to. The other aspect of water security is that of the destructive element of water. Since this applies mainly with regards to water in its unmanaged state, this aspect was dropped as this study focusses on water security at a household level from managed irrigation.

For the purpose of this study, household water security was defined as access by the irrigating household to sufficient and reliable water of suitable quality to meet their agricultural use needs and their ability to assert the water rights against other parties. The key aspects of water security in this definition are; access to reliable and adequate water supply, the ability of the household to pay for the water, and their right or entitlement to the water which they are able to assert against other parties. Water security was, therefore, understood as a continuum of these above-mentioned components, where a household scoring high on these components is more water secure than the one scoring less. Water insecurity was, thus, defined as the perceived difficulty farmers face in securing adequate and reliable access to water for agricultural production (Rijsberman, 2006; Komnenic *et al.*, 2009). Cullis and O'Regan (2004) define water insecurity as a lack of capability to obtain water or as lack of entitlement for water. The water security variable is, therefore, aimed to capture whether farmers have or lack these capabilities.

2.3 Overview of irrigation in the developing countries

Irrigation refers to "the purposive, organized, controlled, and artificial supply of water to a cropped area in order to complement rainfall and to overcome drought, and to reach a given crop production objective" (Tlou *et al*., 2006:12). Irrigation water is applied to ensure that the water available in the soil is sufficient to meet crop water needs and thus reduce water deficit as a limiting factor in plant growth (Van Averbeke *et al.*, 2011). Irrigation farming plays an important role in food production and food security in the world today. About 30% of the world's food production comes from about 18% of the total cultivated land under irrigation (FAOSTAT, 2012). There are wide variations in the proportion of irrigated agricultural land in the developing world, with 37% in Asia, 15% in Latin America, 6% in Africa and 4% in Sub-Saharan Africa (FAOSTAT, 2012). Irrigation, therefore, currently plays a less significant role in African agriculture compared to other regions as Africa's irrigated cultivated land is way lower than the world average.

As highlighted earlier, Lipton *et al.* (2003) argued that Africa's poor performance in terms of poverty reduction can be to a large extent attributed to its less reliance on irrigation farming. According to Lipton *et al.* (2003), differences across regions, countries and areas within countries in terms of irrigation access is an important factor in determining rates of poverty reduction. The fact that Asia has experienced significant poverty reduction, while poverty has increased in Africa (Faurès and Santini, 2008; Bacha *et al.*, 2011) in recent years is no coincidence but an indication of the key role irrigation plays in poverty reduction, *ceteris paribus* (Lipton *et al.*, 2003). As reported by You *et al.* (2010), agricultural production in Africa is almost entirely rain-fed despite that rainfall is highly variable and insufficient in many cases (You *et al.*, 2010). Low levels of irrigation in Africa are as a result of high irrigation investment costs, declining world food prices, perceived failures of many past irrigation projects, limited government commitment, rugged topography and poor rural infrastructure, heterogeneous and fragmented farmers, low population densities; and diets tied to crops with low water requirements (Inocencio *et al.*, 2007; You *et al.*, 2010).

It is largely acknowledged in the literature that the Green Revolution in Asia could not have happened without investments in irrigation water (Lipton *et al.*, 2003; Hussain, 2007a; Hussain, 2007b; Turral *et al.*, 2010). Irrigation was an important element of the Green Revolution package which not only lifted large numbers of rural Asians out of poverty but also created conditions that were conducive for economic development (Turral *et al.*, 2010). A similar development path as that of Asian countries has been recommended for Africa (Lipton, 1996 cited in Van Averbeke, 2012). This is so, given that the potential of irrigation development for Africa, and Sub-Saharan Africa in particular, is large (Inocencio *et al*., 2007; You *et al*., 2010). According to You *et al*. (2010), there is a need to prioritise irrigation development in Africa not only because of the existence of water resources, but also because of the high value of irrigated agriculture on the continent and the large number of rural poor that could benefit from productivity enhancement as a result of irrigation investment.

Many countries in Sub-Saharan Africa, South Africa included, have realised the important role of irrigation in food production, and irrigation investments have increased in the region. You *et* *al.* (2010) reported that the average rate of expansion of irrigated area over the past 30 years was 2.3% in both Sub-Saharan Africa and all of Africa. Total irrigated land in Africa is estimated to be about 12.2 million hectares and six countries, namely Egypt, Madagascar, Morocco, Nigeria, South Africa and Sudan account for nearly 75% of this total irrigated land (FAOSTAT, 2012). The 1.3 million hectares of irrigated land in South Africa constitute about 11% of the total irrigated land in Africa. Despite some notable irrigation expansion, the developmental impact of smallholder irrigation in Sub-Saharan Africa has been limited and below expectations (Inocencio *et al.*, 2007; García-Bolanos *et al.*, 2011).

According to Van Averbeke *et al.* (2011), irrigated agriculture presents an attractive investment in South Africa as the water deficits caused by low and erratic rainfall limits rain-fed crop production in most of South Africa. DWAF (2004) agreed, noting that water scarcity is a major constraint to socio-economic development in South Africa. Therefore, the government of South Africa has invested significantly in irrigation development in South Africa. Smallholder irrigation, particularly, has received high priority in the rural areas to reduce poverty and ensure household food security. The next section discusses the nature of smallholder irrigation in South Africa.

2.4 The nature of smallholder irrigation in South Africa

The agricultural sector is the highest consumer of water in South Africa, accounting for about 62% of the total water used, while it directly contributes only about 4% of GDP (NDA, 2007; Kanyoka *et al.*, 2008). Although there are efforts to change it, South Africa’s agricultural sector in general, and the irrigation sector in particular, is characterised by a dualistic production structure (Backeberg and Sanewe, 2010). This dualistic production structure consists of two categories of farmers: the large-scale farmers and the small-scale farmers. Large-scale irrigation refers to the modern, commercial irrigation operations undertaken by an estimated 28,350 farmers whose majority are white men (Backeberg, 2006; Van Averbeke, 2008). The large-scale commercial farmers produce for local and export markets (Backeberg and Sanewe, 2010). Small-scale irrigation, in contrast, refers to the traditional, subsistence irrigation activities undertaken by an estimated 200,000-250,000 farmers whose majority are black women (Backeberg, 2006; Tlou *et al.*, 2006). The small-scale irrigators mainly produce for household consumption.

Small-scale irrigation farming uses about 4% of all irrigation water, while the large-scale commercial farming uses the remaining 96% of irrigation water (Perret, 2002). Whereas the main criteria often used to classify farmers as small-scale include land size, purpose of production (subsistence or commercial), and income level (whether poor or rich), racial group plays a big role in classifying South African farmers (Fanadzo, 2012). In the South African context, small-scale farmers are defined as black[1] farmers most of whom reside in the former homelands (Machethe *et al.*, 2004; Fanadzo, 2012). Terms used to describe small-scale farmers in South Africa include smallholder farmers, resource-poor farmers, peasant farmers, food deficit farmers, household food security farmers and land reform beneficiaries (Machethe *et al.*, 2004). It is generally accepted that the divide between large-scale commercial farms and small-scale farms in South Africa is a legacy of the racially discriminatory policies of the past (Van Averbeke, 2008; Vink and van Rooyen, 2009).

According to Vink and van Rooyen (2009), the policies during the apartheid era were biased towards the white-dominated large-scale farms, while inhibiting agricultural growth and development among the black-dominated small-scale farms. Therefore, as highlighted by Denison and Manona (2007b), the word smallholder in South Africa not only recognises a characteristic of small farm size, but also a partially developed link to the larger economic system. While large-scale farmers have access to fully formed external markets, small-scale farmers do not (Denison and Manona, 2007b). The fact that the market-oriented part is dominated by white farmers and the subsistence part by black farmers is a cause for concern from a political perspective (Backeberg, 2006). There is, therefore, a political desire to improve the productivity, profitability and sustainability of smallholder agriculture in South Africa through investments in smallholder irrigation schemes (Backeberg, 2006; Denison and Manona, 2007b).

Van Averbeke (2008) categorized smallholder irrigation into four groups, namely (i) farmers on irrigation schemes; (ii) independent irrigation farmers; (iii) community gardeners; and (iv) home gardeners. This study is concerned particularly with the smallholder irrigators operating on irrigation schemes. Although smallholder irrigation schemes vary in size (Fanadzo, 2012), Van

[1] It should be noted, however, that not every black farmer is a smallholder farmer and that smallholder farmers are not a homogenous group (Machethe *et al*., 2004).

Averbeke (2008) defined smallholder irrigation schemes as irrigation projects larger than 5 ha in size that were established in the former homelands or in the resource poor areas by black people or agencies. These irrigation projects involve many farmers and their major objective is to assist in rural poverty reduction and development (Van Averbeke, 2008). According to Van Averbeke (2012), these irrigation schemes were established specifically for occupation by black farmers and they involve multiple plot holdings depending on a shared distribution system for access to irrigation water. The key features of the smallholder irrigation schemes are that they usually involve a gravity-based supply system, farmers have limited average plot sizes, and production is prominently subsistence oriented (Perret, 2002; Perret and Geyser, 2007).

About 302 smallholder irrigation schemes existed in South Africa in 2010, with a command area of 47,667 ha (Van Averbeke *et al.*, 2011; Fanadzo, 2012; Van Averbeke, 2012). This represents about 48% of the total smallholder irrigation area in the country and about 4% of the 1.3 million ha under irrigation at the national level (Backeberg, 2006; Van Averbeke, 2008). Van Averbeke *et al*. (2011) presented a number of key facts about smallholder irrigation in South Africa. In terms of the beneficiaries, the study reported that there were 34,158 plot holders in smallholder irrigation schemes in 2010. Rivers were reported to be the main source of water for smallholder irrigation schemes in South Africa, while water was mainly pumped to the plots. According to the study, a total of 96.7% of smallholder irrigated land obtained its water from rivers, while small percentage obtained water from either groundwater (3.0%), municipal water (0.2%) or spring water 0.1%. The study also reported that water was pumped on 48.5% and gravitated on 34.6% of the smallholder irrigated land. The remainder (16.9%) relied on a combination of both gravity and pumping.

The largest number of smallholder irrigation schemes is located in Limpopo Province (about 56%), followed by the Eastern Cape Province (about 23%), and then KwaZulu-Natal Province (about 12%) (Denison and Manona, 2007b; Van Averbeke *et al.*, 2011). The above-mentioned percentages indicate that 80% of smallholder irrigation schemes in South Africa are located in these three provinces, while the remainder are scattered across the other provinces. As reported in Van Averbeke *et al*. (2011), smallholder irrigation sustainability is a major challenge in South Africa. Of the 296 smallholder irrigation schemes with known operational status in 2011, above

30% were not operational. Table 2.1 shows the operational status of smallholder schemes by province in South Africa in 2010.

Table 2.1 Operational status of smallholder irrigation schemes by province in South Africa, 2010

Province	**Number of operational schemes**	**Number of non-operational schemes**	**Number with unknown operation status**	**Total**
Limpopo	101	69	0	170
Eastern Cape	51	16	5	72
KwaZulu-Natal	35	0	1	36
Mpumalanga	7	2	0	9
Western Cape	7	1	0	8
Northern Cape	2	1	0	3
Free State	1	1	0	2
North West	2	0	0	2
Total	206	90	6	302

Source: Van Averbeke *et al*. (2011).

The majority of these non-operational schemes were located in the Limpopo and Eastern Cape provinces, with 69 and 16 non-operational schemes, respectively. In terms of operational status, the KwaZulu-Natal province fared very well. All of the smallholder irrigation schemes with known operational status were operational in KwaZulu-Natal, and it was the only province with such a remarkable statistic. Use of pumps was cited as the major cause of smallholder irrigation scheme collapse in South Africa (Van Averbeke *et al.*, 2011). The majority of the non-operational smallholder schemes were those that involved pumping of water. According to Van Averbeke *et al*. (2011), about 84% of the 90 non-operational schemes engaged in an irrigation system that involved pumping of water while only 16% of the non-operational schemes were gravity-fed.

This implies that, as highlighted by Van Averbeke (2012), there is a higher chance of gravity-fed smallholder schemes to remain operational compared to those involving pumping water. The overheard costs associated with pumps, and high maintenance pump costs make them unsustainable for smallholder irrigation schemes (Van Averbeke, 2012). To understand some of the reasons why some of smallholder irrigation schemes were non-operationally, the next section provides a brief history of smallholder irrigation development in South Africa, drawing mainly from Van Averbeke (2008) and Fanadzo *et al*. (2010).

2.5 The history of smallholder irrigation development in South Africa

Four periods of smallholder irrigation development in South Africa have been identified in the literature (Van Averbeke, 2008; Fanadzo *et al*., 2010). These are:

- the peasant and mission diversion scheme era;
- the smallholder canal era;
- the independent homeland era, and;
- the irrigation management transfer (IMT) and revitalization era.

Irrigation was introduced to South Africa in the 19th century after the arrival of European settlers (Perret, 2002; Van Averbeke, 2008). According to Van Averbeke (2008), there is little evidence of the use of irrigation during pre-colonial times, and smallholder irrigation development was as a result of technology transfer from colonial settlers to the locals. This period of smallholder irrigation development is described as the peasant and mission diversion scheme era (Van Averbeke, 2008; Fanadzo *et al*., 2010). This era was associated with missionary activity and the emergence of African peasant farming, particularly in the Eastern Cape (Fanadzo *et al.*, 2010). Van Averbeke (2008) reported that these schemes were typically small, with very little land under irrigation. As a result, these schemes were not that important in people's livelihoods, and ceased to function by the end of the 19th century (Van Averbeke, 2008). This highlights the importance of ensuring that development projects play a significant part in the beneficiaries' livelihoods, otherwise the beneficiaries would lose interest and stop participating as soon as external support and/or funding is withdrawn.

The second era of smallholder irrigation development, the smallholder canal era, lasted from about 1930 until about 1960 (Fanadzo *et al*., 2010). The smallholder canal era was characterized by the development of schemes to provide families in the Native or Bantu areas with a full livelihood (Van Averbeke, 2008; Fanadzo *et al*., 2010). Natives or Bantu areas, also known as homelands or Bantustans, were territories set aside for black inhabitants of South Africa as part of the policy of apartheid (Speelman, 2009). Most of the irrigation schemes in the smallholder canal era started after the publication of the report from the Tomlinson Commission in 1955 on the socio-economic development of the homelands (Perret, 2002). This report and the implementation of some of its recommendations changed the settlements, land use patterns and irrigation development in black rural areas (Van Averbeke *et al*., 1998, cited in Perret, 2002). According to Denison and Manona (2007a), at least 37% of the existing irrigation area was developed during this era.

The third period of smallholder irrigation development occurred during the time when independent homelands were set up, hence the era is described as the independent homelands era (Van Averbeke, 2008; Fanadzo *et al*., 2010). This era covered the period 1970-1990 (Fanadzo *et al*., 2010). The independent homelands era saw a number of new irrigation schemes being established with funding from the South African government (Van Averbeke, 2008). According to Van Averbeke (2008), the motivation for the development of these schemes was to give credibility to the concept of independence of the homelands. The policy of independent homelands was aimed at establishing self-government for each of the different African tribes. Therefore, improving the economic and social conditions in the homelands through smallholder irrigation schemes was deemed important for this policy to succeed (Van Averbeke, 2008; Fanadzo *et al*., 2010).

About 64 of the existing schemes covering about 13,000 ha of land were established during this era (Denison and Manona, 2007a). These schemes were large, and their management was placed in the hands of specialised parastatals (Laker, 2005). Management of these large schemes proved complex and costly to maintain without government support (Laker, 2005). Consequently, the dismantlement of homeland parastatals after democratization in 1994 without transfer of management skills to local communities was followed by immediate partial or total collapse of these large schemes (Bembridge, 2000; Perret, 2002; Laker, 2004). The collapse of these schemes highlights the importance of appropriate technology that takes into account the skills levels of the beneficiaries. Otherwise, there is a need for governments to implement exit strategies that seek to empower the beneficiaries to operate the projects on their own first before withdrawal of support.

The IMT and revitalization era began in the 1990s and is currently underway (Van Averbeke, 2008; Fanadzo, 2012). IMT refers to the transfer of the responsibility of managing, operating and maintaining irrigation schemes from the state to farmers (Van Averbeke, 2008). Van Averbeke, (2008) reported that at least 62 schemes were developed in the early period of the 1990s with a focus on food security. During this era, some existing irrigation schemes were also identified as important for economic development, and the need for their revitalisation was prioritised. This revitalisation of the schemes was linked with IMT, which was a global trend (Van Averbeke, 2008). Though IMT is noble and it has been used successfully elsewhere in the world (Shah *et al.*, 2002), the transfers were rushed in South Africa, leading to smallholder irrigation collapses (Perret, 2002).

Consequently, as mentioned earlier, there is a general consensus in the literature that smallholder irrigation projects have failed as development initiatives in South Africa (e.g., Bembridge, 2000; Perret, 2002; Hope *et al*., 2008; Yokwe, 2009; Fanadzo, 2012). Although the assessment of economic performance of irrigation schemes by the 1955 Commission was highly positive (Van Averbeke, 2008), the more recent assessments have mostly reported that the success of smallholder irrigation has been limited in South Africa. However, even though performance has been below expectations, and many schemes have collapsed, it remains a relevant question to determine the welfare impacts of those schemes that are still operational. This is so, given the poverty and inequality reduction objectives of the water policies in South Africa. The next section presents the water policies in South Africa, and how they relate to smallholder irrigators.

2.6 Water policies and smallholder irrigation in South Africa

Since 1994, the South African government has undertaken many reforms aimed at addressing rural poverty and inequalities inherited from the past regime (Perret and Geyser, 2007). The White paper on Water Policy (DWAF, 1997), the National Water Act (NWA) of 1998 (DWAF, 1998), National Water Resource Strategy-1 (NWRS-1) (DWAF, 2004) and the National Water Resource Strategy-2 (NWRS-2) (DWA, 2012) are among the important policy documents that shape the current water policy in South Africa. This set of policy documents has put South Africa among the leaders in water reform. The National Water Act (NWA) of 1998 in particular has been lauded by many researchers as a progressive policy with the most promising legal framework to address the country's challenges in the water sector (Perret, 2002; Hodgson, 2006; Tlou *et al.*, 2006; Movik, 2009; Speelman, 2009). The NWA initiated several changes in the management and use of water in South Africa.

While water was allocated on a riparian system during apartheid, the new water law abolished riparianism and water access was separated from land ownership. Water is now understood as a common resource which cannot be privately owned by individuals, but is owned by the public with the state acting as the custodian of the water resources in the public interest (DWAF, 1998). The government allocates water use rights to individuals who are supposed to apply and be registered. The allocation between uses and users is based on the need to achieve optimum and long-term benefits for the society from their use (DWAF, 1998). Water rights allocations are time limited to allow for flexibility. Licenses are granted on a five year cycle with a maximum length of forty years (DWAF, 1998) . A licensee may apply to the responsible authority for the renewal of the license. Hodgson (2006) argued that time limited licenses are a source of insecurity if, for instance, license renewals are not certain. Secure water rights help to expand opportunities for farmers by reducing risks associated with appropriation by external agents, and lengthening farmers' planning and investment horizons (Tyler, 2007).

Water access was characterized by racial and gender inequity during the apartheid era (Movik, 2009). Therefore, the NWA sought to ensure that water is shared on an equitable basis, so that the needs of those without water for productive and consumptive activities are met regardless of their gender or race (DWAF, 1998). The NWA also emphasised the need for efficiency, equity and sustainability in the use of the water resources. The NWA represents a unique approach as it has sought to incorporate issues of racial and gender equity in water reform, something that has not been done by many countries (Faysse and Gumbo, 2004; Hodgson, 2006). Many modern water policies allocate water resources to activities with the highest productivity per cubic meter, benefitting predominantly the economically and politically well-to-do (Boelens *et al.*, 2007). However, researchers have reported that the reallocation of water resources to promote equitable distribution in South Africa has progressed slowly (Anderson *et al.*, 2008; Movik, 2009; Muller *et al.*, 2009; Van Koppen *et al.*, 2009).

Movik (2009) reported that water redistribution has been hindered by an emergency of views that purport that the continuation of the status quo is pivotal for economic stability and sustainability. Water redistribution to the historically disadvantaged individuals (HDIs) has been perceived as associated with low production and/or productivity, thus posing a high degree of risk of destabilizing the economy (Movik, 2009). Moreover, achieving gender equity in water access has been hampered by culture, especially in the rural areas (Kemerink *et al.*, 2011). Therefore, although the equity vision established by the South African water act is clear, actually achieving that vision on the ground has been elusive (MacKay *et al.*, 2003).

Whereas irrigating farmers were organized into irrigation boards (IBs) before, the NWA called for the transformation of all the IBs into Water User Associations (WUAs) (DWAF, 1998). The WUAs are expected to incorporate all users in the defined area of jurisdiction, whether they have a formal water entitlement or not (Faysse, 2004). It is through these WUAs that water user groups like smallholder farmers should secure water rights. It was also envisaged that the transformation from IBs to WUAs would enable better participation of HDIs in the management of water resources (Faysse, 2004). Although incorporating smallholder irrigators into WUAs holds promise, there has been little progress with the establishment of WUAs so far (Perret, 2002; Tlou *et al*., 2006; Speelman, 2009). The government is currently working on the transformation of all irrigation boards into WUAs by 2014 and the required transformation plan, according to DWA (2012), is already in place. It remains to be seen if this would happen as envisaged, and whether these new WUAs will successfully work as vehicles for building capacity of smallholder farmers.

One important aspect of the WUAs is their role in irrigation schemes. Each irrigation scheme is to be managed by a WUA, which will take charge of both water management, and cost recovery for water services (Perret and Geyser, 2007). The WUA is expected to achieve financial sustainability by selling water and water services to farmers, who it is assumed are willing and/or able to pay (Perret, 2002; Backeberg, 2006). The NWA pointed to the need to introduce water pricing and full cost recovery. Although introducing water pricing and full cost recovery would be viable in the long-run, the NWA acknowledged the need to waive these water charges for a determined time so that the disadvantaged groups could also access water for productive purposes such as agriculture (DWAF, 1998). Speelman (2009) reported that there was yet to be water charges in many smallholder irrigation schemes. Speelman (2009) and Yokwe, (2009) argued that introducing water charges would lead many of the small-scale farmers to become bankrupt as they currently do not make enough money to cover other costs despite not paying for water. Perret and Geyser (2007) also argued that achieving full cost recovery is unrealistic in developing countries like South Africa because of the subsistence-oriented nature of smallholder irrigation schemes.

The NWA also sought to ensure widespread stakeholder participation which includes the poor, women and those in rural areas in the water sector (DWAF, 1998). However, this stakeholder participation as envisaged in the NWA has not been accomplished (Kemerink *et al*., 2011). Although there has been establishment of water management structures meant to promote stakeholder participatory governance, this has not materialized in rural areas (Malzbender, 2005). The participation of the poor, the majority being women, has often been limited in rural areas because of language and illiteracy (Marlzbender, 2005; Kemerink *et al*., 2011). The water policy also acknowledged the importance of farming in rural areas, stressing that water should not be transferred from agriculture to other sectors based on water productivity as this would destroy the backbone of the rural economies (DWAF, 1998). This is why the introduction of water markets needs to be regulated. Farolfi and Perret (2002) gave evidence that if allowed to trade water rights, the small-scale farmers would easily transfer all their rights to the mining sector because of the high water productivity of mining compared to agriculture.

Generally, despite its noble intentions, the setback of the NWA has been in the implementation of its provisions. Many of the challenges faced in the water sector, according to DWA (2012), are related to poor implementation of good policies and strategies. Tlou *et al*. (2006) agreed, adding that the NWA remains unclear about the implementation of key issues such as water rights, local institutions, and water markets. Tlou *et al*. (2006) noted that the NWA has been difficult and slow to implement especially in smallholder irrigation farming. It should be highlighted, however, that the fact that the NWA states the need for such reforms to take place offers hope that ultimately, the smallholder farmers and the poor will play a meaningful role in the South African water sector. The importance of smallholder irrigation in reducing poverty in the rural areas is compelling, and the next section describes the poverty-irrigation inter-linkages.

2.7 Irrigation, water security and household welfare linkages

Many studies have argued that ensuring smallholder farmers' access to irrigation is important for poverty reduction and achieving household food security in developing countries (Hussain and Hanjra, 2004; Molden *et al*., 2007; Gebregziabher *et al.*, 2009; Muller *et al*., 2009). Irrigation is an essential part of the package of technologies, institutions and policies that underpins increased agricultural output (Hussain, 2007a). Thus, as a production input in agriculture, irrigation water is an important socio-economic good, with a positive role in poverty alleviation (Hussain and Hanjra, 2004). However, Hussain and Hanjra (2004) warned against perceiving access to irrigation alone as the solution to all rural poverty problems. Instead, irrigation farming should be understood as forming part of a broader livelihood strategy (which also includes non-farming projects) among the majority of rural people (Van Averbeke and Mohamed, 2006). Hussain and Hanjra (2004) highlighted that, even though irrigation water is only a single element in the poverty equation, it plays a disproportionately dominant role.

Hussain and Hanjra (2004) discussed in detail the main pathways through which access to irrigation reduces poverty. According to Hussain and Hanjra (2004), access to irrigation enables farmers to adopt new technologies and intensify cultivation, leading to increased productivity, overall higher production, and greater returns from farming. However, it is not just participation in an irrigation scheme that results in these positive effects, but access to reliable irrigation water. As was concluded by Hope *et al*. (2008), participation in an irrigation scheme although a necessary condition, is not sufficient to ensure improved household welfare. It is important that the individual farmers have secure access to adequate and reliable water. It is the access to reliable water under irrigation which actually affects the farmers' incentives to invest in improved inputs and technologies (Hussain and Hanjra, 2004; Tyler, 2007).

In contrast, uncertainties regarding how much water would be available to a particular farmer results in low incentives to invest in improved inputs and technologies (Faurès and Santini, 2008). Faurès and Santini (2008) argued that uncertainty regarding access to a reliable irrigation water supply causes farmers to apply less seed and fertilizer than they might otherwise do. This highlights the importance of ensuring water security, not just irrigation participation, among the farmers. A household's access to irrigation, coupled with physical, socio-economic and institutional factors, results in household water security. Figure 2.1 sketches the important inter-linkages among the physical aspect of irrigation, the socio-economic circumstances of the farmer, and the institutional and organizational structure.

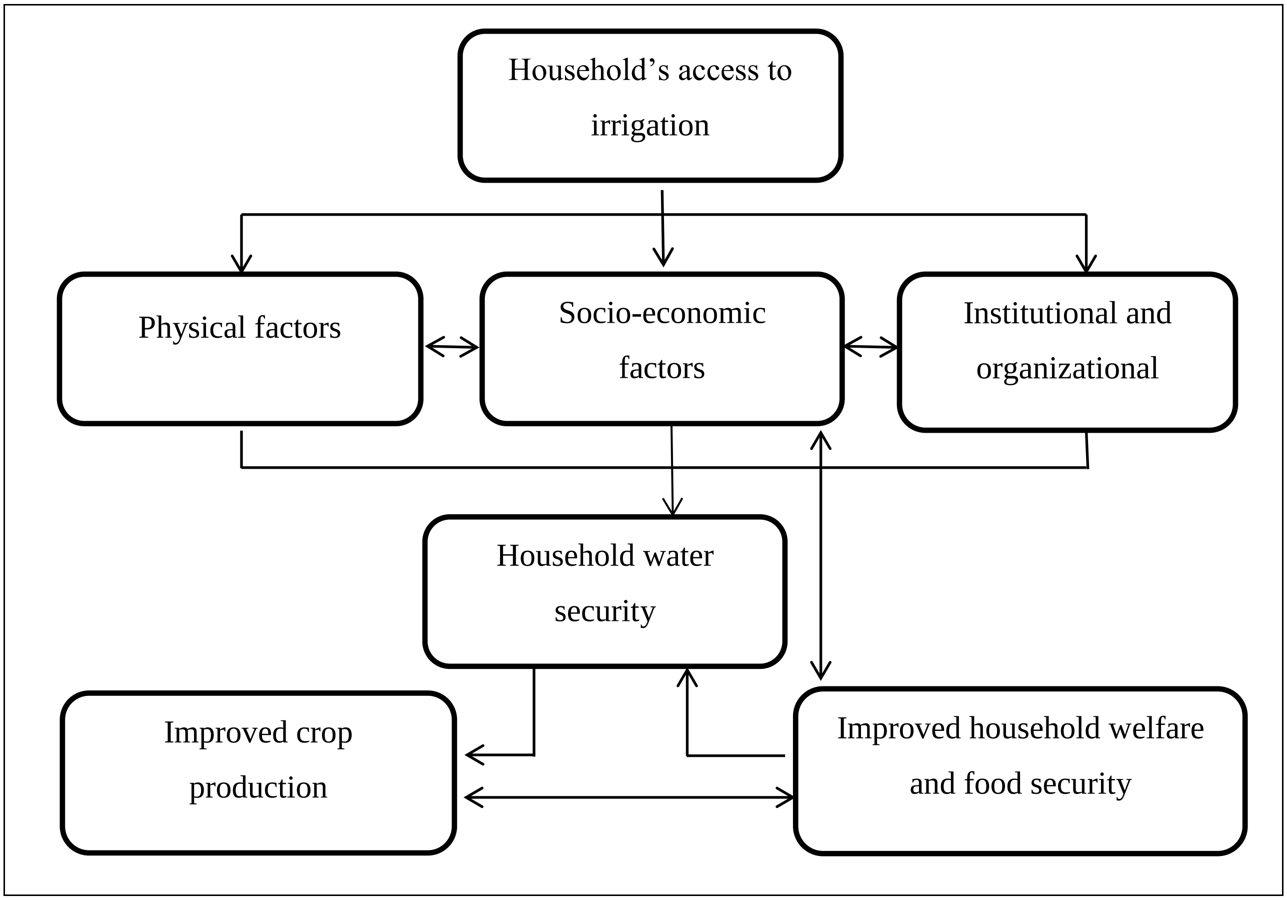

Figure 2.1 Linkages between smallholder irrigation, water security and household welfare

Source: Grey and Sadorf (2007) and Muller *et al*. (2009)

The physical aspect of irrigation includes the canal infrastructure, pumps, etc., that ensure reliable water supply. The socio-economic circumstances of the farmer are the factors (such as gender, income sources, geographic location in the scheme, etc.,) which influence access to irrigation water and the ability to pay for the water and water-related services. The institutional and organizational structure involves irrigation committees, farmer associations, and rules and regulations that ensure water rights are respected and that conflicts are resolved. Heterogeneity within the scheme in terms of gender, plot sizes, income sources and social capital variables influence households' capacity to participate in the WUAs, management of the scheme, making and enforcement of water resource use rules and regulations, and the resolution of emerging conflicts (Kamara *et al.*, 2002). It is this capacity that determines the water security level of an individual irrigating household.

The preceding figure indicates that while household's access to irrigation is important, it is water security which gives the household the incentives to invest in improved inputs and technologies. Household water security also encourages investments in improved water management and agricultural technologies (Kumar, 2003) and this leads to improved crop output and household welfare. Improved household welfare has a positive feedback to crop production and household water security. Improved incomes enhance the ability of a household to invest in improved technologies, pay for water and thus enhance water-use security. Despite its importance, water security has not been achieved in South Africa, leaving many farmers water insecure (Muller *et al*., 2009).

Water insecurity stems from a combination of the physical environment, built infrastructure, and institutions or human governance (Norman *et al.*, 2010; Zeiton, 2011). The physical environment highlights the hydrological patterns of the area while built infrastructure speaks of artificial water storage facilities such as dams. Zeiton (2011) argued that efforts to achieve water security have failed because the prevailing water policies in many countries have been narrowly focusing on the physical processes. The narrow and deterministic approach blames water insecurity chiefly on physical phenomena and reacts through infrastructural development (Zeiton, 2011). Fanadzo (2012) highlighted that this was the case in South Africa for a long period, with poor irrigation infrastructure viewed as the single major cause of poor performance and the government has invested huge sums of money towards repairing irrigation infrastructure.

Several researchers have, however, argued that infrastructure development alone as a dominant part of intervention in irrigation has failed in South Africa and beyond (Denison and Manona, 2007a; Innocencio *et al*., 2007; Faurès and Santini, 2008; Zeiton, 2011). It has been argued that the development of water infrastructure and institutions should go hand-in-hand to achieve water security (Grey and Saddoff, 2007; Zeiton, 2011). One other major cause of water security is the geographic location of an individual farmer along the water channel. Downstream farmers are usually economically worse off than farmers upstream because of heightened uncertainties regarding water availability downstream compared to upstream (Mbatha and Antrobus, 2008).

This is because downstream farmers are usually water insecure, and their production decision uncertainties result in economic inefficiencies. The economic disadvantage translates to political disadvantage, which has the effect of further worsening water insecurity. Hence, efforts in irrigation schemes should be exerted to improve household level access to reliable and sufficient water to enable farmers to improve productivity within current cropping patterns and to consider diversifying their crop choices (Faurès and Santini, 2008). According to Faurès and Santini (2008), water security has substantial influence on the motivation, ability and success of smallholders in maximizing production and the value of investments in the water sector. Therefore, authors such as Kumar (2003) and Van Averbeke (2008) have emphasised the need for equitable access to and control over irrigation water for irrigation schemes to operate successfully and contribute to household food security. Water insecurity increases the vulnerability of the politically and economically weaker poor water users (Bruns *et al.*, 2005).

Kumar (2003) highlighted three concerns that need to be addressed to ensure irrigation has the desired impacts on food security: adequate supply of irrigation at national (or scheme) level, water security for the farmers at household level, and adequate economic incentives for farmers to maximize their production from the available land and water with least environmental consequences. While it is clear that there is a need to create and confer water security to individual farmers to ensure irrigation effectiveness in poverty reduction, water security is not the only enhancing factor. The next section presents briefly other factors that improve the effectiveness of access to smallholder irrigation in reducing poverty.

2.8 Factors that influence poverty reduction capacity of smallholder irrigation

It has been largely established that farmers with access to irrigation perform better than those without (Tyler, 2007; Namara *et al*., 2010). However, evidence from across the developing world indicates that smallholder irrigation has been successful in some areas, while it has performed poorly in other areas. Irrigation has not been successful in ensuring rural poverty reduction in Sub-Saharan Africa (Inocencio *et al.*, 2007). The factors that influence the success of smallholder irrigation schemes in reducing poverty at household level are, *inter alia*, institutions, land tenure, and support services and infrastructure (such as credit, extension, markets, information services, roads and training). These factors are briefly explained in the following sub-sections.

2.8.1 Institutions

Many researchers have concluded that the poor performance of smallholder irrigation in South Africa is due to institutional issues (Machete *et al*., 2004; Van Averbeke *et al*., 2011; Fanadzo, 2012). Van Averbeke *et al*. (2011) argued that poor institutional support is at the heart of the poor performance of smallholder irrigation schemes in South Africa. According to Van Averbeke (2008), the successful co-operation among smallholders in the management of their irrigation schemes depends on functional water institutions and organizations to guide collective action. Water institutions are defined broadly to include organizations and capacity, as well as governance, policies, laws and regulations and incentives in water management (Grey and Sadoff, 2007). Water institutions address issues ranging from water allocation, quality, rights and pricing, to asset management and service delivery performances (Grey and Sadoff, 2007). Bruns *et al*. (2005) noted that improved water institutions can raise water productivity and enhance rural livelihoods. Without the development of appropriate institutions, irrigation water infrastructure will be poorly managed and may not support rural economic growth (Grey and Sadoff, 2007).

The development of smallholder irrigation systems in South Africa has often followed a top down approach with very little input from the farmers the schemes were intended to serve (Tlou *et al*., 2006). The responsibility for the management and even the implementation of the two important functions of sharing of water and maintaining the canals on South African smallholder irrigation schemes was previously the responsibility of the state (Van Averbeke, 2008). This, according to Tlou *et al.* (2006), is why farmers have had little control and interest in the sustainable and profitable running of such schemes.

However, the smallholder irrigation policy was reviewed following regime change in South Africa in 1994. The responsibility to manage the irrigation schemes was being transferred to farmer communities through the adoption of IMT programmes (Perret, 2002). According to Denison and Manona (2007a), IMT programmes necessitate institutional clarity. That is, clear and enforceable rules of engagement regarding the water management are critical to reduce institutional uncertainties. This will allow behavioural change in farming where greater risks are accepted and greater returns can be achieved by the irrigators (Denison and Manona, 2007a). Denison and Manona (2007a) highlighted the need for separating the water-related institutional functions (rules of scheme operation) from the agricultural, organisational and support elements in South Africa. According to the study, excessive institutionalisation of the agricultural production elements (such as input sourcing and marketing) can hamper individual enterprise and profitability. This suggests the need to balance the level of institutional support to give the farmers without inhibiting their initiatives and entrepreneurship.

2.8.2 Land tenure security

Land tenure is the relationship, whether legally or customarily defined, among people with respect to land (Hodgson, 2004). Land tenure status is an important factor in determining the productivity of farmers (Machethe *et al*., 2004; Tekana and Oladele, 2011). Economists argue that secure land rights enhance investment incentives (Besley, 1995; Brasselle *et al.*, 2002; Fenske, 2011). Farmers with secure land rights are expected to be both more willing and able to undertake investment in inputs and technology for three reasons: the assurance effect, the realisability effect, and the collateralisation effect (Brasselle *et al.*, 2002). The assurance effect points to the fact that farmers have a greater incentive to undertake investments when they are convinced that they will receive the benefits of their investment, which implies their right or ability to maintain long-term use over their land (Brasselle *et al.*, 2002; Fenske, 2011).

The realisability effect, on the other hand, implies that farmers would likely improve their land productivity through investments when that land can easily be sold or rented (Brasselle *et al.*, 2002). In other words, secure land rights allow for gains from trade (Fenske, 2011). More so, farmers are more able to invest when secure freehold titles are established as the land acquires collateral value and access to credit becomes easier (Besley, 1995; Brasselle *et al.*, 2002). This collateralisation effect is very important especially as formal lenders require collateral to lend to farmers. According to Fenske (2011), the most obvious means by which land rights increase access to capital is through the ability to use land as collateral.

Tekana and Oladele (2011) suggested that providing security of tenure is a pre-condition for intensifying agricultural production in rural South Africa. For farmers to be productive, they should have ownership rights so that they can sell or rent their land and also that their children can inherit the land (Tekana and Oladele, 2011). Machethe *et al*. (2004) argued that the tenure which prevails in smallholder areas limits tenure security and also hampers the exchange of land for productive use. The common practice in smallholder irrigation schemes in South Africa of granting to scheme farmers the permanent status of tenants only does not foster the motivation to invest. For instance, Mnkeni *et al.* (2010) found out that the farmers on quitrent and right-to-occupy land tenure arrangements in Zanyokwe irrigation scheme in the Eastern Cape had no sense of ownership and hardly invested in new technologies. Mnkeni *et al.* (2010) argued that these insecure land tenure arrangements undermined the interest and commitment of irrigators to farming.

Perret (2002) and Denison and Manona (2007a) agreed, adding that scheme farmers should have a title-deed to their irrigated plots, as insecure land tenure limits not only the incentive to make investments but provides no room for a land-leasing market as well. According to Perret (2002), the lack of clear and secure land tenure system is one of the main reasons for low productivity on irrigation schemes as it hampers establishment of a land-leasing market. It has been reported that those farmers who currently have rights access to the irrigated land tend to avoid leasing their plots as they are not sure if they would be able to claim back their land when they want it back (Perret, 2002; Denison and Manona, 2007a). Consequently, most of the high-value irrigation land on the smallholder irrigation schemes is not being utilized in South Africa because of land tenure problems (Denison and Monona, 2007a).

The other challenge is that landholdings in the form of Permission-to-Occupy (PTO) are generally allocated to men (Denison and Manona, 2007a). The implication is that although women are responsible for over 60% of farming activity in the smallholder irrigation sector, decisions are made mainly by men (Denison and Manona, 2007b; Altman *et al*, 2009). This disempowers the women and could reduce their incentives to produce. Moreover, in most irrigation schemes, access to water is linked to access to land as the size of the land one owns determines the amount of water one can access (Molden *et al*., 2007; Namara *et al.*, 2010). Namara *et al.* (2010) argued that this link further disadvantages women as land allocation has been historically skewed against women. It is, however, important not to overstretch the importance of secure land rights in improving women's livelihoods. Jackson (2003) called for a multi-faceted approach, that acknowledges the primacy of land rights and also of other factors (such as credit, extension and information services) in tackling the agricultural production constraints affecting women.

2.8.3 Technology type

The need for appropriate technology for smallholder farmers cannot be overemphasised. According to Horst (1998, cited in Turral *et al*., 2010), irrigation is a socio-technical process which will succeed if technology is matched with human needs, conditions and institutional arrangements. The smallholder farmers need small-scale, low cost and labour-intensive irrigation techniques as they lack capital and/or credit (Lipton *et al*., 2003). Such irrigation techniques are more likely to be of benefit to the poor than large-scale, capital intensive technologies (Lipton *et al*., 2003). In South Africa, it has been concluded that the smallholder irrigation schemes that were designed to use the large-scale, capital intensive technologies always collapse as soon as external funding is withdrawn (Van Averbeke *et al*., 2011).

Higher operating costs and greater maintenance requirements in intensive pressurised irrigation systems lead to their high likelihood of failure compared to simple gravity-fed systems (Van Averbeke *et al*., 2011). Van Averbeke (2012) found a strong and statistically highly significant correlation between the operational status of smallholder irrigation schemes in Vhembe district and hydraulic head, indicating that gravity-fed schemes were more likely to be (and remain) operational than pumped schemes. One important technology aspect is that of synergy. If not complemented by other technologies, irrigation alone will not succeed in reducing poverty. The success of the Green Revolution, for example, was established upon the use of technologies such as fertilizers and high yielding varieties to take advantage of moisture availability under irrigation (Hussain, 2007b).

2.8.4 Farmer participation

Farmer participation is a key success factor in enhancing agricultural productivity (Backeberg and Sanawe, 2010). Experience elsewhere in Sub-Saharan Africa has shown that smallholder irrigation schemes can succeed if farmers participate in their design and management (FAO, 2000). Yet, a number of smallholder irrigation schemes were planned and established following a centralised estate design in South Africa (Fanadzo *et al*., 2010). Control over farming activities and decision making was strictly enforced by central management with little or no input from farmers (Perret, 2002). According to Perret (2002), this created a high level of dependency among farmers in the schemes and poor performance when farmers were left to manage the schemes on their own.

Mnkeni *et al*. (2010) argued that the poor maintenance of irrigation infrastructure at smallholder irrigation schemes is as a result of the fact that farmers do not view the scheme infrastructure as their property. To ensure that ownership is entrenched in the minds of the irrigators, Mnkeni *et al*. (2010) recommended that all revitalisation and development initiatives at the irrigation schemes should involve the irrigators in a participatory way at all stages of the processes. Denison and Manona (2007b) agreed, emphasising that the overall performance of interventions in irrigation systems is a demand-driven mode. Interventions offered with a high level of farmers' involvement in irrigation projects, has been better than those provided with support in a supply-driven mode with moderate or low levels of farmer participation (Denison and Manona, 2007b). The study recommended that service providers should be more client-focused and customer-oriented, and include wider stakeholders' participation with the empowerment of water user organisations such as farmers' associations and their involvement. As explained earlier, the South African water policies have put several strategies whose implementation would result in meaningful farmer participation.

2.8.5 Information services, infrastructure support and market access

Access to relevant information and markets, among other support services, are fundamental to the success of irrigation projects (Faurès and Santini, 2008). Irrigation farming is more likely to be successful when information supply to farmers and market development are prioritised in the overall irrigation intervention design (Denison and Manona, 2007b). The small-scale farmers especially lack information on the availability of credit, inputs and market information (DAFF, 2011). Viable input and output markets enable smallholders to obtain inputs and sell produce at competitive prices (Faurès and Santini, 2008). The success of irrigation development in the past in South Africa can be related to marketing potential of produce and the level of profitability of farming (Backeberg, 1994 cited in Denison and Manona, 2007a). According to Denison and Manona (2007a), smallholder schemes will not succeed without profitability even if all other components are in place. Commercialization and the production of higher-value crops are common denominators in schemes that have been successful in South Africa (Denison and

Manona, 2007a). Yet, commercialization implies the need to connect the smallholder irrigators with markets for their produce.

Market participation of small-scale farmers is a function of transaction costs (costs associated with the search for trading partners, negotiating and drafting an agreement) (Makhura, 2001; Ortmann and King, 2010). Transaction costs are higher when farms are isolated from market information sources by an inadequate information support (Makhura, 2001). Farmers need useful information on market opportunities, production methods and weather forecasts to make decisions. DAFF (2011) noted that small-scale farmer's decision making process has been poorly supported due to poor management and dissemination of required information. Backeberg and Sanewe (2010), on the other hand, reported that the low levels of farmer education limit access to information and understanding of commercial farming concepts and development processes in smallholder irrigation schemes.

Other than that there is currently inadequate information reaching small-scale farmers, the other challenge has been that information is mostly disseminated not in the first language of farmers. A lack of communication technology, particularly that providing market information using their first language, implies that small-scale farmers are at a disadvantage in the recently liberalised and now highly competitive South African agricultural market. Mthembu (2008) found strong relationships between rural poverty and isolation from information support infrastructure in the former KwaZulu-Natal homelands. Mthembu (2008) concluded that the high transaction costs had contributed significantly in creating barriers to market entry by resource poor farmer, resulting in their poverty. DWA (2012) agreed, highlighting that it is unlikely that irrigation access will enable people to truly escape from poverty without access to timely and reliable information and markets.

One aspect of market access is that of ensuring good road and communication infrastructure. Makhura and Mokoena (2003) highlighted that under-investment in rural infrastructure, such as road and communication networks is what is inhibiting small-scale agriculture. The poor rural infrastructure curtails access to input and output markets, subsequently increasing small-scale farmers' production and transaction costs (Makhura and Mokoena, 2003). According to Mthembu (2008), investment in rural infrastructure should be prioritised as this will increase small-scale farmers' competitiveness in the market. This is because access to good road and communication infrastructure reduces transaction costs for both services and technology, leading to better prices for small-scale farmers (Mthembu, 2008). According to Bryant (2005, as cited in Mthembu, 2008), these investments would help integrate small-scale farmers into modern market chains and promote long-term development.

2.8.6 Extension and farmer training support

Developing the skills base of farmers is the primary objective of extension. Extension officers bridge the gap between available technology and farmers' practices by providing technical advice, information and training (Treguetha *et al.*, 2010). However, due to the low number of extension officers, the accessibility of extension by the small-scale farmer is limited in South Africa (Greenberg, 2010). Hall and Aliber (2010) reported that only about 11% of the rural households contact an extension officer in a year. This implies that only a small fraction of the farmers get advice and/or training on modern farming methods. As a result, limited knowledge of crop production among farmers has been cited as one constraint to improved crop productivity in smallholder irrigation schemes (Machethe *et al*., 2004; Fanadzo *et al*., 2010; Fanadzo, 2012). According to Fanadzo *et al*. (2010), low yield levels caused by poor crop and water management practices by the farmers is arguably the main reason for the failure of many smallholder irrigation schemes in South Africa.

Moreover, the education and training of the extension officers has also been under scrutiny. DAFF (2011), for instance, identified poor training of extension officers rather than the size of the workforce as a major challenge in the delivery of technological packages to small-scale farmers. The farmers too are generally critical of the extension officers' skills and capacity. Vink and van Rooyen (2009) reported that farmers are of the opinion that they have better skill levels than the extension officers. Farmers also claim that extension officers lack basic project management skills (Treguetha *et al*., 2010). Consequently, the farmers in many cases are reluctant to implement the advice and recommendations of extension workers.

According to Backeberg and Sanewe (2010), smallholder farmers do not have adequate technical expertise to operate viable farming projects. Backeberg and Sanewe (2010) highlighted that since the majority of the smallholder farmers' main experience in crop production has been through trial and error, they do not possess all the skills required for commercial production such as irrigation management, crop management, financial management, etc. Thus, there is a need to train the smallholder irrigation scheme members and provide knowledge specifically for commercial agriculture for them to practice sustainable farming (Backeberg and Sanewe, 2010).

2.9 Irrigation project impact evaluation techniques

The impact of smallholder irrigation investments on household welfare has been examined using different methods across the developing world. Few studies have used qualitative methods while many have used quantitative econometric techniques. Qualitative impact evaluation focuses on understanding processes, behaviours, and conditions as they are perceived by the individuals or groups being studied (Baker, 2000). Qualitative impact evaluation methods include rapid rural appraisal, beneficiary assessment, stakeholder analysis, and a wide range of social assessment methods (Bamberger, 2000). These techniques provide insight into the ways in which households and communities perceive an irrigation project and how they are affected by it (Baker, 2000).

The benefits of qualitative assessments are that they are flexible, can be specifically tailored to the needs of the evaluation using open-ended approaches, can be carried out quickly using rapid techniques, and can greatly enhance the findings of an impact evaluation (Baker, 2000; García-Bolanos *et al.*, 2011). However, the subjectivity involved in data collection, the lack of a comparison group, and the lack of statistical robustness are the setbacks of qualitative impact evaluation methods (Baker, 2000). Use of mainly small sample sizes in qualitative methods makes it difficult to generalize to a larger, representative population (Baker, 2000). Ravallion (2008) argued that, although qualitative impact evaluation can be a valuable complement to quantitative methods, it is unlikely to provide a credible impact evaluation on its own. Hence, qualitative evaluation techniques have rarely been used on their own in evaluating irrigation impacts.

Quantitative impact evaluations use quantitative data from statistically representative samples to assess causality using econometric methods (Baker, 2000). They dominate the literature on examining the impact of irrigation on household welfare. There are two designs in quantitative impact evaluation techniques: experimental (randomized) designs and quasi-experimental (non-randomised) designs (Ravallion, 2008; Baker, 2000; Bamberger, 2000). Experimental or randomized designs are applicable if the intervention is allocated randomly among beneficiaries.

This random assignment process creates comparable treatment and control groups that are statistically equivalent to one another, given appropriate sample sizes (Dillon, 2008; Baker, 2000). Randomization generates a control group that has the same distributions of both observed and unobserved characteristics as the treatment group (Smith and Todd, 2005). Consequently, experimental or randomized designs are generally considered the most robust of the evaluation methodologies (Ravallion, 2008; Baker, 2000).

However, due to the fact that the experimental or randomized designs are often too expensive, unethical or simply impossible, they are rarely used in irrigation project impact evaluations (Baker, 2000; Smith and Todd, 2005). Participating in an irrigation project is rarely a random event, but a targeted intervention (Bacha *et al*., 2011). In fact, the assignment of anti-poverty programs typically involves purposive placement, reflecting the choices made by those eligible and the administrative assignment of opportunities to participate (Ravallion, 2008). Therefore, randomized experiments are not always possible or cannot be plausibly implemented when dealing with anti-poverty programs (Baker, 2000).

Quasi-experimental or non-random methods are used to carry out an evaluation when it is not possible to construct treatment and comparison groups through experimental design (Baker, 2000; Ravallion, 2008). These techniques generate comparison groups that resemble the treatment group, at least in observed characteristics, through econometric methodologies, (Baker, 2000; Ravallion, 2008). In contrast to experimental designs, evaluation methods that use non-experimental data tend to be less costly and less intrusive (Smith and Todd, 2005). Also, for some questions of interest, they are the only alternative (Smith and Todd, 2005). Quasi-experimental or non-random impact evaluation methods include matching methods, double-difference methods, Heckman selection model, instrumental variable methods, and reflexive comparisons (Baker, 2000; Blundell and Costa-Dias, 2000). These methods have been used widely in the irrigation impact evaluation.

The major obstacle in implementing a quasi-experimental evaluation strategy is choosing among the wide variety of estimation methods available (Smith and Todd, 2005). This choice is important given the accumulated evidence that impact estimates are often highly sensitive to the estimator chosen (Smith and Todd, 2005; Dillon, 2011). Among quasi-experimental evaluation techniques, matched-comparison techniques are generally considered a second-best alternative to experimental design (Baker, 2000; Ravallion, 2008). However, project impact evaluators should be open-minded about methodology, adapting to the problem, setting and data constraints (Ravallion, 2008). The appropriate methodology for non-experimental data depends on three factors: the type of information available to the researcher, the underlying model and the parameter of interest (Blundell and Costa-Dias, 2000). According to Khandker *et al.* (2010), it is advisable to use more than one analytical model for triangulation purposes and robustness checks.

2.10 Irrigation impact on household welfare: Evidence from the empirical literature

The evidence from international literature on the role played by smallholder irrigation on household welfare presents a mostly positive picture. Whereas few studies such as Jen *et al.* (2002) found an insignificant link between irrigation and input use or productivity of farming practices, there are a number of studies in different countries which show that irrigation has served as the key driver in increasing household income and alleviating rural poverty (e.g., Hussain *et al*., 2006; Namara *et al*., 2008; Dillon, 2011; Kuwornu and Owusu, 2012).

Hussain *et al.* (2006) evaluated the impact of small-scale irrigation schemes on poverty alleviation in Pakistan using descriptive statistics. They used the FGT indices to measure poverty. The study found that poverty levels were higher in rain-fed than in irrigated areas. For example, poverty head count ratio was found to be 37% in rain-fed areas, compared to 29% in irrigated areas. Interestingly, the study found that poverty head ratio was even much lower (23%) in areas that practiced both irrigated and rain-fed farming. Namara *et al.* (2008) studied the role played by access to irrigation on rural poverty and inequality in Ethiopia using the logistic regression model. As expected, the poverty incidence, depth and severity values were lower for farmers that had access to irrigation compared to the non-irrigators. The main conclusion of the study was that the incidence, depth and severity of poverty were not affected by mere access to irrigation but by the intensity of irrigation use. The study concluded that there was an economy of scale in the poverty-irrigation relationship.

Gebregziabher *et al*. (2009) and Kuwornu and Owusu (2012) evaluated the impact of access to small-scale irrigation on farm household welfare using the propensity score method (PSM). According to Gebregziabher *et al*. (2009), the average income of non-irrigating households was less than that of the irrigating households by about 50% in Ethiopia. The study also found that farm income is more important to irrigating households than to non-irrigating households, and off-farm income was negatively related with access to irrigation. Kuwornu and Owusu (2012) concluded that irrigation investment in Ghana is justified due to significant irrigation contribution to consumption expenditure per capita in farm households. Dillon (2011) investigated the impact of small-scale irrigation investments on household consumption, assets and informal insurance in Mali using both PSM and the matched difference-in-difference method. The strength of this study was its use of panel data. Both estimation methods confirmed the positive role played by small-scale irrigation on household consumption and asset accumulation.

Tesfaye *et al*. (2008) and Bacha *et al*. (2011) both assessed the impact of small-scale irrigation on household welfare in Ethiopia using the Heckman's two-step estimation procedure. Both studies observed significant welfare differences between irrigators and non-irrigators, and concluded that access to irrigation had played a part in those observed differences. Tesfaye *et al.* (2008) found that about 70% of the irrigation users were food secure while only 20% of the non-users were food secure in Filtino and Godino irrigation schemes in Ethiopia. The two studies found that irrigation participation was also influenced by unobservable factors, highlighting the need to model for unobservable variables in irrigation impact evaluations.

As highlighted in the previous sections, most of the studies on smallholder irrigation schemes in South Africa have argued that smallholder irrigation schemes have failed to meet the rural development and rural poverty reduction objectives. A review by Fanadzo (2012) concluded that smallholder irrigation schemes in South Africa have failed to bring about the expected social and economic development in rural areas. However, most of these studies reviewed have not done any in-depth quantitative evaluations of the impact of smallholder irrigation on rural household poverty and food security but have mainly been descriptive. Most of these studies have relied on nothing more than gross margin or correlation analysis (e.g., Yokwe, 2009; Hope *et al*., 2008).

Van Averbeke (2012) investigated the factors that contribute to differences in the performances of smallholder irrigation schemes in Vhembe district in South Africa. Using correlation analysis, the study found that gravity-fed schemes were more likely to be (and remain) operational compared to pumped schemes. Whereas associations between cropping intensity and scheme characteristics were not very strong, the study found that cropping intensity was most strongly correlated with water restrictions at scheme level. This highlights the importance of ensuring household water security. The study reported that water security among irrigators was caused, at least in part, by the front-end blocks extracting more than their share, leaving too little for the tail-end blocks. Front-end tail-end differences in access to water among farmers were commonly reported on canal schemes.

Although arguing that smallholder performance has been below expectations, gross margin analysis by Yokwe (2009) and Hope *et al*. (2008) indicated that irrigators have somewhat greater gross margins per ha compared to non-irrigators. For the Zanyokwe and Thabina smallholder irrigation schemes, Yokwe (2009) found greater gross margin per ha among irrigators for all the crops that were included. Hope *et al*. (2008), on the other hand found that smallholder irrigation provides expected incomes and food benefits for those plot holders with secure irrigation access, i.e., those with head plots. For example, head plots had an estimated average gross annual farm of US$2,047 per year compared to US$543 per year for the tail plots. Both studies, however, are limited as they rely on gross margin analysis. Gross margin analysis is descriptive, and does not account for other relevant socio-economic variables such as educational level, farmer experience, etc., that may influence the revenue differences between irrigators and non-irrigators. The welfare differences between irrigators and non-irrigators cannot be attributed to access to irrigation without controlling for these other important variables.

One attempt to evaluate the household welfare impact of smallholder irrigation in South Africa was a case study of the Taung irrigation scheme by Tekana and Oladele (2011). Using the OLS procedure, the study concluded that irrigation plays a central role in the improvement of rural livelihood and food security. However, Baker (2000) and Bacha *et al*. (2011) point that self-selection and endogeneity associated with irrigation participation results in biased estimates from the OLS estimating technique (Greene, 2003). The impact of access of irrigation is either overestimated or underestimated by OLS regression depending on whether the irrigation scheme beneficiaries are more or less able to realize the potential benefits of irrigation due to certain unobservable factors (Baker, 2000). Therefore, the results of Tekana and Oladele (2011) could be biased, pointing to the need for irrigation impact evaluation studies in South Africa that account for selection bias.

The above literature indicates that although there have been a number of comprehensive impact evaluations in other countries, this has not been the case in South Africa. Since smallholder irrigation schemes are not homogenous between countries, as explained earlier, there remains a case for in-depth quantitative impact evaluations specific to South Africa. The next chapter describes the research methodology that was employed in this study to achieve this objective.

2.11 Summary

Smallholder irrigation plays an important role in the fight against rural poverty in developing countries. Smallholder irrigation development in South Africa began in the nineteenth century due to contact with the European settlers and it has since then gone through different eras of development. Although participating in an irrigation scheme is necessary, it is not sufficient to lead to improved household welfare. Water security encourages investments in improved water management and agricultural technologies such as fertilizer and high yielding varieties, leading to increased agricultural production and improved household welfare. Irrigation impact on household welfare has been done using both qualitative and quantitative evaluation techniques. Quantitative impact evaluation methods, particularly quasi-experimental econometric methods, have been more widely applied in irrigation project impact evaluations. Most of the studies have concluded that smallholder irrigation plays a positive role in household welfare. However, the conclusion in South Africa has generally been that smallholder irrigation has performed below expectations. This chapter has presented some evidence based on the available literature and the rest of the succeeding empirical chapters give more evidence for South Africa, drawing from the survey data analysis.

CHAPTER 3 RESEARCH METHODOLOGY

3.1 Introduction

This chapter introduces the methodological approaches that were used in this study. The study area is briefly described before discussing data collection procedures and methods. The conceptual framework is then discussed, followed by a close look at the analytical models that were used in this study. Empirical methods that include PCA, the PSM method and the treatment effects model are explained in this chapter.

3.2 Study area description

The Tugela Ferry irrigation scheme is located in Msinga local municipality in the Mzinyathi District in KwaZulu-Natal Province. It is situated 120 km north of Pietermaritzburg, and the closest town is Greytown, which is located about 48 km from the scheme. Figure 3.1 (overleaf) shows the location of the Tugela Ferry area in the map of South Africa (See arrow).

Dearlove (2007) provided a brief description of the geographic setting and socio-economic profile of the Msinga municipality. Msinga is composed of six traditional authority areas, namely; Bomvu, Mabaso, Mthembu, Mchunu, Ngome, and Qamu. The land in the Tugela Ferry irrigation scheme falls under three of the six different traditional authorities listed above. The population of Msinga is estimated to be 160,000 people, in an area of 2,500 km^2, implying a population density of 64 people per square kilometre (Dearlove, 2007). According to Dearlove (2007), approximately 30% of the Msinga municipal area comprises commercial farmland, while 70% is traditional land held in trust by the Ingonyama Trust. The study also reported that in terms of gender, women dominate in Msinga, comprising 58% of the population while men are about 42%. Men are fewer as they leave the rural area to search for employment opportunities in other areas. The study noted that the majority of the Msinga population (68%) is illiterate, particularly women. Msinga has few economic resources and little economic activity and is characterized by high poverty levels. Moreover, the area is characterized by high unemployment rates leading many to be involved in subsistence and informal activities. Almost half of the total households earn incomes less than R800 per month (Dearlove, 2007).

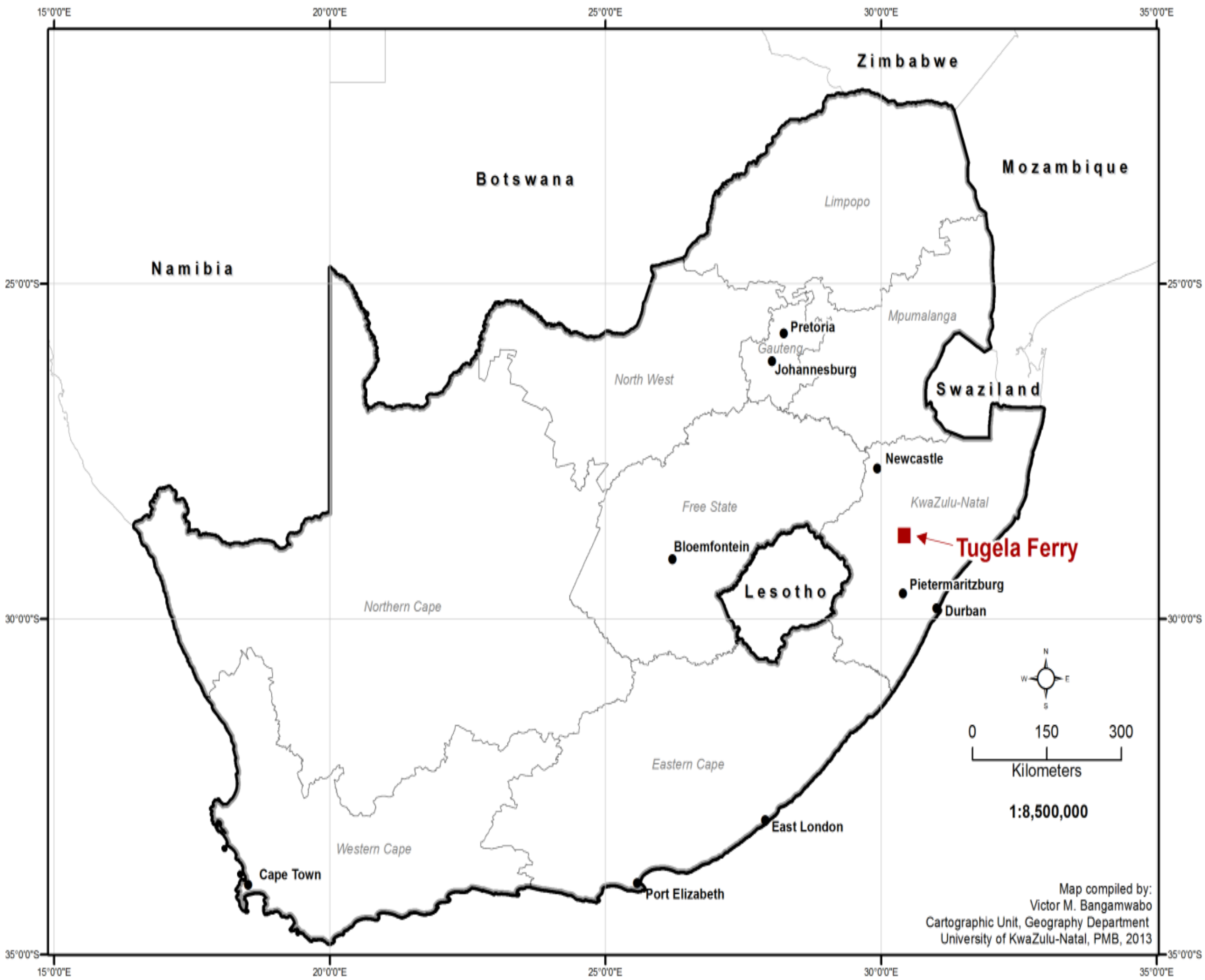

Figure 3.1 Location of the Tugela Ferry irrigation scheme in South Africa

Subsistence agriculture, involving both crop and livestock production, forms the basis of the Msinga people's livelihood and plays a significant role in the welfare of the poor in the area. Crop production is mainly practiced in areas adjacent the Tugela and Mooi rivers. Rain-fed crop production is difficult because the area is both hot and dry. Msinga is situated in a dry to semi-arid zone with mean rainfall of 600-700 mm per annum and very high summer temperatures of up to 44^0 C (Cousins, 2012). The area is characterised by frequent droughts, making irrigated plots the main site of household food production (Cousins, 2012). Irrigation farming also offers many of these rural people an opportunity to increase their incomes and participate in the local economy. The Tugela Ferry and Mooi irrigation schemes play an important role in the local economy of Msinga as a source of food, employment and market for agricultural inputs.

The Tugela Ferry irrigation scheme is located on both banks of the Tugela River. The scheme was planned and constructed by the Natal Native Trust between 1898 and 1902 and has been operational ever since (Cousins, 2012). The scheme consists of seven blocks of irrigable land covering 837 ha of which approximately 540 ha is flood-irrigated, and is amongst the largest in the province (Cousins, 2012; Fanadzo, 2012). A total of about 1,500 irrigators participate in the irrigation scheme growing various crops such as maize, cabbage, potatoes, tomatoes, onions, beans, beetroot, spinach and butternut. According to Cousins (2012), the Tugela Ferry irrigators comprise about 15 per cent of all smallholder irrigation farmers in the KwaZulu-Natal province.

The land in the scheme is owned by three different traditional authorities (Mthembu: Block 1-5; Mabaso: 7A; and Bomvu: 7B). The ownership of Block 6 is uncertain, and it is currently not operating due to conflicts regarding its ownership. Farmers in the irrigation scheme were initially allocated two plots of 0.1 ha in size. Overtime, some farmers have managed to acquire more plots through leasing or borrowing from neighbours. The main access to land is through the traditional authorities, who allocate land to households. Selling of land is not permissible under the current traditional land tenure system. Land is to be returned to the traditional authority for re-allocation if the owner is no longer using it. Discussions with the farmers indicated that land allocations in the scheme are governed along the patriarchal nature of the area. For example, land is mainly registered to men, with women mainly getting registered after the death of the husband. Most women get access to land through marriage. Sons are the ones that can inherit the plots, while daughters cannot. Many people gain access to land through borrowing from other farmers. There is competition for land between farming and the expanding Tugela Ferry town. The need to evaluate the role played by the irrigation scheme on local people's welfare to justify its existence in an area with increasing competition for land is without doubt relevant.

The source of water to the different blocks of the irrigation scheme is the Tugela River. A canal 31 km in length is used to draw water under gravity for blocks 1-3 and 5; while a diesel pump is used for block 4B and electric pumps for blocks 4A and 7. Initially, all the blocks obtained water from the main canal, but water shortages have meant that only four blocks benefit from the gravity-fed canal while other blocks use motorized pumps. The initial canal infrastructure has deteriorated such that it is hardly capable of supplying the four blocks relying on gravity. Irrigators take turns to divert irrigation water to their plots, getting water at least once per week. Farmers reported inequities in water distribution at both scheme and block levels, as was highlighted by Mnkeni *et al*. (2010). The next section describes the data collection methods that were employed in this study.

3.3 Data collection methods

Data were collected over a period of three weeks in November 2012 by five enumerators who speak Zulu, the local language. The enumerators were trained in data collection methods and the contents of the questionnaire before going for the survey. Also, questionnaires were pre-tested before being administered. A sample of five households was interviewed in different blocks of the irrigation scheme during questionnaire pre-testing. Questions that were not clear during questionnaire pre-testing were modified to make them clearer. Possible responses that were not captured in the closed ended questions were also added to reduce the number of responses getting to 'other'. Questionnaire pre-testing was also used in improving translation of the questionnaire to the local language. Pre-testing was also used to improve the reliability and validity of the questionnaire, i.e., ensuring that there was consistency of measurement and ensuring that the instrument measures what it is intended to measure. The sampling procedure and data collection tools that were used are discussed below.

3.3.1 Sampling procedure

A stratified random sampling technique was used to select the respondents. Households were categorized into two strata: irrigation participants and non-participants. A list of the irrigating farmers was obtained from extension officers, and farmers stratified according to their irrigation system i.e., whether they use gravity, electric or diesel pumps to divert water to their plots. The reason for stratification according to the irrigation system was to capture the differences that exist in the distribution of water in the different systems. From these sub-strata, simple random selection was done to obtain a sample of 185 irrigating farmers such that every irrigation system was represented by at least 10% to the final sample of irrigators. A sample of 185 irrigating households was considered appropriate as it represents above 10% of the 1,500 irrigating farmers in the Tugela Ferry irrigation scheme (Terre-Blanche *et al.*, 2006).

More than 10% proportional sample size was collected from those relying on the diesel pump. There is only one block using a diesel pump, and it has only 68 members. Maintaining proportional representation would have meant that only seven people would have been sampled among the diesel pump dependent irrigators. This small number of people would not have allowed good statistical comparisons between farmers using the different irrigation systems. Therefore, 30 farmers were interviewed in block 4B instead of just seven. There was no list for non-irrigators; therefore the non-irrigators that were interviewed were identified during the survey. A sample of 70 non-irrigators in the same geographic area was randomly interviewed to provide a counterfactual or control group. Since the population is largely homogenous, this sample size was considered large enough to provide a reliable control and provide for a reasonable number of matching counterfactual households. These non-irrigators were from the same location and geographic area so that all their characteristics matched that of irrigators.

3.3.2 Data collection instruments

Primary data were collected using structured questionnaires, key informant interviews and focus group discussions (See Appendix A for the questionnaire and Appendix B for the focus group discussion guide). Information on basic household head characteristics such as sex, age, marital status and education level was collected using the questionnaire. The questionnaire also included measures of household wealth such as the household assets, livestock, and type of houses; agricultural production activities; household expenditure, income amounts and sources. More so, the questionnaire sought to elicit farmers' perceptions of the sufficiency and reliability of the irrigation water, their ability to pay for the water, and the security of their rights to the water. The same questionnaire was used for both irrigators and non-irrigators, but with extra sections to cover specific questions related to the irrigation scheme. The approach adopted in the survey is in line with Jalan and Ravallion (2003) who suggested that in project impact evaluations, it is important that the same questionnaire be administered to both groups, and that project participants and non-participants are from the same economic environment.

Key informant interviews and focus group discussions were done to obtain explanations to issues captured in the questionnaires. Four key informants were interviewed, two of which were extension officers while two involved farmers who were knowledgeable with issues pertaining to the farming activities in the scheme. Two focus group discussions were used to collect qualitative data which was used to explore people's knowledge and perceptions concerning their water security, gender issues and their welfare. Focus group discussions and key informant interviews were used to generate data that complemented the structured questionnaire by providing the explanations and issues behind quantitative data. As explained in previous sections, the benefit of these qualitative assessments is that they can greatly enhance the findings of an impact evaluation. Qualitative assessments provide a better understanding of stakeholders' perceptions, priorities, and the conditions and processes that may have affected project impact (Baker, 2000).

3.4 Conceptual framework

Irrigation water is a critical production input in agriculture. As highlighted by Hussain and Hanjra (2004), it is an important socio-economic good with a positive role in poverty alleviation. Irrigation directly impacts on household incomes by increasing farm revenues. There are two potential ways through which irrigation increases farm revenues. Firstly, it increases annual revenue per acre of land through its direct positive effect on total crop production in a given cropping season. Irrigation enhances the use of agricultural inputs (such as fertilizer and high yielding varieties), which, in turn, improves the productivity of land (Gebregziabher *et al*., 2009). Moreover, irrigation water not only increases crop yields per hectare but reduces crop yield variability, thus stabilising household incomes (Tyler, 2007; Namara *et al*., 2008). Secondly, irrigation may increase farm revenue by allowing a plot to be planted for an extra crop season for a given year, i.e., irrigation induces the possibility of double cropping.

Although it increases costs to the farmers (due to increased fertilizer use, water charges as well as soil fertility losses due to water logging and salinisation), the benefits of irrigation outweigh these additional costs. Irrigation water has high marginal returns, high enough to cover additional costs involved in water source development, scheme development and recurrent operating costs (Innocencio *et al*., 2007). The net result of these increased benefits and increased costs are significant profit margins to the farmers, leading to improved household incomes. The impact of irrigation on household incomes would increase household expenditure, *ceteris paribus* (Kuwornu and Owusu, 2012). Increased household expenditure implies improved welfare and food security of the household. Indirectly, irrigation benefits the landless through higher wages as it results in higher marketed surpluses and increased employment opportunities (Jin *et al.*, 2012). Moreover, irrigation benefits the poor as it may lead to lower food prices. Lower food prices are especially beneficial to the poor since the poor spend a disproportionally large share of their income on food (Jin *et al.*, 2012). Therefore, irrigation development benefits not only the participants but the non-participants as well through these spill-over effects.

However, as has been highlighted in previous sections, irrigation participation although necessary, is not enough to induce farmers to produce more. It is mainly the water secure irrigators that invest more on improved agricultural inputs and technologies, and thus enjoy more benefits from irrigation participation than the water insecure irrigators. Therefore, the study aimed to evaluate the impact of small-scale irrigation schemes from two angles. First, it aimed to compare welfare differences between irrigators and non-irrigators, i.e., the extent to which irrigators are better-off compared to their non-irrigating counterparts. The second dimension of the evaluation was a comparison of the welfare differences between water secure and water insecure irrigators.

The main issue in impact evaluation is that of missing data. Subjects cannot be observed in both statuses at the same time, i.e., participation in an irrigation project and non-participation in the project is mutually exclusive. In the absence of data on counterfactual outcomes i.e., outcomes for irrigation participants had they been non-irrigators, the impact evaluation problem becomes that of missing data. Unless the irrigation project participation was randomized, the missing data is not random (Cuong, 2007). Irrigators select into the project based on their decisions and project administrators' decisions, implying that project participation is non-random. Impact evaluation can be rigorous in identifying project impacts by using different models to construct comparison groups for participants (Khandker *et al.*, 2010). In light of these challenges, the next section describes the analytical approaches that were adopted to achieve the objectives of this study.

3.5 Data analytical methods

Different econometric models were used to achieve the specific objectives of this study. Table 3.1 gives the specific objectives and the corresponding analytical methods that were used.

Table 3.1 Study objectives and data analysis approaches

Objective	Data analysis method
To evaluate the impact of smallholder irrigation on household welfare	Treatment effect model Propensity score matching (PSM) method
To investigate the factors that determine the irrigator's water security level	Principal component analysis (PCA) Ordinary least squares (OLS)
To investigate the impact of water security on the irrigators' welfare	Treatment effect model Propensity score matching (PSM) method

As shown in Table 3.1, the treatment effect regression model was used to evaluate the impact of the Tugela irrigation scheme on welfare. PSM was used as a robust check on the results of the treatment effect regression model. PCA was used to generate the water security index, and this index was used as a dependent variable in the OLS regression to determine the factors that affect the water security level of the irrigators. PSM and the treatment effect model were then applied to investigate the impact of water security on household welfare. These different econometric models are explained in detail in the following sections. Variables that were used in these econometric models are presented in Table 3.2 (overleaf). The variables and the codes as they were used in Stata analyses are presented in Appendix C.

Household consumption per adult was used as the dependent variable to capture the welfare of the farmers. The water security index generated by PCA was used as the dependent variable to capture the perceived water security levels of irrigating farmers. Different socio-economic variables presented in Table 3.2 were used as independent variables in the different models that were estimated. The specifications of the different models estimated in this study are presented in the following sections.

Most of the variables presented in Table 3.2 are straightforward in their derivation. Two variables, however, need further clarification on how they were generated. Household size in adult equivalents and livestock size in tropical livestock units (TLU) were generated using recommended scales. Appendix D indicates the scales that were used to calculate household size in adult equivalents.

Table 3.2 Description of variables

Variable	Variable description
Dependent variables	
Household consumption per adult equivalent	Total household consumption expenditure per adult equivalent in a year (Rands)
Water security index	Water security index generated by PCA
Independent variables	
Irrigation participation	1= Irrigator, 0 = Non-irrigator
Water security status	1= Water secure, 0 = Water insecure.
Gender	Household head gender: 1=Male, 0 = Female
Age	Household head age (years)
Education level	Household head education level (years of schooling)
Marital status	Household head marital status: 1=Married, 0=Otherwise
Household size	Household size in adult equivalents
Household size square	Household size square in adult equivalents
Religion	Household main religion (1=Christianity, 0=Otherwise)
Grant	Access to government welfare grants (1=Yes, 0=No)
Land size	Household total land size (ha)
Irrigated land	Household irrigated land (ha)
Off-farm income	Off-farm income (Rands)
Farm income	Total income from farming activities (Rands)
Livestock size	Livestock size in Tropical Livestock Units (TLU)
Soil fertility	Farmers' perception of soil fertility status: 1=Good, 0= Poor
Extension	Access to extension service (1=Yes, 0=No)
Credit	Access to credit (1=Yes, 0=No)
Training	Agricultural skills training (Yes=1, No=0)
Market	Market access (1=Yes, 0=No)
Road	Road access (1=Yes, 0=No)
Scheme distance	Distance of household to the irrigation scheme (km)
Duration of scheme membership	Years household has been a member of the irrigation scheme
Pump_1	Pump used (1=Electric pump, 0=Gravity or otherwise)
Pump_2	Pump used (1=Diesel pump, 0=Gravity or otherwise)
Location_1	Location along the primary canal (1=Head-end, 0=Middle or otherwise)
Location_2	Location along the primary canal (1=Tail-end, 0=Middle or otherwise)
Association member	Member of farmer association (1=Yes, 0=No)
Decision making	Scheme level decision making participation (1=Yes, 0=No)
Occurrence of conflicts	Occurrence of conflicts (1=Yes, 0=No)

As shown in Appendix D, people of different gender and age have different energy requirements. Therefore, instead of using household size in numbers, the approach used in this study was to use the recommended scales to adjust household sizes to reflect the energy requirements of different households with different household compositions. The scales that were used to calculate tropical livestock units (TLU) are presented in Appendix E. Following the same reasoning concerning household size, using the numbers to determine the livestock size is limited as it would have meant that two goats, for instance, would have been equated to two cattle. The tropical scales presented in the above table, although they are also limited as they do not cater for the sex and age of the animals for instance, offer a useful way of comparing livestock sizes despite differing livestock compositions.

3.5.1 Descriptive statistics

Descriptive analysis for all the variables was carried out as a first step in data analysis. Descriptive analysis involved looking at means, frequencies and standard deviations of the variables. The t-test was used to make comparisons between irrigators and non-irrigators with respect to relevant continuous variables, and the χ^2-test was used to test the degree of association between the irrigation access variable and other relevant categorical variables. Descriptive analysis is important as it can inform decisions on which variables to include in the impact analysis stage, and highlights data management issues, such as coding of variables and missing values (Vyas and Kumaranayake, 2006).

3.5.2 The Foster, Greer and Thorbecke (FGT) poverty measures

Although poverty is a multidimensional phenomenon, most empirical work on poverty measurement is based on incomes or consumption expenditures (Hussain and Wijerethna, 2004; Namara *et al.*, 2008). As highlighted earlier, there is lack of consensus regarding the measurement of other forms of deprivation. Therefore, the approach followed in this study is the material dimension of poverty expressed in monetary values. Between income and expenditure, expenditure was chosen because it is the preferred poverty metric in developing countries (Achia *et al.*, 2010). Whereas incomes are often under-estimated, expenditure has been found to better reflect the true welfare status of households in the developing countries (Achia *et al.*, 2010). A poor household was thus defined as one with expenditure less than a specified level to meet basic food and non-food needs.

Based on the minimum per capita adult equivalent caloric intake (at 2,200 kcal per day) (Bacha *et al.*, 2011), a figure of R5,276.64 per adult equivalent per annum was used as the poverty line. This figure was taken from that reported by Frye (2005), and then adjusted using the consumer price index (NDA, 2012) so that it reflects the current purchasing power of the rand. The FGT poverty measures were calculated to examine the incidence, depth and severity of poverty among irrigators and non-irrigators. The incidence of poverty (headcount index) measures the share of the population below the poverty line. The poverty depth index (poverty gap), on the other hand, captures information regarding how far off households are from the poverty line. The poverty severity index (poverty gap square) takes into account not only the distance separating the poor from the poverty line (the poverty gap), but also the inequality among the poor. That is, a higher weight is placed on those households who are further away from the poverty line.

The FGT poverty measures were calculated as specified below:

$$P_\alpha = \frac{1}{n} \sum_{i=1}^{q} \left[\frac{(z - Y_i)}{z}\right]^{\alpha} \qquad [1]$$

Where: P_α is the FGT poverty index, n is the number of sample households, Y_i is consumption expenditure per adult equivalent of the i^{th} household, z represents the cut-off poverty line, q is the number of households below the poverty line and α is the poverty aversion parameter. The poverty aversion parameter is a non-negative parameter indicating the degree of sensitivity of the poverty measure to inequality among the poor. A larger α gives greater emphasis to the poorest of the poor, indicating greater sensitivity of the poverty measure to inequality among the poor (Foster *et al.*, 1984; Namara *et al.*, 2008). The poverty aversion parameter takes a value of 0, 1, or 2.

If $\alpha = 0$, then the result of equation 1 is a poverty head count index, which measures the incidence of poverty within the sample. When $\alpha = 1$, the result of equation 1 is a poverty gap index, which measures depth of poverty or the average consumption shortfall of the poor from the poverty line. Finally, if $\alpha = 2$, the result is a squared poverty gap, which measures the severity or intensity of poverty (Foster *et al.*, 1984; Bacha *et al.*, 2011). The FGT poverty measures were calculated using the Distributive Analysis Stata Package (DASP) version 2.2, an ado Stata file created by Araar and Duclos (2012).

3.5.3 The treatment effect regression model

The term treatment effect means a causal effect of a binary variable on a continuous variable of interest (Khandker *et al.*, 2010). The major econometric problem in evaluating project impacts is selection bias (Maddala, 1983). Selection bias arises from the fact that treated individuals may differ from the non-treated for reasons other than treatment status. Smallholder irrigation usually purposively targets the poor, which are more likely to be poor without access to irrigation (Baker, 2000). It is expected that irrigation participants would have had far less consumption expenditure in the absence of the irrigation project (Baker, 2000). Therefore, using OLS when there is selection bias would underestimate the effect of irrigation participation on household welfare.

Heckman (1979)'s basic model of selectivity has been widely applied in evaluating program benefits (or treatment effects) (Maddala, 1983; Greene, 2003). The model corrects for the selection bias that arises from unobservable factors by estimating two equations: the selection (participation) equation and the response (outcome) equation. The discussion of the treatment effect model below derives from mainly Heckman (1979), Maddala (1983) and Greene (2003), and interested readers may consult these texts for detailed discussions. To understand how the treatment effect model (as estimated using Heckman's two-step procedure) works, consider access to irrigation as the treatment variable. It must be noted, however, that the same explanations below hold for the impact of water security, with water security replacing irrigation access as the treatment variable.

Assume that evaluating the impact of irrigation access on welfare involves estimation of the following equation:

$$Y_i = \beta x_i + \delta P_i + \varepsilon_i \qquad [2]$$

Where: Y_i is the consumption expenditure per adult equivalent of household *i*; x_i is a vector of household characteristics; P_i is a dummy variable indicating whether or not household *i* irrigates; β is a vector of coefficients to be estimated; δ is the impact parameter and ε_i residual term.

Estimating equation 2 using OLS would result in biased and inconsistent estimates due to possible biases arising from sample selection (Maddala, 1991; Greene, 2003). As explained before, irrigation participation cannot be treated as exogenous since the likelihood of an individual household to have access to irrigation or not may be based on some selection process (Ravallion, 2008). The estimate δ in equation 2 is biased and inconsistent estimates (Heckman, 1979). The welfare difference between irrigators and non-irrigators, therefore, cannot be attributed to access to irrigation so long as selection bias exists (Bacha *et al.*, 2011).

Selection bias could be as a result of selection on observables or unobservables. Selection on observables can be controlled by including all the variables in the model. Selection on unobservables is difficult to control by adding these variables as these variables are difficult to capture and not observed. Variables such as managerial ability, motivation, propensity to bear risks, etc., are some examples of variables that are hard to capture. Excluding these unobservable variables gives a biased estimate of δ as a result of omission of relevant variable specification error (Heckman, 1979). The treatment effect regression model is used in impact evaluation as it corrects for the selection bias that arises from unobservable factors. The treatment effect model is able to test and control for sample selection biases and thus results in unbiased and consistent estimates (Green, 2003). The treatment effect model involves the estimation of two equations: the selection (participation) equation, and the response (outcome) equation. The participation equation is used to generate a selection variable (inverse Mills ratio) which when included in equation 2, the OLS estimates become unbiased and consistent.

Assume that irrigation participation is a linear function of the exogenous covariates (z_i) and the residual error u_i. Specifically, assume that the irrigation participation is modelled as follows:

$P^*_i = \gamma z_i + u_i$,

$P_i = 1$ if $P^*_i > 0$, and 0=Otherwise. [3]

Where: P^*_i is the latent endogenous variable such that P_i takes a value of 1 when P^*_i is greater than zero; z_i is a vector of household characteristics that influence household's access to irrigation; γ are the coefficients to be estimated; and u_i is the residual term.

Suppose that ε_i and u_i have a bivariate normal distribution with zero means and correlation ρ:

$\varepsilon_i \sim N(0,\sigma)$; $u_i \sim N(0, 1)$ and $corr(\varepsilon_i, u_i) = \rho$

Therefore, according to Green (2003), the difference in expected consumption between irrigators and non-irrigators is:

$$E[Y_i|P_i=1] - E[Y_i|P_i=0] = \delta + \rho\sigma\left[\frac{\phi(\gamma z_i)}{\Phi(\gamma z_i)\{1-\Phi(\gamma z_i)\}}\right] \quad [4]$$

Where: ϕ is the density function of a standard normal variable, Φ is the cumulative distribution function of a standard normal distribution; δ, z_i, σ, ρ and γ are as defined above. Estimating equation 2 without correcting for selectivity is actually estimating equation 4. When $\rho = 0$, OLS regression of equation 2 provides unbiased estimates, but when $\rho \neq 0$ the OLS estimates are biased as can be seen in equation 4.

The irrigation participation equation (equation 3) was estimated during the first stage of the treatment effect model. The selection equation captured the factors influencing participation in the irrigation project. The dependent variable for this first stage of the treatment effect regression procedure was irrigation participation (P_i). P_i was a latent variable which represents a household's probability of participation in the irrigation project. The independent variables (z_i) were the relevant observable variables such as household head age, education level, gender, etc. For this purpose, a probit model was estimated in this study because the error term of this model is normally distributed, which is one of the assumptions underlying the treatment effect model. Using the selection equation (equation 3), the inverse Mills ratio was constructed as follows:

$$\lambda_i = \phi(\gamma z_i) / \Phi(\gamma z_i) \quad [5]$$

Where: λ_i is the inverse Mills ratio term, ϕ is the density function of a standard normal variable, Φ is the cumulative distribution function of a standard normal distribution, z_i and γ are as defined above. The second stage of the treatment effect regression procedure involved adding the inverse Mills ratio to the response or outcome equation (equation 2) and estimating the equation using OLS as follows:

$$Y_i = \beta x_i + \delta P_i + \beta_\lambda \lambda_i + \varepsilon_i \quad [6]$$

Where: Y_i is total household consumption expenditure per adult equivalent; x_i is a vector of household characteristics; P_i indicates whether a household is an irrigation beneficiary or non-beneficiary; λ_i is the inverse Mills ratio, ε_i is the error term; while β and δ are parameters that were estimated.

Y_i was a continuous variable measuring total food and non-food expenses incurred by households in a year. The food items produced and consumed by the household were converted to their market values using average prices. A non-significant coefficient of the inverse Mills ratio indicates that there is no self-selection problem while a significant coefficient term implies sample selection problem. Due to the inclusion of the selectivity term, the impact coefficient δ in equation 6 is unbiased although it is inefficient as the disturbance term ε_i is heteroskedastic (Greene, 2003). The correct standard errors can be generated from an asymptotic approximation or by resampling, such as through a bootstrap. The Stata software package, which was used in this study, automatically corrects for that bias in standard errors.

The main assumption required to guarantee reliable estimates of the outcome equation is the existence of at least one additional explanatory variable in the selection equation which has no direct effect on the outcome (Blundell and Costa-Dias, 2000; Heckman and Vytlacil, 2005). This variable is required to have a non-zero coefficient in the selection equation and to be independent of the error term ε_i. Even though the model would be identified, including the same number of variables in the selection and outcome equations would lead to the multicollinearity problem in the outcome equation which results in very imprecise estimates (Sartori, 2003). Although it is often difficult to find a variable that affects selection and does not affect outcome (Sartori, 2003), an effort was made in this study to ensure that the consumption expenditure equation included one variable less than the irrigation participation equation.

There are two approaches to estimating the sample selection model under the bivariate normality assumption: the two-step procedure (as explained above) and full information maximum likelihood (Maddala, 1983). Although the two-step procedure has the desirable large-sample property of consistency, various studies have investigated and criticised its small-sample properties. Puhani (2000) provides a review of some of the papers that critique the two-step method. One major limitation of the two-step procedure is that it is less efficient compared to the full information maximum likelihood method. Both methods need the same level of restrictive assumptions (e.g., the normality assumption is necessary for consistency), implying that the two-step estimator is no more robust than the full information maximum likelihood. Therefore, unlike previous irrigation impact studies such as Tesfaye *et al*. (2008) and Bacha *et al*. (2011), the full information maximum likelihood results were reported in this study. The two-step procedure was also done, however, and the results presented in the appendices. Puhani (2000) advised that the two-step model estimation and presentation of its results should be done as a starting point and for comparison with the more efficient full information maximum likelihood estimator.

3.5.4 Principal component analysis (PCA)

PCA was used to generate the water security index of irrigating households. PCA is a multivariate statistical technique used to reduce the number of variables without losing too much information in the process (Achia *et al*., 2010). PCA has been used by several authors to construct an asset-based poverty index which gives the socio-economic status of households (Filmer and Pritchett, 2001; Vyas and Kumaranayake, 2006; Achia *et al*., 2010; Howe *et al*., 2012). Following the same logic, PCA was used to create the water security index, which was used to determine the water security status of an irrigating household.

Irrigators were asked to rank using their perceptions the correctness/truthfulness of statements which depicted components of water security. Perceived water security was thus assessed by the extent to which irrigators agreed or disagreed with statements such as "water to my plot is reliable" or "I have secure rights to the water". The rankings took the value of 0 when the respondent strongly disagreed with the statement, through to 4 when the respondent strongly agreed. Likert scales with at least 5 categories are recommended as they limit distortions in data scaling caused by ordinal data, leading to reasonably robust correlation coefficients (Garson, 2008). Perceptions of farmers were used because farmers plan their investment and production decisions based on their perceptions (Besley, 1995; Crewett *et al.*, 2008; Speelman, 2009). PCA was then used to extract factor scores to construct the water security index.

From an initial set of 12 correlated water security variables that were identified, PCA created uncorrelated indices or components, where each component was a linear weighted combination of the initial water security variables. In each component, the water security indicators were given eigenvalues, which can be interpreted as the weight by which each original water security indicator should be multiplied to get the component score (Howe *et al*., 2012). Variables with low standard deviations would carry a low weight while those with high standard deviations carry a high weight from the PCA (Howe *et al*., 2012). In PCA, the components are ordered so that the first component (PC_1) explains the largest possible amount of variation in the original data. The second component (PC_2) explains additional but less variation than the first component and is uncorrelated with the first component (PC_1). Subsequent components are uncorrelated with previous components, while explaining smaller and smaller proportions of the variation of the original variables. PCA works best when variables are correlated and also when the distribution of variables varies across cases (Vyas and Kumaranayake, 2006). The higher the degree of correlation among the original variables in the data, the fewer components required to capture common information (Morrison, 2005).

Use of PCA is predicated upon the assumption that data are continuous. This assumption was violated in this study by using ordinal variables. To correct the statistical error of using ordinal variables in a PCA analysis, polychoric correlation instead of the Pearson correlations were calculated and then the resulting correlation matrix used in the PCA analysis (Howe *et al.*, 2012). Only the factor scores (eigenvectors) of the first PC were used to construct the water security index since the aim was to create a single measure of the water security status of the irrigators. The first PC captures the largest variation, hence its selection. The first PC created was then used as a dependent variable in an OLS regression to determine the determinants of water security. The independent variables of the OLS model included household characteristics such as age, gender, educational level, etc.

3.5.5 Propensity score matching (PSM) method

The impact of water security on household welfare was evaluated using both the treatment effect model and the PSM method. In order to apply these empirical methods, the continuous water security index generated by PCA above had to be modified to become a binary variable. Both the treatment effect model and PSM require a binary treatment variable. Therefore, there was a need to determine the water security status of an individual irrigator using the water security index. The challenge in categorizing irrigators into two groups of those water and insecure was in determining the cut-off line. Many studies on the socio-economic status of households have used the 40^{th} percentile as the poverty line (Filmer and Pritchett, 2001; Vyass and Kumaranayake, 2006; Achia *et al.*, 2010). The same approach was adopted in this study, and the water security index at the 40^{th} percentile was employed as the cut-off line.

The water security variable, therefore, took the value 1 for households above the cut-off line, and 0 otherwise. Thus, as per the demands of the empirical models used, water security was thought of as a binary treatment; household consumption expenditure as an outcome; water secure households as a treatment group; and water insecure households as a control group. The treatment model was estimated as explained in Section 3.5.3, with water security replacing irrigation access as the treatment variable. The following paragraphs provide a discussion of how PSM was used to estimate the water security impact on household welfare.

PSM is a method widely used in the estimation of the average treatment effects of a binary treatment on a continuous scalar outcome (Gebregziabher *et al.*, 2009; Dillon, 2011; Kuwornu and Owusu, 2012). It uses non-parametric regression methods to construct the counterfactual under the assumption of a selection on observables (Baker, 2000; Blundell and Costa-Dias, 2000). This assumption is commonly called the conditional independence or the unconfoundedness assumption (Khandker *et al.*, 2010). PSM is useful when only observed characteristics are believed to affect selection (Khandker *et al.*, 2010). The main purpose of matching is to re-establish the conditions of an experiment when no such data are available (Blundell and Costa-Dias, 2000).

To understand how PSM was employed in this study, assume that S_i denotes the water security of household *i*; and that it can take two values; namely $S_i = 1$ if the household is water secure; and $S_i = 0$ if the household is water insecure. Further assume that if the i^{th} household is water insecure, then its consumption expenditure level is Y_{0i}, which stands for household consumption expenditure when $S = 0$. If household is water secure, then its consumption expenditure is Y_{1i}. Therefore, the Average Treatment Effect (ATE) on the whole sample is estimated as follows:

$$ATE = E[\Delta_i] = E[Y_{1i} - Y_{0i}]$$

$$= E[Y_{1i} - Y_{0i} \mid S_i=1] \Pr(S_i=1) + E[Y_{1i} - Y_{0i} \mid S_i=1] \Pr(S_i=0) \qquad [7]$$

Where: $E[\Delta_i]$ is the expected impact on household i; Pr is the probability, and other variables are as defined above. The ATE is the weighted average, which tells us what the expected effect of the water security would be on average consumption expenditure level for the entire population (Cobb-Clark and Crossley, 2003).

The interest of this study, however, was to evaluate the impact of water security on those households that are actually water secure. The focus is on estimating the Average Treatment effect on the Treated (ATT), the expected treatment effect over the sample of water secure irrigation participants, which is estimated as follows:

$$ATT = E[\Delta_i | S_i=1] = E[Y_{1i,t} | S_i=1] - E[Y_{0i,t} | S_i=1] \quad [8]$$

Where: $E[\Delta | S_i=1]$ is the expected treatment effect; $E[Y_{i1} | S_i=1]$ is the average expenditure of water secure irrigators, and $E[Y_{i0} | S_i=1]$ is the average expenditure of the water secure households had they not been water secure. The ATT tells us what change in consumption expenditure (outcome) was realized by those households which are water secure subject to their water security status.

Since the consumption expenditure level of water secure households if they were not insecure cannot be observed, the missing data was generated using the propensity score procedure (Baker, 2000; Ravallion, 2008; Gebregziabher *et al.*, 2009). Propensity scoring uses survey data to construct a comparison group by matching water secure households to insecure households from the community population over a set of socio-economic variables such as education level, gender, age, family size, etc. Estimating the propensity score, which is simply the probability that a household is water secure, is a crucial step in using matching as an evaluation strategy. The probit model, as specified in equation 3 (Section 3.4.3) was used to generate the propensity scores. The explanatory variables were the farmer characteristics such as gender, education level, agricultural training, access to extension, credit, etc.

An estimate of the propensity score is not enough to estimate ATT as the probability of observing two units with exactly the same value of the propensity score is, in principle, zero (Becker and Ichino, 2002). As such, various matching algorithms have been proposed in the literature to determine the region of common support, and the most widely used are the nearest neighbour matching, radius matching, Kernel matching, and stratification matching (Becker and Ichino, 2002; Smith and Todd, 2005). The nearest neighbour matching and Kernel matching were used in this study. The nearest neighbour was chosen because it is generally used in practice due to its ease of implementation, while Kernel matching is a recently developed technique that is gaining popularity in non-experimental literature (Smith and Todd, 2005; Dillon, 2011).

The main advantage of the matching method is that it does not rely on a specific functional form of the outcome, thereby avoiding linearity imposition, multicollinearity and heteroskedasticity issues (Cuong, 2007). Therefore, PSM was also used to evaluate the impact of irrigation participation on household welfare to provide robust checks on the results of the treatment effect regression model discussed earlier. To evaluate irrigation impact using PSM, the same approach as outlined above was followed, with irrigation participation replacing water security as a binary treatment; irrigators becoming the treatment group while non-irrigating households were the control group. PSM was estimated using Stata ado files created by Becker and Ichino (2002).

The major limitation of the PSM method is its reliance on the degree to which observed characteristics derive irrigation participation (Khandker *et al.*, 2010). Selection on unobservable characteristics violates PSM's conditional independence assumption, resulting in unreliable estimates (Khandker *et al.*, 2010). As such, the treatment effect model was also done to evaluate the impact of water security on household welfare. In conclusion, the two impact evaluation methods were used in evaluating both the impact of irrigation and the impact of water security on household welfare for triangulation purposes.

3.6 Summary

The Tugela Ferry irrigation scheme is located in Msinga local municipality in KwaZulu-Natal Province on both banks of the Tugela River. Primary data were collected using a structured questionnaire; administered using a stratified random sampling technique. Data were analysed using descriptive statistics and econometric techniques. Descriptive statistics involved t-tests, χ^2 tests and the FGT poverty indices. Different econometric methods (such as the treatment effect model, PCA, OLS, and PSM) were used in this study. The impact of irrigation participation and water security on household welfare was examined using both the treatment effect model and the PSM method. These two econometric approaches have their own limitations, and the use of both methods is to provide robustness checks on the results. PCA was used to generate the water security index while OLS was used to estimate the determinants of water security. The irrigation impact results from these different estimation methods are presented in the next chapter, while the water security impact results are presented in chapter 5.

CHAPTER 4 IRRIGATION IMPACT RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter presents the main findings of the study concerning irrigation impact on household welfare. The results presented in this chapter seek to achieve the first objective of the study, which is to evaluate the impact of the Tugela Ferry irrigation scheme on household welfare[2]. The treatment effect model was used to achieve this objective, while the PSM method was used to provide robustness checks of the treatment effect model. Before presenting the econometric results, however, the next section describes the main characteristics of the sample.

4.2 Descriptive statistics

4.2.1 Household demographics and socio-economic characteristics

The total number of households that were interviewed is 256, comprising of 70 non-irrigators and 186 irrigators. However, 5 households were discarded in the final sample for analysis due to missing information. The total sample size analysed was thus 251, comprising of 65 non-irrigators and 185 irrigators. Descriptive analyses of both continuous and categorical variables indicated that there were no significant differences between the irrigators and non-irrigators in terms of their demographics. The results of descriptive analyses are presented in Table 4.1 and Table 4.2. Table 4.1 presents the results from continuous variables while Table 4.2 presents the results from categorical variables.

The t-test results, presented in Table 4.1, indicate that there were no statistically significant differences between household age, household size and education levels. Since these households are from one community, it is expected that their demographics do not vary significantly. The age statistics for both groups suggest an ageing farmer population, with the much younger generation moving to more lucrative and higher

[2] A more condensed version of this chapter, entitled: The impact of smallholder irrigation on household welfare: The case of Tugela Ferry irrigation scheme in KwaZulu-Natal, South Africa, was submitted to the Water SA journal and is under review

paying ventures in the non-farm sectors. Discussions with the farmers indicated that the youths were shunning the agricultural sector because it is less paying compared to other sectors.

Table 4.1 Continuous variables description

Variable definition	Non-irrigators (N=65)		Irrigators (N=186)		T-test
	Mean	**Std. Dev**	**Mean**	**Std. Dev**	
Household age (years)	58.55	16.08	56.88	12.83	0.84
Household size in numbers	5.98	3.14	6.30	2.69	-0.77
Household size in adult equivalents	4.34	2.24	4.84	2.20	-1.59
Education level in years	2.48	3.85	2.32	3.64	0.30
Total land size (ha)	0.59	0.73	0.24	0.15	6.16***
Non-irrigated land size (ha)	0.61	0.72	0.03	0.08	10.77***
Value of assets (Rands)	66950.38	114753	135186.8	1028149	-0.53
Livestock units in TLU	3.18	4.99	3.22	9.76	-0.03
Off-farm income (Rands)	42332.84	28465.19	36333.66	44701.01	1.01
Farm income (Rands)	321.46	806.98	15341.31	9191.28	-13.1***
Food expenditure (Rands)	3484.42	1999.79	4631.23	3002.47	-2.86***
Nonfood expenditure (Rands)	642.11	879.48	1345.14	1326.01	-3.98***
Total expenditure (Rands)	4126.53	2368.14	5976.37	3862.35	-3.63***
Share of food expenditure (%)	0.87	0.14	0.79	0.13	-4.15***

Notes: ***, ** and * means significant at 1%, 5% and 10% levels, respectively

Source: Household survey (2012)

Irrigators were found to have bigger families (both in numbers and adult equivalents) compared to non-irrigators, indicating a high labour demand for irrigation farming. However, the difference in household sizes between irrigators and non-irrigators was not significant. The results in Table 4.1 also indicate that the respondents had not achieved higher levels of education, with an average of below 3 years of education for both irrigators and non-irrigators. Although there was no statistically significant difference between the educational level of irrigators and non-irrigators, discussions with the farmers indicated that more household members of irrigators are educated compared to non-irrigators. This result, consistent with Tesfaye *et al*. (2008), suggests that money from irrigation is also being invested in services such as education for children. The irrigators reported that even though their welfare may not seem to have improved after they joined the irrigation scheme, they had managed to educate their children. “My lifestyle has not changed much now that I have a plot. But all my kids are educated”, reported one farmer with a sense of achievement.

Generally, there were high levels of illiteracy in the study area as highlighted by Dearlove (2007), while there were no statistically significant differences between irrigators and non-irrigators. Descriptive analyses, presented in Table 4.2, indicated that a high proportion of the farmers (65%) had never attended school, with only about 35% having attended school for at least a year. This percentage of illiterate people is close to that reported by Dearlove (2007), who reported that illiteracy is about 68% in Msinga. However, it is less than the above 80% illiteracy rate reported by Mnkeni *et al*. (2010). The difference could be attributed to different ways illiteracy was measured. Whereas Mnkeni *et al*. (2010) looked at the ability to read and write in defining illiteracy, this study defined illiterate farmers as those who never attended school. It is possible that some farmers who attended school for a year or two may still be unable to read or write, hence Mnkeni *et al*. (2010)’s higher illiteracy figure.

In terms of land endowment, Table 4.1 show small land holdings for irrigators compared to non-irrigators. Whereas irrigators had an average of only 0.24 ha plot sizes per individual household, the non-irrigators operated on average about 0.6 ha per household. This implies that the land intensive nature of irrigation farming is such that irrigators have to operate less land, while the non-irrigators need to put more land under cultivation to cater for the extensive and risky nature of dry-land farming. Compared to non-irrigators, the irrigators can achieve a given welfare level from a smaller land as irrigation access enhances land productivity. The results also show that irrigators operated small non-irrigated land (0.03 ha). In fact, a number of irrigators operated no non-irrigated land at all. This is particularly true of those farmers who stay in areas closer to the irrigation scheme. The demand for land near the scheme is high, such that outside irrigated land, farmers only have their yards with very small extra land. Otherwise, most of the land near the irrigation scheme is irrigated. However, the situation is different when one moves further away from the scheme, where some irrigators do operate about 0.5 ha of non-irrigated land.

Irrigators had far higher farm income compared to non-irrigators. This statistically significant difference indicates that access irrigation improves the opportunities for farmers to engage in profitable farming activities. Farming contributes modestly to the total household incomes in the area, contributing only about 15%. This percentage is less but close to the 18% reported by Dearlove (2007) as contribution of farming to income in the Msinga area. Irrigators had more assets and bigger livestock sizes compared to non-irrigators. However, these differences are not significant. Although non-irrigators had higher off-farm income compared to irrigators, this difference was also not significant. This difference in off-farm income does suggest that the high labour demands of irrigation limits irrigators from looking for other opportunities of augmenting household income.

Irrigators, on the other hand, had far higher farm income compared to non-irrigators. This statistically significant difference indicates how the climatic conditions hinder rain-fed crop production in the study area, and the farm income of non-irrigators is mainly from livestock production. It must be highlighted, however, that farming contributes modestly to the total incomes in the area, contributing on average about 15%. This percentage is less but close to the 18% reported by Dearlove (2007) as contribution of farming to income in the Msinga area. Table 4.1 also indicates that irrigators' welfare status was generally above that of non-irrigators as shown by their statistically significantly higher (by 45%) total expenditures per adult equivalent. There were statistically significant differences between irrigators and non-irrigators in terms of both food and non-food consumption. Non-irrigators spend much of their income on food, with food expenses contributing an average of 87% of total consumption expenditure.

Women play a dominant role in both irrigation and non-irrigation farming, as shown by percentages presented in Table 4.2. The table above indicates that the majority (65.15%) of the households were female-headed, which supports the widely encountered phenomenon in Africa.

Table 4.2 Categorical variables description

Variable definition	Categories	Non-irrigators (%) (N=65)	Irrigators (%) (N=186)	χ^2 test
Household head sex	0=female	65.15	66.84	0.063
	1=male	34.85	33.16	
Household marital status	1=single	13.64	12.30	1.06
	2=married	50.00	57.22	
	3=divorced	4.55	3.74	
	4=widowed	31.82	26.74	
Household main religion	0=no religion	7.58	5.38	1.49
	1=traditional	36.36	35.48	
	2=Christian	56.06	57.53	
	3=Muslim	0.00	1.61	
Literacy	0= illiterate	66.15	63.98	0.0996
	1=literate	33.85	36.02	
Access to extension services	0=no	64.62	29.07	25.82***
	1=yes	35.38	70.97	
Access to credit	0=no	76.92	65.78	2.7852*
	1=yes	23.08	34.22	
Access to good roads	0=no	69.23	46.24	10.21***
	1=yes	30.77	53.76	
Training	0=no	90.77	88.17	0.3278
	1=yes	9.23	11.83	
Perception of land quality	0=bad	30.77	12.85	25.53***
	1=good	32.31	44.18	
	2=very good	36.92	42.97	

Notes: ***, ** and * means significant at 1%, 5% and 10% levels, respectively

Source: Household survey (2012)

Most of the farmers were married and were of the Christian persuasion, with no statistically significant difference between irrigators and non-irrigators. Table 4.2 also indicates that there was a statistically significant difference between the support services that irrigators get compared to non-irrigators. The majority of the irrigators reported that they had access to extension, credit and good roads while the majority of the non-irrigators had none. The pressure on the government to ensure that projects do not fail results in that skewed distribution of support to irrigators. Also, irrigators perceived their soils to be of good quality, while the majority of the non-irrigators felt that their soils were infertile.

Descriptive analysis presented above highlights the fact that although the irrigators and non-irrigators have the same demographic patterns, the welfare of the irrigators is higher than that of non-irrigators. The question, then, is to what extent is the welfare difference between irrigators and non-irrigators as a result of irrigation participation and not of other factors? The econometric analyses presented in the following sections seek to answer this pertinent question. Before the econometric analyses, however, the next section presents results from FGT poverty analysis.

4.2.2 FGT poverty indices according to irrigation access and gender

The FGT poverty indices also indicated that the irrigators are better-off than non-irrigators in terms of welfare. Table 4.3 indicates that poverty incidence is higher among non-irrigators compared to irrigators, with 75% of non-irrigators in the study area classified as poor compared to 55% of irrigators.

Table 4.3 FGT poverty indices according to irrigation status

FGT poverty index	Non-irrigators	Irrigators	Total sample
Poverty headcount index (α=0)	0.75	0.55	0.61
Poverty gap index (α=1)	0.31	0.16	0.20
Squared poverty gap index (α=2)	0.17	0.06	0.09

Source: Household survey (2012)

However, poverty incidence was generally high across the whole sample, i.e., even among irrigators. The study area experiences high levels of poverty as shown by high (60%) poverty incidence. The results are consistent with studies such as Hussain *et al.* (2006) and Namara *et al.* (2008). For example, Hussain *et al.* (2006) found that poverty incidence was 37% among non-irrigators compared to 29% among irrigators in Pakistan. These figures are lower than the ones reported here, highlighting the fact that poverty levels are lower in Pakistan compared to South Africa. Namara *et al.* (2008), on the other hand, found poverty incidences of 58.5% among irrigators and 77.1% among non-irrigators. The study also found that the incidence of poverty among the sample households was still higher (58.5%) irrespective of access to irrigation. Comparisons of the figures indicate that poverty levels are more pronounced in Ethiopia than in South Africa.

Table 4.3 also indicates that the depth and severity of poverty was higher among the non-irrigators than among irrigators. The poverty gap index, a measure of depth of poverty, is 31% for non-irrigators and 16% for irrigators. This implies that the current consumption level of the poor non-irrigators would have to increase by 31% to lift them out of poverty. On the other hand, the poor irrigators need their consumption level to be increased by only 16% to lift their consumption level above the poverty line. The squared poverty gap index (poverty severity) indicates that inequality among the poor is higher for non-irrigators than it is for irrigators. The poverty gap index also shows that the consumption level of the poor in the study area needs to be increased by 20% to lift them out of poverty. The small poverty gap index square (9%) implies that inequality among the poor is generally low in the study area.

The analysis of the FGT poverty indices indicates that although poverty is prevalent for both groups, it is more pronounced among non-irrigators. Figure 4.1 shows poverty incidence at different poverty lines according to irrigation access.

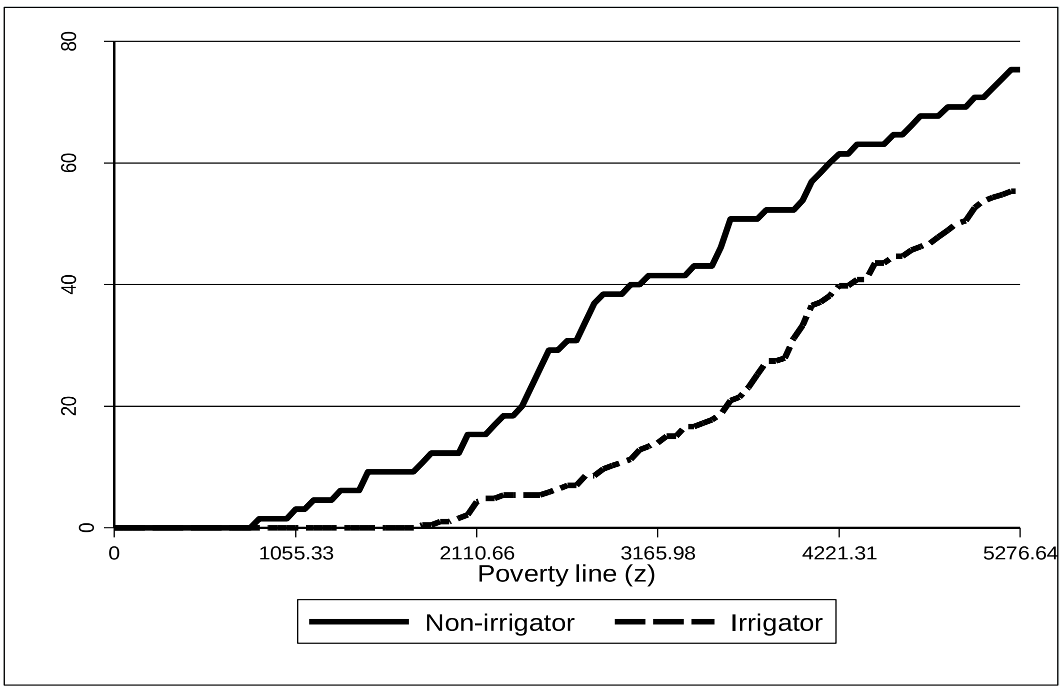

Figure 4.1 Poverty incidence at different poverty lines according to irrigation access

Source: Household survey

The preceding figure indicates that the irrigators generally have lower poverty incidence levels compared to non-irrigators at different poverty lines assumptions. One important aspect of any project impact evaluation is the determination of the gender implications of the project. Further FGT poverty analysis indicated that, contrary to general opinion, poverty was more pronounced among male-headed households than it is among female-headed households. Table 4.4 presents FGT poverty measures according to gender.

Table 4.4 FGT poverty indices according to household head gender

FGT poverty index	**Female**	**Male**	**Total sample**
Poverty headcount index (α=0)	0.58	0.65	0.61
Poverty gap index (α=1)	0.19	0.21	0.20
Squared poverty gap index (α=2)	0.09	0.10	0.09

Source: Household survey (2012)

As shown in Table 4.4, 58% of the female-headed households were classified as poor while 65% of the male-headed households were classified as poor. An explanation here could be that most rural development interventions target women, leading to more poverty reduction among female-headed households than in male-headed households. Table 4.4 also indicates that poverty is deeper among male-headed households than in female-headed households. The poverty gap index implies that the consumption expenditure of female-headed will have to be increased by 19% to take them out of poverty, while that of the poorest male-headed will have to be increased by 21% to take them out of poverty. The poverty incidence curves presented in Figure 4.2 indicate that although poverty incidence fluctuates at low poverty lines, female-headed households have generally less poverty incidence compared to male-headed households.

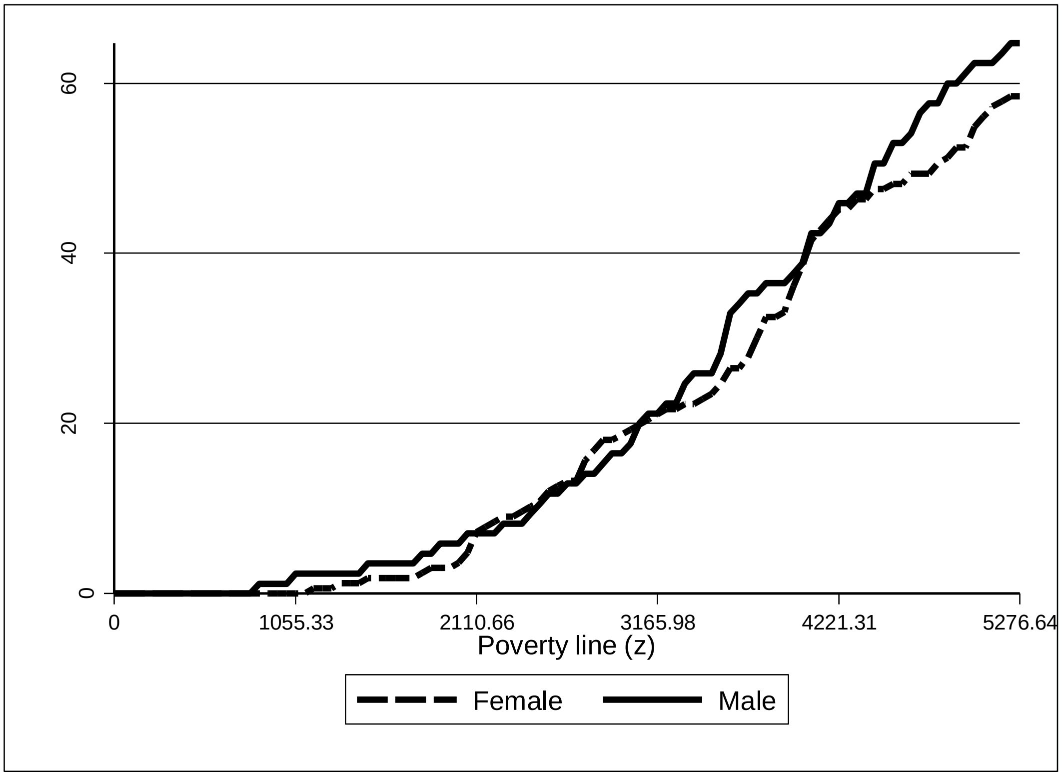

Figure 4.2 Poverty incidence at different poverty lines according to household head gender

Source: Household survey

However, the difference is small, as highlighted by the closeness of the two poverty curves. This implies that poverty incidence is to a large extent gender neutral in the Msinga area. The next section provides econometric models that were used to determine the extent to which irrigation increases household consumption.

4.3 Empirical results

The treatment effect model was used to evaluate the impact of access to irrigation on household consumption expenditure. The first stage of the treatment effect model involved estimating the participation model and the results are presented in the next sub-section. The outcome model, the second stage of the treatment effect model, was estimated and the results are presented in the subsequent sub-section. The last sub-section presents results from PSM, which was estimated to provide robustness checks.

4.3.1 Factors influencing participation in irrigation

The binary probit model was estimated to determine the household characteristics and resource endowments that predict household's participation in irrigation farming. Table 4.5 (overleaf) presents the results of the binary probit model. The results indicate that, collectively, all estimated coefficients are statistically significant since the LR statistic has a p-value less than 1%. The pseudo R^2 value is about 60% which is high for cross sectional data. The model also correctly predicted about 91% of the cases, confirming that the model fits the data well.

The results show that factors such as land size, perceived soil fertility, household size, and access to support services (such as market and extension services) are significant determinants of irrigation participation. Accordingly, as the size of land operated by a household increases, the chances of being an irrigator decline by about 31%. This implies that irrigators tend to intensify their farming, while rain-fed farmers try to put more land under cultivation. This is in line with previous studies (e.g., Tesfaye *et al*., 2008; Dillon, 2011). The results also indicate that the perceived quality of land has a positive influence on irrigation participation. Those farmers who perceived their soil fertility to be good had a 21% more chance of being irrigators than those who felt that their soils are infertile. This result is not unexpected, as irrigation comes at a cost such that only those farmers with good land quality expecting better yield would engage in irrigation farming. This is consistent with results from Bacha *et al* (2011) and Tesfaye *et al*. (2008).

Increasing household size was found to increase the probability of practicing irrigation farming. A unit increase in household size in adult equivalents results in an increase in the probability of irrigation participation of 7%. Increasing family size implies availability of cheap labour, hence the higher chances that the household will participate in irrigation farming. However, the relationship between household size and irrigation participation is not linear but inverted U-shaped, as shown by the negative coefficient of household size square. This implies that although increasing family size increases the likelihood of irrigation participation, it reduces it at a certain stage.

Table 4.5 Determinants of irrigation participation: Probit regression results

Variables	Coefficients		Marginal effects	
	Value	**Std. error**	**Value**	**Std. error**
Value of assets (Rands)	-8.86E-07	8.07E-07	-1.11E-07	9.98E-08
Off-farm income (Rands)	-7.10E-06	8.54E-06	-9.34E-07	1.07E-06
Land size (ha)	-2.414***	0.744	-0.31***	0.0879
Soil fertility (1=Good, 0=Bad)	1.654***	0.402	0.208***	0.0435
Livestock size in TLU	-0.0063	0.014	-0.00082	0.00175
Age	0.095	0.076	0.011	0.00959
Age square	-0.00084	0.00063	-0.0001	7.93E-05
Gender (1=Male, 0=Female)	-0.154	0.305	-0.016	0.0386
Education level (years in school)	-0.038	0.048	-0.0052	0.0061
Household size in adult equivalents	0.588***	0.211	0.074***	0.0253
Household size square	-0.039**	0.016	-0.005**	0.00196
Access to grant (1=Yes, 0=No)	0.667	0.633	0.077	0.0801
Access to credit (1=Yes, 0=No)	-0.443	0.316	-0.058	0.0400
Market access (1=Yes, 0=No)	1.926***	0.402	0.243***	0.0413
Access to extension (1=Yes, 0=No)	0.938***	0.341	0.121***	0.0411
Access to roads (1=Yes, 0=No)	0.388	0.318	0.048	0.0398
Access to training (1=Yes, 1=No)	-0.131	0.527	-0.018	0.0675
Married (1=Married, 0=Otherwise)	-0.120	0.484	-0.021	0.0609
Religion (1=Christian, 0=Otherwise)	0.526	0.326	0.066	0.0406
Distance from scheme (km)	-0.114***	0.026	-0.014***	0.0029
Constant	-5.471**	2.498		
Correctly predicted	90.8			
LR $\chi^2(19)$	172.26***			
Pseudo R^2	0.5999			
N	251			

Notes: ***, ** and * means significant at 1%, 5% and 10% levels, respectively

Source: Household survey (2012)

Irrigation farming can only absorb a certain amount of labour, and increasing family size beyond that reduces labour returns, hence bigger families tend to look for other opportunities that have higher returns for their labour. The results also show that perceived access to the market increases the likelihood of households participating in irrigation farming. The farmers who reported that the market is easily accessible to them have a 24% chance of being irrigators than those who reported otherwise. As irrigation is meant to enhance productivity and marketable surplus, it is not surprising that those farmers with better market access are more likely to participate in irrigation schemes. Access to extension services also improves the likelihood of irrigation participation, and extension officers are more visible in irrigation projects. Farmers who reported contact with extension officers have a 12% chance of irrigating than those who reported otherwise. This result is consistent with findings by Gebregziabher *et al*. (2009).

The positive relationship between support services and irrigation can also be viewed as the tendency of government support to be concentrated to those households engaged in projects, a common practice by the South African government. Such an effort is rare in rain-fed smallholder agriculture. In Tugela Ferry, the Department of Agriculture is located right next to the irrigation scheme, making it more convenient to offer support services to the irrigators compared to the distant non-irrigators. This focus on farmers in projects has resulted in government support benefiting few people. As explained by Hall and Aliber (2010), the problem in South Africa has not been lack of support by the government, but the uneven distribution of that support to the farmers. However, it should also be highlighted that access to services by irrigators is also due to their entrepreneurship or initiatives. In reality, being an irrigator enhances entrepreneurship of the farmers. Irrigators take initiatives and try to find new markets and make follow ups to government institutions such as extension offices to get service, a practice not common among non-irrigators.

As expected, distance of farmer's homestead from the irrigation scheme had a negative influence on the farmer being an irrigator. Nearness to the scheme implies less time taken to the scheme, and ensures ease of management. Since the bulk of the farmers walk to the scheme, then the closer the farmer is to the scheme, the higher his/her chance of being an irrigator. Although not statistically significant, the negative sign on gender highlights that female-headed households are more likely to participate in irrigation farming than male-headed households. This suggests that men have more opportunities in other sectors than women. Education had a negative but non-significant relationship with irrigation participation, suggesting that the educated people have higher opportunities elsewhere than the uneducated.

4.3.2 Impact of access to irrigation on household welfare: Treatment model results

Table 4.6 shows the results from the second stage of the treatment effect model and OLS. Although previous studies (e.g., Bacha *et al*., 2011; Tesfaye *et al*., 2008) have highlighted the likely endogeneity between irrigation participation and consumption expenditure, the Hausman test (F=0.74, p=0.39) indicated that there was no evidence of endogeneity between the two variables at the conventional 10% significance level in this study. Thus, OLS was used in the second stage of the treatment effect model as it results in consistent and unbiased estimates. Household distance from the scheme, although included in the selection equation, was excluded in the second stage of the treatment effect model to satisfy the condition for precise estimation of the coefficients.

The insignificant *rho* in the treatment effect model indicates that there is no evidence of selection bias at the conventional 10% significance level. These findings demonstrate the possible insignificant effect of unobservable factors on household consumption expenditure per adult equivalent. The insignificant *rho* implies that those farmers who select into the irrigation sample have no higher welfare relative to those with average characteristics drawn at random from the population. Therefore, the OLS results in Table 4.6 presented for comparison purposes are consistent and unbiased, and are close to those estimated using the treatment effect model.

Henceforth, explanations concentrate on the treatment effect model results, although the same explanations do apply to the OLS results. The treatment effect model fits the data very well, as indicated by the high χ^2 and pseudo R^2 values. The Stata software program automatically corrects the standard errors (for heteroskedasticity) of the treatment effect model. The estimated coefficients are, therefore, unbiased and consistent, while the standard errors are efficient. Whereas the treatment effect model results presented in Table 4.6 are estimated using the full information maximum likelihood, the two-step model results are presented in Appendix F. As expected, the standard errors of the full information maximum likelihood estimators were generally smaller than those of the two-step estimators, indicating the gain in efficiency as a result of using more information.

Table 4.6 Impact of access to irrigation on household welfare: Treatment effect model and OLS results

Variable	Treatment effect model		OLS model	
	Coef.	**Std. err**	**Coef.**	**Std. err**
Constant	7552.6***	2120.9	7383.5***	2199.9
Value of assets (Rands)	0.00014	0.0008	0.00011	0.0008
Off-farm income (Rands)	0.019**	0.009	0.018*	0.0094
Land size (Ha)	722.49*	387.45	639.45*	386.56
Soil fertility (1=Good, 0=Poor)	138.78	478.61	246.87	475.03
Livestock size in TLU	26.99*	16.01	26.65	16.69
Age	37.87	71.17	43.76	73.79
Age square	0.015	0.616	-0.037	0.638
Gender (1=Male, 0=Female)	-278.01	314.68	-289.23	327.96
Education level (Years in school)	102.03**	42.71	100.87**	44.54
Household size in adult equivalents	-2529.8***	230.8	-2504***	237.90
Household size square	148.60***	18.10	147.13***	18.77
Access to welfare grant (1=Yes, 0=No)	-358.33	655.07	-360.63	683.53
Access to credit (1=Yes, 0=No)	503.15*	313.11	485.02	325.69
Market access (1=Yes, 0=No)	185.74	387.08	306.67	365.24
Access to extension (1=Yes, 0=No)	672.34**	336.48	715.47**	345.68
Agricultural training (1=Yes, 0=No)	883.48*	455.59	874.44*	475.21
Access to good roads (1=Yes, 0=No)	1655.4***	313.45	1684.6***	324.41
Married (1=Married, 0=Otherwise)	1.427	447.13	3.47	466.56
Religion (1=Christian, 0=Otherwise)	-83.21	299.06	-58.49	310.06
Irrigation (1=Irrigator, 0=Non-irrigator)	2216.14***	622.97	1888***	451.31
/athrho	-0.119	0.164	-	-
/lnsigma	7.674***	0.045	-	-
Wald Chi^2(39)/F-test	452.69***		21.08***	
Adj R^2	-		0.62	
N	251		251	
rho	-0.11858	0.1615		
sigma	2151.251	96.471		
lambda	-255.088	348.84		
LR test of independent equations (rho=0):	$\chi^2 = 0.46$ p = 0.50			

Notes: ***, ** and * means significant at 1%, 5% and 10% levels, respectively

Source: Household survey (2012)

The results indicate that irrigation access significantly increases household consumption per adult equivalent as shown by a positive estimated coefficient of irrigation access with a p-value less than 1%. Access to irrigation enabled farmers in the study area to practice double cropping, and also grow crops such as cabbages and potatoes commercially. As a result, the irrigators were able to generate more money and achieve higher consumption expenditure compared to their non-irrigating counter parts. The consumption expenditure per adult equivalent per year of an irrigator was R2,216.14 more than that of a non-irrigator, *ceteris paribus*. This result is consistent with the findings of previous studies (e.g., Tesfaye *et al*., 2008; Gebregziabher *et al*., 2009; Bacha *et al*., 2011; Kuwornu and Owusu, 2012). The conclusion here is that even though smallholder irrigation has admittedly failed in South Africa as many schemes have collapsed after government withdrawals, those irrigation schemes that remain operational are playing an important role in rural poverty reduction.

The other factors that influenced household consumption were off-farm income, land size, livestock size, education level, family size and access to support services and infrastructure (such as credit, extension services, agricultural training and good roads). In line with expectations, access to more land increases household welfare in the rural areas. The households are dependent upon agricultural activity for their livelihood, and more land implies more opportunities of improving production.

The positive sign on livestock size implies that having more livestock gives the households an opportunity to sell during periods of shock. Livestock production is an important livelihood strategy in the Msinga area. Farmers, particularly the non-irrigators, depend heavily on livestock production for their household welfare. Livestock are kept for both food consumption and are sold during the lean periods of the household. The results also support a widely held view that education is critical in the fight against poverty. Additional years of schooling of the household head were found to be positively related with consumption expenditure. Education implies more opportunities of generating income, and also implies better understanding of new and improved farming technologies. This result is consistent with findings from Namara *et al.* (2008) and Tekana and Oladele (2011).

As expected, households with many members consumed less per adult equivalent than those with fewer members. The relationship between family size and household total consumption expenditure was non-linearly, indicating that as the family size increases, the welfare of a family decreases but only up to a certain point. The U-shaped relationship between welfare and family size implies that beyond a certain point, welfare increases with increasing family size. This may be due to the labour-intensive nature of farming. Beyond a certain point, increasing labour within a household enables agricultural intensification. This result is consistent with findings from Bacha *et al*. (2011) and Kuwornu and Owusu (2012).

Access to support services and infrastructure (such as credit, extension, agricultural training and good road network) played an important role in improving household welfare. Those households with access to these services and infrastructure consumed more than those without. The farmers indicated that they use credit to buy agricultural inputs and sometimes for meeting family emergencies. Access to credit support also ensures that farmers can secure inputs in time. This leads to improved agricultural output, resulting in increased farm revenues. Extension services imply access to new technologies which help improve agricultural production, while access to agricultural training improves farmers' skills. Most of the farmers in the scheme use only trial and error, and those who have received some form of training are better-off as they would put these into use.

As expected, access to a good road network has a positive impact on household food security. Those households connected by good road networks have better opportunities than those connected with poor roads. Good road network implies ease of accessing main market centres such as the Tugela Ferry town or Greytown. Due to the rugged topography of the Msinga municipal area, certain areas are relatively isolated from the main centres and the farmers struggle to access potential markets and other services. The above empirical model results have indicated that the Tugela Ferry irrigation scheme has significantly improved household welfare. However, the results of the treatment effect model are only robust if the normality assumption is met. To support the treatment effect results and provide a robustness check, the PSM model which is non-parametric was estimated. No impact evaluation technique is perfect, and it is, therefore, always desirable to triangulate (Baker, 2000).

4.3.3 Impact of access to irrigation on household welfare: PSM results

Since there is no evidence of selection bias due to unobservables as indicated by the insignificant *rho* in the treatment effect model, the PSM method would result in unbiased and robust impact estimates. The balancing property was selected in estimating propensity scores. The use of the balancing property ensures that a comparison group is constructed with observable characteristics distributed equivalently across quintiles in both the treatment and comparison groups (Smith and Todd, 2005). In constructing the matching estimates, the common support was imposed. Heckman *et al.* (1997) encouraged dropping treatment observations with weak common support as inferences can be made about causality only in the area of common support. All standard errors were bootstrapped with 1000 repetitions following Smith and Todd (2005) and Dillon (2011).

Two matching methods, the nearest neighbour and Kernel matching methods were used to estimate the impact. Comparing results across different matching methods can reveal whether the estimated project effect is robust (Khandker *et al.*, 2010). PSM results presented in Table 4.7 support the conclusion that irrigation access does improve household expenditure, indicating that irrigators spend between R2,170 and R2,301 more than the non-irrigators depending on the matching method used. Detailed PSM results are attached as Appendices G, H and I.

Table 4.7 Impact of access to irrigation on household welfare: PSM results

Matching method	**Number of households**		**ATT**	**t-test**
	Treatment	**Control**		
Nearest neighbour	186	20	2301.12 (851.75)	2.702***
Kernel matching method	186	40	2170.31 (612.96)	3.541***

Notes: ***, ** and * means significant at 1%, 5% and 10% levels, respectively

Source: Household survey (2012)

The preceding table indicates that both the nearest neighbour and Kernel matching methods point to the fact that irrigation access has a significant effect on household welfare. The nearest neighbour matching method identified 20 matching households as control, and concluded that irrigation access results in an increase of about R2,301 in consumption expenditure per adult equivalent per year over that of non-irrigators. The Kernel matching method, on the other hand, identified 40 matching households as control, and was somewhat conservative compared to the nearest neighbour matching method in calculating the impact estimate. The Kernel matching method concluded that irrigation access results in a gain of R2,170 in consumption expenditure of the irrigators. The PSM, although reporting slightly lower irrigation impact estimates, support the conclusion made by the treatment effect model that irrigation access has a significantly positive influence on consumption expenditure.

In conclusion, it is noteworthy mentioning that the OLS and PSM estimates are smaller than treatment effect model irrigation impact estimates. The OLS and PSM models do not model the possible correlation between the selection and outcome equations, hence they underestimate the impact of irrigation on household welfare.

4.4 Summary

This chapter has presented the important results of this study pertaining to the welfare impact of the Tugela Ferry irrigation scheme. Although the demographic characteristics of the farmers were not significantly different, the irrigators were characterized by better welfare indicators compared to non-irrigators. The FGT poverty indices also indicated that poverty is more pronounced among non-irrigators than among irrigators. However, it must be noted that poverty incidence is still high among irrigators as well. The econometric models that were used to estimate the impact of irrigation access on welfare indicated that access to irrigation improves household welfare. Both the treatment effect and PSM methods indicated that irrigators have a significantly higher consumption expenditure compared to non-irrigators, highlighting the central role played by irrigation access on rural poverty reduction. However, poverty incidence was generally high across the whole sample, i.e., even among irrigators, indicating the high levels of poverty prevalent in the study area.

CHAPTER 5 WATER SECURITY IMPACT RESULTS AND DISCUSSIONS

5.1 Introduction

Irrigation participation, although one of the important rural development interventions for poverty reduction, the previous chapter has supported the view that it is not sufficient. There was a high poverty incidence among the irrigators as well. This study hypothesized that it is water security, not just irrigation participation, which results in significant poverty reduction. The objective of this chapter, therefore, was to investigate this hypothesis. Analysis in this chapter involved only the sample of 185 irrigators. The water security index was created using PCA while OLS regression model was used to determine the factors affecting household water security level. The treatment effect regression model was used to evaluate the impact of water security on household welfare, with PSM method done for comparison purposes. Before presenting the econometric model results, however, the next section presents the key irrigation scheme descriptive variables.

5.2 Description of key socio-economic variables of the irrigators

Most of the main socio-economic descriptive variables of irrigators have been presented in Tables 4.1 and 4.2, and discussed in the preceding chapter. Key points to be highlighted from the two tables in the previous chapter is that the irrigators were mainly women (66.84%), were generally of old age (mean = 56.88 years), were highly illiterate (63.98%), and had very small non-irrigated land (mean = 0.03 ha). Table 5.1 below focuses on the key descriptive variables of the irrigators which were not presented in the preceding chapter. Before explaining the results presented in Table 5.1, two continuous descriptive variables, household distance from the scheme and irrigated land size, are discussed.

Most of the irrigators were situated close to the irrigators, with an average distance of 3.53 km from the scheme. Some scheme members lived as close as 200 m from the scheme, while others stay as far as above 20 km from the scheme. On average, the irrigators operated 0.2 ha of irrigated land. This indicates that most farmers still operate the 2 plots that they were initially allocated in the scheme. Whereas some farmers had been members of the irrigation for as long as 60 years, others were in their first year. On average, farmers had been members of the scheme for about 17 years.

Table 5.1 Key descriptive variables of irrigators

Variable	Categories	Percentage (%)
Initial plot ownership	1=allocated	37.16
	2=inherited	33.88
	3=borrowed or borrowing	26.23
	4=bought	2.73
Mode of diverting water	1=gravity	31.89
	2=electric pump	52.43
	3=diesel pump	15.68
Plot geographic location along the primary canal	1=head	33.70
	2=middle	39.13
	3=tail	27.17
Occurrence of conflicts over water	0=rare	12.82
	1=often	26.92
	2=always	60.26
Farmer association member	0=no	19.23
	1=yes	80.77
Canal maintenance participation	0=rare	10.26
	1=sometimes	46.15
	2=always	43.59
Scheme management ratings	0=poor	19.78
	1=average	35.71
	2=good	44.50
Scheme management participation	0=no	65.03
	1=yes	34.97
Scheme impacted welfare?	0=no	17.03
	1=yes	82.97

Source: Household survey (2012)

Table 5.1 shows that most of the irrigators were either allocated (37.16%) or inherited (33.88%) their initial plots in the scheme. Borrowing or leasing (26.23%) were also important in ensuring access to the irrigation plots. However, very few (2.75%) farmers had bought the plots they were operating. Buying or selling of plots is illegal under the traditional land tenure security prevalent in the area, although there is evidence of a small informal market for land. The results also demonstrate that the majority (52.43%) of the farmers in the scheme depended on the electric pump to divert water to their plots.

Farmers in block 4A (the largest with about 1,000 members), and block 7, use electric pumps to divert water from the Tugela River to their plots. After the electric pump, farmers depend on gravity, while diesel is used by a small number of irrigators. The Tugela Ferry irrigation was originally designed to operate using gravity, but pumps had to be introduced due to water shortages in those blocks further downstream. The blocks still depending on gravity are blocks 1-3 and 5. Discussions with the farmers indicated that blocks 3 and 5 face serious water shortages, and only the first two blocks were the ones getting adequate water from the original gravity-depended system.

In terms of geographic location along the primary canals diverting water into the respective blocks, most of the irrigators interviewed were located in the middle, while the others were either at the head-end or tail-end of the canals. Conflicts among the farmers were reported to be very common. Only 12.82% of the farmers felt that occurrence of conflicts was rare, while the remainder reported that occurrence of conflicts was common. The main cause of conflicts was reported to be over access to water. Those farmers on the head-end of the primary canal were reportedly drawing more water than their share, resulting in tail-end farmers failing to irrigate even during their turn to irrigate. The affected farmers would try to talk with the head-end farmers, leading to conflict outbreaks.

Irrigators using pumps reported that they face water access problems due to frequent engine breakdowns, small engine sizes and the rising electricity or diesel costs. Those relying on gravity had to contend with the unreliability of the water-flow to their plots. The head-end versus tail-end conflict, although generally affecting all the irrigators in the scheme, had more negative effects on the gravity-reliant irrigators. Since they do not pay for water, it was reportedly difficult for them to fight for their right to the water. Although the specific problems vary depending on mode of drawing water, the irrigators generally reported that there were water supply and distribution issues that were affecting individual irrigators according to their socio-economic circumstances such as gender, marital status, age, etc.

The other major cause of conflicts was reportedly the fact that other farmers would try to irrigate ahead of others, not according to the queuing order. The irrigation system is operated on a first-come-first-serve basis, implying that those farmers who would have come first ought to irrigate first. However, some farmers were reportedly disregarding this rule, causing conflicts as a result. According to women, men have a tendency to forcefully irrigate ahead of women even if the women would have come first. The patriarchal nature of the area disempowers women, as it is a taboo for women to challenge men.

The farmers, particularly the women, reported that they find solace in working as groups. The bulk of the irrigators were members of farmer associations in the scheme. According to the farmers, being a member of an association brought the advantage that the members would support each when faced with different challenges in the scheme. Being a group also was reportedly helping the women’s concerns to be heard and resolved. The irrigators also reported that they do participate in clearing logs and grass from the canal at least sometimes. Most of the scheme members felt that the management of the scheme was average to good, while the majority felt they were not participating in the general management activities of the scheme at the scheme level. The majority felt that the scheme was playing an important role in their welfare. In light of the issues raised above, it is important to empirically determine the factors that influence water security in the scheme. To be able to do this, there was a need to generate the water security variable. The PCA results for generating the water security index are presented in the next section.

5.3 The water security index

The water security index was generated using PCA. The perceptions of farmers relating to water security components were ranked using a Likert scale, and PCA used to extract the water security index. The sample size of 185 irrigators was considered sufficient following Garson (2008)’s rule of 10, which states that there should be at least 10 cases for each item in the instrument being used. The components of water security that were used to extract the water security index were 12, implying that they needed at least 120 cases using the rule of 10.

Six principal components were extracted using polychoric correlations instead of the Pearson correlations. Of the six components extracted, only two components that had

Eigen values greater than one were retained using the Kaiser criterion. Table 5.2 presents the two PCs that were retained, explaining 95.69% of the variance in the data. The first PC (PC_1) explained 67.79% of the variation, while the second PC (PC_2) explained 27.9% of the variation. Detailed results are presented in Appendix J.

Table 5.2 Water security index generation: PCA results

Variables	**Principal Components**	
	PC_1	**PC_2**
Water reliability	0.6520	-0.3510
Water consistency	0.7606	-0.3251
Water sufficiency	0.7289	-0.4980
Water quantity satisfaction	0.7622	-0.4911
Water quality satisfaction	0.6564	-0.3695
Willingness to pay	0.7036	0.4155
Ability to pay	0.6716	0.5726
Never failed to pay	0.7238	0.5381
Will never fail to pay	0.6376	0.6370
Water use rights security	0.3573	0.0638
Registered water user	0.4778	0.1486
Canal maintenance satisfaction	0.5921	-0.1863
Eigen value	5.1297	2.1114
% of variance explained	67.79	27.90

Source: Household survey (2012)

PC_1 indicates that almost all the variables are dominant, and they move in the same direction. This component indicates that those households which are water secure perceived water supply to be reliable, felt that water supply was consistency to their plots, were happy with the quantity and quality of water in their plots, were able and willing to pay for the water, had never failed to pay and they felt they will never fail to pay for water in the future. PC_1 indicates that perceived security of rights to water and being a registered water user were less dominant among the water security variables. There was less variation in the ratings pertaining to water use rights and formal registration, with most farmers indicating that they were water secure even though they are not formally registered. This implies that the smallholder irrigators do not necessarily need to be registered or to be given formal rights to be water secure. The informal traditional structures play a huge role in shaping their perceptions of water-use security. PC_2 was dominated by the three water security components that spoke of the ability to pay for the water. At most, this principal component captures the ability to pay dimension of water security, leaving other dimensions. Therefore, PC_1 was used to generate the water security index because it explained the highest variation (about 68%) and it captured most of the water security components.

5.4 Determinants of perceived water security

Table 5.3 presents the determinants of perceived water security that were estimated using OLS. The water security index generated using PCA was the dependent variable. The model fits data very well, as indicated by a highly significant F value. An R^2 value of 0.43 is considered relatively high for cross sectional data. Heteroskedasticity was remedied by use of robust standard errors. The model had no problem of multicollinearity, as it had a low average variance inflation factor (VIF) of 1.26. The Ramsey's RESET test indicated that the model had no omitted variables (See Appendix K, for detailed model results and model diagnostics). Therefore, the OLS model's estimated coefficients are unbiased, consistent and efficient.

The results indicate that factors such age, income, duration of scheme membership, occurrence of conflicts, method of pumping water, location in the scheme and access to agricultural training influenced irrigators' perceived water security level. The results indicate that age plays a positive role in determining the perceived water security level of the irrigators. Age speaks of experience and wisdom in handling the water challenges and conflicts in the scheme, hence its positive influence on perceived water security.

As expected, having more off-farm income increased perceived water security. More off-income implies the ability to pay for water without failure, thus improving water security especially in those blocks that pay for water. In blocks where water is being paid for, paying for water is a pre-requisite for the irrigators to receive water to their plots. Therefore, having higher off-income serves to guarantee that even when irrigation farming does not perform well, the irrigator is able to source money to pay for water from other sources.

Table 5.3 Determinants of water security: OLS results

Variable	Coefficients	
	Value	Std. Err.
Age (years)	0.01441**	0.00721
Gender (1=Male, 0=Female)	0.09926	0.16391
Marital status (1=Married, 0=Otherwise)	0.02035	0.25851
Education level (Years of schooling)	-0.0281	0.02625
Religion (1=Christian, 0=Otherwise)	0.12199	0.15988
Value of assets (Rands)	1.41E-08	1.24E-07
Livestock size in TLUs	-0.0053	0.00514
Off-farm income (Rands)	1.5E-05***	3.47E-06
Irrigated land size (ha)	0.15253	0.89518
Distance from scheme (km)	-0.0054	0.01733
Duration of scheme membership (years)	-0.0176***	0.0055
Occurrence of conflicts (1=Yes, 0=No)	-0.6469***	0.15561
Participation in canal maintenance (1=Yes, 0=No)	0.23197	0.20104
Farmer association member (1=Yes, 0=No)	0.38608**	0.1599
Scheme management participation (1=Yes, 0=No)	0.1748	0.1489
Pump_1 (1=Electric pump, 0=Gravity or otherwise)	0.63564***	0.179
Pump_2 (1=Diesel, 0=Gravity or otherwise)	0.45794**	0.22428
Location along the canal_1 (1=Head, 0=Middle or otherwise)	0.631***	0.17237
Location along the canal_2 (1=Tail, 0=Middle or otherwise)	-0.3943**	0.18807
Access to extension (1=Yes, 0=No)	0.27079	0.18371
Access to agricultural training (1=Yes, 0=No)	0.5988***	0.20845
Access to credit (1=Yes, 0=No)	-0.2139	0.18491
Constant	1.25059**	0.51775
$F(22, 162)$	11.98***	
R^2	0.43	
N	185	

Notes: ***, ** and * means significant at 1%, 5% and 10% levels, respectively

Source: Household survey (2012)

Occurrence of conflicts in water distribution was also a significant factor that reduced the perceived water security levels of the irrigators. Those farmers who reported that they had encountered conflicts in their blocks felt less water secure than those without conflicts. Some upper-end farmers were reportedly blocking water from flowing downstream in the canal until they are done with irrigating themselves. This is not only a major cause of conflicts, but also a critical determinant of water insecurity in the Tugela Ferry irrigation scheme.

Contrary to apriori expectations, the duration of scheme membership in years had a negative influence on water security. One would have expected that those farmers who have been members of the scheme would have learnt some strategies of ensuring water security to their plots. Multicollinearity was shown to be not the problem, as the VIF was only 1.35 and the scheme membership duration variable was not correlated with age as suspected. The negative influence of duration of scheme membership may be explained as indicating that the farmers who have had the experience of going through all the water problems that have befallen the scheme members in the past have developed pessimism regarding water security in the scheme. Water supply has been relatively reliable in recent years, particularly after the introduction of pumps for the other blocks, hence the optimism of the new comers.

The mode by which water is channelled to farmer's plots also played a significant role in determining the perceived water security level of the farmers. There was a significant difference between the farmers using an electric pump than those using gravity. The irrigators using diesel pump also felt they were more water secure compared to gravity-fed irrigators. The level of organization and farmers' active participation in the blocks with motorized pumps implies that they perceive themselves to be more water secure than the gravity irrigators. The farmers using gravity, because they do not pay for water, are limited in terms of demanding water when it does not reach their plots, resulting to their vulnerability to water insecurity. Block 5, a block using gravity, for instance, was largely uncultivated in the past year because water did not reach the block. There was limited activity in block 3 as well, another block using gravity.

It must be highlighted, however, that this should not be taken as a contradiction to Van Averbeke (2012)'s conclusions that gravity-fed schemes are less likely to collapse after government withdrawal compared to motorized schemes. Whereas the farmers may feel that they are less water secure under gravity-fed systems, the low cost of maintaining gravity-based irrigation systems results in their sustainability in the long-run. This is, of course, at the expense of the investment incentives of the farmers. The argument here is that in terms of poverty reduction effectiveness, it is more preferable that household water security be established in irrigation schemes. This calls for ways of the encouraging farmer initiative and active participation in the gravity-fed systems to improve their sense of water security.

In line with expectations, geographic location in the scheme significantly determined the perceived water security level of the farmers. Farmers who were located in the head-end of the primary canal perceived themselves to be more water secure than those located in the middle-end of the canal. On the other end, farmers on the tail-end predictably felt they were more vulnerable to water shortages compared to those located in the middle-level. Since no farmer can control the amount of water he or she receives, those who are near the water source have a greater chance to withdraw more water, while those located far from the source receive less water, leading to their water insecurity. Water distribution is a major problem in South African irrigation schemes, and this result is consistent with results from Denison and Manona (2007a), Hope *et al*. (2008), Van Averbeke (2008) and Mnkeni *et al*. (2010).

Farmers who had received agricultural training felt more water secure compared to those who did not receive any. The χ^2 analysis indicated that the trained farmers were more likely to rate water sufficiency to their plots higher than the untrained farmers. This implies that although both the trained and untrained farmers may draw the same quantity of water to their respective plots, the trained would apply the water conservation strategies leant. While the untrained irrigators would need more water, the trained irrigators are more likely to perceive themselves to be water secure at lower water volumes compared to the untrained irrigators. Another reason why the trained irrigators felt more water secure has to do with their confidence levels. Their confidence in their agricultural production abilities means they feel that they will always be able to pay for the water and water-related services.

Members of farmer association perceived that they were more water secure compared to the non-members of farmer associations. Joining a farmer association empowers farmers to have their voices heard through collective action. Members of irrigator associations were reportedly at an advantage in terms of water access as they had people to fight in their corner in times of water shortages and conflicts. Although the results indicate that the male irrigators are more water secure than female irrigators, this was not significant.

As reported above, the men were sometimes reportedly forcing their way to accessing water at the expense of women. The model, however, indicate that this may not have led to significant differences in perceived water security levels. The model results also highlight that the married farmers had higher perceived water security levels compared to the unmarried. This was, however, also insignificant at the conventional 10% significance level.

One option of generating the water security index was to simply add the ratings instead of using PCA. This was done and the index generated through addition used as the dependent variable in the OLS model. Generating the water security index by simply adding the ratings did not give results that differed from those estimated using the index generated from PCA. The PCA method of generating the index is more robust, and thus it was more preferred.

5.5 FGT poverty indices according to water security status

The water security index was used to classify irrigators into two categories: those who are water secure and those who are water insecure. The water security status variable was thus a categorical variable taking the value 1 for the water secure irrigators, and 0 for the water insecure. The last 40% of the irrigators were cut-off as water insecure, while the rest were treated as water secure. While there is no strong justification for the choice of the 40% percentile, this approach is used by many researchers to determine the relative poverty status of households, and is adopted here to determine the relative water security status of irrigators. This is because no arbitrary value could be used as the cut-off point, since no such value exists as yet. Table 5.4 presents the FGT poverty indices which show the differences in welfare between the water insecure and water secure irrigators. The results indicate that water secure irrigators experience less poverty compared to water insecure irrigators.

Table 5.4 FGT poverty indices: Differences between water secure and insecure irrigators

FGT poverty index	Water insecure	Water secure	Total sample
Poverty headcount index (α=0)	0.58	0.53	0.55
Poverty gap index (α=1)	0.17	0.15	0.16
Squared poverty gap index (α=2)	0.07	0.05	0.06

Source: Household survey (2012)

The incidence of poverty was higher (58%) among water insecure irrigators compared to that of water secure irrigators (53%). The results also indicate that whereas the consumption expenditure of water insecure farmers would need to be raised by 17% for them to be above the cut-off line, the consumption expenditure of the poor water secure irrigators will need a 15% increase. Inequalities are low in both groups, as indicated by squared poverty gap index of 7% for water insecure farmers and 5% of water secure farmers. Although these poverty differences may seem small, the question is: are they significant? The next section presents the empirical results that seek to answer this question.

5.6 Empirical results

The impact of water security on welfare was estimated using the treatment effect model and the PSM method. Irrigators who are water secure, as has been explained earlier, may differ in many (measured and unmeasured) characteristics from people who do not. Water security could be influenced by some external process (e.g., political process, intelligence, experience and managerial ability) which may result in certain farmers being more water secure than others. If these characteristics are related to household consumption expenditure, the coefficient of the water security variable may catch up these effects and be biased and inconsistent if estimated using OLS regression. As such, the treatment effect model was used to determine the impact of water security on household welfare as it accounts for this selection process. The water security variable was used as a binary variable as explained above.

The probit model was used to estimate the probability that a household will be water secure in the first stage of the treatment effect model. The probit results are presented in

Appendix J. The purpose of the probit model was to estimate propensities that a household will be water secure. The results of the probit model indicated that determinants of water security were age, livestock size, income, duration of scheme membership, conflict occurrence, pumping method, geographic location in the scheme, and agricultural training. These are the same factors that were identified using the OLS regression in Section 5.3, except for livestock size. This, coupled by the fact that generating the water security index by mere addition of ratings generated relatively similar results, indicates that the model results are robust.

A significant livestock size variable implies that livestock size had a positive influence on the chances of being water security. This can be explained as indicating the importance of livestock as a livelihood activity in the area. Selling livestock to meet the household expenses, which may include paying for water and water-related services, was reportedly common in the study area. The following section presents the results from the second stage of the treatment effect model.

5.6.1 Impact of water security on household welfare: Treatment model results

The Hausman test (F=2.22, p=0.14) indicated that there was no evidence of endogeneity between water security and consumption expenditure at the conventional 10% significance level. Therefore, the OLS procedure was used during the second stage of the treatment effect model. The model relied on the non-linearity assumption for identification since the same number of variables appears in the water security and response equations (Sartori, 2003). Because the household distance from scheme variable was insignificant in the water security equation, excluding it in the outcome equation would not have improved identification, hence the reliance on the non-linearity assumption for model identification. The results of the treatment effect regression model are presented in Table 5.4, while the less efficient results estimated using the two-step procedure are presented in Appendix M. The OLS results are presented in Table 5.4 for comparison purposes.

Table 5.5 Impact of water security on household welfare: Treatment effect model and OLS results

Variables	**Treatment effect model**		**OLS model**	
	Coef.	**Std. Err.**	**Coef.**	**Std. Err.**
Constant	1.251	0.518	2936.1	2279.6
Age (years)	-3.229	24.64	9.7	27.4
Gender (1=Male, 0=Female)	-814.34	583.85	-830.7	533.6
Marital status (1=Married, 0=Otherwise)	716.1	816.99	591.4	1265.4
Education level (Years of schooling)	91.1	80.29	71.1	78.7
Religion (1=Christian, 0=Otherwise)	-140.59	549.64	-136.8	606.7
Value of assets (Rands)	0.00079	0.0012	0.0007	0.0005
Livestock size (TLU)	-23.91	26.87	-18.6	15.8
Off-farm income (Rands)	0.0629***	0.014	0.07***	0.019
Irrigated land size (Ha)	1679.1	2614.36	1668	3762.9
Household distance from scheme (km)	-42.01	67.86	-35.4	56.3
Scheme membership (years)	48.26**	21.75	30.1	19.7
Conflicts occurrence (1=Yes, 0=No)	604.4	646.4	156.8	657.3
Canal maintenance (1=Yes, 0=No)	-697.56	708.51	-554.1	746.4
Association member (1=Yes, 0=No)	293.14	569.61	549.3	494.9
Scheme management (1=Yes, 0=No)	36.4	567.5	45.6	575
Pump_1 (1=Electric pump, 0=Gravity)	-1156.86*	684.27	-425.3	722.3
Pump_2 (1=Diesel pump, 0=Gravity)	-974.92	902.92	-392.2	847
Canal location_1 (1=Head, 0=Middle)	-684.88	642.58	-126.6	666.7
Canal location_2 (1=Tail, 0=Middle)	-645.87	638.93	-1059**	494
Access to extension (1=Yes, 0=No)	161.86	659.04	372	554.2
Access to training (1=Yes, 0=No)	484.35	878.28	1123.8	1019.5
Access to credit (1=Yes, 0=No)	1274.96**	575.7	1081.5	714.3
Water secure (1=Secure, 0=Insecure)	3706.9***	1252.1*	1171	682.5
/athrho	-0.524**	0.246	-	-
/lnsigma	8.121***	0.069	-	-
Wald χ^2 (43)/F-test	102.98***		3.6***	
R^2	-		0.34	
N	185		185	
rho	-0.48	0.189		
sigma	3363.26	230.4		
lambda	-1617.87	712.34		
LR test of independent equations (rho=0):	χ^2 = 3.38* p = 0.067			

Notes: ***, ** and * means significant at 1%, 5% and 10% levels, respectively

Source: Household survey (2012)

The significant *rho* in the treatment effect regression model indicates that there is selection bias in the model. The OLS results are, therefore, biased and inconsistent. Henceforth, the discussions are based on the selection bias corrected treatment effect model estimates. The treatment effect regression model fits the data relatively well, as shown by highly significant Wald χ^2 value. In line with expectations, the results indicate that water security has a significant impact on household welfare. Water secure households consumed significantly higher than water insecure households. As a result, the hypothesis put forward cannot be rejected at the 5% significance level. In passing, it should be noted that OLS underestimates the impact of water security due to selection bias. Other factors that influenced household welfare were off-farm income, duration of scheme membership, use of electric pump and access to credit.

The treatment effect model indicates that increasing off-income increases household welfare. This result is not surprising, as one would expect households to spend their earnings from non-farm activities on meeting their consumption needs. An interesting result in this model is that duration of scheme membership had the effect of increasing household welfare. This implies that those households that have been part of the scheme for longer periods have higher consumption expenditures. The experienced irrigation members have established connections from input suppliers to output buyers, resulting in them making more money than the new comers. This result highlights that, although these veteran irrigators are generally pessimistic about their water security as shown in the previous sections, they are the ones enjoying better welfare compared to new comers.

The results also indicate that access to credit improves household welfare. This indicates the important role of credit in irrigating farming as it ensures farmers can buy inputs in time. The farmers reported that saving money was difficult, and most of the farmers were spending the money on other household needs and then fail to buy the inputs for the next crop. Borrowing then helps in filling this gap, hence the improved welfare of those with access to credit. PSM was estimated to provide robustness checks to the treatment effect model results and results presented in the next section.

5.6.2 Impact of water security on household welfare: PSM results

Table 5.6 presents results from the PSM model that was estimated for comparison purposes with the treatment effect model results. The household variables indicators used in the probit specification to generate the propensity scores satisfied the balancing property (See Appendix N for detailed results). As explained in the previous chapter, the balancing property was selected in estimating propensity scores, while the common support was imposed and all standard errors were bootstrapped with 1,000 repetitions in constructing matching estimates.

The PSM results, presented in Table 5.6, indicate that water security has a significant impact on the household welfare status of irrigators. Water secure irrigators consumed between R1,983.45 and R2,274.14 more than the water insecure irrigators based on the matching method adopted. Two matching estimators, the nearest neighbour and the Kernel matching methods were employed as robustness checks.

Table 5.6 Impact of water security on household welfare: PSM results

Matching method	Number of households		ATT	Std. err	t-test
	Treatment	Control			
Nearest neighbour	111	35	2274.14	851.286	2.671***
Kernel matching method	111	59	1983.45	601.774	3.296***

Notes: ***, ** and * means significant at 1%, 5% and 10% levels, respectively

Source: Household survey (2012)

The nearest neighbour matching method identified 34 comparable control households, while the Kernel matching method identified 59 control households from the 74 water insecure irrigators. The average expenditure gain estimated using the nearest neighbour matching method is higher than that of the Kernel matching method, indicating that the Kernel matching method is somewhat conservative. To conclude, both matching methods indicate that water security plays an important role in poverty reduction in rural areas. Comparing the results across the different matching methods indicate that the estimated project impact is robust. The PSM results support conclusions by Hope *et al*. (2008) that security of irrigation access plays a key role in determining the poverty reduction impact of irrigation.

It is important to highlight that whereas the OLS and PSM impact estimates are generally close to each other, the treatment effect model impact estimate is significantly higher than all estimates. Interestingly, it is the treatment effect model results that are more robust in the presence of selection bias on unobservable characteristics. The PSM method is robust when there is only selection on observables. However, selection on unobservables as indicated by a significant *rho* in the treatment effect model violates that assumption leading to a biased PSM estimate. In conclusion, all the models and their variations indicate that water security plays an important role in household welfare.

5.7 Summary

This chapter has indicated that it is water security that is desirable, as water secure irrigators had higher consumption expenditures compared to water insecure irrigators. The results imply that ensuring water security is vital for irrigation to achieve its objective of reducing rural poverty. However, it must be noted that both water secure and water insecure households were characterized by higher levels of poverty, indicating the prevalence of poverty in the study area. Based on these results and the analysis done in the thesis, the next chapter highlights the main conclusions and proposes several recommendations. This last chapter also highlights the remaining research questions that deserve investigation in the future.

CHAPTER 6 CONCLUSIONS AND POLICY RECOMMENDATIONS

6.1 Recap of the research objectives and methodology

The study's general objective was to evaluate the impact of smallholder irrigation and water security on rural household consumption expenditure. It had two impact evaluation parts. Firstly, the objective of the study was to evaluate the impact of smallholder irrigation on household welfare. Secondly, the study aimed to evaluate the impact of water security on household welfare. It was argued in the study that irrigation participation alone is not sufficient in poverty reduction. It is also vital that individual irrigators have water security at the household level. The second evaluation dimension makes this study different from many others that assume that irrigation participation results in the same level of water access by individual irrigators. Since water security is least understood, the study also sought to generate the water security index using PCA.

Using a total sample of 185 irrigators and 66 non-irrigators which was generated through a stratified random sampling procedure, data analysis involved both descriptive and econometric techniques. Descriptive analysis made use of the t-tests, χ^2 tests and FGT poverty measures, while econometric analysis involved methods such as PCA, OLS, PSM and treatment effect model. Data from qualitative sources (key informant interviews and focus group discussions) were used to contextually interpret the quantitative results from the econometric models. This chapter presents the main conclusions of this study. Based on the empirical results, the chapter also draws several policy recommendations. Furthermore, the last section of this chapter presents the remaining knowledge gaps and suggests areas of further investigation in the future.

6.2 Conclusions

This study found that, although the irrigators and non-irrigators had the same demographic patterns, the welfare of the irrigators was better than that of non-irrigators. The analysis of the FGT poverty indices indicated that, even though poverty is prevalent for both groups, it was more pronounced among non-irrigators. The majority of the non-irrigators in the study were classified as poor compared to irrigators. The econometric models indicated that the irrigators had significantly higher consumption expenditures compared to non-irrigators. Therefore, it was concluded that smallholder irrigation plays a positive role in rural poverty reduction. The implication of this finding is that, although smallholder irrigation schemes have admittedly failed in the sense that many have collapsed after government withdrawal in South Africa, when operational, they play an important role in poverty reduction in the rural areas. Therefore, government investment in smallholder irrigation for rural poverty reduction should continue.

However, it must be highlighted that poverty incidence is also high among irrigators, as the majority of this group were classified as poor. This may be the reason why many researchers and policy makers have been disappointed by the poverty reduction performance of smallholder irrigation in South Africa. What is clear from this study is that even though smallholder irrigation access reduces poverty among farmers, it is not enough on its own to significantly reduce poverty to low levels. This should not be interpreted as failure of smallholder irrigation, but an indication of the need for a holistic package of complimentary rural development strategies where smallholder irrigation plays a part. As has been noted by some studies, smallholder irrigation is not a ‘magic bullet’ that completely eradicates poverty on its own. Clearly, reducing poverty to low levels in the poor rural areas of South Africa will require several strategies, and it is unconceivable that there is one strategy capable of single-handedly accomplishing that.

This study has also demonstrated that one way of enhancing the effectiveness of smallholder irrigation in poverty reduction is to ensure that irrigators are water secure at the household level. The empirical results presented in the preceding chapter indicated that perceived water security had a significant impact on the household welfare status of irrigators. Water secure irrigators were found to consume more than the water insecure irrigators, and the incidence of poverty was found to be higher among water insecure irrigators compared to that of water secure irrigators. Given the evidence that water security enhances the poverty reduction effectiveness of smallholder irrigation, the study also investigated the determinants of water security.

The empirical results indicated that factors such as age, off-farm income, use of pumps, location on the upper-end of the canal and access to training increase household water security level while factors such as size of irrigated land and location on the tail-end of the canal decrease the level of household water security. One implication of this result is that there is a need to introduce more pumps in different blocks to enhance water security in the Tugela Ferry. The small motor pumps (diesel or electric) that are used in blocks 4 and 7 have significantly improved the farmers' perceived water security levels, compared to those blocks relying solely on gravity. Two blocks in the Tugela Ferry irrigation scheme that may need to be given pumps are blocks 3 and 5, while blocks 1 and 2 could still rely on the original gravity system as water is reliable in the latter two blocks.

One other important conclusion of this study is that it highlights the importance of access to support services (such as extension, credit, agricultural training, market support, etc.) in poverty reduction efforts. These support services were found to positively influence irrigation participation, water security and household welfare. Despite their significant role in poverty reduction, few farmers receive these government services. There is a need for increased government visibility among the smallholder farmers to enhance the poverty reduction effects of smallholder farming. For example, the role played by training in enhancing perceived water security was significant. Training farmers in water conservation techniques would go a long way in improving water efficiency in the farmer's individual plots, resulting in their improved perceived water security. With the same water quantities, the trained farmers would be in a better water security level compared to the untrained farmers. The implication of this conclusion is that there may not be a need to improve the volume of water reaching the irrigators' plots to improve their perceived water security level, but ensuring the wise use of water would be an important strategy. Since training and field visits are common in the area, it is recommended that the water conservation modules be strengthened.

To sum up, smallholder irrigation is negatively correlated with rural poverty, and thus should continue to be prioritised in the poverty-stricken rural areas of South Africa. There is also a need to ensure water security among irrigators for better welfare outcomes. In light of the empirical results and research conclusions, the following section provides specific recommendations to policy makers.

6.3 Policy recommendations

Based on the empirical results, this study recommends that:

- Smallholder irrigation should continue to be supported by the government as it plays an important role in the welfare of rural households;
- A holistic approach should be adopted in addressing poverty in the rural areas. Access to irrigation alone is not enough to significantly reduce poverty as poverty prevalence was still high even among the irrigators. Other rural micro-projects and development initiatives (such as sewing projects, poultry projects, etc.) should be supported among irrigators so that rural poverty is significantly reduced;
- Water security among the irrigators should be prioritised by policy makers, as there was less poverty among the water secure farmers compared to the water insecure farmers. Specifically, it is recommended that pumps be introduced for blocks 3 and 5 in the Tugela Ferry irrigation scheme to enhance their water security status. In fact, introducing small motorised pumps could be the answer to most of the water access challenges in the smallholder irrigation sector;
- Agricultural training, particularly in water conservation techniques, should be offered and emphasised to irrigators. Water security is not only a matter of water supply but also a function of the efficient use of the diverted water.
- Farmer empowerment and participation should continue to be promoted. The blocks where farmer participation was high were found to be more water secure than those with little farmer participation. Specifically, it is recommended that farmer associations be promoted in the scheme, particularly at block level. The formation and running of these associations should be farmer-led and farmer-driven, with outsiders only involved at a coordination level and offering technical support as it is needed.

6.4 Areas of further study

The single difference method of project impact evaluation based on cross section data adopted in this study can be strengthened by using panel data. It is, therefore, recommended that data be collected for several seasons and more robust methods such as difference-in-difference methods that use panel data be used to evaluate the impact of smallholder and water security on household welfare. There is greater need for panel datasets that observe small-scale irrigators over time to better understand the dynamics of irrigation. Moreover, it is clear that irrigation benefits non-irrigators indirectly through its spill-over effects. It is suggested that a study be done to determine the extent to which non-irrigators benefit from the Tugela Ferry smallholder irrigation scheme. The welfare impacts of the irrigation could be understated in this study as the non-irrigators may be also benefitting from the scheme. Although the study has highlighted how perceptions of irrigators could be used to generate the water security index, the water security concept needs further empirical investigation. There may be a need to modify or add more water components beyond those that were identified in this study, while objective measurements of components such as the water source reliability and volume sufficiency employed.

REFERENCES

Achia, T.N.O., Wangombe, A. and Khadioli, N. 2010. A logistic regression model to identify key determinants of poverty using Demographic and Health Survey data. *European Journal of Social Sciences* 13(1):38-45.

Aliber, M. 2009. Exploring Statistics South Africa's national household surveys as sources of information about household-level food security. *Agrekon* 48(4):384-409.

Aliber, M. and Hart, T.G.B. 2009. Should subsistence agriculture be supported as a strategy to address rural food insecurity? *Agrekon* 48(4):434-458.

Altman, M., Hart, T. and Jacobs, P. 2009. Household food security status in South Africa. *Agrekon* 48(4):345-361.

Anderson, A.J., Mahlangu, M.S., Cullis, J. and Swartz, S. 2008. Integrated monitoring of water allocation reform in South Africa. *Water SA* 34(6):731-737.

Araar, A. and Duclos, J.-Y. 2012. DASP: Distributive Analysis Stata Package. Université Laval PEP, CIRPÉE and World Bank.

Bacha, D., Namara, R., Bogale, A. and Tesfaye, A. 2011. Impact of small-scale irrigation on household poverty: Empirical evidence from the Ambo District in Ethiopia. *Irrigation and Drainage* 60:1-10.

Backeberg, G.R. 2006. Reform of user charges, market pricing and management of water: Problem or opportunity for irrigated agriculture? *Irrigation and Drainage* 55:1-12.

Backeberg, G.R. and Sanewe, A.J. 2010. Towards productive water use and household food security in South Africa. Revised paper originally presented at the 6th Asian Regional Conference of ICID held in Yogyakarta, Indonesia,10-16 October 2010.

Baker, J.L. 2000. *Evaluating the impact of development projects on poverty: A handbook for practitioners.* Washington, D.C: World Bank.

Bamberger, M. 2000. The evaluation of international development programs: A view from the front. *American Journal of Evaluation* 21(1):95-102.

Becker, O.S. and Ichino, A. 2002. Estimation of average treatment effects based on propensity scores. *The Stata Journal* 2(4):358-377.

Bembridge, T. 2000. Guidelines for rehabilitation of small-scale farmer irrigation schemes in South Africa. WRC Report 891/1/00. Pretoria, South Africa: Water Research Commission.

Besley, T. 1995. Property rights and investment incentives: Theory and evidence from Ghana. *The Journal of Political Economy* 103(5):903-937.

Blundell, R. and Costa-Dias, M. 2000. Evaluation methods for non-experimental data. *Fiscal Studies* 21(4):447-468.

Boelens, R., Bustamante, R. and de Vos, H. 2007. Legal pluralism and the politics of inclusion: Recognition and contestation of local water rights in the Andes. *In:* Van Koppen, B., Giordano, M. and Butterworth, J. (eds.) *Community-based water law and water resource management in developing countries.*

Brasselle, A.-S., Gaspart, F. and Platteau, J.-P. 2002. Land tenure security and investment incentives: Puzzling evidence from Burkina Faso. *Journal of Development Economics* 67:373-418.

Bruns, B.R., Ringler, C. and Meinzen-Dick, R.S. (eds.). 2005. *Water rights reform: Lessons for institutional design.* Washington D.C: Vistaar Publications.

Cobb-Clark, D.A. and Crossley, T. 2003. Econometrics for evaluations: An introduction to recent developments. *The Economic Record* 79(247):491-511.

Cousins, B. 2012. Smallholder irrigation schemes, agrarian reform and 'accumulation from below": Evidence from Tugela Ferry, KwaZulu-Natal. Paper for a conference on 'Strategies to overcome poverty and inequality: Towards Carnegie III', University of Cape Town, South Africa, 3-7 September 2012.

Cremers, L., Ooijevaar, M. and Boelens, R. 2005. Institutional reform in the Andean irrigation sector: Enabling policies for strengthening local rights and water management. *Natural Resources Forum* 29:37-50.

Crewett, W., Bogale, A. and Korf, B. 2008. Land tenure: Continuity and change, shifting rulers, and the quest for state control. CAPRi Working Paper no. 91. Washington, D.C: International Food Research Institute (IFPRI).

Cullis, J. and O'Regan, D. 2004. Targeting the water-poor through water poverty mapping. *Water Policy* 6(5):397-411.

Cuong, N.V. 2007. An introduction to alternative methods in program impact evaluation. Discussion paper no. 33. Wageningen, The Netherlands: Mansholt Graduate School of Social Sciences.

DAFF. 2011. South African agricultural production strategy. Pretoria: DAFF (Department of Agriculture, Forestry and Fisheries).

Dearlove, P.D. 2007. *Msinga municipality integrated development plan 2005/2006*. KwaZulu-Natal Department of Local Governance and Traditional Affairs. Available at:

http://devplan.kzntl.gov.za/idp_reviewed_2007_8/IDPS/KZ244/Adopted/Msinga%20IDP.pdf.

Denison, J. and Manona, S. 2007a. Principles, approaches and guidelines for the participatory revitalization of smallholder irrigation schemes. Volume 1: A rough guide for irrigation development practitioners. WRC Report TT 309/07. Pretoria, South Africa: Water Research Commission.

Denison, J. and Manona, S. 2007b. Principles, approaches and guidelines for the participatory revitalisation of smallholder irrigation scheme. Volume 2: Concepts and cases. WRC Report TT 308/07. Pretoria, South Africa: Water Research Commission.

Dillon, A. 2008. Access to irrigation and the escape from poverty: Evidence from Northern Mali. Washington, D.C: International Food Policy Research Institute.

Dillon, A. 2011. The effect of irrigation on poverty reduction, asset accumulation, and informal insurance: Evidence from Northern Mali. *World Development* 39(12):2165-2175.

DWA. 2012. *Proposed National Water Strategy 2 (NWRS-2): Managing water for an equitable and sustainable future*. Pretoria: Department of Water Affairs (DWA). Available at: http://www.info.gov.za/view/DownloadFileAction?id=173116 [Accessed 12 October 2012].

DWAF. 1997. *White Paper on a National Water Policy for South Africa*. Pretoria: Department of Water Affairs and Forestry (DWAF). Available at: http://www.dwaf.gov.za/Documents/Policies/nwpwp.pdf [Accessed 13 March 2012].

DWAF. 1998. *National Water Act (Act no. 36 of 1998)*. Pretoria: Department of Water Affairs and Forestry (DWAF). Available at: http://www.dwaf.gov.za/IO/Docs/nwa.pdf [Accessed 15 March 2012].

DWAF. 2004. *National Water Resource Strategy*. Pretoria: Department of Water Affairs and Forestry (DWAF). Available at: http://www.dwaf.gov.za/Documents/Policies/NWRS/Default.htm [Accessed 26 April 2012].

Fanadzo, M. 2012. Revitalisation of smallholder irrigation schemes for poverty alleviation and household food security in South Africa: A review. *African Journal of Agricultural Research* 7(13):1956-1969.

Fanadzo, M., Chiduza, C. and P.N.S, M. 2010. Overview of smallholder irrigation schemes in South Africa: Relationship between farmer crop management practices and performance. *African Journal of Agricultural Research* 5(25):3514-3523.

FAO. 2000. Socio-economic impact of smallholder irrigation development in Zimbabwe. Rome, Italy: Food and Agriculture Organization (FAO) of the United Nations.

FAO. 2001. FAO's state of food insecurity 2001. Rome: Food and Agriculture Organization (FAO) of the United Nations.

FAO. 2006. *Food security. Policy Brief 2*. Rome, Italy: Food and Agricultural Organization (FAO). Available at: ftp://ftp.fao.org/es/esa/policybriefs/pb_02.pdf [Accessed 3 August 2012].

FAOSTAT. 2012. *FAO AQUASTAT*. Available at: http://www.fao.org/nr/water/aquastat/dbase/index.stm [Accessed 20 November 2012].

Farolfi, S. and Perret, S. 2002. Inter-sectoral competition for water allocation in rural South Africa: Analyzing a case study through a standard environmental economics approach. Working Paper 2002-23. Pretoria: University of Pretoria.

Faurès, J.-M. and Santini, G. 2008. Water and the rural poor: Interventions for improving livelihoods in sub-Saharan Africa. Rome, Italy: Food and Agriculture Organization of the United Nations.

Faysse, N. 2004. An assessment of small-scale users' inclusion in large-scale water user associations of South Africa. Research Report 84. Colombo, Sri Lanka: International Water Management Institute.

Faysse, N. and Gumbo, J. 2004. The transformation of irrigation boards into water user associations in South Africa: Case studies of the Umlaas, Komati, Lomati and Hereford irrigation boards. Volume 2. Working Paper 73. Colombo, Sri Lanka: International Water Management Institute.

Fenske, J. 2011. Land tenure and investment incentives: Evidence from West Africa. *Journal of Development Economics* 95:137–156.

Filmer, D. and Pritchett, L.H. 2001. Estimating wealth effect without expenditure data-or tears: An application to educational enrollments in states of India. *Demography* 38(1):115-132.

Foster, J., Greer, J. and Thorbecke, E. 1984. A class of decomposable poverty measures. *Econometrica* 52(3):761-766.

Frye, I. 2005. Constructing and adopting an official poverty line for South Africa: Some issues for consideration. A discussion document. South Africa: National Labour and Economic Development Institute.

García-Bolanos, M., Borgia, C., Poblador, N., Dia, M., Seyid, O.M.V. and Mateosa, L. 2011. Performance assessment of small irrigation schemes along the Mauritanian banks of the Senegal River. *Agricultural Water Management* 98:1141-1152.

Garson, G.D. 2008. *Factor Analysis: Statnotes from North Carolina State University Public Administration Program*. Available at: http://www2.chass.ncsu.edu/garson/pa765/factor.htm [Accessed 4 February 2013].

Gebregziabher, G., Namara, R.E. and Holden, S. 2009. Poverty reduction with irrigation investment: An empirical case study from Tigray, Ethiopia. *Agricultural Water Management* 96:1837-1843.

Greenberg, S. 2010. Status report on land and agricultural policy in South Africa. Research Report 40. Cape Town: Institute for Poverty, Land and Agrarian Studies (PLAAS), University of Western Cape.

Greene, W.H. 2003. *Econometric Analysis.* 5th Edition. New Jersey: Prentice-Hall, Inc.

Grey, D. and Sadoff, C.W. 2007. Sink or swim? Water security for growth and development. *Water Policy* 9:545-571.

GWP. 2000. Towards water security: A framework for action. Stockholm: Global Water Partnership (GWP).

Hall, R. and Aliber, M. 2010. The case of re-strategizing spending priorities to support small-scale farmers in South Africa. Working Paper 17. Cape Town: Institute for Poverty, Land and Agrarian Studies (PLAAS), University of Western Cape.

Hart, T. 2009a. Exploring definitions of food insecurity and vulnerability: Time to refocus assessments. *Agrekon* 48(4):362-383.

Hart, T. 2009b. Food security definitions, measurements and recent initiatives in South Africa and Southern Africa. A paper submitted as part of the Food Security Project "Ensuring affordable quality food for poor households: Considering the short- and long-term contribution of food security to the government's poverty and unemployment reduction strategies". ComMark Trust and the Human Sciences Research Commission (HSRC).

Heckman, J.J. 1979. Sample selection bias as specification error. *Econometrica* 47(1):153-162.

Heckman, J.J., Ichimura, H. and Todd, P. 1997. Matching as an econometric evaluation estimator: Evidence from evaluating a job training programme. *Review of Economic Studies* 64(4):605-654.

Heckman, J.J. and Vytlacil, E. 2005. Structural equations, treatment effects, and econometric policy evaluation. *Econometrica* 73(3):669-738.

Hendriks, S.L. 2005. The challenges facing empirical estimation of household food (in)security in South Africa. *Development Southern Africa* 22(1):103-123.

Hodgson, S. 2004. Land and water: The rights interface. Food and Agriculture Organisation (FAO) Legislative Study 84. Rome, Italy: FAO of the United Nations.

Hodgson, S. 2006. Modern water rights: Theory and practice. Food Agriculture Organisation (FAO) Legislative Study 92. Rome, Italy: FAO of the United Nations.

Hope, R.A., Gowing, J.W. and Jewitt, G.P.W. 2008. The contested future of irrigation in African rural livelihoods: Analysis from a water scarce catchment in South Africa. *Water Policy* 10:173-192.

Howe, L.D., Galobardes, B., Matijasevich, A., Gordon, D., Johnston, D., Onwujekwe, O., Patel, R., Webb, E.A., Lawlor, D.A. and Hargreaves, J.R. 2012. Measuring socio-economic position for epidemiological studies in low- and middle-income countries: a methods of measurement in epidemiology paper. *International Journal of Epidemiology* 41:871-886.

Hussain, I. 2007a. Pro-poor intervention strategies in irrigated agriculture in Asia: Issues, lessons, options and guidelines. *Irrigation and Drainage* 56(2-3):119-126.

Hussain, I. 2007b. Poverty-reducing impacts of irrigation: Evidence and lessons. *Irrigation and Drainage* 56(2-3):147-164.

Hussain, I. and Hanjra, A. 2004. Irrigation and poverty alleviation: Review of the empirical evidence. *Irrigation and Drainage* 53:1-15.

Hussain, I. and Wijerathna, D. 2004. Irrigation and income-poverty alleviation: A Comparative analysis of irrigation systems in developing Asia. Colombo, Sri Lanka: International Water Management Institute.

Hussain, M., Hussain, Z. and Ashfaq, M. 2006. Impact of small-scale irrigation schemes on poverty alleviation in marginal areas of Punjab, Pakistan. *International Research Journal of Finance and Economics* 6:193-200.

Inocencio, A., Kikuchi, M., Tonosaki, M., Maruyama, A., Merrey, D., Sally, H. and de Jong, I. 2007. Costs and performance of irrigation projects: A comparison of Sub-Saharan Africa and other developing regions. IWMI Research Report 109. Colombo, Sri Lanka: International Water Management Institute.

Jackson, C. 2003. Gender analysis of land: Beyond land rights for men? *Journal of Agrarian Change* 3(4):453-480.

Jalan, J. and Ravallion, M. 2003. Estimating the benefit incidence of an antipoverty program by propensity score matching. *Journal of Business and Economic Statistics* 21(1):19-30.

Jen, S., Huang, J., Hu, R. and Rozelle, S. 2002. The creation and spread of technology and total factor productivity in China's agriculture. *American Journal of Agricultural Economics* 84(4):916-930.

Jin, S., Yu, W., Jansen, H.G.P. and Muraoka, R. 2012. The impact of irrigation on agricultural productivity: Evidence from India. Selected poster prepared for presentation at the International Association of Agricultural Economists (IAAE) Triennial Conference, Foz do Iguaçu, Brazil, 18-24 August 2012.

Kamara, A., van Koppen, B. and Magingxa, L. 2002. Economic viability of small-scale irrigation systems in the context of state withdrawal: The Arabie scheme in the Northern province of South Africa. *Physics and Chemistry of the Earth* 27:815-823.

Kanyoka, P., Farolfi, S. and Morardet, S. 2008. Households' preferences and willingness to pay for multiple use water services in rural areas of South Africa: An analysis based on choice modelling. *Water SA* 34(6):715-723.

Kemerink, J.S., Ahlers, R. and van der Zaag, P. 2011. Contested water rights in post-apartheid South Africa: The struggle for water at catchment level. *Water SA* 37(4):585-594.

Khandker, S.R., Koolwal, G.B. and Samad, H.A. 2010. *Handbook on impact evaluation: Quantitative methods and practice.* Washington, D.C: The World Bank.

Komnenic, V., Ahlers, R. and van der Zaag, P. 2009. Assessing the usefulness of the water poverty index by applying it to a special case: Can one be water poor with high levels of access? *Physics and Chemistry of the Earth* 34:219-224.

Kumar, M.D. 2003. Food security and sustainable agriculture in India: The water management challenge. IWMI Working paper 60. Colombo, Sri Lanka: International Water Management Institute.

Kuwornu, J.K.M. and Owusu, E.S. 2012. Irrigation access and per capita consumption in farm households: Evidence from Ghana. *Journal of Development and Agricultural Economics* 4(3):78-92.

Laker, M.C. 2005. Best management practices for small-scale subsistence irrigation farming through participatory adaptive research: Report on a visit to Dzindi irrigation scheme. WRC project K5/1464//4. Pretoria: Water Research Commission.

Lipton, M., Litchfield, J. and Faures, J.-M. 2003. The effect of irrigation on poverty: A framework for analysis. *Water Policy* 5:413-427.

Machethe, C.L., Mollel, N.M., Ayisi, K., Mashatola, M.B., Anim, F.D.K. and Vanasche, F. 2004. Smallholder irrigation and agricultural development in the Olifants river basin of Limpopo Province: Management transfer, productivity, profitability and food security issues. WRC Report No 1050/1/04. Pretoria, South Africa: Water Research Commission.

MacKay, H.M., Rogers, K.H. and Roux, D.J. 2003. Implementing the South African water policy: Holding the vision while exploring an uncharted mountain. *Water SA* 29(4):353-358.

Maddala, G.S. 1983. *Limited-dependent and qualitative variables in economics.* New York: Cambridge University Press.

Maddala, G.S. 1991. A perspective on the use of limited-dependent and qualitative variables models in accounting research. *The Accounting Review* 66(4):788-807.

Makhura, M. and Mokoena, M.R. 2003. Market access for small-scale farmers in South Africa: Status-quo analysis. Paper presented at the HSRC Conference, 12-13 June 2003.

Makhura, M.T. 2001. *Overcoming transactions costs barriers to market participation of smallholder farmers in the Northern Province of South Africa.* PhD thesis, University of Pretoria.

Malzbender, D., Goldin, J., Turton, A. and Earle, A. 2005. Traditional water governance and South Africa's "National Water Act" -Tension or Cooperation? Paper presented on the International workshop on 'African Water Laws: Plural Legislative Frameworks for Rural Water Management in Africa', Gauteng, South Africa, 26-28 January 2005.

Matshe, I. 2009. Boosting smallholder production for food security: Some approaches and evidence from studies in sub-Saharan Africa. *Agrekon* 48(4):483-511.

Mbatha, C.N. and Antrobus, G.G. 2008. Institutions and economic research: a case of location externalities on agricultural resource allocation in the Kat River basin, South Africa. *Agrekon* 47(4):470-490.

Mnkeni, P.N.S., Chiduza, C., Modi, A.T., Stevens, J.B., Monde, N., van Der Stoep, I. and Dladla, R.W. 2010. Best management practices for smallholder farming on two irrigation schemes in the Eastern Cape and KwaZulu-Natal through participatory adaptive research. WRC Report No. TT 478/10. Pretoria, South Africa: Water Research Commission.

Molden, D. (ed.) 2007. *Water for food, water for life: Comprehensive assessment of water management in agriculture.* London: Earthscan.

Morrison, D.F. 2005. *Multivariate statistical methods.* 4th Edition. United States of America: Duxberry Press.

Movik, S. 2009. The dynamics and discourses of water allocation reform in South Africa. STEPS Working Paper 21. Brighton: STEPS.

Mthembu, N. 2008. *Perceptions of barriers to market participation among three farmer groups in rural KwaZulu-Natal*. MSc Thesis, University of KwaZulu-Natal.

Muller, M., Schreiner, B., Smith, L., van Koppen, B., Sally, H., Aliber, M., Cousins, B., Tapela, B., van der Merwe-Botha, M., Karar, E. and Pietersen, K. 2009. Water security in South Africa. DBSA Working Paper Series No.12. Midrand: Development Bank of Southern Africa (DBSA).

Namara, R.E., Hanjra, M.A., Castillo, G.E., Ravnborg, H.M., Smith, L. and van Koppen, B. 2010. Agricultural water management and poverty linkages. *Agricultural Water Management* 97:520-527.

Namara, R.E., Makombe, G., Hagos, F. and Awulachew, S.B. 2008. Rural poverty and inequality in Ethiopia: Does access to small-scale irrigation make a difference? *In:* Awlachew, S.B., Loulseged, M. and Yilma, A.D. (eds.) *Impact of irrigation on poverty and environment in Ethiopia*. Colombo, Sri Lanka: International Water Management Institute (IWMI).

NDA. 2007. *Sectoral overview and performance: Economic performance of the agricultural sector*. Pretoria: National Department of Agriculture. Available at: http://www.nda.agric.za/docs/StratPlan07/07sectoral.pdf [Accessed 18 August 2012].

NDA. 2012. *Abstracts of agricultural statistics*. Pretoria: National Department of Agriculture (NDA). Available at: http://www.nda.agric.za/docs/statsinfo/Ab2012.pdf [Accessed 18 April 2012].

Norman, E., Bakker, K., Cook, C., Aunn, G. and Allen, D. 2010. Water security: A primer. Policy report as part of research project entitled: Developing a Canadian water security framework as a tool for improved water governance for watersheds. Canada: Canadian Water Network.

Ortmann, G.F. and King, R.P. 2010. Research on agri-food supply chains in Southern Africa involving small-scale farmers: Current status and future possibilities. *Agrekon* 49(4):397-417.

Peden, D., Tadesse, G. and Misra, A.K. 2007. Water and livestock for human development. IWMI Part 4. Sri Lanka: International Water Management Institute (IWMI).

Perret, S. 2002. Water policies and smallholding irrigation schemes in South Africa: A history and new institutional challenges. *Water Policy* 4(3):283-300.

Perret, S. and Geyser, M. 2007. The full financial costs of irrigation services: A discussion on existing guidelines and implications for smallholder irrigation in South Africa. *Water SA* 33(1):67-78.

Pinstrup-Anderson, P. 2009. Food security: Definition and measurement. *Food Security* 1:5-7.

Puhani, P.A. 2000. The Heckman correction for sample selection and its critique. *Journal of Economic Surveys* 14(1):53-68.

Ravallion, M. 2008. Evaluating anti-poverty programs. *In:* Evenson, R.E. and Schultz, T.P. (eds.) *Handbook of Agricultural Economics.* Amsterdam, North-Holland.

Rijsberman, F.R. 2006. Water scarcity: Fact or fiction? *Agricultural Water Management* 80:5-22.

Sartori, A. 2003. An estimator for some binary-outcome selection models without exclusion restrictions. *Political Analysis* 11:111-138.

Schultz, B. and Uhlenbrook, S. 2007. Water security: what does it mean, what may it imply? Discussion Draft Paper. Delft, The Netherlands: UNESCO-IHE, Institute of Water Education.

Shah, T., van Koppen, B., Merrey, D., De Lange, M. and Samad, M. 2002. Institutional alternatives in African smallholder irrigation: Lessons from international experience with irrigation management transfer. IWMI Research Report 60. Colombo, Sri Lanka: International Irrigation Management Institute.

Sishuta, B. 2005. Small-scale irrigation development for sustainable rural development: A case study of the Tyhefu irrigation scheme. *African Sociological Review* 9(2):184-206.

Smith, J. and Todd, P. 2005. Does matching overcome LaLonde’s critique of nonexperimental estimators? *Journal of Econometrics* 125(1-2):303-353.

Smith, L.E.D. 2004. Assessment of the contribution of irrigation to poverty reduction and sustainable livelihoods. *International Journal of Water Resource Development* 20(2):243-257.

Speelman, S. 2009. *Water use efficiency and influence of management policies, analysis for the small-scale irrigation sector in South Africa.* PhD Thesis, Ghent University.

Speelman, S., Farolfi, S., Frija, A., D’Haese, M. and D’Haese, L. 2010. The impact of the water rights system on smallholder irrigators’ willingness to pay for water in Limpopo province, South Africa. *Environment and Development Economics* 15:465-483.

Tekana, S.S. and Oladele, O.I. 2011. Impact analysis of Taung irrigation scheme on household welfare among farmers in North-West province, South Africa. *Journal of Human Ecology* 36(1):69-77.

Terre-Blanche, M., Durrhheim, K. and Painter, D. 2006. *Research in practice: Applied methods for social sciences.* Cape Town: University of Cape Town Press.

Tesfaye, A., Bogale, A., Namara, R.E. and Bacha, D. 2008. The impact of small-scale irrigation on household food security: The case of Filtino and Godino irrigation schemes in Ethiopia. *Irrigation Drainage Systems* 22(2):145-158.

Tlou, T., Mosaka, D., Perret, S., Mullins, D. and Williams, C.J. 2006. Investigation of different farm tenure systems and support structure for establishing small-scale irrigation farmers in long term viable conditions. WRC Report No. 1353/1/06. Pretoria, South Africa: Water Research Commission.

Treguetha, N., Vink, N. and Kirsten, J. 2010. *Presidency fifteen year review project: Review of agricultural policies and support instruments in South Africa 1994-2009*. Available at: http://www.npconline.co.za/MediaLib/Downloads/Home/Tabs/Diagnostic/Economy2/agriculture%20presidency%20fifteen%20year%20review%20%20final_reportjuly2010%20final.pdf [Accessed 8 August 2012].

Tshuma, M.C. 2012. A review of the poverty and food security issues in South Africa: Is agriculture the solution? *African Journal of Agricultural Research* 7(28):4010-4020.

Turral, H., Svendsen, M. and Faures, J.-M. 2010. Investing in irrigation: reviewing the past and looking to the future. *Agricultural Water Management* 97:551-560.

Tyler, S. 2007. Water demand management, poverty and equity. IDRC Water Demand Management Research Series Working Paper 2. International Development Research Centre (IDRC).

Van Averbeke, W. 2008. Best management practices for small-scale subsistence farming on selected irrigation schemes and surrounding areas through participatory adaptive research in Limpopo Province. Draft Final Report of WRC Project K5/1464//4. Pretoria: Centre for Organic and Smallholder Agriculture (COSA), Department of Crop Sciences, Tshwane University of Technology.

Van Averbeke, W. 2012. Performance of smallholder irrigation schemes in the Vhembe District of South Africa. *In:* Kumar, M.D. (ed.) *Problems, Perspectives and Challenges of Agricultural Water Management.* Rijeka, Croatia: InTech.

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

Van Averbeke, W. and Mohamed, S.S. 2006. Smallholder irrigation schemes in South Africa: Past, present and future. Pretoria: Centre for Organic and Smallholder Agriculture, Department of Crop Sciences, Tshwane University of Technology.

Van Koppen, B., Sally, H., Aliber, M., Cousins, B. and Tapela, B. 2009. Water resources management, rural redress and agrarian reform. DBSA Working Paper Series No.7. Midrand: Development Bank of Southern Africa (DBSA).

Vink, N. and van Rooyen, J. 2009. The economic performance of agriculture in South Africa since 1994: Implications for food security. Working Paper Series No 17. Midrand, Pretoria: Development Bank of Southern Africa (DBSA).

Vyass, S. and Kumaranayake, L. 2006. Constructing socioeconomic status indexes: How to use Principal Component Analysis. *Health Policy and Planning* 21(6):459-468.

Wale, E.Z. 2004. *The economics of on-farm conservation of crop diversity in Ethiopia: Incentives, attribute preferences and opportunity costs of maintaining local varieties of crops.* PhD Thesis, University of Bonn.

World Bank. 2005. Introduction to poverty analysis. Washington D.C: The World Bank.

World Bank. 2008. World Bank Report 2008: Agriculture for development. Washington D.C: The World Bank.

Yokwe, S. 2009. Water productivity in smallholder irrigation schemes in South Africa. *Agricultural Water Management* 96:1223-1228.

You, L., Ringler, C., Nelson, G., Wood-Sichra, U., Robertson, R., Wood, S., Guo, Z., Zhu, T. and Sun, Y. 2010. What is the irrigation potential for Africa? A combined biophysical and socioeconomic approach. IFPRI Discussion Paper 00993. Wasington, DC: International Food Policy Research Institute (IFPRI).

Zeiton, M. 2011. The global web of national water security. *Global Policy* 2(3):286-296.

APPENDICES

Appendix A: Questionnaire used for data collection

University of KwaZulu-Natal

Discipline of Agricultural Economics

The impact of smallholder irrigation on household welfare: The case of Tugela Ferry irrigation scheme

Questionnaire

All the information provided here will be treated as **STRICTLY CONFIDENTIAL**.

Name of interviewer……………………………………………………………………………..

Date:……………………………………………………………………………………………..

Household name/ reference number:………………………………………………………………

1. Household demographics

1.1 What is the total number of your household members? Please complete table below (*Record household head* details in the first row*).

Household member	Position in the household	Age	Gender	Marital status	Education level (*Specify, e.g. Grade 5*)	Main occupation	Availability in the farm (*Days per week*)

Key

Household position	Gender	Marital status	Main occupation	
1 Household head*	1 Male	1 Single	1=Fulltime farmer 6=Student	
2 Spouse	2 Female	2 Married	2=Regular salaried job 7=Retired	
3 Daughter /son		3 Divorced	3=Temporary job 8=Other (specify)	
4 Other (specify e.g., cousin) ……………………………		4 Widowed	4=Unemployed	
			5=Self employed	

* *Household head refers to the* de facto *household head that stays in the household for 4 or more days per week*

1.2 Are any of your household members receiving a government grant? Yes=1, No=0		
1.3 If yes on 1.2, how many are on the:	Old age grant?	
	Child grant?	
	Disability grant?	
1.4 What is the household's main religion? No religion=0 Traditional=1 Catholic=2 Protestant=3 Pentecostal=4 Other (Specify)………………………=5		

2. Household expenditure patterns and income sources

2.1 Please indicate the food items your household bought, the frequency and the cost incurred in buying the food items in the last month? (*Complete table below*)

List of food items consumed by the household	Quantity consumed *(specify units e.g., kg, l)*	Quantity bought *(specify units e.g., kg, l)*	Frequency bought per month	Price/unit	Total amount
Mealie meal					
Rice					
Flour					
Vegetables and fruits					
Sugar					
Salt and spices					
Eggs					

Samp						
Oil						
Margarine						
Fish						
Beans						
Meat	Beef					
	Chicken					
	Sheep					
	Pork					
Tea / coffee						
Beverages / soft drinks						
Other (specify)						

2.2 Did your household ever experience food shortages during the past 12 months? Never=0 Sometimes=1 Always=2	

2.3 Answer questions 2.31-2.39 using the answers below. 0=Never 1=Rarely= Once or twice in the past four weeks 2=Sometimes= Three to ten times in the past four weeks 3=Often= More than ten times in the past four weeks	
2.31 In the past four weeks, did you worry that your household would not have enough food?	
2.32 In the past four weeks, were you or any household member not able to eat the kinds of foods you preferred because of lack of resources?	
2.33 In the past four weeks, did you or any household member have to eat limited variety of foods due to lack of resources?	
2.34 In the past four weeks, did you or any household member have to eat some foods that you really did not want to eat because of lack of resources?	
2.35 In the past four weeks, did you or any household member have to eat less than you felt because there was not enough food?	

2.36 In the past four weeks, did you or any household member have to eat fewer meals in a day because there was not enough food?	
2.37 In the past four weeks, was there ever no food to eat of any kind in your household because of lack of resources to get food?	
2.38 In the past four weeks, did you or any household member go a whole day and night without eating anything because there was not enough food?	
2.39 In the past four weeks, did you or any household member go to sleep at night hungry because there was not enough food?	

2.4 Please indicate the non-food items your household mainly spent money on, how much was spent and the frequency in the past 12 months (*Complete table below*)

Expenditure item/s		Total amount	Frequency
Educational	School fees		
	Stationary (books, pens, pencils, etc)		
	Uniforms		
	Other (*specify*)		
Service bills	Electricity		
	Water		
	Telephone		
	Other (*specify*)		
Medical expenses			
Transport			
Clothing			
Toiletries (soap, washing powder, etc)			
Entertainment (tobacco, liquor, etc)			
Home (furniture, maintenance, etc)			
Other (specify)			

2.5 What were the sources of your household income in the last 12 months? (*Indicate approximately how much each source contributed and how often*).

Source of household income		Total amount (Rands)	How often? *e.g. monthly*
Remittances			
Agricultural activities	Irrigation farming		
	Dry land farming		
	Livestock production		
Arts and craft			
Permanent employment			
Temporary employment			
Welfare grants			
Other (specify)			

3. Land

3.1 What is the total area of land your household operates? (*If irrigator, include both dry land and irrigated land*)	Dry land	ha
	Irrigated land	ha
3.2 How much land was cultivated in the past 12 months?	Dry land	ha
	Irrigated land	ha
3.3 How far away is your household to the Tugela Ferry irrigation scheme?		km
3.4 Are you a member of the Tugela Ferry irrigation scheme? Yes=1 No=0. If No, proceed to question 3.6.		
3.5 If yes in 3.2, how long have you been a member of the Tugela Ferry irrigation scheme?		years
3.6 Which block do you belong to?		

3.7 Indicate the number of plots you have, their sizes and the means of ownership by completing the table below (*Include both irrigated and dry land plots if irrigator*).

Plot number	Size of plot (ha)	Means of ownership	Farming practice	Land fees paid for the plot per year
1=Maize 6=Cabbage 2=Tomatoes 7=Beans 3=Potatoes 8=Onions 4=Sugarcane 9=Butternut 5=Spinach 10=Other (specify)……………………..	Means of ownership 1=Allocated 4=Bought 2=Inherited 5= Other (Specify) 3= Borrowed/leasing		Farming practice 1=Irrigated 2=Dry land	

3.8 Generally, are you satisfied with the present security of your land? Yes=1 No=0	(a) Dry land	
	(b) Irrigated land	
3.9 Rate the quality of your land for crop production 1=Poor 2=Good	(a) Dry land	
	(b) Irrigated land	

4. Cropping and marketing system

4.1 Please indicate the crops you planted in the past summer (rainy) season, the area you planted, the output you produced and the costs you incurred (*Complete the table below*).

Crop name	Area planted (ha)	Farming practice	Quantity harvested *(specify units e.g., kg)*	Quantity sold *(specify units e.g., kg)*	Price per unit	Output market	Inputs used	Quantity purchased (and used)	Cost per unit	Input supplier

Key

Crops		Farming practice	Market outlet		Inputs used		Supplier
1 Maize	6 Cabbage	Irrigated=1	1=Local shop	5=Shops in town	1 Fertilizers	6 Seeds	1 Local shop
2 Tomatoes	7 Beans	Dry land=2	2=Neighbors	6=Other (specify)	2 Herbicides	7 Pesticides	2 Town (specify)
3 Potatoes	8 Onions		3=Contractor		3 Labor	8 Tillage	3 Co-operative
4 Sugarcane	9 Butternut		4=Hawkers		4 Transport	9 Packaging	4 Donation/ friend
5 Spinach	10 Other (specify)				5 Marketing	10 Other (Specify)	

4.2 Please indicate the crops you planted in the past winter (dry) season, the area you planted, the output you produced and the costs you incurred (*Complete the table below*).

Crop name	Area planted (ha)	Farming practice	Quantity harvested *(specify units e.g., kg)*	Quantity sold *(specify units e.g., kg)*	Price per unit	Output market	Inputs used	Quantity purchased (and used)	Cost per unit	Input supplier

Key

Crops		Farming practice	Market outlet		Inputs used		Supplier
1 Maize	6 Cabbage	Irrigated=1	1=Local shop	5=Shops in town	1 Fertilizers	6 Seeds	1 Local shop
2 Tomatoes	7 Beans	Dry land=2	2=Neighbors	6=Other (specify)	2 Herbicides	7 Pesticides	2 Town (specify)
3 Potatoes	8 Onions		3=Contractor		3 Labor	8 Tillage	3 Co-operative
4 Sugarcane	9 Butternut		4=Hawkers		4 Transport	9 Packaging	4 Donation/ friend
5 Spinach	10 Other (specify)				5 Marketing	10 Other (Specify)	

4.3 How often do you fail to sell your farm produce due to lack of market? Never=0 Sometimes=1 Always=2	

5. Water (Jump to section 7 if non-irrigator)

5.1 How is water pumped to reach your irrigation plot(s)? Gravity=1 Electric pump=2 Diesel pump=3	
5.2 What is your position along the primary canal? Head=1 Middle=2 Tail=3	
5.3 What is your position along the secondary canal? Head=1 Middle=2 Tail=3	
5.4 Do you pay any fees for water or water related services? Yes=1 No=0	
5.5 If yes in 5.4, how much per 0.1ha per month?	R
5.6 How many times per week do you have access to water in your plot(s)?	days

5.7 Please rate the extent to which you agree with the following statements pertaining to water access to your irrigation plot(s) (*Tick appropriate box*).

	Strongly disagree=1	Disagree=2	Neutral=3	Agree=4	Strongly agree=5
Water is reliable					
I always get water in my plot(s)					
Water is sufficient for my cropping requirements					
I am satisfied with the water I receive in my plot(s)					
I have the ability to pay for water and water-related services					
I never fail to raise money to pay for water or water related-services					
I will always be able to raise money to pay for water or water-related services?					
My right or claim to water is secure					
I have problems with too much water in my plot(s)					

5.8 Do you face conflicts in water sharing in the scheme? Yes=1 No=0	
5.9 If yes in 5.8, how frequently do you face conflicts in water sharing in the scheme 1=Very rare 2=Rare 3=Often 4=Very often	
5.10 Do you ever fail to receive irrigating water on your allocated irrigation day?	

Yes=1 No=0	
5.11 If yes in 5.10, how often does it happen? 1=Very rare 2=Rare 3=Often 4=Very often	
5.12 What do you do if you don't receive water on your irrigating day? Nothing=0 Report to the irrigation committee=1 Talk to farmers upstream myself=2	
5.13 If you report to the committee or talk to other farmers yourself in 4.12, how often has your problem been heard and resolved? Never=0 Sometimes=1 Always=2	
5.14 In your opinion, who should pay for water services? 0= No one, government only 1=Everyone in the scheme 2=Only those irrigating a lot 3=Only those that are making more money	
5.15 If water supply and water related services were to be improved, how much will you be willing to pay per 0.1ha plot per year for those supply and services improvements? 0=None 1=A given amount per 0.1ha per year (specify in Rands/0.1ha/year)……………….... 2=An amount depending on your farm income (specify as %)………….	

6. Scheme management

6.1 Is there a farmer association in the irrigation scheme? Yes=1 No=0	
6.2 If yes in 6.1, are you a member of the farmer association? Yes=1 No=0	
6.3 How would you rate the overall scheme management Very poor=0 Poor=1 Average=2 Good=3 Very good=4	
6.4 Do you participate in management of the scheme? Yes=1 No=0	
6.5 If yes in 6.4, are you satisfied by your participation in the management of the scheme? Not at all=0 Somewhat=1 Absolutely=2	
6.6 Do you know about water user associations? Yes=1 No=0	
6.7 If yes in 6.6, are you a member of a water user association Yes=1 No=0	
6.8 If no in 6.6, would you be interested in joining a water user association? Yes=1 No=0	
6.9 Generally, do you think the Tugela Ferry irrigation scheme has improved your welfare as a farmer? No=0 Yes=1	

7. Support services

7.1 Did you use any credit or loan facility in the past 12 months? Yes=1 No=0	

7.2 If yes in 7.1, what was the main source of credit/loan? Relative or friend=1 Money lender=2 Savings club (stokvel)=3 Input supplier=4 Financial institution=5 (Specify name of financial institution…………………………) Output buyer =6 Other=7(Specify)……………………)	
7.3 What was the purpose of the loan/credit? Family emergency=1 Agricultural purposes=2 Other (specify……………………………………)=3	
7.4 Were you able to pay back the loan/credit in time? Yes=1 No=0	
7.5 Did you receive funding or any other sources of credit support from government in the past 12 months? Yes=1 No=0	
7.6 If yes in 7.5, how often? Sometimes=1 Always=2	
7.7 Did you have any contact with extension officer in the past 12 months? Yes=1 No=0	
7.8 If yes in 7.7, how often did you contact extension officers? Sometimes=1 Always=2	
7.9 If yes on 7.7, did you invite the extension officers? Yes=1 No=0	
7.10 Are the extension officers from: 1=Government/parastatal? 2=Non-governmental organisation (NGO)? 3=Private company?	
7.11 Did you receive any free inputs in the past 12 months? Yes=1 No=0	
7.12 If yes in 7.11, what was the source? 1=Government 2=Non-governmental organisation (NGO) 3=Private company	
7.13 If yes in 7.11, please specify the type of inputs received………………………………………….	
7.14 What is your main source of farming information 0=None 1=Radio/television 2=Extension officer 3=Cell phone/SMS 4=Internet 5=Newspaper 6=Other farmers 7=Other (specify)……………………………….	
7.15 Do you understand the information disseminated by the main information source in 6.14? Not at all=0 Somewhat=1 Absolutely=2	

7.16 Are you satisfied with the following infrastructure in your farming area?

	Strongly disagree=1	Disagree=2	Neutral=3	Agree=4	Strongly agree=5
a) Road accessibility					
b) Markets					
c) Electricity					
d) Storage dams					
e) Water supply					

8. **Asset and livestock ownership**

8.1 Do you own the following assets? (*Indicate number owned in the appropriate box, zero if not owned*)

Block, tile house		Car		Telephone		Tap	
Block, zinc house		Motor cycle		Cell phone		borehole	
Round, thatch house		Bicycle		TV		Protected well	
Round pole and mud or shack house		Tractor		Radio		Unprotected well/ dam	
Spades		Wheel barrow		Plough		Water tank	
Hoes		Knapsack sprayer		Other (specify)		Other (specify)	

8.2 Do you own the following livestock? (*Indicate number owned in the appropriate box, zero if not owned. Complete table below*)

Livestock type	Number currently owned	Money spent on feeds, chemicals, vet services, etc in the past 12 months	Number sold in the past 12 months	Price per unit	Number slaughtered for family purpose in the past 12 months
Cattle					
Goats					
Sheep					
Pigs					
Chickens					
Other (specify)					

9. Concluding remarks

9.1 Final general comments……………………………………………………………………….
………………………………………………………………………………………………………
………………………………………………………………………………………………………

Siyabonga/Thank you

Appendix B: Focus group discussion guide

1. Opportunities, challenges and constraints faced as farmers/irrigators/women
2. Solutions to the challenges and constraints?
3. How can we describe water security? Supply? Affordable? Rights/entitlements to the water?
    - Proportion of farmers have water security i.e., is the water reliable?
    - Reasons for lack of water security
    - Differences of water security by gender
4. Skills (production, harvesting, farm management & marketing) necessary for effective participation in agriculture?
    - What is the level of competence of the farmers in these agricultural skills?
    - Does the level of competence in different skills differ between men and women? How? (Explore)
5. Training offered to farmers.
    - Is there training specifically meant for women?
    - What are the weaknesses/shortcomings of the training?
6. Is there any specialization in the farming activities undertaken: Cropping (production & marketing), livestock
7. Institutional arrangements regarding access to land and water? Disincentives to use of land and water by gender.
8. What are the challenges faced when marketing?
    - Are the challenges faced by women different from those faced by men?
9. Does the Tugela Ferry irrigation scheme improve livelihoods of irrigators significantly more than that of non-irrigators or community at large? In what ways?

Appendix C: Variable codes as used in Stata estimations

Variable code	Variable description
conseq	Total household consumption expenditure per adult equivalent in a year
watersec_4	Water security index generated by PCA
wats40_4	Water security status (1=Water secure, 0=Water insecure)
irrigat	Irrigation access (1=Irrigator, 0=Non-irrigator)
gender	Household head gender (1=Male, 0 = Female)
age	Household head age in years
educat	Household head (years of schooling)
marstatus	Household head marital status (1=Married, 0=Non-married)
adulteq	Household size in adult equivalents
adlteqsq	Household size square in adult equivalents
relgn	Household main religion (1=Christianity, 0=Otherwise
grant	Access to government welfare grants (1= Yes, 0=No)
landsize	Household total land size in hectares (ha)
irrland	Household irrigated land in hectares (ha)
nofinceq	Off-farm income (Rands)
tlu	Livestock size in Tropical Livestock Units (TLU)
asetveq	Value of assets (Rands)
soilq3	Farmers' perception of soil fertility status: 1=Good, 0= Poor
extaces	Access to extension service (1= Yes, 0=No)
credtuse1	Access to credit (1=Yes, 0=No)
training	Agricultural skills training (Yes=1, No=0)
mkt1	Market access (1=Yes, 0=No)
road1	Road access (1=Yes, 0=No)
sch_dist	Distance of household to the Tugela irrigation scheme
sch_yrs	Years household has been a member of the Tugela irrigation scheme
Pump1	Pump used (1=Electric pump, 0=Gravity or otherwise)
Pump2	Pump used (1=Diesel pump, 0=Gravity or otherwise)
loc_pr1	Location along the canal (1=Head-end, 0=Middle or otherwise

lo_pr2	Location along the canal (1=Tail-end, 0=Middle or otherwise
asocmemb	Member of farmer association (1=Yes, 0=No)
schmnpart	Scheme level decision making participation (1=Yes, 0=No)
conflict	Occurrence of conflicts (Yes=1, No=0)
Part_canal	Participation in canal maintenance (Yes=1, No=0)

Appendix D: Equivalence scales of recommended energy intakes by age categories

Category	**Age (Years)**	**Average energy allowance per day (Kilocalories)**	**Equivalence scale**
Infants and children	0-0.5	650	0.22
	0.5-1	850	0.29
	1-3	1300	0.45
	4-6	1800	0.62
	7-10	2000	0.69
Males	11-14	2500	0.86
	15-18	3000	1.03
	19-25	2900	1
	25-50	2900	1
	51+	2300	0.79
Females	11-14	2200	0.76
	15-18	2200	0.76
	19-25	2200	0.76
	25-50	2200	0.76
	51+	1900	0.66

Source: NRS (1989), cited in Wale (2004).

Appendix E: Tropical livestock units (TLU) scales

Animal	**Scale**
Cattle	1
Sheep	0.10
Goats	0.10
Pigs	0.20
Chickens	0.01

Source: Peden *et al.* (2007).

Appendix F: Impact of access to irrigation on household welfare: Treatment effects model estimated using two-step procedure

Variable	Treatment effects model	
	Coef.	Std. err
Constant	7694.27***	2143.60
Value of assets (Rands)	0.00016	0.00076
Off-farm income (Rands)	0.019**	0.0090
Land size (Ha)	792.05*	410.34
Livestock size in TLU	27.28*	16.058
Age	32.93	71.98
Age square	0.059	0.62
Soil fertility (1=Good, 0=Poor)	48.23	509.78
Gender (1=Male, 0=Female)	-268.60	316.04
Education level (Years in school)	103.00**	42.87
Household size in adult equivalents	-2551.84***	235.20
Household size square	149.84***	18.30
Access to welfare grant (1=Yes, 0=No)	-356.40	656.87
Access to credit (1=Yes, 0=No)	518.34*	315.28
Market access (1=Yes, 0=No)	84.43	433.19
Access to extension services (1=Yes, 0=No)	636.22*	344.30
Agricultural training (1=Yes, 0=No)	891.04*	457.06
Access to good roads (1=Yes, 0=No)	1630.95***	317.72
Marital status (1=Married, 0=Otherwise)	-0.287	448.36
Religion (1=Christian, 0=Otherwise)	-103.92	302.44
Irrigation (1=Irrigator, 0=Non-irrigator)	2491.00***	813.99
Mills lambda	-468.36	532.87
Wald Chi^2	494.08***	
N	251	
rho	-0.217	
sigma	2157.11	
lambda	-468.36	

Note: *** means significant at 1%; **significant at 5%; *significant at 10% significance levels.

Appendix G: Irrigation participation propensity scores

```
. pscore irrigat asetveq nofinceq landsize TLU soilq3 age gender educat adulteq adlteqsq grant credtuse mkt1 ext
> aces road1 training marstatus relgn  sch_dist_01, pscore(irrigat_2) comsup


****************************************************
Algorithm to estimate the propensity score
****************************************************


The treatment is irrigat

    IRRIGAT |      Freq.     Percent        Cum.
------------+-----------------------------------
          0 |         65       25.90       25.90
          1 |        186       74.10      100.00
------------+-----------------------------------
      Total |        251      100.00


Estimation of the propensity score

Iteration 0:   log likelihood = -143.56463
Iteration 1:   log likelihood = -74.890805
Iteration 2:   log likelihood = -62.233396
Iteration 3:   log likelihood = -58.921672
Iteration 4:   log likelihood = -58.279081
Iteration 5:   log likelihood = -58.257245
Iteration 6:   log likelihood = -58.257223

Probit regression                                 Number of obs   =        251
                                                  LR chi2(19)     =     170.61
                                                  Prob > chi2     =     0.0000
Log likelihood = -58.257223                       Pseudo R2       =     0.5942

------------------------------------------------------------------------------
     irrigat |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
     asetveq |  -7.32e-07   7.94e-07    -0.92   0.356    -2.29e-06    8.23e-07
    nofinceq |  -4.80e-06   8.12e-06    -0.59   0.554    -.0000207    .0000111
    landsize |   -2.44659   .7457677    -3.28   0.001    -3.908268   -.9849121
         TLU |  -.0067887   .0135921    -0.50   0.617    -.0334287    .0198512
      soilq3 |   1.522321   .3805579     4.00   0.000     .7764407      2.2682
         age |   -.006161   .0113912    -0.54   0.589    -.0284874    .0161655
      gender |  -.1059787   .2994782    -0.35   0.723    -.6929452    .4809877
      educat |  -.0618666   .0450033    -1.37   0.169    -.1500714    .0263381
     adulteq |   .6266711   .2055257     3.05   0.002      .223848    1.029494
    adlteqsq |  -.0406426   .0157924    -2.57   0.010    -.0715951   -.0096902
       grant |     .58551   .6101884     0.96   0.337    -.6104372    1.781457
    credtuse |  -.4599219   .3137783    -1.47   0.143    -1.074916    .1550723
        mkt1 |   1.821204   .3752358     4.85   0.000     1.085756    2.556653
     extaces |   1.040383   .3284124     3.17   0.002     .3967062    1.684059
       road1 |   .3713062   .3122743     1.19   0.234    -.2407401    .9833525
    training |   -.081455   .5182631    -0.16   0.875    -1.097232     .934322
   marstatus |  -.1962825   .4619599    -0.42   0.671    -1.101707    .7091422
       relgn |   .5120821   .3208513     1.60   0.110    -.1167748    1.140939
 sch_dist_01 |  -.1149652   .0263898    -4.36   0.000    -.1666884   -.0632421
       _cons |  -2.520704   1.199356    -2.10   0.036    -4.871398   -.1700102
------------------------------------------------------------------------------
Note: 2 failures and 0 successes completely determined.


Note: the common support option has been selected
The region of common support is [.06452187, .99999969]


Description of the estimated propensity score
in region of common support

                 Estimated propensity score
-------------------------------------------------------------
      Percentiles      Smallest
 1%     .0872609       .0645219
 5%     .1926912       .0733444
10%     .4127772       .0872609       Obs                 226
25%     .7370653       .1036384       Sum of Wgt.         226

50%     .9563171                      Mean           .8225408
                        Largest       Std. Dev.      .2574173
75%     .9982122       .9999841
90%      .999819       .9999874       Variance       .0662637
95%     .9999474       .9999978       Skewness      -1.510927
99%     .9999874       .9999997       Kurtosis       4.133488
```

```
******************************************************
Step 1: Identification of the optimal number of blocks
Use option detail if you want more detailed output
******************************************************
```

The final number of blocks is 7

This number of blocks ensures that the mean propensity score
is not different for treated and controls in each block

```
**********************************************************
Step 2: Test of balancing property of the propensity score
Use option detail if you want more detailed output
**********************************************************
```

The balancing property is satisfied

This table shows the inferior bound, the number of treated
and the number of controls for each block

Inferior of block of pscore	IRRIGAT 0	1	Total
.0645219	10	2	12
.2	7	2	9
.4	10	11	21
.6	8	19	27
.8	2	12	14
.9	2	25	27
.95	1	115	116
Total	40	186	226

Note: the common support option has been selected

```
*******************************************
End of the algorithm to estimate the pscore
*******************************************
```

Appendix H: Impact of access to irrigation on household welfare: PSM using nearest neighbour matching

```
. attnd conseq irrigat asetveq nofinceq landsize TLU soilq3 age gender educat adulteq adlteqsq grant credtuse mk
> t1 extaces road1 training marstatus relgn  sch_dist_01, pscore(irrigat_2) comsup bootstrap rep(1000)


 The program is searching the nearest neighbor of each treated unit.
 This operation may take a while.



ATT estimation with Nearest Neighbor Matching method
(random draw version)
Analytical standard errors

---------------------------------------------------------
n. treat.   n. contr.         ATT   Std. Err.           t
---------------------------------------------------------

      186          20    2301.115    2045.617       1.125

---------------------------------------------------------
Note: the numbers of treated and controls refer to actual
nearest neighbour matches




Bootstrapping of standard errors

command:     attnd conseq irrigat asetveq nofinceq landsize TLU soilq3 age gender educat adulteq adlteqsq grant
> credtuse mkt1 extaces road1 training marstatus relgn sch_dist_01     , pscore(irrigat_2)   comsup
statistic:   r(attnd)
(obs=251)

Bootstrap statistics

Variable |    Reps   Observed       Bias   Std. Err.   [95% Conf. Interval]
---------+-----------------------------------------------------------------
     bs1 |    1000   2301.115   -268.922   851.7466    629.6972  3972.533  (N)
         |                                             292.4344  3218.798  (P)
         |                                             322.5819  3229.174 (BC)
---------------------------------------------------------------------------
                              N = normal, P = percentile, BC = bias-corrected


ATT estimation with Nearest Neighbor Matching method
(random draw version)
Bootstrapped standard errors

---------------------------------------------------------
n. treat.   n. contr.         ATT   Std. Err.           t
---------------------------------------------------------

      186          20    2301.115     851.747       2.702

---------------------------------------------------------
Note: the numbers of treated and controls refer to actual
nearest neighbour matches
```

Appendix I: Impact of access to irrigation on household welfare: PSM using Kernel matching method

```
. attk conseq irrigat asetveq nofinceq landsize TLU soilq3 age gender educat adulteq adlteqsq grant credtuse mkt
> 1 extaces road1 training marstatus relgn  sch_dist_01, pscore(irrigat_2) comsup bootstrap rep(1000)


 The program is searching for matches of each treated unit.
 This operation may take a while.


ATT estimation with the Kernel Matching method

---------------------------------------------------------
n. treat.   n. contr.         ATT   Std. Err.           t
---------------------------------------------------------

      186          40    2170.313           .           .

---------------------------------------------------------
Note: Analytical standard errors cannot be computed. Use
the bootstrap option to get bootstrapped standard errors.



Bootstrapping of standard errors

command:     attk conseq irrigat asetveq nofinceq landsize TLU soilq3 age gender educat adulteq adlteqsq grant c
> redtuse mkt1 extaces road1 training marstatus relgn sch_dist_01     , pscore(irrigat_2) comsup    bwidth(.06)
statistic:   r(attk)
(obs=251)

Bootstrap statistics

Variable |   Reps  Observed       Bias   Std. Err.   [95% Conf. Interval]
---------+-------------------------------------------------------------------
     bs1 |   1000  2170.313  -48.78974   612.9556    967.4848  3373.141  (N)
         |                                            816.021  3158.515  (P)
         |                                            711.358  3151.976 (BC)
-----------------------------------------------------------------------------
                              N = normal, P = percentile, BC = bias-corrected


ATT estimation with the Kernel Matching method
Bootstrapped standard errors

---------------------------------------------------------
n. treat.   n. contr.         ATT   Std. Err.           t
---------------------------------------------------------

      186          40    2170.313     612.956       3.541

---------------------------------------------------------
```

Appendix J: PCA generation of the water security variable

```
. polychoric  reliable constnt sufcient qntsatfd qltsatfd wilngpay ablepay pay_fail monalway rightsec reg_user cansatfd
```

Polychoric correlation matrix

	reliable	constnt	sufcient	qntsatfd	qltsatfd	wilngpay	ablepay	pay_fail	monalway	rightsec	reg_user
reliable	1										
constnt	.63243102	1									
sufcient	.68844902	.77135075	1								
qntsatfd	.61580322	.7370652	.80459215	1							
qltsatfd	.46319154	.61317276	.63414948	.74024627	1						
wilngpay	.32148978	.38513805	.28602686	.34403987	.29939205	1					
ablepay	.16394874	.36977075	.22460244	.2692515	.20840344	.79072453	1				
pay_fail	.24636313	.37023955	.2717916	.28461419	.33081019	.69236173	.78447486	1			
monalway	.25992323	.29154825	.15122973	.13399576	.15760556	.64851967	.75978831	.86664831	1		
rightsec	.12982744	.25472843	.21184059	.22736891	.26300778	.20999401	.24360464	.27859945	.29020681	1	
reg_user	.36732782	.25953522	.23266102	.2709739	.22979881	.44504399	.36839487	.34279329	.40686013	.31018452	1
cansatfd	.46634714	.41592571	.49315866	.58939025	.47425804	.36863747	.25559354	.34847656	.24486337	.23055626	.25461754

	cansatfd
cansatfd	1

```
. display r(sum_w)
185

. matrix r = r(R)


. factormat r, n(185)
(obs=185)
```

Factor analysis/correlation   Number of obs = 185
Method: principal factors   Retained factors = 6
Rotation: (unrotated)   Number of params = 57

Factor	Eigenvalue	Difference	Proportion	Cumulative
Factor1	5.12971	3.01832	0.6779	0.6779
Factor2	2.11139	1.80154	0.2790	0.9569
Factor3	0.30985	0.05312	0.0409	0.9979
Factor4	0.25674	0.05239	0.0339	1.0318
Factor5	0.20435	0.06540	0.0270	1.0588
Factor6	0.13895	0.14922	0.0184	1.0772
Factor7	-0.01027	0.05332	-0.0014	1.0758
Factor8	-0.06359	0.01088	-0.0084	1.0674
Factor9	-0.07447	0.03429	-0.0098	1.0576
Factor10	-0.10876	0.02360	-0.0144	1.0432
Factor11	-0.13237	0.06227	-0.0175	1.0257
Factor12	-0.19463	.	-0.0257	1.0000

LR test: independent vs. saturated: chi2(66) = 1575.26 Prob>chi2 = 0.0000

Factor loadings (pattern matrix) and unique variances

Variable	Factor1	Factor2	Factor3	Factor4	Factor5	Factor6	Uniqueness
reliable	0.6520	-0.3510	0.3208	-0.1629	0.0237	-0.0880	0.3140
constnt	0.7606	-0.3251	-0.0516	-0.1618	0.0715	0.1635	0.2551
sufcient	0.7289	-0.4980	-0.0152	-0.1352	0.0544	0.0412	0.1975
qntsatfd	0.7622	-0.4911	-0.1263	0.0583	-0.0799	-0.0251	0.1514
qltsatfd	0.6564	-0.3695	-0.1826	0.1830	0.0410	-0.0026	0.3640
wilngpay	0.7036	0.4155	0.0091	-0.0406	-0.2684	-0.0222	0.2580
ablepay	0.6716	0.5726	-0.1422	-0.0928	-0.1486	0.0993	0.1603
pay_fail	0.7238	0.5381	-0.1404	0.0022	0.1706	-0.1110	0.1254
monalway	0.6376	0.6370	0.0999	-0.0393	0.2104	-0.0335	0.1308
rightsec	0.3573	0.0638	0.0669	0.2897	0.0945	0.1595	0.7455
reg_user	0.4778	0.1486	0.3163	0.1649	-0.0845	0.0896	0.6072
cansatfd	0.5921	-0.1863	0.0156	0.1610	-0.0639	-0.2119	0.5396

Appendix K: Determinants of water security level: OLS results

```
. regress watersec_4 age gender marstatus educat relgn asetveq tlu totinceq irrland sch_dist  sch_yrs conflct part_can asocmb schmnp
> a1  pump1 pump2 loc_pr1 lo_pr2 extaces training credtuse1, r
```

Linear regression

Number of obs =	185
F(22, 162) =	11.98
Prob > F =	0.0000
R-squared =	0.4313
Root MSE =	.99481

watersec_4	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
age	.01441	.0072062	2.00	0.047	.0001797	.0286403
gender	.0992604	.1639064	0.61	0.546	-.2244081	.422929
marstatus	.0203519	.2585068	0.08	0.937	-.4901256	.5308294
educat	-.0281298	.0262463	-1.07	0.285	-.0799587	.0236992
relgn	.1219929	.1598792	0.76	0.447	-.1937232	.4377089
asetveq	1.41e-08	1.24e-07	0.11	0.909	-2.30e-07	2.58e-07
tlu	-.0053334	.0051393	-1.04	0.301	-.015482	.0048152
totinceq	.0000151	3.47e-06	4.36	0.000	8.25e-06	.0000219
irrland	.1525313	.8951823	0.17	0.865	-1.615199	1.920262
sch_dist	-.0054053	.0173298	-0.31	0.756	-.0396267	.0288162
sch_yrs	-.017642	.0054975	-3.21	0.002	-.0284979	-.006786
conflct	-.6469295	.1556121	-4.16	0.000	-.9542191	-.3396399
part_can	.2319724	.2010397	1.15	0.250	-.165024	.6289687
asocmb	.3860799	.1599042	2.41	0.017	.0703147	.7018452
schmnpa1	.1747954	.148901	1.17	0.242	-.1192418	.4688326
pump1	.635644	.1790049	3.55	0.001	.2821603	.9891278
pump2	.4579364	.22428	2.04	0.043	.015047	.9008257
loc_pr1	.6309972	.1723689	3.66	0.000	.2906176	.9713769
lo_pr2	-.3943219	.1880676	-2.10	0.038	-.765702	-.0229419
extaces	.2707869	.1837078	1.47	0.142	-.0919837	.6335576
training	.5987995	.2084463	2.87	0.005	.1871772	1.010422
credtuse1	-.213916	.1849127	-1.16	0.249	-.5790659	.151234
_cons	1.250585	.5177453	2.42	0.017	.2281854	2.272985

```
. estat vif
```

Variable	VIF	1/VIF
pump2	1.58	0.631503
age	1.52	0.655857
extaces	1.42	0.706196
pump1	1.38	0.725842
educat	1.37	0.728778
sch_dist	1.35	0.738867
part_can	1.33	0.753815
sch_yrs	1.30	0.769743
gender	1.24	0.805151
loc_pr1	1.23	0.814431
relgn	1.21	0.827182
schmnpa1	1.21	0.827352
asocmb	1.20	0.830363
irrland	1.20	0.836495
credtuse1	1.18	0.844733
lo_pr2	1.18	0.845785
totinceq	1.17	0.853533
conflct	1.16	0.862387
asetveq	1.15	0.868653
training	1.15	0.868785
marstatus	1.14	0.879257
tlu	1.11	0.898500
Mean VIF	1.26	

```
. estat ovtest

Ramsey RESET test using powers of the fitted values of watersec_4
       Ho:  model has no omitted variables
                 F(3, 159) =      0.25
                  Prob > F =      0.8602
```

Appendix L: Determinants of household's water security status: Probit results

Variables	Coefficients		Marginal effects	
	Value	Std. Err.	Value	Std.Err.
Constant	-1.875**	0.845	-	-
Age (years)	0.017	0.011	0.0047*	0.0027
Gender (1=Male, 0=Female)	-0.077	0.298	-0.033	0.073
Marital status (1=Married, 0=Otherwise)	-0.113	0.352	-0.062	0.084
Education level (Years of schooling)	-0.021	0.037	-0.0031	0.0092
Religion (1=Christian, 0=Otherwise)	-0.058	0.254	0.011	0.063
Value of assets (Rands)	6.4E-07	4.6E-06	-5E-08	2.3E-07
Livestock size in Tropical Livestock Units (TLU)	0.071**	0.033	0.015*	0.0091
Off-farm income (Rands)	4.6E-05***	1.5E-05	6E-06**	3.3E-06
Irrigated land size (ha)	0.169	1.227	-0.032	0.314
Distance from scheme (km)	0.0048	0.032	0.0015	0.0078
Scheme membership (years)	-0.035***	0.010	-0.01***	0.0023
Conflicts occurrence (1=Yes, 0=No)	-0.645**	0.309	-0.19***	0.072
Participation in canal maintenance (1=Yes, 0=No)	0.220	0.343	0.051	0.084
Farmer association member (1=Yes, 0=No)	0.429*	0.250	0.116*	0.062
Scheme management participation (1=Yes, 0=No)	-0.017	0.270	0.0075	0.067
Pump_1 (1=Electric pump, 0=Gravity)	1.198***	0.304	0.323***	0.063
Pump_2 (1=Diesel, 0=Gravity)	0.937**	0.392	0.244***	0.092
Location along the canal_1 (1=Head, 0=Middle)	0.750***	0.268	0.208***	0.062
Location along the canal_2 (1=Tail, 0=Middle)	-0.551**	0.276	-0.146**	0.064
Access to extension (1=Yes, 0=No)	0.420	0.299	0.105	0.075
Access to agricultural training (1=Yes, 0=No)	1.437***	0.549	0.307**	0.121
Access to credit (1=Yes, 0=No)	-0.119	0.270	-0.063	0.065
Correctly predicted	74.59			
LR $Chi^2(21)$	75.41***			
Pseudo R^2	0.30			
N	185			

Notes: *** means significant at 1%; **significant at 5%; *significant at 10% significance levels.

Source: Household survey (2012)

Appendix M: Impact of water security on household welfare: Treatment effects model using two-step procedure

Variables	Treatment effect model	
	Coef.	Std. Err.
Constant	2396.171	1908.66
Age (years)	-10.3958	28.3838
Gender (1=Male, 0=Female)	-805.273	620.154
Marital status (1=Married, 0=Otherwise)	785.0717	874.019
Education level (Years of schooling)	102.1641	86.9334
Religion (1=Christian, 0=Otherwise)	-142.661	583.684
Value of assets (Rands)	0.000844	0.00131
Livestock size in Tropical Livestock Units (TLU)	-26.8224	28.8844
Total household income (Rands)	0.05822***	0.01645
Irrigated land size (Ha)	1685.266	2776.25
Distance from scheme (km)	-45.6407	72.2809
Scheme membership (years)	58.32043**	27.7806
Conflicts occurrence (1=Yes, 0=No)	851.9925	784.66
Participation in canal maintenance (1=Yes, 0=No)	-776.906	762.171
Farmer association member (1=Yes, 0=No)	151.4557	642.803
Scheme management participation (1=Yes, 0=No)	31.3516	602.691
Pump_1 (1=Electric pump, 0=Otherwise)	-1561.54*	956.069
Pump_2 (1=Diesel pump, 0=Otherwise)	-1297.27	1079.02
Location along the canal_1 (1=Head, 0=Otherwise)	-993.713	830.946
Location along the canal_2 (1=Tail, 0=Otherwise)	-417.137	763.992
Access to extension (1=Yes, 0=No)	45.59662	722.25
Access to agricultural training (1=Yes, 0=No)	130.5959	1079.29
Access to credit (1=Yes, 0=No)	1381.986**	633.05
Water security (1=Water secure, 0= Water insecure)	5109.763**	2531.31
Mills lambda	-2478.54*	1523.97
Wald Chi^2	112.41***	
N	185	
rho	-0.48	0.189
sigma	3363.26	230.4
lambda	-1617.87	712.34

Notes: *** means significant at 1%; **significant at 5%; *significant at 10% significance levels.

Source: Household survey (2012)

Appendix N: Impact of water security on household welfare: PSM results

```
. pscore wats40_4 age gender marstatus educat relgn asetveq tlu totinceq irrland sch_dist conflct part_can asocmb schmnpa1  pump1 pu
> mp2 loc_pr1 lo_pr2 extaces training  credtuse1, pscore(wat40_4) comsup blockid(myblock)


****************************************************
Algorithm to estimate the propensity score
****************************************************


The treatment is wats40_4

   wats40_4 |      Freq.     Percent        Cum.
------------+-----------------------------------
          0 |         74       40.00       40.00
          1 |        111       60.00      100.00
------------+-----------------------------------
      Total |        185      100.00


Estimation of the propensity score

Iteration 0:   log likelihood = -124.50716
Iteration 1:   log likelihood = -92.868946
Iteration 2:   log likelihood = -89.838746
Iteration 3:   log likelihood = -89.176314
Iteration 4:   log likelihood = -89.150378
Iteration 5:   log likelihood = -89.150362

Probit regression                                 Number of obs   =        185
                                                  LR chi2(21)     =      70.71
                                                  Prob > chi2     =     0.0000
Log likelihood = -89.150362                       Pseudo R2       =     0.2840

------------------------------------------------------------------------------
    wats40_4 |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
         age |   .0025488   .0100008     0.25   0.799    -.0170524    .0221501
      gender |  -.0362575   .2723869    -0.13   0.894    -.5701261     .497611
   marstatus |  -.1423202   .3251363    -0.44   0.662    -.7795757    .4949354
      educat |  -.0147928   .0355197    -0.42   0.677    -.0844101    .0548244
       relgn |  -.0397888   .2423388    -0.16   0.870    -.5147642    .4351866
     asetveq |   4.07e-08   1.05e-06     0.04   0.969    -2.02e-06    2.10e-06
         tlu |   .0510899   .0336945     1.52   0.129      -.01495    .1171299
    totinceq |   .0000246   .0000135     1.82   0.068    -1.82e-06     .000051
     irrland |  -.4031272    1.19801    -0.34   0.736    -2.751184     1.94493
    sch_dist |   .0124964   .0299767     0.42   0.677    -.0462569    .0712498
     conflct |  -.7530413   .2943338    -2.56   0.011    -1.329925   -.1761576
    part_can |   .1896585    .317606     0.60   0.550    -.4328379    .8121548
      asocmb |    .456687   .2451986     1.86   0.063    -.0238934    .9372675
    schmnpa1 |  -.1120022   .2529411    -0.44   0.658    -.6077576    .3837532
       pump1 |   1.097059   .2734054     4.01   0.000     .5611942    1.632924
       pump2 |   .9711295   .3836565     2.53   0.011     .2191765    1.723082
     loc_pr1 |   .7815221   .2656183     2.94   0.003     .2609197    1.302124
      lo_pr2 |  -.4746379    .255407    -1.86   0.063    -.9752264    .0259507
     extaces |   .2435148   .2891469     0.84   0.400    -.3232027    .8102323
    training |   1.112299   .4533876     2.45   0.014     .2236754    2.000922
   credtuse1 |   -.341202   .2540961    -1.34   0.179    -.8392212    .1568172
       _cons |  -.9547206   .7797241    -1.22   0.221    -2.482952    .5735105
------------------------------------------------------------------------------
Note: 0 failures and 1 success completely determined.


Note: the common support option has been selected
The region of common support is [.13965493, 1]


Description of the estimated propensity score
in region of common support

                 Estimated propensity score
-------------------------------------------------------------
      Percentiles      Smallest
 1%      .166779       .1396549
 5%     .2183404        .166779
10%     .2897864       .1702004       Obs                 172
25%     .4420329       .1985104       Sum of Wgt.         172

50%     .6185159                      Mean            .6388962
                        Largest       Std. Dev.       .2499753
75%      .863476       .9998233
90%     .9765974         .99998       Variance        .0624876
95%     .9855713       .9999996       Skewness       -.1428071
99%     .9999996              1       Kurtosis        1.830786


******************************************************
Step 1: Identification of the optimal number of blocks
Use option detail if you want more detailed output
******************************************************


The final number of blocks is 6

This number of blocks ensures that the mean propensity score
is not different for treated and controls in each block
```

```
************************************************************
Step 2: Test of balancing property of the propensity score
Use option detail if you want more detailed output
************************************************************
```

The balancing property is satisfied

This table shows the inferior bound, the number of treated and the number of controls for each block

Inferior of block of pscore	wats40_4 0	1	Total
.1396549	3	1	4
.2	19	9	28
.4	24	23	47
.6	9	31	40
.8	4	10	14
.9	2	37	39
Total	61	111	172

Note: the common support option has been selected

```
*******************************************
End of the algorithm to estimate the pscore
*******************************************
```

```
. attnd fdexeq4 wats40_4 age gender marstatus educat relgn asetveq tlu totinceq irrland sch_dist conflct part_can asocmb schmnpa1  p
> ump1 pump2 loc_pr1 lo_pr2 extaces training  credtuse1, comsup bootstrap rep(1000)
```

The program is searching the nearest neighbor of each treated unit.
This operation may take a while.

ATT estimation with Nearest Neighbor Matching method
(random draw version)
Analytical standard errors

n. treat.	n. contr.	ATT	Std. Err.	t
111	35	2274.139	786.072	2.893

Note: the numbers of treated and controls refer to actual nearest neighbour matches

Bootstrapping of standard errors

```
command:     attnd fdexeq4 wats40_4 age gender marstatus educat relgn asetveq tlu totinceq irrland sch_dist conflct part_can asocmb
> schmnpa1 pump1 pump2 loc_pr1 lo_pr2 extaces training credtuse1     , pscore()   comsup
statistic:   r(attnd)
(obs=185)
```

Bootstrap statistics

Variable	Reps	Observed	Bias	Std. Err.	[95% Conf. Interval]		
bs1	1000	2274.139	-477.0856	851.286	603.6254	3944.653	(N)
					64.97716	3452.915	(P)
					1113.999	3948.149	(BC)

N = normal, P = percentile, BC = bias-corrected

ATT estimation with Nearest Neighbor Matching method
(random draw version)
Bootstrapped standard errors

n. treat.	n. contr.	ATT	Std. Err.	t
111	35	2274.139	851.286	2.671

Note: the numbers of treated and controls refer to actual nearest neighbour matches

```
. attk fdexeq4 wats40_4 age gender marstatus educat relgn asetveq tlu totinceq irrland sch_dist conflct part_can asocmb schmnpa1  pu
> mp1 pump2 loc_pr1 lo_pr2 extaces training  credtuse1, pscore(wat40_1) comsup bootstrap rep(1000)


 The program is searching for matches of each treated unit.
 This operation may take a while.



ATT estimation with the Kernel Matching method

---------------------------------------------------------
n. treat.   n. contr.         ATT   Std. Err.           t
---------------------------------------------------------

      111          59    1983.466           .           .

---------------------------------------------------------
Note: Analytical standard errors cannot be computed. Use
the bootstrap option to get bootstrapped standard errors.




Bootstrapping of standard errors

command:     attk fdexeq4 wats40_4 age gender marstatus educat relgn asetveq tlu totinceq irrland sch_dist conflct part_can asocmb s
> chmnpa1 pump1 pump2 loc_pr1 lo_pr2 extaces training credtuse1     , pscore(wat40_1) comsup    bwidth(.06)
statistic:   r(attk)
(obs=185)

Bootstrap statistics

Variable |  Reps   Observed       Bias   Std. Err.   [95% Conf. Interval]
---------+-----------------------------------------------------------------
     bs1 |  1000   1983.466  -63.43858   601.7743    802.5791  3164.352  (N)
         |                                           767.8194  3110.102  (P)
         |                                           865.1194  3307.474 (BC)
---------------------------------------------------------------------------
                              N = normal, P = percentile, BC = bias-corrected


ATT estimation with the Kernel Matching method
Bootstrapped standard errors

---------------------------------------------------------
n. treat.   n. contr.         ATT   Std. Err.           t
---------------------------------------------------------

      111          59    1983.466     601.774       3.296

---------------------------------------------------------
```