DECLARATION

I, Georgina Wambui Njiraini, declare that this thesis is my original work and has not been submitted for the award of a degree in this or any other university.

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DEDICATION

To my parents Peterson and Gladys Njiraini; for their tireless efforts towards my education, May God bless you abundantly dear mum and dad.

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LIST OF ABBREVIATIONS AND ACRONYMS

CRS	Constant Returns to Scale
DEA	Data Envelopment Analysis
DEAP	Data Envelopment Analysis Program
DF	Debreu-Farrell
DMU	Decision Making Unit
EMCA	Environmental Management and Coordination Act
GAMs	General Algebraic and Modeling system
GoK	Government of Kenya
IWUE	Irrigation Water Use Efficiency
Ksh	Kenya Shilling
LNRA	Lake Naivasha Riparian Association
LNMIC	Lake Naivasha Management Implementation Committee
LP	Linear Programming
Max	Maximum
Min	Minimum
MDG	Millennium Development Goals
MLE	Maximum Likelihood Estimation
OLS	Ordinary Least Squares
SFA	Stochastic Frontier Analysis
Std. Dev.	Standard Deviation
TE	Technical Efficiency
VRS	Variable Returns to Scale
WARMA	Water Resource Management Authority
WUE	Water Use Efficiency

ABSTRACT

Water is critically important to the livelihoods of many populations especially the rural poor primarily engaged in agriculture. In many developing countries, water is a major factor constraining agricultural output and their incomes. Additionally, a large percent of the world's food supply comes from irrigated agriculture, and agriculture is the single largest user of fresh water on the planet and it is also the largest economic activity of the rural poor. Therefore, improved water management for agriculture through efficient use can improve the livelihoods of a great proportion of the rural communities.

This study investigated technical and water use efficiency in small holder irrigation farming in the Naivasha basin. The study used farm household data to; explore the overall technical efficiency, water use efficiency and establish the factors influencing water use efficiency. Data envelopment analysis, general algebraic and modeling system and Tobit regression methods were used in analyzing cross sectional data from 201 small scale irrigation farmers in the lake Naivasha basin.

The results indicated that on average, small scale farmers were only 63 percent technically efficient indicating that substantial inefficiencies occurred in farming operations of the sample farm households. The sub-vector efficiencies for water demonstrated even larger inefficiencies. Average water use efficiency was only 31 percent again indicating that more farms were highly inefficient in the use of water compared to overall technical efficiency. It implies that when all other inputs remain constant, the current output could be produced using, on average, 69 percent less irrigation water. Therefore, there is a considerable scope for reducing the water use, even with the technology currently available. This means that if efficiency improves, it should be possible to reallocate a fraction of the water to other water demands without really endangering production or the role small-scale irrigation might play for rural development.

This study also demonstrated that crop choice, choice of irrigation technologies and the level of farm fragmentation were significant factors influencing water use efficiency in small holder irrigation in the Naivasha basin. Therefore, policy intervention in terms of better water management are recommended whereby water use efficiencies should be well integrated in agricultural research and policy formulation processes to ensure continued and sustainable use and efficient allocation of natural resources thus enhancing food availability and incomes for the rural poor. With regard to the efficiency findings from this study, it is recommended that more emphasis should be laid on orienting farmers towards appropriate choice of irrigation technologies, appropriate choice of crop combinations in their farms and the desirable level of farm fragmentation since these are important in explaining water use efficiency.

CHAPTER 1: INTRODUCTION

1.1 Background information

The impact of human activities on the environment threatens a significant share of the world's natural resources with extinction, including wetlands (Crook and Clap, 1998). There is little doubt that the global area of wetlands has decreased at an ever increasing rate. This conversion to agriculture, urban and other uses has profound ecological impacts at local and global scales as well as significant social and economic impacts on resource users (Adger, 2000). There is also growing international awareness of the importance of value of natural resource such as wetlands in the lives of rural communities throughout the world (Shackleton, 2006).

Water resources development and management is imperative for sustainable agriculture (Ashraf *et al.,* 2007). Water is critically important to the livelihoods of more than one billion people particularly for the 850 million rural poor primarily engaged in agriculture. In many developing countries, water is a major factor constraining agricultural output, and income of the world's rural poor (Namara *et al.*, 2009). Additionally, forty percent of the world's food supply comes from irrigated agriculture, and that percentage will increase as populations grow and arable land resources decrease. Agriculture is the single largest user of fresh water on the planet and it is also the largest economic activity of the rural poor. With 75 percent of the world's poor living in rural areas and relying on agriculture for at least part of their income, improved water management for agriculture through efficient use can improve the livelihoods of a great proportion of the rural communities (Jacomia, 2005). In this context of water scarcity, the scrupulous allocation among different users and uses poses a management challenge (Nagaraj, 1999).

Due to increased population pressure, commercialization of agriculture, rapid urbanization and fast economic growth, water is emerging in most parts of the world as a severe constraint, not only to intensify agricultural production but also to meet the increasing needs of other sectors like industries, tourism, rural and municipal use. Since water resources have become increasingly scarce, there is need for an institutional framework to ensure sustainability and social optimum use (Nagaraj, 1999).

1.1.1 Water resource management

In most countries the institutional arrangement for the development and distribution of water supplies rests with public agencies. However, the performance of this centralized approach to water resource management has proven to be unsatisfactory (Nagaraj, 1999). Results also emerging from experiments in community management are mixed and suggest that there are problems associated with structured attempts to manage common pool resources (Kumar and Karande, 2000), but to a certain extent the collective action through user groups has yielded desirable results in terms of better up-keep of irrigation infrastructure, efficiency in water resource use, financial viability, improved productivity of irrigation and overall sustainability.

There is also considerable evidence that centralized management of common pool resources is not able to provide the right incentives for sustainable resource use, thus the increased support for community based management (Adhikari, 2005). Local users are seen to be in a better position to discern the local ecological, technical, economic and social conditions hence in a better position to devise well adapted rules, procedures and sanction mechanisms that are capable of gaining broad support among resource users.

In recent years, development strategies have undergone a dramatic shift with the emphasis changing from the state being the major player toward greater participation by the community (Yercan, 2003). Devolution of responsibility and control over natural resources from government agencies to user groups has become a widespread policy trend that cuts across countries and natural resource sectors, encompassing water and especially irrigation with emphasis on increasing the participation of resource users in the management of the resources (Meinzen-Dick *et al*, 2002). It is also widely recognized that an integrated approach to freshwater management offers the best means of reconciling competing demands with supplies and a framework where effective operational actions can be taken (Alfarra, 2004).

Moreover many natural resource management practices such as irrigation, forestry, rangeland, or watershed management require cooperation among individuals (Knox and Meinzen-Dick, 2001). Collective action is widely recognized as a positive force for rural development in Africa and getting together with others can also allow individuals to better cope with risk particularly when neither the private sector nor the government provides any safety nets or insurance against risk (Place *et al*, 2004). However, though the theoretical advantages of user management have been convincing and the impetus for devolution policies strong, the actual outcomes of devolution programs in various sectors and countries have been mixed. The stated objectives of such programs in terms of positive impact on resource productivity, equity among stakeholders, poverty alleviation, organizational and environmental sustainability are often not met. Resources have not always been used more efficiently than under state management, nor have the benefits been distributed equitably. In some cases the resource base has been depleted. Experience has shown that the emergence of strong enough local management cannot be automatically assumed (Knox and Meinzen-Dick, 2001).

1.1.2 Wetlands in Kenya

In Kenya, Wetlands cover about 2-3% of the total area and harbor a substantial proportion of the country's water resources (GoK, 2002-2008). They are an important ecosystem as they are sites of exceptional biodiversity, have enormous social and economic value such as supporting family livelihoods as bases for crop production, grazing animals, fishing, and harvesting medicinal plants among others. Ecologically, wetlands are instrumental in water storage, flood control, groundwater recharge and discharge, erosion control and sediment/toxicant retention (purification) (Mwakubo *et al.*, 2004; Odote, 2009). However despite their utility, they continue to be degraded and lost due to pressure from agricultural and development activities.

In efforts to stem the degradation and conversion of wetlands, Kenya acceded to the global convention governing the management of wetlands in 1990 i.e. Ramsar convention which obligates the country to meet the standards stipulated in the convention such as promoting wise use of wetland and making conservation considerations within its natural resource planning processes. In addition to its international obligations, Kenya has revised several policies and legislations in the past 10 years incorporating modern views of sustainable development and citizen participation i.e. the Environmental Management and Coordination Act (1998), the Water Act (2002) and Forest Act (2005). Other Acts, such as the Wetlands legislation, are currently being formulated. The country is presently engaged in a policy and legislative discourse in the National Land Policy Formulation Process and Wildlife Management Act; the latter under Kenya Wildlife Service. Furthermore, several new government institutions have been created under the new laws, such as the National Environmental Management Authority (NEMA), an environmental compliance organization, and the Water Resources Management Authority (WRMA), with the Catchment Areas Advisory Committee (CAAC) and the Water Resources Users Organizations (WRUAs) as the regional and local sub-bodies.

In these new institutional settings the Ministries are now only responsible for policy development and some high level control. In cases where previously the Ministry of Water had full control over the management of water resources now part of this has been devoluted to the lowest level, the WRUAs. Unfortunately, the design of various policies and the interactions between Ministries are unclear, especially with respect to the question how to deal with institutional overlaps and conflicts, prioritization of programmes and activities, and hierarchy of laws. Moreover, the devolution of power and the consequent decentralizing mechanisms may lead to new "rules" in the way governmental and non-governmental actors communicate with each other in the usual Kenyan stakeholder processes.

1.1.3 Lake Naivasha basin

Lake Naivasha is Kenya's second largest fresh water lake and the only freshwater lake in the Rift valley. It is served by river Malewa which is its largest tributary feeding in 90 percent of the water and river Gilgil and Karati which bring in the remaining 10 percent (Harper, 2002). There is intensive agriculture by commercial farmers around the lake shore mainly engaging in horticultural enterprises where production has been predominantly of high value products such as cut flowers, fruit and out-of-season vegetables for European markets. In contrast, the wider catchment comprises predominantly land tilled for subsistence crops employing bucket and drip irrigation methods to produce maize, beans, cabbages tomatoes and French beans with a few of the farmers selling their output (Harper, 2002).

The whole basin is now an ecosystem in crisis as it's at risk of extinction because of human induced land use changes that have led to its degradation. There is heightened demand and competition for environmental resources especially land, water and forestry between various user groups as evidenced by water reduction in the lake by about 3 meters and area covered by water has shrunk by a half of the total area which is further accelerated by adverse weather conditions (Mireri, 2005). The region's water catchment is also destroyed by deforestation which reduces amounts of water feeding into the lake through its tributary rivers. Thus the pressure on water resources in the basin is expected to increase, as population and industrial activity grow. Therefore, increasing water use efficiency (WUE) associated with irrigated crop production and finding the factors affecting this WUE would be a way for the farmers of this region to increase their agricultural production while sustainably managing the water use as there is little or no prospect for expansion of the water resources (Harper, 2004).

1.2 Problem statement

Lake Naivasha basin has experienced; growth in population, human settlement, intensive commercial farming, tourism and geothermal production which have put intense pressure on natural resources in the watershed and this threatens the area's integrity and especially the water resource. Increased demand for scarce environmental resources such as water and biomass has lead to the excessive abstraction of surface and ground water resources, depletion of forestry resources, pollution of water bodies and siltation of the lake (Mireri, 2005).

Water from the rivers and the lake provide a wide range of opportunities for various activities in the area, which in turn have produced a conflict of interests between different stakeholders (upper catchment, farmers and urban people). This has created pressure on the lake and river water level and its quality (Alfarra, 2004). Demand of water for domestic use, agriculture, and industry continues to increase rapidly due to increasing population levels and immigration in the basin thus the need and concern for more efficient water use.

Alfarra (2004) observes that the main problem in the area is not the shortage of water but the management of the resource between multiple users and uses. It is apparent that efficiency in water use has not been attained and there is lack of proper institutions and organization in management (Harper, 2004). Various stakeholders in the basin have organized themselves to come together in management as the Lake Naivasha Riparian Association (LNRA) and promote sustainable use of water by calling for farmer group formation especially for those higher in the catchment hence the choice of small scale irrigators for this study. The small scale irrigators are also chosen for this study because they occupy a wider basin area in terms of area and population i.e. 650 000 people compared to 160 000 living around the lake. It's also of importance because the upper catchment population is highly significant in that it is indirectly responsible for maintaining the inflow into the rivers, the lake, and the aquifers (Harper, 2004). They utilize water for domestic and livestock, as well as for farming and sediments and agrochemicals from the upper basin end up in the lake. Whatever soil, woodland, and land management activities the upper catchment dwellers do, it will eventually affect the system's hydrology and quality (Harper, 2004).

A coordinated framework of management has not been adopted and an unclear division of responsibilities between the different regulating institutions persist in this basin and the main weakness of the existing laws is that they do not quantify sustainability or define sustainable abstractions. The Management Plan stresses the importance of an accurate water balance but does not answer the question of what would be the total sustainable abstraction of water from the basin. Every single abstraction from the basin results in a lowering of the mean water level and how much drawdown is socially, economically and ecologically acceptable is not defined. Thus disputes about the exact effect of abstractions on the whole basin, the size of the irrigated area and how much can be safely abstracted persists. Therefore, the prevailing system of uncoordinated water resources management in the basin cannot sustain the ever-increasing water needs of the various expanding sectors. Hence a strategy must be sought to integrate the various sectoral needs against the available water resources in order to attain both economic and ecological sustainability.

Previous efficiency studies have not specifically focused on the use of water as an input and this study therefore comes in to fill this gap with an aim to assess water use efficiency and its determinants together with the possibility of collective action as a way of management.

1.3 Purpose and objectives

The purpose of this study is to assess the technical efficiency of the small holder irrigation farming within the Lake Naivasha basin.

The **specific objectives** of this study are;

1. To assess water use efficiency in small scale irrigation farming in lake Naivasha basin.
2. To examine factors influencing water use efficiency among small scale farmers.

Hypotheses to be tested

1. Small scale farmers are water use efficient
2. Demographic and socio economic factors: Age, gender, crop choice, farmer group, household size, level of farm fragmentation, farm size, education, irrigation technology individually do not influence water use efficiency

1.4. Justification

Lake Naivasha is unique within the central latitudes of the Rift valley for being a fresh water lake unlike all the other lakes in the valley. The lake has international value as a Ramsar wetland, which in the last two decades has grown to become the main site of

Kenya's horticultural industry, one of the largest earners of foreign currency (Harper & Mavuti, 2004). Lake Naivasha basin plays a very important role in national development and contributes to about 70 percent of Kenyan flower export, 15 percent of Kenyan electric power and is home to attractive tourist sites. However this will not be the case in future if the current heightened pressure on the basins water is not controlled through efficient use and organized management among the many users and uses.

Better water management can certainly contribute to the attainment of Millennium Development Goals (MDGs). It addresses MDG 1 in that investments in water resources management and the delivery of water services are central to poverty reduction and secondly ensuring environmental sustainability thus addressing MDG 7. Combating poverty is the main challenge for achieving equitable and sustainable development and water plays a vital role in relation to human health, livelihoods, economic growth as well as sustaining ecosystems. Poverty reduction which is a complex issue, needs specific targeted actions to ensure support to the weak and marginal communities in terms of policy, technical, institutional, environmental and financial aspects and water is one such component of poverty reduction strategy but hitherto this has not been well articulated (Reba, 2003). Therefore, integrated land and water management and low cost technologies such as efficient water use which is manageable by the local people can sustain water supply for production and protect the ecosystems and environment on which the poor often rely for their livelihoods.

According to Vision 2030, better conflict resolution under the political pillar also has a water dimension since many conflicts in rural Kenya tend to be resource-based with a bias towards shared water sources. Efficient water management will, therefore, not only contribute to sustainable long-term economic growth, but also to poverty reduction, conflict resolutions and security which will lead to attainment of the economic, social and political priority projects suggested by Vision 2030.

Therefore the knowledge of water use efficiencies and inefficiencies especially in subsistence irrigation farming of the upper catchment would be valuable for the local community, extension service providers and policy makers since it can help to guide policies towards increased water use efficiency in the face of rising water scarcity. It is also of particular importance for policy makers, because it not only creates awareness concerning inefficiencies in water use, but also provides insight into possible improvements by exploring the determinants of these inefficiencies.

1.5 Organization of the study

This study is divided into five chapters. Chapter 1 gave an introduction of the study, problem statement, hypothesis, objectives and the justification of the study. Chapter 2 explores the literature on previous efficiency studies relevant to this study. Chapter 3 discusses the methodology employed in this study i.e. the theoretical basis for the empirical approaches that were used to achieve the study objectives. Chapter 4 discusses the results of the analysis while chapter 5 gives the study summary, conclusions, recommendations and suggests areas for further research.

CHAPTER 2: LITERATURE REVIEW

2.1 Concept of efficiency

Farrell (1957) in his pioneering work on efficiency argued that the problem of measuring economic efficiency is not only important for economic theory but also useful in policy making and implementation process. He asserted that determination of actual efficiency levels is essential for theoretical discourse and practical application in various economic activities. In essence, efficiency forms the bedrock of policy, planning and business approaches to sustainable development. It is however, an elusive concept, defined differently by different disciplines. The economist, the engineer and the policy maker, for example, all will define efficiency according to their questions (Mulwa, 2006). For the purposes of this study, the focus will be on technical efficiencies.

According to Koopmans (1951), a producer is technically inefficient if an increase in any output requires a reduction in at least one other output or an increase in at least one input; and if reduction in any input requires an increase in at least one other input or a reduction in at least one output. Thus a technically efficient producer could produce the same output with less of at least one input, or could use the same inputs to produce more of at least one output meaning that they would not require employing more resources.

Debreu (1951) and Farrell (1957) define technical efficiency as one minus the maximum equi-proportionate reduction in all inputs that still allows continued production of given outputs. A score of unity indicates technical efficiency because no equi-proportionate input reduction is feasible, and a score of less than unity indicates technical inefficiency.

Efficiency in allocation of scarce resources to obtain optimal gains is central to neoclassical theory of production economics. The economic theory of production provides the framework for most empirical research on productivity and efficiency. Efficiency thus refers to the global relationship between all outputs and inputs in a production process (Díaz *et al.*, 2004). The performance of a farm can be evaluated based on different efficiency measures, namely technical, allocative and economic efficiency. Technical efficiency can be defined as the ability of a decision-making unit (e.g. a farm) to produce maximum output given a set of inputs and technology. Technical efficiency is one component of economic efficiency where the latter is defined as the product of technical efficiency and allocative efficiency .In turn, allocative efficiency refers to the ability to produce a given level of output using cost-minimizing input ratios (Thiam *et al*, 2001).

This study will be limited to the calculation of technical efficiencies due to the lack of pricing for water input hence allocative and economic efficiencies could not be derived. It uses the measures that originate from the seminal work on technical efficiency by Farrell (1957), where technical efficiency is defined as the ability of a farm to produce the maximum feasible output from a given bundle of inputs,(output-oriented measure) or to use minimum feasible amounts of inputs to produce a given level of output, (input-oriented measure) (Coelli *et al.*, 2002; Díaz *et al.*, 2004a, b). Input-oriented models will be chosen in this study to reflect the reality in agriculture where the main aim is to use resources more efficiently and not to increase production (Díaz *et al.*, 2004).

2.2 Using DEA to measure efficiencies

Two major approaches to measure efficiency have been in use, namely parametric and non-parametric approaches, i.e. the stochastic frontier production function (SFA) approach and the Data Envelopment Analysis (DEA) methodology. The parametric approach consists of specifying and estimating a parametric production function (or its dual cost or profit function) representing the best available technology and provides a convenient framework for conducting hypothesis testing, and the construction of confidence intervals while the nonparametric approach involves the use of linear programming to construct a piecewise linear envelopment frontier over the data points such that all observed points lie on or below the production frontier.

The DEA methodology has some important advantages over the econometric approach to efficiency measurement. Firstly, because it is non-parametric there is no need to make assumptions concerning the functional form for the frontier technology or the distribution of the inefficiency term. Secondly, the approach permits the construction of a surface over the data, which allows the comparison of one production method with the others in terms of a performance index. In this way DEA provides a straightforward approach to calculating the efficiency gap that separates each producer's behavior from best productive practices, which can be assessed from actual observations of the inputs and outputs of efficient firms. The real advantage of DEA modeling is that it allows the specification of a multi-product, multi-input firm. Another major advantage of non-parametric DEA that is in line with this study is the calculation of sub-vector efficiency for irrigation water use (Haji, 2006; Reig-Martinez and Picazo-Tadeo, 2004; Malano *et* *al*., 2004; Wadud and White, 2000; Shafiq and Rehman, 2000; Reinhard *et al*., 2000; Frija *et al*., 2009; Helfand and Levine, 2004; Oude-Lansink and Reinhard, 2004; Arega *et al*., 2006).

Calculating sub-vector technical efficiencies using a stochastic frontier approach would be highly problematic in terms of computation (Speelman *et al*., 2008; Frija *et al*., 2009; Oude-Lansink *et al*., 2002). Production technology can confound the efficiency results and worse still, curvature conditions (e.g. concavity of inputs) are not globally satisfied when using the popular translog specification. Therefore, the DEA approach is more suitable for the calculation of sub-vector efficiencies because it is more flexible by avoiding a parametric specification of technology, assumptions about the distribution of efficiency and allows curvature conditions to be imposed easily (Oude-Lansink *et al*., 2002). Finally, when using DEA, efficiency measures are not significantly affected by a small sample size, as long as the number of inputs is not too high in comparison to the sample size (Speelman *et al*., 2008).

The disadvantages of DEA, however, are that it is deterministic and sensitive to measurement errors and other noise in the data. Several studies comparing both methodologies have shown that results from both methods are highly correlated (Alene and Zeller, 2005; Arega *et al*., 2006; Wadud and White, 2000). Thus DEA approach is chosen for the current study based on the evidence from previous studies that there is no significant difference between the two approaches (Haji, 2006). A meta-analysis also conducted by Thiam *et al*., (2001) on the sensitivity of production efficiency estimates to the choice of the methodology in the developing countries' agriculture using 32 technical efficiency studies indicated that estimates were independent of the methodology employed. Even the prior expectation that the efficiency scores are lower for stochastic frontiers than the deterministic models was not observed. Moreover, Coelli and Perelman (1999) compared three different methods that have been used to estimate multi-input distance functions, i.e., parametric linear programming, corrected ordinary least square and DEA and concluded that the researcher can safely select one of these methods without too much concern for their choice having a large influence upon results (Haji, 2006). Thus the choice of method depends upon the objective of the research and the type of data available hence this study will use a DEA approach because of its flexibility and the possibilities of calculating sub-vector efficiencies.

2.3 Link between adoption of new technologies and improvement in efficiency

Schultz (1964), ''poor but efficient'' hypothesis, implies that opportunities for production gains through efficiency improvement are limited and hence new technologies must be introduced to enhance the productivity of farming systems. Research and extension services should therefore generate and promote appropriate new technologies to enhance the productivity of agricultural systems through means such as intensive intercropping of annual and perennial crops. The development of newer varieties that have higher yield potential and are suitable for different agro ecological zones are seen as an important factor to consider in improving efficiency (Arega *et al.*, 2006; Rahman and Hassan, 2008).

Adoption of new technologies is evidenced to increase productivity in the shift from conventional to organic farming (Oude-Lansink, 2002; Tzouvelekas *et al.*, 2001). In his study, Oude-Lansink (2002) compared productivity and technical efficiencies of organic verses conventional farming in Finland and found out that organic farms were more efficient relative to their own technology but used less productive technology than conventional farms. Productivity of individual inputs on organic farms was lower than their productivity on conventional farms. The differences in productivity are a suggestion that the technologies applied in conventional farming had more potential than in organic farming whereby food is produced using lower amounts of scarce resources. Thus the high efficiency in organic farming suggests that farmers in low yield areas are more likely to shift to organic farming and this finding is in line with that of Oude- Lansink and Pietola (2002).

Overall trends are also considered to be more significant when studying large irrigation areas comprising many districts as they show which crops may increase or decrease performance and which irrigation methods can yield a more efficient use of water. This is useful in management to decide or choose between reducing labor input or water consumption or substituting current crops for more profitable ones in a given irrigation district. The study of spatial efficiencies indicates that the modernization of irrigation towards the use of localized irrigation systems, in addition to increasing the efficiency of water use, may lead to overall improved performance in irrigated agriculture (Diaz, 2004)

2.4 Making efficient use of existing technologies to improve efficiency in production

Haji (2006) and Coelli *et al* (2002) observed that given limited resources, the generally low level of economic efficiency is an indication of the existence of substantial potential to improve smallholders' productivity by improving the efficiency of production rather than creating and transferring new technologies. Future increases in food production will originate from improvements in performance of existing agriculture rather than development of new resources as a large proportion of the available land and water resources have already been developed and there is limited scope for further increase in the use of these resources (Wadud and white, 2000; Malana and Malano, 2006).

In Samsun province of Turkey, the potential to improve technical efficiency under current technology was reported in a study by Bozoglu and Ceyhan (2007). In this study, the technical efficiency of the sample vegetable farms improved from 0.56 to 0.95 when efficient use of available resources was implemented and this was especially with regard to credit. Better use of available resources is also seen to improve technical efficiency of extensive livestock farming systems in Extremadura, Spain through better use of own produced pastures to reduce the amount of feedstuff to be bought thus saving on costs and reductions in manpower (Gasper *et al.*, 2009). Dhungana *et al* (2004) also argues that efficient use of available technologies is more cost effective than introducing new technologies.

2.4.1 Inefficiency arising from overuse of resources

Making efficient use of resources to improve efficiency implies that current technologies are either being overused or under used. For the case of overuse, the available inputs of production such as labor, fertilizers and pesticides may be in use in excess of what is actually required and this result in waste (Coelli *et al.*, 2002). For example, in Nepal, variations in 'use intensities' of resources such as seed, labor, fertilizers and mechanical power in addition to farm-specific attributes were seen to be the main causes of allocative, technical and scale inefficiencies for rice farmers (Dhungana *et al.,*2004).

The extent of inefficiency in lower-ranked wheat units in Pakistan and the overuse of irrigation and fertilizers were identified as the major sources of inefficiency among farmers at the regional and inter-regional levels. However, it was noted that low productive farmers may not become efficient by simply reducing the level of inputs as there was need for a detailed analysis to determine other underlying causes of inefficiencies, including environmental factors and agricultural practices (Malana and Malano, 2006).

Gasper *et al* (2009) also noted that inefficiencies come mainly from an excessive use of inputs, especially of labor and expenditure on animal feed for the case of livestock farming (because of the inadequate use of natural resources available), and from levels of outputs not suited to the characteristics of the farms, and thus, far from their potential. In many instances, the quantities of inputs used are unjustifiably higher than what would be required to achieve their present levels of crop output hence raising the cost of production. It is recommended that by identifying the sources of inefficiencies the results could be used to investigate avenues for improvements in both technology and resource use efficiency on farms (Shafiq and Rehman, 2000).

In many cases and especially in small holder farming, water as an input to production is also over utilized and this result in technical inefficiencies of farms. For example, in the North West province of South Africa, Speelman *et al* (2008) reported that there was need for more efficient water use due to the increasing pressure on the resource and also due to water scarcity. Technical inefficiencies were observed under both variable and constant returns to scale in their study and sub-vector efficiencies for water proved to be very low, indicating that if farmers became more efficient using the technologies that were currently available, it would be possible to reallocate a fraction of the irrigation water to other water demands without threatening the role of small-scale irrigation.

In small scale green house farming of Teboulba Tunisia, irrigation water use efficiency was found to be 42 percent which implied that when all other inputs remained constant, the current output could be produced using, on average, 58 percent less irrigation water. It was concluded that farmers' technical training in greenhouse management, investments in water saving technologies and the existence of a fertigation technique on farm had a significant and positive effect on their level of efficiency. However, Irrigation Water Use efficiency (IWUE) was significantly and negatively affected by the proportion of total farm land allocated to greenhouses (Frija *et al.*, 2009).

2.4.2 Inefficiency arising from underuse of resources

Inefficiency also arises from under utilization of existing resources. For example, in a study by Ekunwe *et al* (2008), it was shown that resources such as land, labor, fertilizer and planting materials were underutilized under traditional practice of Yam farming in Nigeria. Therefore, it was in conclusion that agricultural production could be improved by efficient use of existing resources. Most producers also underutilize labor especially for harvesting but were efficient in allocation of other resources, therefore potential to increase yield exists if producers could be more efficient under the present technologies (Ayanwale and Abiola, 2008).

Similarly, Ogundari and Ojo (2008) reported that there was considerable room for improvement in the Maize-Yam crop production under Taungya farming of Nigeria whereby technical efficiency could be increased by 19% through better use of available resources in the studied area. About 75% of the variations in output from the frontier were attributed to differences in the farmer's technical efficiency; the resource productivity revealed that farm size and number of trees, labor and operating expenses were significantly associated with changes in the output of the respondents.

2.5 Farm size, institutions and efficiency

The majority of studies of agricultural productivity in developing countries support the view that there is an inverse relationship between productivity and farm size (Berry and Cline, 1979; Barrett, 1996). If this is so, then land reform could contribute to improving both equity and efficiency in agriculture. Most of such studies, however, are based on partial measures of productivity such as yield which are biased in favor of small producers. It is likely that the inverse relationship would be less pronounced, or perhaps even reversed, if a measure of total factor productivity (TFP) were used instead. It has also been suggested that the inverse relationship might weaken in a region characterized by rapid modernization.

Helfand and Levine (2004) explored the relationship between farm size and technical efficiency in the Center-West of Brazil which is a region characterized by high levels of modernization and highly large farms. In their study, they showed that the relationship between farm size and technical efficiency was more complex than an inverse relationship where productivity falls as farm size rises, it was found to be a U-shaped relationship whereby for farms up to about 1000–2000 ha, efficiency did fall as farm size rose, but beyond this size it started to rise again. The most important reasons why the inverse relationship broke down related to preferential access by large farms to institutions and services that help lower inefficiency (such as rural electricity, technical assistance and access to markets) as well as more intensive use of the technologies and inputs that raise productivity. Hence the recommendation for access to institutions and goods that are often provided by the public sector as they are key determinants of differences in efficiency

In agreement with this finding are Gorton and Davidova (2004) who argue that improving the institutional environment for small farms will be more beneficial than appeals for farm amalgamation. In their study to compare performance of family farms and corporate farms, it was concluded that there is no clear cut evidence of corporate farms being inherently less efficient for all farming activities than family farms. Where significant differences have been found in favor of family farms against the average corporate farm, the best corporate farms still tend to perform as well as the best family farms.

Farm size is seen to have a positive impact on overall technical efficiency in Dutch pig farming. This was reflected by the number of hectares of land put into use and this result suggested that large farms, ceteris paribus were doing better overall more efficiently than small farms (Oude-Lansink and Reinhard, 2004).

Similarly, Olson and Vu (2009) showed that farm size (as measured by the log of farm income) was the only explanatory variable consistently associated with higher technical efficiency unlike other explanatory variables that varied between analysis methods. Farmers with large farm sizes were also most technical efficient with a mean of 0.8877 followed by medium farm size with a mean of 0.8687 while small farm size had the least mean of 0.8638 in a study examining technical efficiency of poultry egg production in Ogun state, Nigeria (Yusuf and Malomo,2007).

In a conditional analysis of the relationship between technical efficiency and size, a positive and significant relationship between technical efficiency and size was also indicated in a study by Alvarez and Arias (2004) in Spanish dairy farming. The study controlled for the effects of output prices, input prices, and quasi-fixed inputs, as suggested by theory. The unconditional relationship between technical efficiency and size was positive as well but stronger than the conditional one. It was concluded that conditional analysis is a part of the efficiency-size puzzle and that the relationship between technical efficiency and size might be affected by farm heterogeneity.

Diseases such as HIV/AIDS also have a role to play in the efficiency-size puzzle. For example, in evaluation of the impact of the health status of farm households with respect to HIV/AIDS on their cropping patterns in Nigeria, Adeoti and Adeoti (2008) reported that HIV/AIDS has led to decreased farm sizes being cultivated by HIV affected households due to shortage of family labor. This has resulted in a reduction in the variety of crops cultivated while the average gross revenue, average gross margin and farm profit on non-HIV affected households remained higher.

2.6 Farm and farmer specific determinants of technical efficiency

Exploring the determinants of technical efficiency or technical inefficiency allows indicating the human and physical resources that must be targeted by public investments to improve farm efficiency hence better policy intervention (Haji, 2006). In his study to measure technical, allocative and economic efficiencies of small-scale vegetable-dominated mixed farming production system in two districts of eastern Ethiopia, Tobit analyses were used to identify what causes efficiency differentials among sample farmers and results showed that the level of the observed technical efficiency was significantly affected by asset, off/non-farm income, farm size, extension visits and family size, whereas asset, crop diversification, consumption expenditures and farm size had significant impact on allocative economic efficiencies.

The importance of off-farm activities was also captured by Chavas *et al* (2005) in Gambia who reported inefficiencies at the household level rather than the farm level. In their study, Technical efficiency was found to be fairly high indicating that access to technology was not a severe constraint for most farm households. Allocative inefficiency by contrast was found to be important for the majority of farm households. On the basis of the Tobit results analysis, imperfections in markets for financial capital and nonfarm employment contributed to significant allocative inefficiency.

In Bangladesh rice farming, large families were found to be more inefficient, thus highlighting a hidden unemployment problem. It was also found that those farmers who had better access to input markets, and those who did less off-farm work, tended to be more efficient. Age, education, experience, soil fertility, extension and training did not have a large influence on efficiency levels (Coelli *et al*., 2002)

Additionally, Wadud and White (2000) while comparing stochastic frontier methodology and DEA for rice farmers in Bangladesh, also examined technical inefficiency as a function of various farm specific socioeconomic factors; environmental factors and irrigation infrastructures and found that the inefficiency effects in agricultural production were positively influenced by the irrigation infrastructure, i.e., diesel-operated irrigation schemes. Electrification programs in rural agricultural production were also critical in reducing the technical inefficiency in production and soil degradation increased technical inefficiency. Farm-specific attributes such as the farmers' level of risk attitude, the farm manager's gender, age, education and family labor endowment were important considerations in explaining allocative, technical and scale inefficiencies (Dhungana *et al.*, 2004)

In measuring the technical efficiency and its determinants in vegetable farming in Turkey, Bozoglu and Ceyhan (2007), reported that the variables of schooling, experience, credit use, participation by women and information score negatively affected technical inefficiency. However, in their study, age, family size, off-farm income and farm size showed a positive relationship with inefficiency.

Years of experience and education also had a positive effect on technical efficiency while household size negatively affected efficiency in poultry egg production in Ogun state, Nigeria. Majority of the farmers were also relatively efficient and their enterprises were found to be profitable (Yusuf and Malomo, 2007).

Consistent with other study findings, the factors found to increase the efficiency level of farms and the sustainability of the farming system in Matale district of Sri lanka were a higher number of farm visits of extension officers, more farmer training and more experience, as well as less sloping land and higher species diversity in the study area. However, unlike in other studies, higher education level decreased the efficiency level as well as more off-farm income sources. Constraints such as, productivity, market, technology, and institution related constraints led to the decline of farmers' income from spice-based agro forestry thus the un-sustainability of the spice based agro forestry system (Lindara *et al.*, 2006).

2.6.1 Farm and farmer specific determinants of water use efficiency

In the few studies that have examined the relationship between sub-vector efficiencies for water and various farm or farmer characteristics report Farm size, landownership, fragmentation, the type of irrigation scheme, crop choice and the irrigation methods applied to have a significant impact on the sub-vector efficiency for water. It is suggested that introduction of water charges could be a trigger for more efficient water use (Speelman *et al.*, 2008; Diaz *et al.*, 2008).

Studies that have analyzed the efficiency of agricultural production in developing countries (Haji, 2006; Malana and Malano, 2006; Chavas *et al.*, 2005; Abay *et al.*, 2004; Binam *et al.*, 2004; Dhungana *et al.*, 2004; Binam *et al.*, 2003; Coelli *et al.*, 2002; Wadud and White, 2000; Shafiq and Rehman, 2000; Reinhard *et al,*. 2000; Helfand and Levine, 2004; Lansinka and Reinhard, 2004; Bozoglu and Ceyhan,2007; Arega *et al,*.2006), have mainly focused on mono-cropping of major food crops like rice, maize or wheat or on cash crops like coffee and tobacco. Besides, these studies have not specifically focused on the use of water. This study focused on water, for which the sub-vector efficiencies were calculated and analyzed. This is relevant given the growing pressure on the water resource due to scarcity and multiple uses.

CHAPTER 3: METHODOLOGY

This chapter contains the theoretical background for the empirical approach chosen to achieve the study objectives. The first section presents the theoretical framework on which the analytical procedures used in this study are anchored. The subsequent sections present model specification and justification. Finally, information on the study area, sampling design, sample size determination, data collection and analytical procedures conclude the chapter.

3.1 Theoretical framework

Two main approaches have been used to obtain estimates of technical efficiency namely parametric and nonparametric [i.e. Stochastic Frontier Analysis (SFA) and Data Envelopment Analysis (DEA)]. The parametric approach consists of specifying and estimating a parametric production function (or its dual cost or profit function) representing the best available technology (Chavas, 2005; Wadud and White, 2000). The Stochastic Frontier Approach was proposed by Aigner *et al.,* (1977) and Meeusen and van den Broeck, (1977). This approach provides a convenient framework for conducting hypothesis testing, and the construction of confidence intervals; however its drawbacks are the need to assume a functional form for the frontier technology and for the distribution of the technical inefficiency term in addition to the results being sensitive to the parametric form chosen (Wadud and White, 2000).

The nonparametric approach was proposed by Farrell (1957), whereby a piecewise linear envelopment of data, as the conservative estimate of the production frontier which envelopes observation points as closely as possible was estimated by solving a system of linear equations. Farrell's approach was generalized to multiple inputs and multiple outputs and reformulated into a mathematical linear programming problem by Charnes *et al.*, 1978. The new approach came to be called data envelopment analysis (DEA). It has an advantage of imposing no a priori parametric restrictions on the underlying technology (Malano, 2006).

In the first step of the analysis in this paper, data envelopment analysis (DEA) was used to calculate measures of efficiency following (Fraser and Cordina, 1999) in which the relationships between all inputs and outputs were taken into account simultaneously (Raju and Kumar, 2006). The method enables the researcher to determine the relative efficiency of a farm and to examine its position in relation to the optimal situation. Moreover, this methodology allows not only technical, but also sub-vector efficiencies to be calculated; a measure that can be used to specifically monitor the efficiency of an individual input in this case water use which is the main aim of this study.

A second step of the study consisted of analyzing the determinants of the efficiency measures following (Frija *et al.*, 2009; Speelman *et al.*, 2008). A Tobit model was estimated as a function of various attributes of the farmers or farms within the sample, allowing deduction on aspects of the farms' human and physical resources that might be targeted by public investment to improve efficiency. The aspect of farmer groups i.e. water users associations was incorporated as one of the exogenous variables to find out its influence on water use efficiency and this has not been the case for previous studies.

3.2 The Variable Returns to Scale DEA Model

According to Banker *et al.*, (1984), the model takes the form;

$$DF^{L}(x,y) = Min\ \phi_k^{VRS}\ \{\phi_k^{VRS} \geq 0\}:$$

$$\begin{aligned} s.t \quad & \sum_{k=1}^{K} \lambda^k y_m^k \geq y_m^*, && m = 1,\ldots,M \\ & \sum_{k=1}^{K} \lambda^k x_n^k \leq \phi_k^{VRS} x_n^*, && n = 1,\ldots,N \\ & \sum_{k=1}^{K} \lambda^k = 1,\ \lambda^k \geq 0, && k = 1,\ldots,K \end{aligned}$$

Where, DF^{L} is the Debreu-Farrell input-oriented efficiency measure, The inputs of the k^{th} DMU are multiplied by parameter ϕ_k^{VRS} to scale them down by the smallest possible factor subject to the constraint that these minimized inputs must still be able to produce the original output bundle. In other words, the aim is to construct a *virtual* DMU for each of the DMUs in the sample using the others in the sample. This virtual DMU is then compared with the real one to determine how the two differ. The parameter ϕ_k^{VRS} is the Farrell TE measure of the k^{th} DMU under VRS and λ is a $(K \times 1)$ vector of weights attached to each of the DMUs. The asterisk defines the DMU under investigation. The first constraint requires that the weighted average of the outputs of all DMUs$(\sum_{k=1}^{K} \lambda^k y_m^k)$, less the output of the k^{th} DMU be greater than or equal to zero. This means that the output of the virtual DMU being constructed has to be at least (y_m^*) units. Similarly, the second constraint requires that this virtual DMU should not use more than (x_n^*) level of inputs. The convexity constraint $\sum_{k=1}^{K} \lambda^k = 1$ ensures that an inefficient firm is only benchmarked against firms of similar size, that is, the projected point (for that DMU) on the DEA frontier is a convex combination of observed DMUs. This convexity restriction is not imposed in the CRS case, hence in a CRS-DEA; a firm may be benchmarked against firms which are substantially smaller or bigger than it (Coelli *et al*,. 1998).

In the case of agriculture, increased amounts of inputs do not proportionally increase the amount of outputs. For instance, when the amount of water to crops is increased, a linearly proportional increase in crop volume is not necessarily obtained; one reason why the variable returns to scale option was more appropriate for this study. Coelli *et al*,. (1998) also adds that estimating technical efficiency using Constant Returns to Scale (CRS) is only appropriate when all firms are operating at an optimal scale, which in reality is not likely due to factors like financial constraints and imperfect competition among others. Such estimations result in measures of technical efficiency confounded by scale inefficiencies. The variable returns to scale (VRS) specification permits technical efficiency measures devoid of scale inefficiencies.

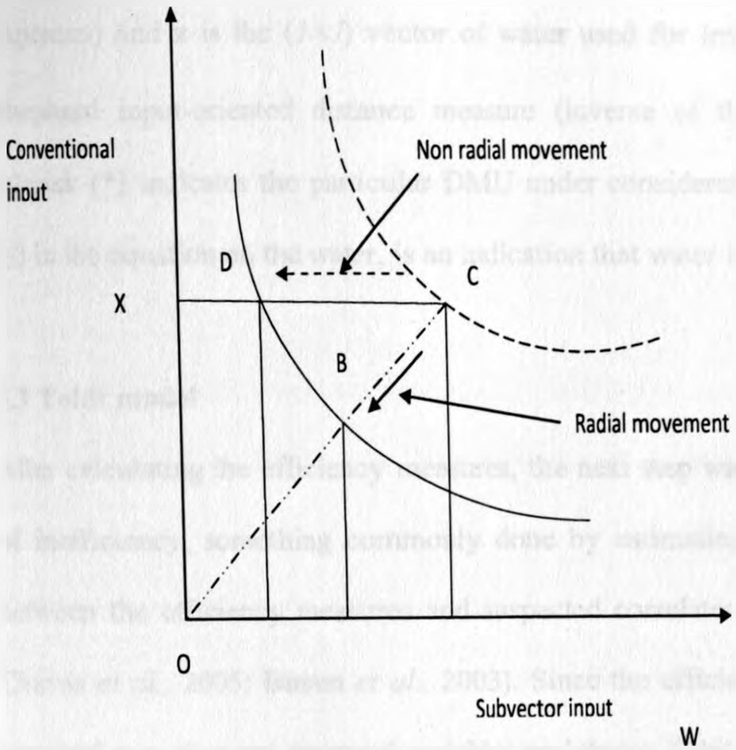
The inputs considered in this study were quantity of water used for irrigation in m^3, labor in man days, land in acres, seeds, fertilizer and pesticides in terms of expenses. For different outputs by farms both quantities and corresponding prices were obtained. Total output was then converted into monetary terms for easier comparison purposes across farms following (Speelman *et al*., 2008 and Frija *et al*., 2009).

3.2.1 Sub-vector efficiencies

Sub-vector efficiency is the efficiency with regard to an individual input. It is assumed that it is possible to reduce or minimize an input say X_1, in this case water, while holding other inputs and outputs constant. The concept looks at the possible reduction in a subset of inputs, holding all other inputs and outputs constant (Oude-Lansink and Silva, 2004, 2003, 2002; Färe *et al.*, 1994). For calculating the efficiency of an individual input in this study, sub-vector efficiency measures were introduced and calculated in GAMs in order to generate technical efficiency measures for water rather than for the entire vector of inputs.

According to Reinhard (1999), the standard radial (equi-proportionate) measure is incapable of identifying the efficiency of individual input used, since such a measure treats the contribution of each input to productive efficiency equally. Individual efficiency is a non-radial notion of input efficiency measure and it allows for a differential reduction of the inputs applied. A non-radial contraction of the sub-vector input only, holding all the other inputs and output constant is also suggested by Ball *et al.*, (1994) and Reinhard *et al.*, (2000). This is demonstrated by the figure below;

Fig 3.2 input oriented water use efficiency



$$D_i(\mathbf{x},\mathbf{y},\mathbf{z}) = Max\left\{(\phi : x,\ y,\ \frac{z}{\phi}) \in T^{watuse}\right\}$$

And in LP form, the equation above becomes;

$$D_i(\mathbf{x},\mathbf{y},\mathbf{z}) = \underset{\phi}{Max}\ \phi\ \{\phi \geq 0\}:$$

$$\begin{aligned} s.t \quad & \sum_{k=1}^{K} \lambda^k y_m^k \geq y_m^{*}, && m = 1,\ldots, M \\ & \sum_{k=1}^{K} \lambda^k z_j^k \leq \phi^{-1} z_j^{*}, && j = 1,\ldots, J \\ & \sum_{k=1}^{K} \lambda^k x_n^k \leq x_n^{*}, && n = 1,\ldots, N \\ & \sum_{k=1}^{K} \lambda^k = 1,\ \ \lambda^k \geq 0, && k = 1,\ldots, K. \end{aligned}$$

where, **y** is a vector of output quantities (in this case, crop output in terms of expenses) for the k^{th} farmer; **x** is a vector of conventional input quantities for the k^{th} farmer (these being labor in man days, land in acres, seeds, fertilizer and pesticides in terms of expenses) and z is the $(I \times J)$ vector of water used for irrigation in m^3. Phi (ϕ) is the Shephard input-oriented distance measure (inverse of the Farrell measure) and the asterisk (*) indicates the particular DMU under consideration. Note the inequality sign ($\leq$) in the equation on the water, is an indication that water is still an input.

3.3 Tobit model

After calculating the efficiency measures, the next step was to identify the determinants of inefficiency, something commonly done by estimating a second-stage relationship between the efficiency measures and suspected correlates of efficiency (Barnes, 2006; Chavas *et al.*, 2005; Binam *et al.*, 2003). Since the efficiency parameters vary between zero and one, they are censored variables and thus a Tobit model was used. In this case, efficiency estimates lie between 0 and 1, hence the point of truncation is 1.

The dependent variable is not normally distributed, since its value lies between 0 and 1. Estimating the model using OLS only, would produce both biased and inconsistent estimates even at asymptotic levels Gujarati (2004). More specifically, OLS underestimates the true effect of the parameters, that is, it attenuates the slope thus the method of maximum likelihood is recommended for Tobit analysis. Therefore, as a second stage in this study, a set of variables were selected as potential determinants of IWUE. Tobit regression was used, which is an alternative to ordinary least squares regression (OLS) for situations in which the dependent variable is bounded from below or above (or both) either by being censored, or by corner solutions (Frija *et al.*, 2009). Accordingly, for the purposes of this study, the empirical model takes the form;

$$\Theta^{k*} = \beta_o + \beta_1 Z_1 + \beta_2 Z_2 + \beta_j Z_j + \varepsilon$$

$$\Theta^{k*} \text{ if } 0 < \Theta^{k*} < 1$$

$$0 \text{ if } \Theta^{k*} < 0$$

$$1 \text{ if } \Theta^{k*} > 1$$

Where Θ^{k} is the DEA sub-vector efficiency index for water used as a dependent variable and Z is a vector of independent variables related to attributes of the farmers within the sample.

Thus the estimated model for this study is;

$$\Theta^{k*} = \beta_o + \beta_1 \text{age} + \beta_2 \text{HHsize} + \beta_{3\,\text{Area cult}} + \beta_4 \text{crop choic} + \beta_5 \text{gender} +$$

$$\beta_6 \text{edu} + \beta_7 D_1 + \beta_8 D2 + \beta_9 \text{fragmntn index} + \beta_{10} \text{user grp} + e$$

In the Tobit analyses various farmer or farm specific factors were regressed on the sub-vector efficiencies for water. The vector of exogenous variables included ; age of the farmer (in years), gender (dummy variable taking 1 if farmer is male and 0 otherwise) and household size (number of members in the household), as well as socio-economic characteristics like education (dummy variable taking 1 if farmer minimally attended primary education and 0 otherwise), cultivated area (total area in acres), crop choice which is the farmer profit per m^3 and a land fragmentation index(Simpson index defined as the sum of the squares of plot sizes divided by the square of the firm size, with higher values of this index indicating more fragmentation). Since this study considered 3 irrigation technologies, two dummy variables were introduced where, β8 andβ9 are the coefficients for the dummy variables included for irrigation techniques (Dummy variable, $D_1=1$ for sprinkler and zero otherwise, while $D_2=1$ for drip and zero otherwise). Bucket was controlled and used as the basis for comparison. Furthermore, a dummy variable taking 1 if farmer participated in a water group and zero otherwise was also included.

It is important to mention at this point that, some variables like gender, age of the household and size of household cannot be considered for policy changes, since they are either fixed or take long periods of time to change. However, their inclusion is important because it shows the relationship between efficiency measures and these variables following (Mulwa *et al.*, 2009)

3.3.1 Further tests

To get better insight in the differences between the measures obtained, some statistical tests were also obtained. First, the correlation between the calculated efficiency measures was assessed using Pearson correlation statistics. Second, the relationship between sub-vector and overall technical efficiency measures was statistically tested using a paired sample t-test. For comparison net profit per m^3 of water, which is another often used measure of water use efficiency, was also calculated because it is also used in this study to arrive at levels of crop combinations. Correlation between this measure and the obtained sub-vector efficiencies was assessed using the Spearman correlation coefficient. The test of correlation between variables used in the Tobit regression was also done and further confirmed through a multicolinearity test (see appendix 1) which showed absence of co linearity between variables used.

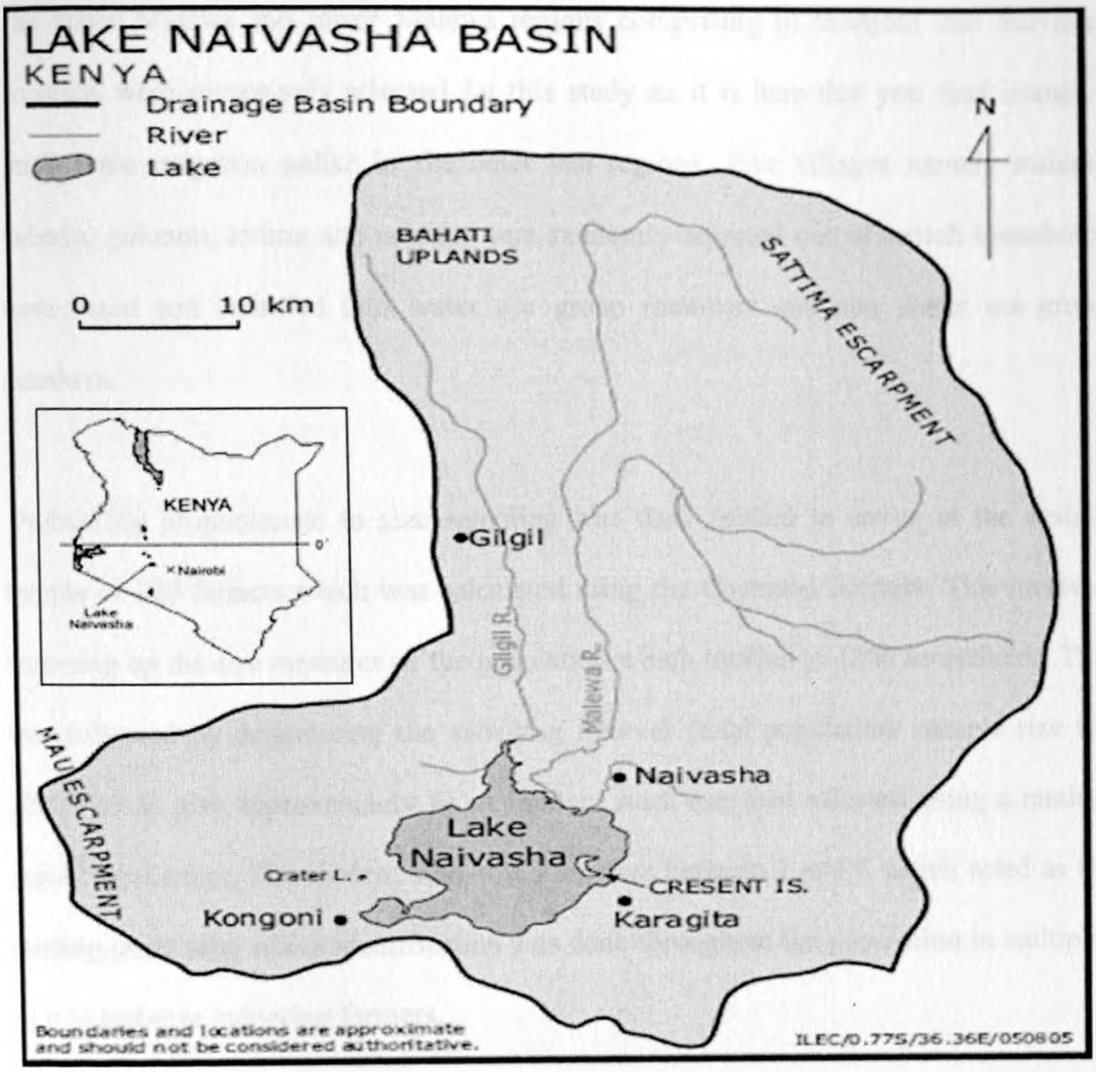
3.4 Research design

3.4.1 Study area

Data was collected from small-scale irrigation farmers situated in the Naivasha basin which touches on the Rift valley and Central provinces from March to April 2010. This catchment area has been subdivided into eleven water resource user associations or groups each occupying a given area of the basin for easier management purposes. The associations are namely, Upper gilgil, Middle Malewa, Upper Malewa, Wanjohi, Mukungi, Upper Turasha, Lake Naivasha, Lower gilgil, Mariba, Lower Malewa and Karati. The water resource management authority of this region has come up with these subdivisions as a way to involve communities of this area in water management.

The most important economic activity in this area, characterized by high unemployment and low education level, is irrigated agriculture and the entire basin is of high agricultural potential. The common farming system is mixed crop and livestock production and farmers mainly grow vegetable crops such as carrots, cabbages, potatoes, garden peas, French beans and snow peas using simple irrigation methods such as bucket, sprinkler and drip.

Figure 3.4 map showing Lake Naivasha basin



Adopted from Becht *et al.*, (2002), (ITC) Netherlands

3.4.2 Sampling design

The upper Malewa and lower Malewa regions comprising of Wanjohi and Naivasha divisions were purposively selected for this study as it is here that you find intensive small scale irrigation unlike in the other sub regions. Five villages namely mahiga, huherio, gatondo, kirima and marula were randomly selected out of which households were listed and stratified into water use group members and non water use group members.

Probability proportionate to size sampling was then applied to arrive at the desired sample of 220 farmers which was calculated using the Cochrane formula. This involved summing up the size measures of the population which totalled to 1200 households. This was followed by determining the sampling interval (total population/ sample size i.e. 1200/220 to give approximately 6). A random start was then selected using a random number generator. The random start was a number between 1 and 6 which acted as the starting point after which identification was done throughout the population in multiples of 6 to arrive at individual farmers.

Semi structured Questionnaires were used to collect data, with a total of 220 farmers being interviewed. However, nineteen questionnaires were dropped for lack of adequate information for analysis; the DEAP program used to arrive at the technical efficiency measures rejected all the DMU's with a zero output hence the final sample included 201 sample farmers, who were considered for this study. During the interviews information was gathered on the farmers household characteristics, farm activities, quantities and costs of inputs used in production, quantities and value of output, the quantity of water used, involvement in farmer groups and irrigation practices. For the different outputs both quantities and corresponding prices were obtained. Total output was then converted into monetary terms, the inputs considered in the efficiency analysis included land (acres), irrigation (m^3), labor (man days), seeds (expenses) fertilizers (expenses) and pesticides (expenses).

3.4.2.1 Determination of sample size

The appropriate sample size was arrived at using the Cochrane formula (1963) given as;

$$No = \frac{z^2 pq}{e^2}$$

Where:

N= is the sample size

Z^2 = is the abscissa of the normal curve that cuts off an area at the tails (equals the desired confidence level e.g. 95%)

e= the desired level of precision

p= the estimated proportion of an attribute of interest in the population which was estimated to 0.82 which was the percentage of the population using water for irrigation.

$q=1-p$ *i.e.* $(1-0.82)=0.18$

The value for z is found in statistical tables which contain the area under the normal curve

3.4.3 Data collection

Both primary and secondary data used in the study was collected between March and April 2010. Primary data were collected at farm level while secondary data were collected at institutional level mainly from LANARUA offices in Naivasha.

3.4.3.1 Data collection instrument

The main data collection instrument was a household survey questionnaire directed at two hundred and twenty sampled households. It contained both closed and open ended questions which required careful probing in interviews. The main respondents to the household survey were the household heads or their spouses. The issues raised at farm level included household characteristics, water-use issues, food crops grown and the expenses of inputs incurred where necessary.

Five enumerators with training up to at least secondary school level and the ability to communicate effectively in English, Kiswahili and local languages were selected. They went through a training which involved explaining the aim of the study, the meaning and implication of each question, interviewing skills and time management during interviews which was done using Kiswahili. A total of 20 small scale irrigators were interviewed during the pretest exercise and this enabled refinement of the questionnaire in order to strengthen its reliability in actual data collection. Subsequently, the semi structured questionnaire was administered in a single visit of 220 farmers.

3.4.3.2 Problems encountered during data collection

A major limitation for this study was that the farmers here do not keep records concerning their farming activities, so data gathered during interviews was based on their recollections. Therefore, the expert knowledge of the WARMA staff and local leaders was used as a supplement to the recollections of the farmers, something that was particularly helpful especially for the estimation of the water use.

Water abstraction for farming is a contentious issue in this region hence the enumerators were treated with a lot of suspicion by the local farmers and hence were required to clearly explain that the information gathered would be treated as confidential and for the sole purpose of research.

Water measurement was also difficult and tedious which involved measurement using buckets in liters per the duration of time farmers were irrigating then converting into m^3 of water used, the expert knowledge of the WARMA staff came in handy and the survey was fortunate to be carried out the same time the WARMA officers were measuring water abstraction and use by the small scale farmers.

3.4.3.3 Data analysis

Data analysis was done using Stata, DEAP program and GAMs. DEAP was used to arrive at the technical efficiency scores for all farms while GAMs was used to arrive at the sub-vector efficiencies for water for every farm. Stata on the other hand was used to conduct the Tobit regression to assess the determinants of water use efficiency.

CHAPTER 4: RESULTS AND DISCUSSION

The study evaluates general technical efficiency, water use efficiency and ascertains important factors that influence it with a view to improve water use efficiency and water abstraction sustainability in small scale irrigators of the lake Naivasha basin. In pursuit of this objective, this chapter presents and discusses key findings from the study. The chapter is organized as follows: the first section gives a brief description of important characteristics of small scale irrigators and their farming activities. This is done to pave way for better understanding of what drives efficiency. The second section presents technical efficiency estimates, further tests to determine the relationship between technical and water use efficiency and factors explaining the observed efficiency. This is followed by discussion of the main results on technical, water use and factors affecting efficiency.

4.1 Description of small holder irrigators in the Naivasha basin

4.1.1 Farmer and farm characteristics

Descriptive statistics presented in Table 4.1 indicate that the average age of the small scale irrigators was 43 years: the youngest was 21 years old and the oldest was 76 years old. Eighty six percent of these small scale irrigators are male while only fourteen percent are female. At least sixty seven percent of house hold heads had acquired primary school education indicating that the average education level in this region was low. The average family had four members while those on the higher side had up to seven members and those with a minimum having only one member. About seventy percent of farmers interviewed worked full time on their farms with only around twenty percent having off farm income from other activities. The common land tenure arrangements were individual ownership from inheritance and with title deeds (91 percent) while communal, rental fell under only 9 percent. In terms of water use groups, about 88 percent of farmers were voluntarily involved in these groups while only 12 percent were not indicating that most farmers were embracing this new idea of community management in natural resource use. Fifty four percent of farmers indicated that they were in irrigation farming to meet their subsistence food requirements while around forty six percent reported that it was for income generation.

Table 4.1: Summary statistics for continuous variables used in the Tobit regression

Continuous variable	mean	Std. Dev.	Min	Max
Age	43.44	14.02	21	76
HH size	3.85	1.15	1	7
Acres	2.45	4.29	0.25	30
Simpson	0.27	0.21	0	1
Crop choice(profit/m^3)	35.61	118.46	-290.58	708.5

Source: own survey, 2010

Table 4.1.2: Summary statistics for dummy variables used in the Tobit regression

Dummy variables	Number of farmers D=1	percentage	Number of farmers D=0	percentage
Gender	172	86%	29	14%
Education	135	67%	66	33%
User group	177	88%	24	12%
Irrigation tech1	159	79%		
Irrigation tech2	33	16%		
Irrigation tech3	9	5%		

Note irrigation tech1=sprinkler, tech2=drip, tech 3=bucket
Source: own survey, 2010

The farmers in this area of study mainly grow vegetable crops using simple irrigation techniques such as bucket, sprinkler and drip. Cabbages, potatoes, garden peas, snow peas and carrots are widely planted, with carrots being produced by 70–90 percent of the farmers. In terms of crop combination, cabbages, carrots and potatoes appear to be the most important crops in this region. The degree of farm fragmentation is moderate with a few farmers on the high side as they divide their fields into several plots, growing about three different crops on average. Furthermore, the variation in input use and output produced is considerably large. The range in land sizes, from 0.25 to 30 acres, crop choice and fragmentation partly explains this (see summary on inputs and outputs). Water use for instance varies between 41 m^3 and 6912 m^3 for a single season while seeds range from Ksh 120 to Ksh 62587 in terms of costs for the same duration.

The value of mean yield realized was Ksh 60,318 with a minimum of as low as Ksh 100 reported mainly due to bad weather hence loss of the entire season. This was especially for farmers who grew maize alone. Expenditure on pesticides was averagely Ksh 1907 with a minimum and maximum of Ksh 100 and Ksh 17100 respectively. For fertilizer, the mean was Ksh 2919 with a minimum and maximum of Ksh 100 and 30000 respectively. Labor was sourced from own family for most of the crops (80 percent) apart from crops such as carrots which required hiring especially during harvesting. Mean labor was thus 76 man days per farm with a minimum of 9 and maximum of 897 man days.

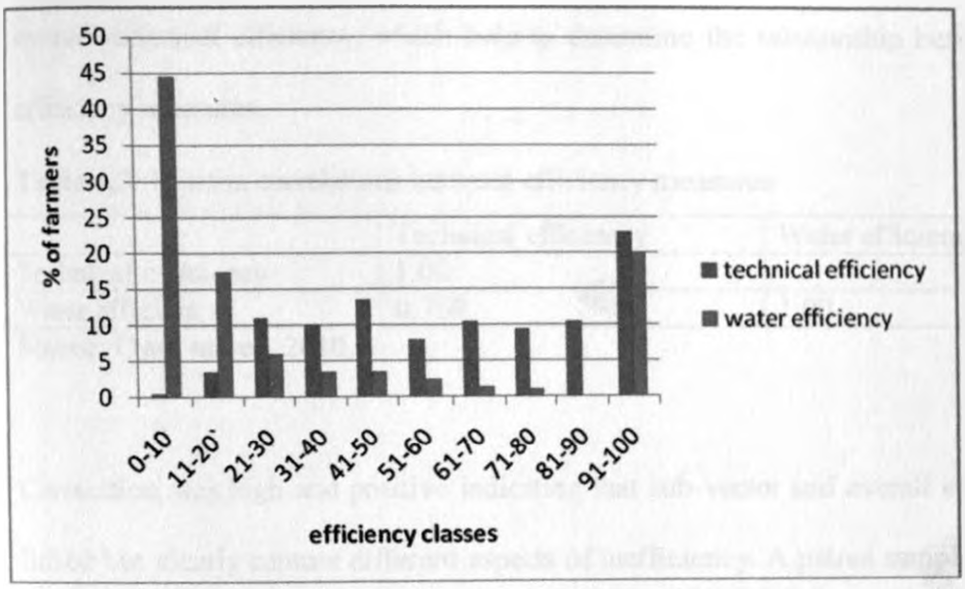
Table 4.2: Summary of inputs and outputs used in efficiency analysis

	Mean	Std. Dev.	Min	Max
Output(Ksh)	60318	126482	100	1362000
Pesticides(Ksh)	1907	2376	100	17100
Fertilizers(Ksh)	2919	3935	100	30000
Seeds(Ksh)	3823	5159	120	62587
Labor(man days)	76	86	9	897
Water(m^3)	1532	1303	41	6912
Land(acres)	2.85	4	0.25	30

Source: own survey, 2010

4.2 Technical and water use efficiencies in the Naivasha basin

Figure 4.2: Overall technical and water-sub-vector efficiencies



Source: own survey, 2010

The bar graph above indicates the frequency distribution of the efficiency estimates obtained by the DEA methods. The average overall technical efficiency for the VRS DEA approach was 0.63 indicating that substantial inefficiencies occurred in farming operations of the sample farm households.

The sub-vector efficiencies for water demonstrated even larger inefficiencies. It is clear that a large percentage (45 percent) of the sampled farmers had their water use efficiency scores lying between 0-10 percent. Average water efficiency was only 0.31, again it is clear that more farms were highly inefficient in the use of water compared to overall technical efficiency.

Table 4.3 gives the correlation statistics between sub-vector efficiency for water and the overall technical efficiency, which help to determine the relationship between the two efficiency measures.

Table 4.3: Pearson correlations between efficiency measures

	Technical efficiency	Water efficiency
Technical efficiency	1.00	
Water efficiency	0.769	1.00

Source: Own survey, 2010

Correlation was high and positive indicating that sub-vector and overall efficiencies are linked but clearly capture different aspects of inefficiency. A paired sample t-test (Table 4.4) further analyzed the equality between sub-vector efficiencies and overall technical efficiencies and the test revealed that sub-vector efficiencies for water were significantly lower than overall technical efficiency measures which implied that in terms of water use farmers failed to reach their overall efficiency level.

Table 4.4: Paired samples t-tests demonstrating the difference between overall technical Efficiency and sub-vector efficiency

	Mean	Std dev	t statistic
Technical efficiency	0.6328	0.2728	18.7***
Water efficiency	0.3194	0.3712	18.7***
Difference	0.3134	0.2375	

Note: *** indicates a 99% significance level.
Source: own survey, 2010

Net profit per m^3 (which is another often used measure of water use efficiency), is 35.6ksh/m^3 on average with a standard deviation of 118.5ksh/m^3(see table 4.1). Looking at the correlation between the sub-vector efficiency measures and the net profit per m^3, the Spearman correlation coefficient is 0.31 meaning that the two measures are independent. This confirms that the net profit per m^3 is not that well suited as an indicator of efficiency.

4.3 Farm and farmer specific factors influencing water use efficiency

The results of the Tobit regressions identifying the characteristics that influence the sub-vector efficiencies for water are presented in Table 4.5 below.

Table 4.5: Tobit estimates of determinants of sub-vector efficiency

	Coefficient	t	p-value
Age	0.0028	1.06	0.288
Household size	0.0245	0.76	0.448
Area cultivated(acres)	-0.0010	-0.10	0.924
Simpson index	-0.3149	-1.85	0.065*
Crop choice(profit/m^3)	0.0014	4.55	.000***
Gender	-0.0017	-0.02	0.986
Education	0.0424	0.64	0.522
User group	0.0160	0.18	0.856
Dummy1=sprinkler	-0.1794	-2.80	0.005***
Dummy2=drip	0.2365	2.06	0.039**
constant	-0.2288	-1.00	0.316
No of observations: 201 Wald chi^2: 57.89 Prob > chi^2 0.0000 Pseudo R^2 : 0.1279 Log Likelihood: -132.58			

Note: *** indicates a 1% significance level, ** is 5% and * indicates a 10% significance level.
Source: own survey, 2010

Results for the Tobit regression model (Table 4.5) shows that the model is highly statistically significant (a p-value = 0.000) showing that it fitted the data well. The test statistics for joint significance of all variables within the model (LR and Wald statistic) also confirmed that the Tobit model was significant.

With regard to the individual variables, the results of the model with VRS specification showed consistency with other studies. Farmers' characteristics (gender, age, education, household size) were not significant, whereas the crop choice was significant. The cultivated area though not significant negatively influenced water efficiency, while crop choice had a positive effect on the efficiency measure. Land fragmentation which is shown by the Simpson fragmentation index was significant at 10 percent, with a p-value of 0.065 and had a negative effect on the sub-vector efficiency for water. The dummies for the irrigation methods, were both significant with the sprinkler method having a negative effect on water use while drip irrigation positively influenced water use efficiency.

4.4 Discussion

The results of the DEA show that substantial inefficiencies occurred among smallholder irrigators within the study area and this is consistent with previous water use efficiency studies such as Frija *et al.,* (2009) and Speelman *et al.*, (2008). A further similarity with these two studies is that the average water use efficiency level always remains lower than the average technical efficiency levels. This further confirms that the main problem in the area is not the shortage of water but the management and allocation of the resource between multiple users and uses.

It is apparent that efficiency in water use has not been attained and there is lack of strong institutions and organization in management which points to an uncoordinated framework of management. For example, a recent meta-analysis by Bravo-Ureta *et al.*, (2007) showed that in less developed countries, mean values of technical efficiency per study averaged about 0.74. Moreover, given the poor performance of the type of irrigation schemes in the areas mentioned in several studies (IPTRID, 2000; Shah *et al.*, 2002; Perret, 2002), substantial inefficiencies were expected.

Secondly, when looking at the water use efficiency, the results indicated that farmers fail to reach their overall technical efficiency levels. As indicated by Nsanzugwanko *et al.*, (1996), and Speelman *et al.*,(2008) this might be explained by the absence of pricing mechanisms for water. Farmers at this moment have no financial incentive to limit their water use or to invest in water saving technologies due to the common pool nature of the water resource. The gradual introduction of water charges through water meters for farmers in this region, which is planned for the coming years, can probably be a trigger for more efficient use. With water efficiency levels standing at only 31 percent for this study, this implies that when all other inputs remain constant, the current output could be produced using, on average, 69 percent less irrigation water; hence the implication that there appears to be a considerable scope for reducing the water use, even with the technology currently available.

This means that if efficiency improves, it should be possible to reallocate a fraction of the water to other water demands without really endangering production or the role small-scale irrigation might play for rural development. Besides, correlation tests showed that poor performance regarding water use efficiency and overall technical efficiency are somewhat linked. This can be explained by the vital role irrigation water plays in the production systems under study as one of the major inputs to production. However, this finding also implies that the introduction of water prices can be a threat to the viability of the poorer performers, because they will be most affected by this additional cost and their farming activities might become financially unviable.

Thirdly, the results of the Tobit model show that the crop choice has a significant impact on the sub-vector efficiency for water. The cultivated area had a negative impact on the sub-vector efficiency for water. Haji, (2006) also reported such a negative impact on overall technical efficiency, attributing it to the labor intensive character of the type of vegetable production he studied. Speelman *et al*., (2008) too reported a negative impact of cultivated area on the sub-vector efficiency for water which was said to be inconsistent with the increasing returns to scale for the overall technical efficiency they found in their DEA outcomes and this explanation would be accepted for this study. However, the Tobit model only considers the sub-vector efficiency. Apparently, the relationship between cultivated area and the totality of farming activities is different from that between cultivated area and the use of water. Therefore further investigation on this matter is needed.

The highly significant and positive effect of crop choice on sub-vector efficiency for water supports the call for selecting crops with higher profits per m^3 of water used or for water saving irrigation technology. Fragmentation has a negative effect under the variable returns to scale specification, indicating that, for a certain size of operation, the sub-vector inefficiency for water is lower if the farm is less fragmented. This is due to the fact that irrigation can be managed more efficiently on larger plots (Wadud and White, 2000; Speelman *et al.*, 2008). The results also indicated that the dummies for irrigation technologies are highly significant meaning that the choice for the irrigation method to use is of prime importance. For instance, farmers using sprinkler irrigation method (which is the most commonly used 79 percent of total sampled farmers) negatively influence the sub-vector efficiency for water while those using drip irrigation positively influence the sub-vector efficiency for water. Hence this further supports the call for selection of water saving irrigation technologies such as drip.

Some other variables are not significant. For example, education has no significant impact on the sub-vector efficiency for water. This is consistent with studies such as those of Haji (2006), Coelli *et al.*, (2002), Speelman *et al.*, (2008) and Wadud and White (2000). The explanation of Coelli *et al.*, (1998) that this could be due to the low average education level in the sample is also acceptable for this study. Dhungana *et al.*, (2004) and Binam *et al.*, (2004) in contrast reported a significant positive effect of education on efficiency for some of the regressions they performed, possibly pointing to a slightly higher average education level in their samples.

Farmer's age also does not contribute significantly to a higher level of efficiency either. A possible explanation is that the two effects of age and experience neutralize each other whereby older and more experienced farmers have more knowledge on their land and traditional practices, but are less willing to adopt new ideas. Sometimes one of the two effects dominates, accounting for the mixed results in literature for the effect of age

(Speelman *et al.*, 2008); negative in the study of Wadud and White (2000) and Binam *et al.* (2003), but positive in the study of Dhungana *et al.*, (2004). In this study, experience was not measured and so an age-experience interaction term could not be included to test the hypothesis above. Consistent with (Coelli *et al.*, (2002), the effect of family size is not significant. On the other hand, Haji (2006) and Dhungana *et al.*, (2004) reported the effect of family size as negative. For gender no significant effect can be shown and finally, the effect of collective action (user group) was not significant in this study and this could be attributed to the fact that the issue of water resource use groups is still a new idea in this region and it is still in the initiation stage. Therefore nothing much has been done through these groups formation and the collective action is still new and weak.

CHAPTER 5: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

This chapter highlights the key findings of the study. Conclusions and recommendations are then drawn on technical and water use efficiencies in light of experiences of the small scale irrigators from the Naivasha basin. Finally, areas for future research are proposed.

5.1 Summary

The global area of wetlands has decreased at an increasing rate due to the conversion to agriculture, urban and other uses which has profound ecological impacts at local and global scales as well as significant social and economic impacts on resource users. There is growing international awareness of the importance of value of natural resources such as wetlands in the lives of rural communities throughout the world and water resources development and management is imperative for sustainable agriculture. Water is critically important to the livelihoods of many populations especially the rural poor primarily engaged in agriculture. In many developing countries, water is a major factor constraining agricultural output and their incomes. Additionally, a large percent of the world's food supply comes from irrigated agriculture, and agriculture is the single largest user of fresh water on the planet and it is also the largest economic activity of the rural poor. Therefore, improved water management for agriculture through efficient use can improve the livelihoods of a great proportion of the rural communities.

Since water resources have become increasingly scarce, there is need for an institutional framework to ensure sustainability and social optimum use which to a certain extent has called for the collective action through user groups which has yielded desirable results in terms of better up-keep of irrigation infrastructure, efficiency in water resource use, financial viability, improved productivity of irrigation and overall sustainability in some parts of the world.

In Kenya, wetlands continue to be degraded and lost due to pressure from agricultural and development activities. For the Naivasha basin it is observed that the main problem in the area is not the shortage of water but the management and allocation of the resource between multiple users and uses. This is evidenced by the low water efficiency results and the significant variables of poor crop choice, poor choice of irrigation technologies and the high level of farm fragmentation which negatively influence water use efficiency.

It is apparent that efficiency in water use has not been attained and there is lack of proper institutions and organization in management at the farm level. Therefore various stake holders in the basin have organized themselves to come together in management to promote sustainable use of water. This is seen or evidenced by the current farmer group formation higher in the catchment in efforts to arrive at a coordinated system of management which is important in that it is the upper catchment farmers who are indirectly responsible for maintaining the water inflow into the rivers because their farming activities eventually affect the systems hydrology.

Since irrigation water is one of the important inputs to production in this basin, overcoming possible constraints to efficiency in its use will contribute to sustainable use of farm resources hence achievement of overall technical efficiency. For this goal to be accomplished, detailed empirical information was required on the existing efficiency levels as the prevailing technical efficiency was not known and the determinants to water use efficiency were not clear. This study hypothesized that despite some progress in water resource management in this basin, small scale farmers were still water use inefficient and there was considerable room for improvement.

Therefore, this study endeavored to investigate whether farmers were water use efficient and whether the effort made in calling for farmer group formation had had impacts on water use efficiency together with other explanatory factors. The study aimed to evaluate water use efficiency in the Naivasha basin with a view to identify important factors influencing it.

A random sample of 220 small scale irrigator households was selected in 2divisions of the Naivasha basin in March 2010. A semi structured questionnaire was used to collect input and output data for this regions farming activities for the year 2009. In addition, data was collected on relevant socio economic factors hypothesized to influence efficiency. These were farmers' education, age, gender, household size, Simpson fragmentation index, crop choice, irrigation technique and collective action of farmer groups.

Descriptive statistics were used to facilitate characterization of small holder farming in order to understand what constrains efficiency in water use. DEAP and GAMs computer programs were used to arrive at technical and water use efficiencies respectively while Tobit regression was used to determine factors influencing efficiency.

5.1.1 Summary of results

The average overall technical efficiency for the DEA estimated was 63 percent indicating that substantial inefficiencies occurred in farming operations of the sample farm households. The sub-vector efficiencies for water demonstrated larger inefficiencies lying at only 31 percent while a large percentage (45 percent) of the sampled farmers had their water use efficiency scores lying between 0-10 percent. The Tobit regression model is highly statistically significant (a p-value = 0.000) and the results showed that farmers' characteristics (gender, age, education, household size, cultivated area) were not significant, whereas the crop choice, Land fragmentation and the dummies for the irrigation methods, were significant .

5.2 Conclusions

This study showed that the smallholder irrigation farmers in the Naivasha basin fail to reach their overall technical efficiency levels and with regard to water use, their efficiency levels are even lower. It appears that farmers have little incentives to use water in an efficient manner in the absence of ownership rights, a water price and the lack of a coordinated system of management and allocation. In this sense, the introduction of water charges for these farmers, which is planned for the coming years by the water resource user association of this region, could be a trigger for more efficient use. There are however indications that the effect of introducing a water price might not be entirely positive. The high correlation between sub-vector efficiencies for water and the overall technical efficiency give cause to worries about the viability of the poor performers under the introduction of a water price.

On the other hand, the low efficiency estimates, suggest that substantial decreases in water use can be attained given existing technology, without compromising the key role in rural development played by small-scale irrigation. In this way there is room for lifting part of the increasing pressure on water resources by reallocating a fraction of the irrigation water elsewhere and the enforcement of rules through the newly formed farmer groups could be of prime importance in this case.

The relationship between the sub-vector efficiency for water and farm and farmers' attributes in addition gives information to policy makers and extension services on how to better aim efforts to improve water use efficiency. For example the positive and significant effect of crop choice on the sub-vector efficiency, should incite extension services to encourage farmers to select crops with higher profit per m^3 of water used. This implies that farmers should be made aware of the way to derive this profit per m^3 of water used so that they have the most current information with regard to the prevailing farm profit levels. Efforts should also be made to orient farmers towards appropriate choice of irrigation technologies in terms of efficiency in water use and the desirable level of farm fragmentation which should be in tandem with the crops with a high profit per m^3 of water used.

5.3 Recommendations

Based on the findings of this study, it is suggested that efficiency concerns especially in the use of natural resources such as water be well integrated in agricultural research and policy formulation processes to ensure continued and sustainable use and efficient allocation of natural resources thus enhancing food availability and incomes for the rural poor. As for the water act and the management plan of this region, they both fail to quantify sustainability or define sustainable abstractions. Therefore, with the water use efficiency results obtained from this study, this could be a good starting point to obtain a drawdown that is socially, economically and ecologically acceptable for the entire basin .thus , the study proposes public policies which are favorable and in line with better management of water use.

From the findings of this study, it is recommended that more emphasis should be laid on orienting farmers towards appropriate choice of irrigation technologies in terms of efficiency, appropriate choice of crop combinations for their farms with regard to the prevailing farm profit levels and the desirable level of farm fragmentation which should be in line with the appropriate crop choices made.

Further efforts should be directed on introduction of ownership rights over natural resources such as water in order to encourage more efficient use. This could be through introduction of water charges, installing water meters and also through better management which is seen to be already taking shape through farmer group formation.

5.4 Suggested research areas

This study prompts the following areas for further research:

This study appropriately used cross sectional data to estimate water use efficiency in small scale irrigation farming. However, cross sectional data does not capture changes in efficiency over time as it only provides information on spatial efficiency variations. Changes in on-farm resources and factors affecting these resources such as weather and other attributes important for crop production take place gradually over time thus indicating the need for time series analysis which would offer insights into temporal variations.

The data used for this study was collected during single visits, based on recall memory. A cross sectional study designed to have multiple visits during key operations such as ploughing, planting, irrigation, weeding and harvesting could improve the accuracy of the data and precision of the estimates.

In conclusion, it should be noted that this study focused on technical efficiency measures. Additional research on allocative and economic efficiency can further determine the scope for production improvements and can add to our understanding of the effect on efficiency of the introduction of a water charges. Further research would also be of prime importance post the water resource use groups formation and full implementation as a way of management.

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Appendix 1: Test for multicollinearity

Test for multicollinearity - partial correlation coefficients

	age	hh size	acres	simpson	prft/m3	gender	edu	LandOwner	usergroup	irrgtntech=1	irrgtntech=2
age	1										
hh size	0.078	1									
acres	0.196	0.041	1								
simpson	-0.138	0.011	-0.350	1							
prft/m3	0.063	0.073	-0.013	-0.072	1						
gender	-0.292	0.184	0.104	0.001	0.066	1					
edu	0.120	-0.127	-0.070	-0.007	-0.009	-0.137	1				
LandOwner	0.167	0.134	-0.017	-0.201	0.083	-0.033	0.006	1			
usergroup	0.091	0.062	0.004	-0.163	-0.115	-0.110	-0.094	0.203	1		
irrgtntech=1	0.037	-0.006	0.076	-0.282	0.121	-0.003	-0.075	0.226	0.150	1	
irrgtntech=2	-0.045	-0.003	-0.095	0.340	-0.128	-0.045	0.052	-0.280	-0.165	-0.864	1

Appendix 2: survey questionnaire

AN ECONOMIC ASSESSMENT OF WATER USE EFFICIENCY IN LAKE NAIVASHA BASIN

Field questionnaire

We are part of a team from the University of Nairobi, who are studying aspects to do with farming activities in this region with emphasis on input use. Your participation in answering these questions is very much appreciated. Your responses will be **COMPLETELY CONFIDENTIAL**.

Part 1-identification

Enumerator's name……………………………date…………………..province………………………

District………………division………………..location………………..Sub location…………………

Name of the respondent………………………………………………………………

Name of the household head if different from the respondent……………………………………………………………………………..

Part 2-land use and house hold characteristics

2.1 What crops did you grow on your farm last year?

(1=maize, 2=beans, 3=peas, 4= French beans, 5= cabbages, 6= tomatoes, 7= carrots, others (specify))

2.2 What was the main objective of growing the crops mentioned?

(1=subsistence, 2= income generation, 3=livestock feeding, 4=others (specify))

2.3 What was the total acreage of your farm in 2009?

(1=owned……, 2=hired……)

Table 1: farm profile

Parcel no.	Size in Acres	Crops grown 1=maize 2=beans 3=peas 4=French beans 5=cabbages 6=tomatoes 7=carrots	Season 1=long 2=short	Area under each Crop	Tenure status 1=Owned with title 2=Owned without title 3=Communal 4= Hired	Method of Acquisition 1=bought 2=gift 3=Inherited 4=Rented 5=other (specify)

The following question regards your input use for the cropping year 2009

Table 2: Input usage

(1=yes, 2=No)

rop ode	Season 1=long 2=short	Pesticide name	Pesticide qty 1=paperbags 2=bucket 3=debes 4=gunny bgs	Cost per unit	Total cost in ksh	seed quantity 1=paperbags 2=bucket 3=debes 4=gunny bgs	Cost per unit	Total cost in ksh	Fertilizer qty 1=paperbags 2=bucket 3=debes 4=gunny bgs	Cost per unit	Total cost in ksh	Labor(man days) 1=weeding 2=ploughing 3=chemical app 4=harvesting

I would like us to talk in detail about how you carried out various farming activities in your farm. Specifically, how you irrigated your crops; water you used in both seasons from planting to harvesting and methods employed. do you usually irrigate your crops?

If yes, fill the table below

Table 3: irrigation water use

Crop irrigated (Codes)	Season 1=long 2=short	Water source 1=river 2=ownwell 3=lake, 4=owntank 5=others specify	Irrigation tech 1=bucket 2=canals 3=drip 4=sprinkler 5=others specify	Frequency of irrigation within growing period 1=daily 2=weekly 3=monthly 4=seasonally	No. of times /each frequency e.g. how many times/day	Water used in 1=m^3 2=liters	Distance to river in km	Mode of transport 1=walking 2=bike 3=car/motorbike	Time spent in hours

This question regards the amounts of various outputs from your farm in the year 2009 and how they were utilized i.e. sale, consumption and other purposes

How much was your total output harvested per crop?

Table 4: farm Output

Crop codes	Produce in units 1=paperbags 2=buckets 3=debes 4=gunny bgs 5=wheelbarrow	Season 1=long 2=short	Qty consumed	Qty sold	Estimated losses	No. of sales	Average sold (No. sales*qty sold)	Market price/unit	Value of produce sold. (avgsold* mkt prce)	Transport costs

The following question regards points of sale for your output

Table 5: nearness to point of sale

Crop code	Where sold 1=from home 2=market name 3=town name	Distance (km)	Mode of transport 1=walking 2=bike 3=car/motorbike	Time spent in hours	Payment mode 1=cash 2=exchange for goods 3=other specify	Comment on offered price 1=good 2=fair 3=bad

1.0 Are there any other costs incurred in the process of production and marketing? Cost/unit……………………

2.0 What constraints did you incur in your farming activities and what solutions would you suggest?……………………………………………………………………………………………

………

The following question regards your household's membership.

1.0 How many people are in your household?

Table 6: house hold characteristics

Name	Relation to HH head 1=head 2=spouse 3=child 4=relative 5=servant 6=other	Age years	gender 1=m 2=f	Marital status 1=single 2=married 3=divorced 4=separated 5=widowed	Level of education in years 1=primary 2=secondary 3=tertiary	Main occupation codes	Months working in the farm in last 12 months	Farm labor participation 1=full time worker 2=part time 3=not a worker	No. of days working in farm /week	Wages/month 1=on farm 2=off farm

Codes for occupation;
1=farming
2=employed
3=self employed off farm,
4=casual laborer,
5=schooling,
6=herding, 7=HH chores,
8=N/A, 9= others (specify)

How much income, did your household receive from other sources in the last cropping year apart from credit?

Table 7: off farm income

sources	Amount in ksh	Earning family member 1=head 2=spouse 3=child 4=relative 5=other
Rented out land		
Sale of livestock products		
Sale of own trees		
Casual village labor		
Regular employment		
Pension income		
Business income		
Dowry		
remittances		

Part 3-collective action

I would also like to know if you are involved in any farmer and water user group, what are the activities and benefits of being a member

1.0 Are you involved in any water user groups?
(Yes=1, No=0)
1.1 If yes, for how long.......................
1.2 And if yes, what were your reasons for volunteering to participate in a water resource use group?..
....
....
....
1.3 If not, ask the reasons then proceed to Q18 onwards..
....
....

(This section applies for farmers involved in water use groups)

2.0 In the last one year, how often did you attend water use group meetings?(1=always, 2=sometimes, 3=never)
3.0 How many members is your group comprised of..........................?
4.0 Do you hold any leadership role/position in your group?(1=yes,2=No)
If yes, what position?
(1=chairman, 2=vice chairman, 3=treasurer, 4=secretary, 5=other, specify)
5.0 Were you involved in a water user group before 2009?
(1=yes, 2=No)
6.0 Did you have friends who were involved on a water group before 2009?
(1=yes, 2=No)
7.0 If yes, how many friends were involved........................?
8.0 Did the group interview you before you joined it?
(1=yes, 2=No)
9.0 If yes to Q8, who interviewed you?
(1=group leaders, 2=members, 3=both)
10.0 How are rules and decisions made in the group?
(1=imposed, 2=leaders only, 3=leaders consult members, 4=leaders by approval of members, 5=consensus, 6=other)
11.0 Overall, are you satisfied with the chairperson of your group?
(1=very satisfied, 2=somewhat satisfied, 3=not satisfied)
12.0 Overall, are you satisfied with the leadership of your group?
(1=very satisfied, 2=somewhat satisfied, 3=not satisfied
13.0 What were the main activities for the year 2009?..
....
....
14.0 Did you buy inputs or sell outputs through the organization?
(Yes=1, No=0)

15.0 In your group meetings, do you discuss issues to do with irrigation water use?
(Yes=1, No=0)

15.1 If yes, is there any agreement on the quantity or limits of water to be drawn for irrigation per farm or farmer...

15.2 If yes, how much...

15.3 Are there any agreed irrigation techniques?(Yes=1, No=0)

15.3.1 If yes, which ones and why...
.........?
(1=bucket2=canals 3=drip 4= sprinkler 5=others specify)

15.3.2 Are there farmers who fail to comply with the agreements?(1=yes, 2=No)

15.3.3 If yes, what are the punishments?
(1=fines, 2=suspended from group, 3=withdrawal of some benefits, 4=other, specify)

16.0 What other concerns/activities does your group undertake..

17.0 Does your group work with other groups with similar goals?(1=never, 2=sometimes, 3=always)

18.0 What challenges do you face in using irrigation water...
....
....

19.0 Has the river water levels declined over the years? (1=yes, 2=No)

20.0 If yes, by how much? (1=very much, 2= slightly, 3=not much)

Table 8: Other benefits from your group

Benefits	Benefits received (1=Yes, 2=No)
Improvement of access to credit	
Improvement of access to market	
Education and training	
Other(specify)	

Are you involved in any other community groups apart from water?

Table 9: Farmer involvement in other community groups

Name of group	Type of group 1=work group 2=self-help 3=merry go round 4=women 5=family	Group functions 1=tree planting 2=water harvesting 3=soil and water conservation 4=irrigation activities 5=Other (specify)	Entry fee	Year joined	Role in group 1=chairman 2=vice chairman 3=treasurer 4=secretary 5=member 6=other	Benefits 1=credit 2=access to market 3=training and education 4=other

Appendix 3: GAMS model

```
*-----------------------------------------------------------------------
* WATER USE EFFICIENCY
*-----------------------------------------------------------------
$ONTEXT
*$OFFLISTING;
*OPTION LIMROW=0;
*OPTION LIMCOL=0;
OPTION LP=CONOPT3;
OPTION NLP=CONOPT3;

$OFFTEXT

*-----------------------------------------------------------------
*DIMENSION DEFINITION
*-----------------------------------------------------------------
SETS  OUTPUT  CROP VALUE /CROPOUT/
    INPUT  CONVENTIONAL INPUTS /PEST,FERT,SEED,LAB,LAND/
    INPUT2  WATER USED /WATER/
    NUMBER   DMUS   /1*201/;

ALIAS (NUMBER,NUM);

*-------------------------------------------------------
*DATA ENTRY
*-----------------------------------------------------------------

$INCLUDE CROP.TXT

$INCLUDE INP.TXT

$INCLUDE WAT.TXT

PARAMETERS
CROPP(OUTPUT)
INPUTP(INPUT)
WATERP (INPUT2)
LAMBDA1(NUMBER,NUM)
PHI1(NUMBER);

*---------------------------------------------------------------------
*MODEL DEFINITION
*-------------------------------------------------------------------
```

```
VARIABLES
      PHI
      LAMBDA (NUM);


POSITIVE VARIABLES LAMBDA ;

EQUATIONS

EQUATION1(OUTPUT)   CROP OUTPUT
EQUATION2(INPUT)    CONVENTIONAL INPUTS
EQUATION3(INPUT2)   WATER USED
EQUATION4  SUM OF LAMDDAS ;

EQUATION1(OUTPUT)..                                                    SUM(NUM,
LAMBDA(NUM)*CROPS(NUM,OUTPUT))=G= CROPP(OUTPUT);
EQUATION2(INPUT)..                                                     SUM(NUM,
LAMBDA(NUM)*IN(NUM,INPUT))=L=INPUTP(INPUT);
EQUATION3(INPUT2)..       SUM(NUM,LAMBDA(NUM)*WA(NUM,INPUT2))=E=
PHI*WATERP(INPUT2);
EQUATION4..SUM(NUM,LAMBDA(NUM))=E=1;

*-----------------------------------------------------------------
*SOLUTION
*-----------------------------------------------------------------

MODEL WATERUSE /ALL/;

LOOP(NUMBER,
CROPP(OUTPUT)=CROPS(NUMBER,OUTPUT);
INPUTP(INPUT)= IN(NUMBER,INPUT);
WATERP(INPUT2)= WA(NUMBER,INPUT2);
*OPTION SOLPRINT=OFF;
SOLVE WATERUSE USING LP MINIMIZING PHI;
LAMBDA1(NUMBER,NUM)= LAMBDA.L(NUM);
PHI1(NUMBER) = PHI.L;


OPTION PHI1:3:0:1;

DISPLAY LAMBDA1,PHI1;
```