Evaluation of Technical and Economic Performance of Smallholder Pumped Irrigation Systems

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other university.

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DEDICATION

I am dedicating this work to my entire family; my father and mother who have been very supportive throughout the entire period and to my sisters and brother who encouraged me to move on despite the many challenges faced.

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ABBREVIATIONS AND ACRONYMS

A	Area (m^2)
AC	(%) available coefficient of water to the crop
ASAL	Arid and Semi Arid Lands
AWSC	Available water storage capacity (mm/m)
BEED	Biomechanical and Environmental Engineering Department
CWR	Crop water requirement (mm/day)
D	Usable soil water stored in the soil (mm)
ET	Evapotranspiration, mm/day
ETa	Actual evapotranspiration, mm/day
ETc	Crop evapotranspiration, mm/day
ETo	Reference crop evapotranspiration, mm/day
Ep	(%) pump working efficiency, %
Epan	pan evaporation, mm
FAO	Food and Agricultural Organization
GOK	Government of Kenya
GPS	global positioning system
h	Field measurements of appropriate crop height, m
HDPE	High density polyethylene
IRn	Net irrigation requirements, mm
JKUAT	Jomo Kenyatta University of Agriculture and Technology
KARI	Kenya Agricultural Research Institute
Kc	crop coefficient,

Kc_{adj}	Adjusted crop coefficient
Kpan	pan coefficient
Ks	Soil coefficient
MDG	Millennium Development Goals
MWI	Ministry of Water and Irrigation
MOSDNKOAL	Ministry of State for the Development of Northern Kenya and other Arid Lands
MSWD	Maximum soil water deficit,mm
NPSHA	Net positive suction head acquired, m
NPSHR	Net positive suction head required,m
NGO	Non governmental organizations
OSEC	Overall seasonal energy cost, Ksh
Pe	Effective rainfall (mm)
PET	Potential evapotranspiration, mm/day
Pm	Average monthly precipitation (mm).
PVC	Polyethylene chloride
Q	Water application rate in m^3/hr or litres/hour
R	Design rainfall (mm)
RAM	Readily available moisture, mm
RD	Crop rooting depth, m
RH_{min}	Mean daily minimum relative humidity, %
SF	Soil water storage factor
STDEV	Standard deviation

SWS	Total soil water storage, mm
TCP	Total production cost (Ksh)
$\mathbf{u_2}$	Wind speed at 2 metres height
V	Velocity (m/s)
Wb	Water stored in the soil which at the beginning of each period, mm
WHO	World Health Organization

ABSTRACT

Pump fed irrigated agriculture has been on the increase particularly in the arid and semi arid regions of Kenya. Smallholder farmers practicing irrigated agriculture apply water to supplement the scarce and unreliable rainfall common in these areas. However, smallholder pumped irrigation systems is faced by many challenges such as lack of appropriate skills during irrigation system selection, design and operation as a result of inadequate technical assistance. Other challenges include lack of appropriate irrigation system components matching farmer's needs, high operation costs, low water use efficiency and labour intensive irrigation activities. The end result of these challenges has been poor smallholder irrigation system performance. It is therefore imperative to investigate the causes of such challenges and offer possible solutions in order to improve pumped irrigation system performance as well as make it more profitable. This research was carried out in semi arid areas of Yatta and Kakuzi divisions which are in Yatta and Thika districts respectively. The research entailed evaluation of the smallholder pumped irrigation systems used in terms of their technical performance, economic viability and the related agricultural water use. The challenges encountered by the smallholder farmers are also documented. Finally an ideal irrigation design system was developed.

The study methodology involved observational study as well as field transect walks to identify the farming systems, irrigation technologies used as well as their adoption rate. Socio - economic surveys using semi structured questionnaires were done covering 80 smallholder farmers. Detailed study was carried out in 10 sample farms where technical performance of pumped irrigation systems was evaluated as well as agricultural water use efficiency. An ideal irrigation design kit suitable for smallholder pumped irrigation system was developed.

The results of the survey found out that there was high uptake of pump fed irrigated agriculture with over 80% of the sampled farmers practicing supplemental irrigation. 94% of the smallholder farmers surveyed were found to use furrow irrigation methods. Only 2% used sprinkler irrigation while none used drip irrigation. Farmers used small motorized pumps to pump water and either conveyed it using pipes or canals for gravity fed systems.

Main challenges facing smallholder pumped irrigated agriculture can be grouped into 5 categories such as lack of information, high cost of running irrigation systems, laxity on the government side, overreliance on traditional irrigation methods and water shortage. The problem of lack of information in market needs for agricultural produce and market prices of the produce, irrigation system component selection, design and operation and amount of water needed for irrigation was noted. High cost of running the irrigation system due to high energy cost (as cited by 65% of the respondents) and high cost of other agricultural inputs was noted. The laxity of the government in providing experienced technical assistance to the farmers particularly during irrigation system component selection, design and operation (as cited by 73% of the respondents), and unregulated water use with only 5% of the studied population having been issued with water permits was noted. 79% of the respondents revealed that there was shortage of irrigation water particularly during the time of high demand of the agricultural produce. Water shortages

could have emanated from use of traditional irrigation methods such as furrow irrigation and lack of modern irrigation techniques at farm level.

Different makes and models of the pumps were being used by farmers in the study area. Small motorized pumps in the range of 4.0 to 6.5 horsepower were being used. An assessment of 10 pumps showed that 60% of them operated below the optimal recommended design efficiency of 60% during irrigation. Analysis of water flow in the pipes indicated that it was within the design flow rate for 40% of the systems evaluated. Head losses for 60% of the pipes assessed exceeded the design limit. The head losses for 9 out of the 10 fittings and accessories used in the 10 irrigation setups operated within the design limit.

The economic analysis of smallholder pumped irrigated agriculture under horticultural crop production is a highly profitable investment. The calculated gross margin analysis showed that on average, 1 hectare of land can result to 1,687,764 Ksh, 236,497 Ksh and 180,892Ksh respectively on season basis for Tomatoes, Water melons and French beans. Tomatoes were found to have the highest net returns per hectare. The benefit cost ratio of the same investment for the three crops considered was greater than one, an indication that the investment is highly profitable and beneficial.

The calculated overall seasonal energy cost showed that on average, over half of the total cost of production resulted from energy use. This was true for the three crops considered and for the two seasons considered.

The water conveyance efficiency was high at 81.42%. Water application efficiency in the ten sample farms under different crops was however low and ranged between 19.5% and 30.0 %.

In the design of an ideal irrigation kit, it was found that pumps with horsepower ranging from 0.7 to 2.26 were suitable for elevations ranging from 0 to15m. Unlike the most widely pumps with horsepower ranging from 4.0 to 6.5, small motorized pumps can offer a great solution in smallholder pumped irrigated agriculture. However, the small motorized pumps were missing from the Kenyan market and this offers an area that can be explored and started.

CHAPTER 1

1.0 : INTRODUCTION

1.1 Background information

The greatest challenge facing the world today is meeting the needs of the food and wood for the ever growing population with an estimated increase of nearly 1 billion people every decade worldwide. This increase in population further causes pressure on available land and water resources (Anderson et al. 1997). This challenge is more predominant in the developing countries. Given that the productivity of irrigated land is nearly three times greater than that of rain-fed land, significant increases in food production will most likely be met by expansion and intensification of irrigation, which currently produces over 40% of the world's food supply and uses approximately 60 to 80% of the world's freshwater supplies (Connor, Schwabe and King, 2008). Connor, Schwabe and King (2008) further stated that the expansion and intensification of irrigated agriculture necessarily means large investments in irrigation infrastructure and, most likely, more water use. Increases in water use by irrigated agriculture for future food production will further stress a system that suffers from water scarcity presently. In addition, recent predictions from climate change models suggest further reductions in freshwater supplies in many of the already water stressed semi-arid and arid regions worldwide. The effects of climate change due to global warming are temperature increases, altered precipitation patterns and changes in the amount of precipitation, all of which will have an impact on the crop water supply-demand relationship. These changes will likely cause increases in crop water use, extension of the growing season and decreases in water availability, depending on changes in the form of precipitation and the timing of precipitation events. If water requirements for agriculture increase, competition for the resource may limit supply (Neilsen et al, 2001).

In Kenya, as in many parts of the sub Saharan Africa, agriculture is the mainstay of the livelihoods of the citizens. The country experiences a variety of climates and is covered by different soils but less than 20 percent of the land area is considered arable under rainfed condition. The remaining 80 percent, classified as arid and semi arid lands (ASALS) experiences water shortages which is a major constraint to agricultural production.

The remaining option in order to supply enough food for the increasing population is to embrace irrigated agriculture. Due the nature of the area, with some areas having higher elevations than others and the need to use groundwater resources, pump fed agriculture takes over from the commonly used gravity fed irrigation systems. Over the years, these modern irrigation technologies have been on an upward trend with the recent introduction of pumps to supply water to the crops, (Ngigi, 1999). The heart of most irrigation systems is a pump. To make an irrigation system as efficient as possible, the pump must be selected to match the requirements of the water source, the water piping system and the irrigation equipment, (Thomas, 1993). Pumps used for irrigation include centrifugal, deep well turbine, submersible and propeller pumps. Actually, turbine, submersible and propeller pumps are special forms of a centrifugal pump.

The introduction of pumps has been met with numerous challenges some of which are pump selection, design and operation. Due to the improper design, several consequences are encountered, for example, public health, waste of natural resources, water pollution, operator safety, economic factors including cost of irrigation, economic return from irrigation and irrigation system life expectancy (Smajstrla, Zazueta and Haman, 1993). The selection and design of an irrigation system is a complex problem to smallholder farmers and requires thorough analysis. Despite their apparent attractiveness in terms of potential productivity, smallholder irrigation systems are, however, not always as efficiently run as they could be. Many farmers/schemes rely on pumping to supply their water needs and are often designed on the basis of minimum investment cost, with little or no thought given to the effect that this might have on operating costs over many years (FAO, 1992). The cost of running the irrigation systems is also on the increase due to high investment and operating costs, especially the increasing cost of fuel (Gay, 1994).

Selection of the most economic method of water application is important in management of irrigation practices. Several methods of water application exist and once the engineering alternatives are isolated, there is the economic problem of determining the least-cost method of applying water (Gay 1994). Water mismanagement resulting to low water use efficiency and ensuing environmental problems such as salinization and water logging leading to declining agricultural productivity has been noted (Ogombe, 2000).

A study was hence commenced to assess the performance of smallholder pumped irrigated agriculture in Kakuzi and Yatta divisions with main emphasis on technical assessment and resulting water use efficiency of these systems. A study tour in the project site identified common methods of irrigation systems used, water pumping devices used and the crops irrigated. A detailed assessment of the performance of these pumped irrigation systems were done in 10 farms. Among the major issues assessed were pumps performance evaluation, energy losses during water conveyance, energy uses, agricultural water use efficiency assessment and economic analysis of pumped irrigated agriculture.

1.2 Problem statement

Smallholder irrigation systems are faced with numerous challenges some of which are technical, economic and environmental in nature. Lack of appropriate skills in irrigation system component selection, design and operation is common in most smallholder systems in Kenya (Kay and Hatcho, 1992). In Kakuzi and Yatta division, majority of the smallholder farmers studied had very little knowledge in irrigation system components selection, design and operation. Technical assistance during irrigation system component selection, design and operation was also missing in the study area. Irrigation components matching farmers needs was also a major concern whereby the available pumps were oversized and not suitable for most terrains.

Rising cost of fuel results to increasing pumping costs and further aggravates the farming system (Gay, 1994). Rising energy prices alters water allocation and distribution. Water extraction and conveyance will become more costly and demand for water pumping will grow as the energy prices continue to rise (Schoengold, Sproul and Zilberman, 2008). Preliminary studies in Kakuzi and Yatta divisions found out that

65% of the smallholder farmers cited energy costs as the most limiting cost in agricultural production.

The agricultural sector is coming under growing pressure to make more efficient use of water. It has been blamed to be the greatest water user and have the lowest water use efficiency and lowest output per unit of water used of all sectors. Especially irrigated agriculture, the greatest water user of all, has been made responsible for inefficient water use and land degradation (Peter and Thomas, 1999). In Kakuzi and Yatta divisions, water use efficiency for irrigation was found to be quite low. This was further aggravated by the diminishing water resources and the increased need for more food due to the increasing population.

1.3 Research objectives

The main objective was assessment of the technical and economic performance of smallholder pumped irrigation systems and development of a suitable ideal irrigation design.

The specific objectives were:

1. To identify and document the smallholder agricultural activities as well as pumped irrigation systems used in Yatta and Kakuzi divisions.
2. To evaluate the technical performance of smallholder pumped irrigation systems in Yatta and Kakuzi divisions.
3. To assess the agricultural water use efficiency of smallholder pumped irrigation systems in Yatta and Kakuzi divisions.
4. To develop a design prototype for smallholder pumped irrigation systems that is appropriate.

1.4. Research Justification

In a bid to ensure increased food production for the ever increasing population, pump fed irrigated agriculture have increased and highly adopted by many smallholder farmers. The result of this high adoption rate is emanating challenges facing the smallholder farmers. Among the challenges facing smallholder farmers have been irrigation system components selection, design and operation, high operating costs of pumped irrigated agriculture and increased competition for water uses due to increased irrigated land and diminishing water resources due to low water use efficiency. Lack of appropriate irrigation equipments was also common. Lack of technical assistance during irrigation system component selection, design and operation was also common and could further be aggravated by the increased number of farmers venturing into irrigated agriculture hence making it impossible for the few trained government personnel to reach them.

It is due to the above findings that a study was commenced to find out the extent to which the above challenges affect smallholder farmers and to find out the possible solutions to the challenges.

1.5 Research limitations

High cost of carrying out the research limited the amount and extent of data collected. The cost of hiring research assistants and compensation for farmers who offered their farms as research sites and irrigation components to be used during the research was unbearable. Other farmers who were interviewed also demanded compensation in order to provide vital information. Inaccessibility of some farms resulted to hiring of motorcycles thus raising transportation cost.

During the interview, some farmers withheld some vital information needed for research thus making it difficult to have a representative discussion of the results. It was also common for some farmers requesting for compensation before agreeing to give out any information that aided in the study.

The large amount of data required per farm led to only 10 sample farms selected and detailed analysis done. Limited test equipments such as tensiometers and Parshall flumes also led to concentration on only 10 farms.

Farmers followed a cropping season and mostly were actively involved in farming when market and prices of the produce was promising. This therefore necessitated data collection only during these seasons. Data for two cropping season was hence collected.

Interferences with some research components set in the farm was common. Tensiometers were left in the farm and the readings taken in the morning. In some cases, they were interfered with thus making the researcher repeat some experiments severally.

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 Irrigation development in Kenya

The land area of Kenya is 582,646 km^2, less than 20 percent of which is classified as medium to high potential land with more than 700 mm of rainfall per year, which is suitable for rain-fed agriculture. The remaining land is classified as arid and semi arid lands (ASALS) and cannot reliably support rain fed agriculture unless other technologies, such as irrigation and water harvesting, are used to augment rainfall for crop production, (Mbatia, 2006).

Table 2.1 shows a tremendous increase in the area under irrigation in the period 1985-2005. This could be attributed to the attention given to this sector by the government and the donors.

Table 2.1. Irrigation development in Kenya (1985 – 2005).

Category	**Developed (ha)**		
	1985	**1998**	**2005**
Smallholder Schemes	17,500	34,650	47,000
National Schemes	11,500	12,000	16,000
Private Irrigation	23,000	40,000	42,800
Total	52,000	87,350	105,800

Source: Republic of Kenya, 2006.

Current estimates indicate that Kenya has a potential for irrigation of 540 000 ha (Republic of Kenya, 2006). About 105 800 ha have been put under irrigation, comprising 20% of the potentially irrigable area. Large commercial farms cultivate

40.5% of irrigated land; government-managed schemes cover 15.1%, while smallholder individual and group schemes take up 44.4% of irrigated land (Republic of Kenya, 2006). Smallholder irrigated agriculture produces the bulk of local horticultural produce consumed in Kenya, as well as some export crops, and a substantial amount of dairy products. In the medium and high rainfall areas, supplementary irrigation based on surface flows has been instrumental in increasing productivity of high-value crops (Herdijk et al 1990 and Mati, 2002).

In Kenya, only 2% of the area is equipped with irrigation infrastructures as compared to the 20% of the potential irrigable land, (Republic of Kenya 2006). The role irrigation can play in agricultural development, by increasing yield, crop quality, development of semi-arid areas and water saving has long been recognized. This is especially so in the development of rural areas in a semi-arid country such as Kenya. Besides, Kenya has a significant export oriented horticulture industry where crop quality is essential. The need for irrigation technologies in agricultural production is hence apparent (Kulecho and Weatherhead, 2006).

2.2 Agricultural activities in Yatta and Kakuzi division

Of the total population in Yatta division, about 17,912 people practice mixed farming and irrigated horticulture representing about 23% while 58,836 (77%) practice mixed farming (livestock, food crops and horticulture). Mixed farming including irrigated horticulture is practiced in Matuu and Kithimani which are in Yatta division whereas in other areas such as Katangi, Livestock/food crops/horticulture is practiced (Isabella, Daniel and James, 2005).

In Kakuzi division of Thika district, horticultural crops, cash crops and even subsistence farming is practiced. In areas near water bodies, farmers rely heavily in irrigated agriculture. In the recent years, the flower industry has penetrated in the division and the climatic condition favors its spread (Republic of Kenya, 2003).

2.3 Food security trends in Yatta and Kakuzi division

Isabella, Daniel and James, (2005) studied the food situation in Yatta division and noted that in the mixed farming zone i.e. livestock/food crops livelihood zone which has over 50% of the district population/horticulture has suffered cumulative poor crop harvest for the last two seasons (long rains 2004 and short rains 2004, the main season) attributed to poor rainfall. This scenario has further been compounded by below normal expected production in the current long rains. These experiences have resulted to most households depleting most of their disposable resources, consequently rendering them more vulnerable to food insecurity. The prospects for an improved food security in the near future appear gloomy, considering that the next rains are expected in October/ November and any harvest will be in February/March, 2006. People in these areas were therefore in dire need of food assistance aimed at increasing resilience to shocks.

The food security situation in the livestock/food crops livelihood zones is below normal. The estimated total number of people in need of food assistance will increase from the current 25,000 to 35, 000 people from four divisions: Katangi, Masinga, Yathui and Yatta divisions. Further studies conducted in 2005 found out that some parts of livestock/food crops zones in Yatta and Ndithini experienced near total crop failure (maize, Millet, beans and cowpeas).

Further study identified that the food situation in Yatta and Katangi division was expected to deteriorate as households had no food stocks from previous harvest and over 90-100% of crop failure was expected (Isabella, Daniel and James, 2005).

In Kakuzi division, irrigated agriculture has been instrumental in playing a key role in food production in the division. Smallholder farmers near the water sources produce enough food which they sell to the nearby farmers further away from reliable water sources. Horticultural crops for local and export market plays a significant role in poverty alleviation and improved living standards of the residents in the division. In areas where irrigated agriculture has not been prioritized due to lack of reliable water sources, farmers have been faced with severe food shortages during the low rainfall periods (Irrigation and Drainage Department (IDD), 2006).

2.4 Water resources in Yatta and Kakuzi division

During the 2009 drought, the water situation in Yatta district worsened while the dry sand river wells deepened the water yield in boreholes significantly dropped. In the marginal mixed farming livelihood zone, the main sources of water were boreholes and traditional river wells. In the mixed farming livelihood zone, the main sources of water were traditional river wells, boreholes and shallow wells. The 2009 drought consequently led to early closer of schools due to water shortages in most parts of the livelihood zone. In some boreholes, the recharge rates declined while salinity levels rose (MOSDNKOAL, 2009).

Several permanent and seasonal rivers such as river Thika, Kabuku and Samuru passes through Thika district. A number of springs have been developed and even in some areas, boreholes have been dug in order to meet the water demand of the residents in the area. Farmers (large scale and smallholder) rely on these water sources for their agricultural activities and particularly during the dry spells, irrigated agriculture dominates the area (Republic of Kenya, 2003).

2.5 Challenges facing smallholder farmers practicing irrigated agriculture in Kenya

The major constraints facing smallholder irrigation in Kenya include shortage of water as well as market availability, instability and unpredictability, both locally and abroad. In addition, farmers are frustrated by middlemen who swindle them or offer very poor prices, even when consumer prices are good (Mati and Penning, 2005 and Kulecho and Weatherhead, 2006). With over 80% of the smallholder irrigation schemes in Kenya being furrow-based, irrigation efficiency is very low hence the need for water saving techniques in the ASAL regions (Kibe et al, 2006). Modern irrigation technologies such as use of drip irrigation were apparently missing in the study area. It has been reported that drip irrigation enhances water use efficiency at farm level and reduces waterlogging and improves soil structure unlike furrow irrigation methods which is widely used in the study area (Hodgson, 1990, Kibe et al, 2006).

Other challenges facing the smallholder farmers are poorly developed facilities for post-harvest processing and handling. There is lack of a national irrigation policy, while inadequate investments have led to poor development of irrigation infrastructure and water storage facilities (Irrigation and Drainage Department, 2006). There is also inadequate technical capacity affecting farmers' organization and participation (Mati, 2008).

Poor selection and design of smallholder irrigation systems is another challenge affecting their performance (Kay and Hatcho, 1992, FAO, 1992). Past studies showed that the results of poor irrigation components selection and lack of engineering approach in design resulted to poor system performance and reduced irrigation system lifespan (Gay, 1994). Seckler (1998) demonstrated on several ways of reducing the high cost of irrigation such as embracing the agronomic, engineering and management techniques. Smallholder irrigation systems are often designed on the basis of minimum investment cost, with little or no thought given to the effect that this might have on operating costs over many years. They are not always as efficiently run as they could be (FAO, 1992). During the purchase of the irrigation equipments, farmers often buy cheap equipments resulting to less money during purchase but much higher costs incurred during the running and operation of the system through maintenance and energy use. An equally important issue to consider is how well the irrigation system is managed once it is operating. The most appropriate system design and selection will be of little use in the hands of an inexperienced or unskilled irrigator. Good equipment is no substitute for good management and, here too, considerable savings in energy and operating costs can be made by ensuring good equipment and water management practices (FAO, 1992). Other challenges facing smallholder irrigation schemes in

Kenya is declining agricultural productivity as well as rising in environmental problems and poor water management (Ogombe, 2000).

2.6 Pumping technologies used in smallholder irrigated agriculture

Several pumps used by smallholder farmers exist in the market. They are classified according to principles of operation and FAO (2001) classifies them into those using kinetic principles i.e. centrifugal force or momentum in transferring energy and the positive displacement pumps, whereby the fluid is displaced by mechanical devices such as pistons, plungers and screws. Mono pumps, treadle pumps and most of the manual pumps fall into this category.

The second classification (Allahwerdi, 1986; Longenbaugh and Duke, 1980) puts the first category of pumps as turbo pumps and depending on the type of discharge, they subdivides these pumps into Radial flow pumps (centrifugal action), Axial flow pumps (propeller- type action), Mixed flow pumps (variation of both) and Positive displacement pumps.

Pump performance characteristics is a factor that should be considered during pump selection. Capacity, head, power, efficiency, required net positive suction head, and specific speed are parameters that describe a pump performance (Robert, Sneed and Cassel, 1996).

Several factors should be considered during pump selection. The pump discharge as well as the operating head should be checked first. The selection of pumps requires the use of manufacturers' pump curves. As a first step, by looking at the various pump curves we can identify a pump that can provide the discharge and head required at the highest possible efficiency. Following the identification of the pump, the NPSHR-Q curve is checked and evaluations are made to ensure that its NPSHA is higher than the NPSHR. When the required discharge and head combination falls outside the performance curve or when it falls at the fringes of the performance curve, that type of pump should not be selected. Another important consideration in selecting a pump is the size of the pump impeller. If the required discharge and head combination falls between two impeller sizes, then the larger impeller will have to be used, but only after it is trimmed down by the manufacturers so that it matches the requested discharge and head (Michael, 1983).

2.7 Hydraulics of water flow in uPVC pipes

2.7.1 Introduction

The increased need to deliver water from one point to another have led to the introduction of different water piping materials. For over 60 years, high value thermoplastic pipes such as polyvinyl chloride (PVC-U) and polyethylene pipes have been used. Their properties and design criteria are well understood (Osry, 2000).

uPVC pressure pipes have been in use at least since the early 1950's. Correctly processed, the material with its high modulus and excellent retention of long-term strength, has proven itself the most successful plastic pressure pipe worldwide, (SANS 1283, 2001). Only in recent years with the development of HDPE in grades PE80 and PE100, and the attacks on chlorine and PVC in certain countries, has the growth rate slowed in comparison with that of HDPE (Hackwell, 2001, Denning, 1998). Unfortunately, failures of uPVC pressure pipes manufactured in the 1960/70's in the

UK led to setbacks for the product which are apparently being experienced to this day. By most accounts, the major cause of these pipeline failures was extrusion processing problems associated with pipeline installation and operational conditions (Stokes, 1998). It is to the credit of the industry in that country and elsewhere, that the extensive work undertaken affected solutions to these problems. Hitch, Benjamin, Marshall and others were at the forefront of these developments (Gotham and Hitch, 1978, Benjamin, 1980, Marshall, 1982, Holloway and Naaktgeboren, 1991). This led not only to a realisation of the importance of processing and gellation with respect to slow crack growth, fracture toughness and stress concentration effects but also to procedures for controlling the properties and quality of uPVC pipes. These involved improvements to the polymer, a better understanding of formulations, a closer involvement of extruder manufacturers and improvements in processing, as well as pipe testing and quality control procedures. A positive outcome to the improvements in the quality of uPVC pipes was a decrease in the factor of safety from 2.5 to 2.0, accepted by most countries in Europe and elsewhere (ISO 4422-2, 1996, SANS 966-Part 1, 2000). Nevertheless, the properties of uPVC remain essentially the same, hence the requirement for the relatively high safety factor.

2.7.2 Pipe selection criteria

Different manufacturers have classified uPVC pipes in different sizes and classes with the most common being classes A, B,C,D and E (Davis and Shirtlif, 2011) and classes 1,2,3,4,5 and 6 as classified by (Jain ,2009). These classifications depend on pressure requirements for the uPVC pipes. Different sizes of pipes exist and are classified according to the norminal and outer diameters. uPVC pipes have a fixed length with the most common one being 6m.

Different design stresses govern the operation of uPVC pipes as outlined by manufacturers with allowable design stress varying depending on temperature of the fluid conveyed (Jain, 2009). The flow velocity of different sizes and classes of uPVC pipes as governed by equation 2.1 and varies for different pipe types and sizes. The equation governs the operation range of the pipes which should always not exceeded. (Davis and Shirtliff, 2011).

$$V = \frac{Q}{A} \qquad 2.1.$$

where V – flow velocity in the pipe (m/s), Q – Pipe discharge rate (m^3/s or litres/s)

A- Cross section area of the pipe (m).

uPVC pipes headlosses should also be within the optimal range and are normally calculated from equation 2.2. Different manufacturers have come up with different criteria for computing the pipe headlosses (Davis and Shirtliff, 2011, Jain, 2009).

$$h_L = \frac{\Delta P}{\ell g} \qquad 2.2$$

where h_L – pipe head loss (m), ΔP – change in pressure for a specified pipe length, ρ- Specific weight of water, g – Acceleration due to gravity (m^2/s).

2.8 Economic analysis of smallholder pumped irrigated agriculture

2.8.1. Gross margin analysis of irrigated agriculture

The process of analysing a farm business has been traditionally divided into two parts general analysis based primarily upon financial accounts and other appropriate records and a more detailed analysis of the individual enterprises on the farm in the form of gross margins for each enterprise (MAFF, 1980). In recent years, with the increasing economic pressure on agriculture, there has been a greater use of cost accounting techniques which result in net margin or profit per enterprise.

A gross margin for an enterprise is its financial output (total income) minus its variable costs. The use of gross margins became widespread in the UK from about 1960, when it was first popularized amongst farm management advisers for analysis and planning purposes (Barnard and Nix, 1979). The gross margin per hectare or per head for crops and livestock can be compared with 'standards' (published averages of what might be typically possible in average conditions) obtained from other farms. Gross margins, however, should only be compared with figures from farms with similar characteristics and production systems. With this reservation in mind, the comparisons can give a useful indication of the production and economic efficiency of an enterprise (Barnard and Nix, 1979).

2.8.2 Benefit cost ratio analysis

Benefit cost analysis is an evaluation and decision making tool which uses set of procedures to define, compare and analyse cost and benefits of any intervention. It is a set of procedures which define and compare costs and benefits. It is also termed as Cost benefit analysis (CBA). There are 3 types of CBA which are Ex ante CBA, Ex post CBA and in medias res and Ex Ante/Ex Post. Ex ante CBA is done before any project or intervention, which assists in the decision about any program, policy, project or regulation. Ex post analysis is done at the end of the project to measure its effectiveness in terms of cost and benefit, which helps in learning actual value of the specific project and its use in further intervention in similar type of projects. In medias res analysis is conducted during the project lifetime (Boardman et al, 1996).

There are different ways of doing financial analysis via BCA including Net Present Value, benefit cost ratio, internal rate of return and the payback period. The formulae of NPV, BCRn, BCRd and payback period are taken from (Zerby and Dively, 1994).

Benefit Cost Ratio (BCR) provides relationship between the cost and benefits of a project which helps in deciding whether the project is a good investment or not. There are 3 kinds of BCR. The undiscounted BCR (equation 2.3) is a ratio of total benefit and the total cost of the project, without using any discounting rate and is not widely used method.

$$BCR_u = \sum_{t=0}^{n} \frac{B_t}{C_t} \qquad 2.3.$$

Discounted BCR (equation 2.4) is the ratio of the total benefit and the total cost using discount rate and is widely applied in the project decision making process.

$$BCR_d = \frac{\sum_{t=0}^{n} \frac{B_t}{(1+r_t)}}{\sum_{t=0}^{n} \frac{C_t}{(1+r_t)}} \qquad 2.4.$$

The net BCR (equation 2.5) is a ratio of the discounted net benefits and costs expressed in percentage, which is calculated as:

$$BCR_d = \frac{NPV}{\sum_{t=0}^{n} \frac{C_t}{(1+r_t)^t}} * 100\% \qquad 2.5$$

The net BCR shows the increased percentage in real wealth generated by the project. Any project with the BCR greater than one is beneficial and accepted (Boardman et al. 1996, Zerby and Dively 1994).

2.8.3. Energy uses for agriculture

Rising energy prices will alter water allocation and distribution. Water extraction and conveyance will become more costly and demand for water pumping will grow as the prices of fuel continue to rise (Schoengold, Sproul and Zilberman, 2008). Past studies done by Amin, Abbas and Komeil (2010) showed that almost half of the total cost of production of Soya beans resulted from energy use. Nowadays, agricultural sector for providing more food needed by the population increase like other sectors has depended on energy sources like electricity and fossil fuels (Hatirli, Ozkan and Fert, 2005). Energy has been a key input of agriculture since the age of subsistence agriculture. It is an established fact worldwide that agricultural production is positively correlated with energy input (Singh, 1999). Agriculture is both a producer and consumer of energy. It uses large quantities of locally available non-commercial energy, such as seed, manure and animate energy, as well as commercial energies, directly and indirectly, in the form of diesel or petrol, electricity, fertilizer, plant protection, chemical, irrigation water, machinery etc. Efficient use of these energies helps to achieve increased production and productivity and contributes to the profitability and competitiveness of agriculture sustainability in rural living (Singh, Mishra and Nahar, 2002). Energy use in agriculture has been increasing in response to increasing population, limited supply of arable land and a desire for higher standards of living (Kizilaslan, 2009). However, more intensive energy use has brought some important human health and environment problems so efficient use of inputs has become important in terms of sustainable agricultural production (Yilmaz, Akcaoz and Ozkan, 2005). Recently, environmental problems resulting from energy production, conversion and utilization increased public awareness in all sectors of the public, industry and government in both developed and developing countries. It is predicted that fossil fuels will be the primary source of energy for the next several decades (Demirbas, 2003, Dincer, 2001). Efficient use of resources is one of the major assets of eco-efficient and sustainable production in agriculture (De Jonge, 2004). Energy use is one of the key indicators for developing more sustainable agricultural practices (Streimikiene, Klevas and Bubeliene, 2007) and efficient use of energy is one of the principal requirements of sustainable agriculture (Kizilaslan, 2009). It is important, therefore, to analyze cropping systems in energy terms and to evaluate alternative solutions (Sartori et al, 2005). Agriculture, a typically resilient sector, has been hard hit disproportionately by the recent energy price increases due to energy's relatively high share of costs and the inability of the farmers to pass along these costs. Energy use, previously thought of as a fixed cost, is now beginning to be viewed as a controllable cost through demand – side energy efficiency and onsite and renewable energy production. Energy efficiency is the streamlining of energy use and cost while maximizing productivity (Sartori et al, 2005). Energy cost is the cost of providing fuel to the irrigation system. In some cases, it can be the most important of the operating costs, and needs to be considered most carefully at the design stage (FAO, 1992). The cost of fuel can be determined from the local market rate. The energy cost is calculated from the seasonal energy demand (FAO, 1992).

In evaluating the energy cost of irrigation the overall seasonal energy cost is normally calculated from the seasonal energy demand, the fuel consumption of the pump, and the cost of fuel based on equation 2.6.

$$OSEC\,(Ksh) = OSED(Kwh) * F_U C(L / Kwh) * CF\,(Ksh) \qquad 2.6$$

where OSEC – Overall seasonal Energy cost (Ksh), OSED – Overall Seasonal energy demand, F_UC – Fuel consumption, CF – Cost of fuel. OSED is computed from equation 2.7.

$$OSED\,(Kwh) = \frac{Q * H}{367 * PPE} \qquad 2.7$$

where Q - volume of water (m^3) pumped, H – Total dynamic Head (m), PPE - pumping plant efficiency (computed from equation 2.8).

$$PPE\,(\%) = FE * PUE * TE * PE * 100 \qquad 2.8$$

where FE – Fuel efficiency, PUE–Pump unit efficiency, TE- Transmission efficiency, PE – Pump efficiency.

According to FAO, 1992, centrifugal pumps have values for fuel efficiency varying from 90 -100% while the power unit efficiency for petrol pumps is 10% and for diesel engines it is 15-35 %. Evaluation of fuel consumption is based on 0.09L/Kwh for diesel and 0.11 L/Kwh for petrol (FAO, 1992).

Transmission efficiency for most centrifugal pumps is usually 100% due to direct coupling with the engine.

Pump efficiency is normally between 40-80% for a pump running at optimum head and speed. Many pumps are not run at optimum head and speed, and so their efficiencies could be much lower. This is particularly true for small pumps where the frictional losses are a higher proportion to the total power requirement (FAO, 1992).

2.9 Water use efficiency for irrigated agriculture

2.9.1. Introduction

Water scarcity is specific, relative to region, location and season. The criterion for water scarcity is that countries with freshwater resources in the range of 1,000 to1, 600 m^3 per capita per year face water stress, with major problems occurring in drought years. When annual internal renewable water resources are less than 1,000 m^3 per person annually, countries are considered water scarce. Below this threshold, water availability becomes a severe constraint on socioeconomic development and environmental quality (Kamel, Theib and Mohammad, 2003).

Currently, 28 countries worldwide, with a total population of 338 million, are considered water-stressed, and 20 of these countries are water scarce. Water shortages will increase dramatically in the next 25 years. By the year 2025, it is projected that 46 to 52 countries, with an aggregate population of about 3 billion, will be water-stressed (Rosegrant, Cai and Cline, 2002).

Agriculture is the largest user of water, accounting for more than 70 percent of water withdrawals worldwide and more than 90 per cent of water withdrawals in low-income developing countries. In middle-income and high-income countries, agriculture accounts for 69 per cent and 39 per cent of water withdrawals respectively. Irrigation projects focused on expanding irrigated area without taking into account the associated rise in water table and salinity. Lack of demand management practices also contributed to a low efficiency of water-use and consequent waste. In addition, improvement in the availability of water-use due to the introduction of advanced technology diverted attention from demand management and reduced emphasis on low-cost alternatives, such as improving efficiency, conservation and reduction of waste through maintenance of the irrigation infrastructure. New strategies for water development and management are urgently needed to avert the severe national, regional and local water scarcities that will depress agricultural production and other end-users (Kamel, Theib and Mohammad, 2003).

Water resource management throughout the world will be one of the most important economic and social issues of the coming century. Water allocation, water quality, growing and changing social demands for water, new technologies, water-use efficiency, economic feasibility and benefit/cost measurement are issues of great concern to research institutions and decision-makers at various levels. Due to the high water demand by the agricultural sector worldwide, improving on-farm water-use efficiency can contribute directly to an increased supply of water for agriculture and other end-users. When the efficiency of irrigation is low, a significant portion of water leaves the field through runoff and deep percolation. Low irrigation efficiency normally is associated with poor timing and a lack of uniformity in water applications, leaving parts of the field over- or under-irrigated relative to crop needs. Improving the efficiency of irrigation requires a better matching of water application to crop needs, in terms of both timing and quantity, thus crops will consume applied water more effectively, yields will be increased, and the amount of water that the irrigator must divert and deliver to the farm will be reduced (Serageldin, 1998).

It has been found that the growth in world requirements for the development of additional water supplies varies between 25 and 75 per cent. Thus, increasing irrigation efficiency would reduce the need for the development of additional water supplies for all sectors in 2025 by roughly one-half (Seckler and Young, 1985).

In most of the major irrigating countries, however, operators of irrigation systems do not have an incentive to supply farmers with a timely and reliable delivery of water that would be optimal for on-farm water-use efficiency and use of other inputs (Serageldin, 1998). Farmers, on their part, generally tend to over-irrigate as a result of their own perceptions of water requirements and their expectations of rainfall and market values. Most of the evidence available in the region on water-use efficiency is mainly based on experimental trials in mono-crop systems, which do not precisely reflect the complex production decisions at the farm level under different environmental, technological and economic conditions.

Given the constraints on new water supplies, Governments must be persuaded to give far greater emphasis to demand management. Demand management covers both direct measures to control water-use, such as regulation and technology, and indirect measures that affect voluntary behavior, such as market mechanism, financial incentives and public education. The mix of demand management measures will vary, but in all cases they aim to conserve water through the increased efficiency and perhaps equity of water use (World Bank, 1994). Direct measures to control water-use are difficult to administer, although rationing can be effective in responding to variability; and regulation of water quality, even if seldom successful, is a universal objective. Technical interventions are important in all sectors to reduce unaccounted-for water losses. Modernization of both distribution and on-farm systems has particular potential. Indirect measures notably include water charges and other financial instruments (ESCWA, 1994).

Studies done to evaluate irrigation efficiencies for surface irrigation systems range from 50% and below but water application efficiencies in the range of 85-95% are achievable in all types of irrigation systems (Ahmad, 1996). This can be achieved through the application of more advanced irrigation management practices, involving in-field evaluation and optimization of the flow rate and irrigation time to suit the individual soil conditions and furrow characteristics (Smith, Raine and Minkovovich, 2005). Substantial reductions in deep drainage are possible by ensuring that irrigation applications do not exceed the soil moisture deficit.

2.9.2 Irrigation efficiency

The amount of water needed during a growing season depends on the crop, yield goal, soil, temperature, solar radiation, and other bio-physical factors. In general, long-season crops require more water than short-season crops. Some crops benefit from irrigation during the entire season, while others are more sensitive during specific growing periods.

In general, the irrigation water requirements is determined using tools like FAO's CropWat or ClimWat, or software provided by many others. The overall approach is however based on the so-called FAO56 approach (Allen et al, 1998). However, with the advantage of satellites more and more location specific information is being used to assess water balances including, ETpot, ETact and ETshort. In this study, the following equations were used in evaluation of the net irrigation requirement from the field balance equation as provided by FAO (2002) as shown in equation 2.9.

$$IR_n = ETC - (Pe - Ge + Wb) + LR \qquad 2.9$$

where: IRn = Net irrigation requirement (mm), ETc = Crop evapotranspiration (mm), Pe = Effective dependable rainfall (mm), Ge = Groundwater contribution from water table (mm), Wb = Water stored in the soil at the beginning of each period (mm), LR = Leaching requirement (mm). The variables are each evaluated separately from the field condition and from equation 2.9, the net irrigation requirement for different crops is evaluated.

Evapotranspiration (ETc) has been long recognized as the most important process that plays an essential role in determining exchanges of energy and mass between the hydrosphere, atmosphere and biosphere. In agriculture, it is a major consumptive use of irrigation water and precipitation on agricultural land. Any attempt to improve water use efficiency must be based on reliable estimates of ET, which includes water evaporation from land and water surfaces and transpiration by vegetation. ET varies regionally and seasonally according to weather and wind conditions (Hanson, 1991). Understanding these variations in ET is essential for managers responsible for planning and management of water resources especially in arid and semi-arid regions of the world where crop water demand generally exceeds precipitation and requires irrigation from surface and/or groundwater resources to meet the deficit.

At field scale, numerous methods of estimating ET are available such as conventional techniques, Bowen ratio (BR), eddy covariance (EC) and lysimeter systems (Prasanna et al., 2007). Other methods of estimating ET include FAO method which was used in this study as shown in equation 2.10 (FAO, 2002).

$$ETc = ETo * Kc_{adj} \tag{2.10}$$

where ETo is reference crop evapotranspiration as expressed by James 1988 as shown in equation 2.11.

$$ETo = Kpan * Epan \tag{2.11}$$

The values of Kc_{adj} (adjusted value for crop coefficient) was computed from equation 2.12 as recommended by FAO 2002. The Kc values are adjusted to suite the extremes of understorey management, irrigation method, humidity and wind speed, length of growth periods, stress levels (water and salinity), stomatal control and canopy cover.

$$Kc_{adj} = Kc(table) + \left(0.04\left(U_2 - 2\right) - 0.004(RH\min - 45)\right) * \left(\frac{h}{3}\right)^{0.3} \tag{2.12}$$

The pan coefficient (Kpan) is normally available for different evaporation pans used and obtained from the meteorological stations while pan evaporation (Epan) is read from the evaporation pan (FAO, 2002). The used values for $Kc_{(table)}$ for this study for the crops considered were read from the table provided by FAO 2002 as shown in table 2.2.

2.2 Kc values at different crop growth stage and maximum crop height.

Crop	$Kc_{initial}$	Kc_{mid}	Kc_{end}	Maximum crop height
French beans	0.5	1.05	0.9	0.4
Water melon	0.4	1	0.75	0.4
Tomatoes	0.6	1.15	0.7-0.9	0.6
Baby corn	0.3	1.15	1.05	1.5

Source: FAO, 2002.

In this study the values of mean wind speed at 2m high (U_2) and mean daily minimum relative humidity (RH_{min}) were obtained from the nearest meteorological station. The height of the crops considered in the field were measured during their growth period.

The effective rainfall which is the actual amount of water used by crops during their crop growth phase is normally computed using different techniques as described by (FAO, 1992 and USDA, 1970). In this study, the USDA method as described in equation 2.13 was used to evaluate the effective rainfall.

$$Pe = SF * \left[0.70917 \left(P_m / 25.4 \right)^{0.82416} - 0.11556 \right] * 10^{0.000955ETC} \qquad 2.13$$

Where the soil water storage factor (SF) was calculated from equation 2.14. The average monthly precipitation (Pm) in mm can be measured directly in the field or data from the meteorological station used.

$$SF = 0.5317 + 0.295164 \left(\frac{D}{25.4} \right) - 0.057697 \left(D/25.4 \right)^2 + 0.003804 \left(D/25.4 \right)^3 \qquad 2.14$$

Where D is the maximum water deficit calculated from equation 2.15.

$$D = MSWD = SWS\,(mm) * AC\,(\%). \qquad 2.15$$

The soil water stored (SWS) is calculated from equation 2.16.

$$SWS = RD(m) * AWSC(mm/m) \quad 2.16$$

where RD is the crop rooting depth measured at different crop growth period. The available water storage capacity of the soil (AWSC) which can be evaluated in the laboratory by measuring the soil pF is normally evaluated by subtracting measured values of field capacity from permanent wilting point as described by (Brower et al, 1985 and Werner, 1993). The availability coefficient (AC (%)) of water for different crops is shown in Table 2.3.

Table 2.3. Availability coefficient of water for different crops.

Availability Coefficients (AC, %)	
Crop	**Maximum Percent (%)**
Peas	35
Potatoes	35
Tree Fruits	40
Grapes	40
Tomatoes	40
Other crops	50

Source; Ministry of agriculture, British Columbia, 2002.

By subtracting the net irrigation requirement from the amount of water applied during irrigation, the water application loss can be found as described by Michael 1983.

Water application and conveyance efficiency as described by Michael in 1983 can be calculated from equation 2.17 and 2.18.

$$E_a = {W_s}/{W_f} * 100 \quad 2.17$$

Where E_a = water application efficiency (%), Ws = water stored in the root zone of the plants, Wf = water delivered to the field (at the field supply channel).

$$E_c(\%) = {Q_2}/{Q_1} * 100 \quad 2.18$$

Where E_c = water conveyance efficiency (%), Q_2= water delivered to the irrigated plot (at the field supply channel), Q_1 = water diverted from the source.

Seepage losses in the canals can be estimated using the inflow-outflow method as described by (Tyagi et al, 2005) as shown in equation 2.19.

$$S = Q_1 + R - Q_2 - Q_f - U \qquad 2.19$$

Where S: Seepage, Q_1: Inflow rate (m^3), R: Rain (m^3), Q_2: Outflow rate (m^3), Q_F: Flow rate that enter to the reach (m^3) from external sources such as runoff, U: flow rate diverted from the reach (m^3), E: daily evaporation (m^3).

2.10 Design of an irrigation system

Irrigational development requires careful design, construction and management to be successful. In small scale irrigation, farmers alone decide when to irrigate and how much water to apply; start and stop the pumps; and generally run the whole scheme with the help of the family or local community (FAO, 1992).

In the design of an irrigation system, a preliminary design is usually done first and is normally done quickly to establish the options available. Once a choice has been made, work proceeds to a detailed design which details every nut and bolt to be purchased and every canal and structure to be constructed (FAO, 1992).

To undertake preliminary design, basic information is needed about the land and crops to be irrigated. However, accurate details about land areas and crops may not be necessary at this stage. The aim of preliminary design is hence to determine the maximum capacity or size of the system to be constructed and the choices available to the farmer. The system capacity must be enough to satisfy the maximum amount of water needed by the crops. The cost of an irrigation system is also a factor of consideration whereby several options are evaluated to arrive at the most feasible design (FAO, 1992). Sprinkler irrigation method, which is one of the pressurized irrigation system, takes water from the source and sprays it to the atmosphere as droplets by means of an enclosed system and under pressure. The water is transmitted to the surface of the soil in equal distribution with the Sprinkler irrigation system to obtain uniform distribution in the crop root zone (Keller and Bliesner, 1990). The spacing and the discharge rate of the sprinkler determine the application rate which should be less than infiltration rate for not producing surface runoff. The degree of uniformity of water distribution depends on the water distribution styles and features of the sprinkler nozzles. The basic function of sprinkler nozzles is to distribute water uniformly, without causing surface flow and excessive drainage from the root zone. For this reason, the sprinkler nozzle is considered to be the most important element of the system. The performance of the sprinkler nozzle determines the productivity and efficiency of the whole system (Keller and Bliesner, 1990; Wilson and Zoldoske, 1997). A successful irrigation regime can be determined by researching all the element factors and then effectively using the data produced. The performance of a sprinkler irrigation system is often evaluated based on water uniformity coefficients collected in an array of measuring devices (i. e., rain-gauge) (Topak et a., 2005).

In sprinkler irrigation system design, the distribution uniformity should be carefully evaluated based on several equations and Christiansen’s uniformity coefficient seems to be the most popular uniformity coefficient used by researchers on the global scale (Keller and Bliesner, 1990; Allen 1993) and is stated below in equations 2.20 and 2.21;

$$CU = 100 * \left(1.0 - \frac{\sum X}{n.m}\right) \qquad 2.20$$

or $$CU = 100 * \left(1.0 - \frac{\sum |Z - M|}{\sum Z}\right) \qquad 2.21$$

where *CU*– coefficient of uniformity (%), Z- amount of water measured in each container while testing uniformity (mm, ml), x= │Z-m│= total absolute value of deviations from average of the amount of water measured in all the accumulation containers (mm, ml), m=(∑ z)/n = Average amount of water (mm, ml), n= the number of water accumulation containers.

A CU of 84% is considered desirable (Keller and Bliesner, 1990) but when it is more than 70% the approximation depths from a rain gauge evaluation tends to follow a normal distribution (Merkley, 2001).

FAO, 1992 described the process of determining the sprinkler irrigation capacity following the equations described below.

The water application rate of the sprinklers which is evaluated from equation 2.22 shows the rate at which a sprinkler discharges water. FAO (1992) also demonstrated on a method of evaluating the number of hours of irrigation per week using sprinkler irrigation system as illustrated in equation 2.22.

$$Water\ application\ rate = \frac{Nozzle\ discharge\ rate}{Area\ covered\ by\ one\ sprinkler} \qquad 2.22$$

The number of hours of irrigation per week is computed from equation 2.23.

$$I_{hrs} = I.I * C.W.R * \frac{100}{I_E} * \frac{1}{W.A.R} \qquad 2.23$$

Where I.I – Irrigation interval, I_{hrs} - Number of hours of irrigation per week, C.W.R – Crop water requirement, I_E – Irrigation efficiency and W.A.R – Water application rate. The amount of water (Scheme water requirement) which is evaluated from equation 2.24 also is an indication of the water that should be supplied in a certain command area for a given day, (FAO,1992).

$$S.W.R = C.W.R * 0.115 * \frac{24}{H_{day}} * \frac{7}{I_{day}} * \frac{100}{I_E} * A \qquad 2.24$$

where S.W.R is the Scheme water requirement, C.W.R – Crop water requirement,

I_E – Irrigation efficiency, H_{day} – Hours of irrigation per day and I_{day} – Days of irrigation. Water application rate for one block computed from equation 2.25 and the number of sprinkler required as described in equation 2.26 also are used in sprinkler irrigation system design.

$$Application\ rate\ for\ one\ block = I_{hrs} * W.A.R \qquad 2.25$$

where I_{hrs} - Number of hours of irrigation per week and W.A.R – Water application rate.

Number of sprinklers required is normally computed from equation 2.26.

$$n = \frac{A_{daily}}{A_s} \qquad 2.26$$

where n – number of sprinklers required, A_{daily} – Area irrigated daily,

A_s – Area irrigated by one sprinkler.

In the design of any irrigation system, the heart of most irrigation systems is a pump (Kay and Hatcho, 1992) and proper selection, use and maintenance of the pump guarantees its prolonged lifespan (Seckler,1998). The required capacity of the pump as calculated from equation 2.27 (FAO, 1992) should also be evaluated to ensure that it matches with sprinkler irrigation capacity.

i) $Q_{total} = n * q$ 2.27

where Q_{total} – Pump discharge rate, n - number of sprinklers required, q- Sprinkler discharge rate.

CHAPTER 3

3.0 METHODOLOGY

3.1 Introduction

This chapter deals with the description of the study area, sampling method adopted, method of survey, detailed data collection and nature and source of data and techniques used in data analysis.

To evaluate the technical, economic and agricultural water usage related with smallholder pumped irrigated agriculture, detailed surveys, field visits and field tests were carried out in Kakuzi and Yatta divisions. The tests included pump performance evaluation, irrigation water use efficiency as well as economic assessment of irrigated agriculture. Weather data for the year 2009 which aided in computation of water losses during irrigation was obtained from the nearby weather stations. A summary of the activities related to each of the specific objectives is given in Table 3.1.

Table 3.1. Specific objectives and the corresponding research activities.

Objective	Supporting research activity
To identify occurrence of smallholder pumped irrigated agriculture	Field transect walks/ observational studies were done to identify the irrigation systems used by the farmers.
Detailed assessment of the Technical and Economic performance of the pumped irrigation systems	10 sample farms were randomly selected and tests to evaluate the pump working efficiency, energy uses and losses during irrigation were carried out. Economic analysis including the gross margin analysis and benefit-cost ratio on horticultural crops grown by farmers practicing pumped irrigation was done as well as evaluation of the overall seasonal energy costs.
To assess the agricultural water use for smallholder pumped irrigation systems.	Water losses during conveyance and application were assessed in detail.
To develop an irrigation design prototype for smallholder farmers practicing pump fed system.	An ideal irrigation system was developed for 1 acre of land under different elevations for three different irrigation methods (sprinkler, closed (drag hose) and open pipe systems).

3.2 Description of the study area

The field experiments as well as field survey was conducted in two different areas as shown in figure 3.1. 80 smallholder farmers (50 in Kakuzi division and 30 in Yatta division) were interviewed through semi structured questionnaire and 10 sample farms were randomly selected where detailed experimental study was conducted. The geographical conditions of the two sites where the study was conducted are shown in table 3.2.

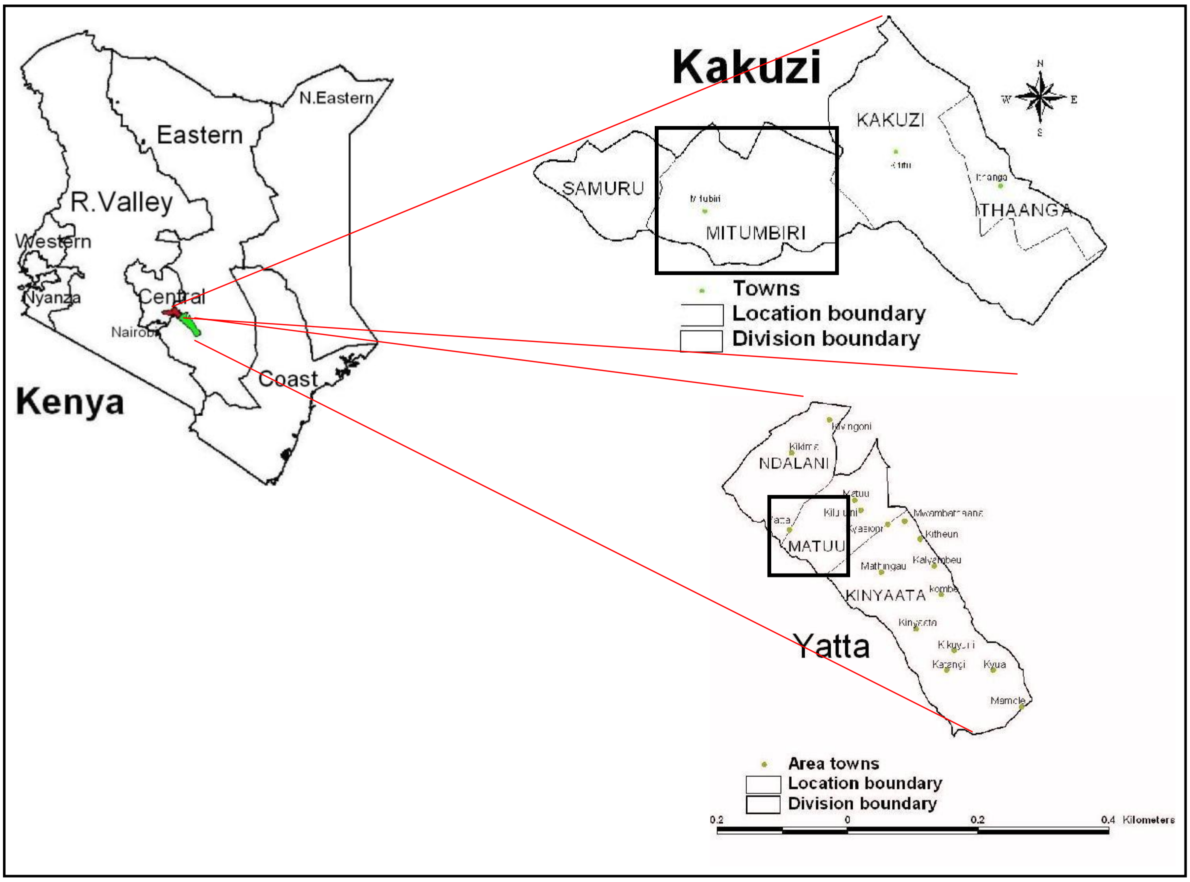

Figure 3.1. Location maps of Kakuzi and Yatta division with area towns and location boundaries.

Table 3.2. The geographical location of the study area including the areas and water sources.

Area	Latitude	Longitude	Area (km^2)	Water sources
Yatta district	-0.8^{0}W,-1.27^{0}E	36.66^{0}N,37.10^o S	4870	Athi river, Yatta furrow
Thika district	-1^0,20' N,-1^0,15'S	36^0 40''w, 37^0,21'E	1040	River Thika, Chania

Kithimani sub location in Yatta division of Yatta district, was chosen as the study site while Mitubiri location of Kakuzi division in Thika district was the second study site.

3.2.1. Hydrology and climate

The main water source available in Yatta division is the Yatta furrow with its intake in Thika River at Mavoloni area. Yatta furrow plays a significant role in water supply to the residents of this area who practice both subsistence farming as well as horticultural farming for both local and export market.

The available water sources in Kakuzi division are rivers, streams, springs and shallow wells. River Thika and Kabuku are the main water sources for the division since they are permanent while river Samuru is seasonal and highly polluted. Other springs such as Kasioni spring in Ithanga location is widely used by the residents. Table 3.3 shows the temperature, annual precipitation and annual evaporation in the study area.

Table 3.3. The temperature, annual precipitation and annual evaporation in the study area.

Area	Minimum temperature	Maximum temperature	Annual precipitation	Annual evaporation
Yatta	13.8^{o}C	30.7^{o}C	754 mm	1623 mm
Thika	11.5^{o}C	27.7^{o}C	943 mm	1485 mm

Rainfall in Yatta districts exhibit distinct bimodal patterns. The first rains fall between mid-March and end of May and are locally known as the long rains (LR). The second rains, the short rains (SR), are received between mid-October and end of December. Average seasonal rainfall is between 250 - 400 mm. Inter-seasonal rainfall variation is large with a coefficient of variation ranging between 45-58 per cent. Temperature ranges between 17-24^{0}C. Evapo-transpiration rates are high and exceed the amount of rainfall most of the year except in the month of November (Fredrick,Lutta and Samuel, 2000). Kakuzi division rainfall distribution is bimodal with high peaks from March to May (long rains), and October to December (short rains). Annual rainfall varies from about 800mm at an altitude of about 1525 m ASL. The annual evapotranspiration increases from about 1250mm at an altitude of 2400 m ASL to about 1800mm at 1100 m ASL (Gathenya, 1999). The temperatures are high at the lower altitudes ranging from 25^{o}C to 30^{o}C but reduces to between 18^{o}C and 20^{o}C towards the higher altitudes of 3500 m ASL.

3.3 Reconnaissance survey

A preliminary survey of the selected areas (Kithimani sub location in Yatta division and Mitubiri location in Kakuzi division) was done to familiarize with the geographical location of the area, weather conditions, main agricultural activities, water sources, soil types of the area and different irrigation technologies practiced by smallholder farmers. Aspects of technology assessed included irrigation components used, water abstraction, conveyance and application mechanisms used.

3.4. Collection of technical and socio-economic data

Structured questionnaires (Appendix 3) were used to gather technical and socio-economic data. The questionnaires detailed the socio-economic status of the people, crops irrigated, varieties, yields, costs incurred such as labour costs, input costs and harvesting costs and the revenue generated from pumped irrigated agriculture.

Technical information such as irrigation methods, water abstraction, conveyance and application methods, irrigation equipments such as pumps, pipes, and other fittings and their selection criteria were also gathered through the questionnaire. Data on mode of operation of irrigation set-ups, farm designs, irrigation scheduling and operation and maintenance costs of these irrigation equipments was collected. Information on methods and knowledge used to determine how much water to apply per irrigation during growing of different crops was also included. The data obtained from the questionnaire as well as the observational data were analyzed statistically using the statistical package SPSS pc + (SPSS Inc, 1993).

3.5. Selection of research sites

10 sample farms were randomly selected in the study area with 5 farms per each site where detailed tests were carried out. In each of the 10 farms, experimental sites were set and detailed assessment done with due regard to the crops irrigated. In 6 farms French beans were grown while Water melon was grown in 2 farms and Tomatoes in the remaining 2 farms.

3.6. Evaluation of technical and economic performance of pumped irrigation systems

3.6.1 Pumping head determination

In each of the 10 sample farms, the total dynamic head was determined based on recommendations by FAO 1992 as shown in equation 3.1. The head from the water source point up to the highest point on the farm was measured using a quickset level and later rechecked using a clinometer.

$$T.D.H = H_S + H_D + H_O + H_F \pm \Delta Z \qquad 3.1.$$

where T.D.H is the total dynamic head, H_S – Suction head, H_D – Delivery head, H_O – Operating pressure, H_F – Friction head loss, ΔZ – Change in elevation.

3.6.2. Pipe head losses determination

Before evaluation of the pipe head losses, their sizes as well as length were measured as shown in table 3.4.

Table 3.4 Pipe sizes and lengths used in the 10 farm setups

Sample farm	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
Pipe diameter (mm)	37.5	37.5	37.5	75	50	37.5	50	37.5	37.5	50
Pipe length (m)	12	40	30	6	30	100	60	78	20	104

To measure the pressure along the pipes during water conveyance, two bourdon pressure gauges were used. One pressure gauge was set adjacent to the pump while the second gauge was set at a specified distance along the pipeline (Plate 3.1). A tape measure was used to measure the length of the pipeline. The pressure difference of the two gauges aided in computation of pipe head losses using equation 2.2 as provided by FAO, 1992. This procedure was repeated for several days during irrigation and for all the 10 sample farms considered. Average values were then computed for all the tested cases and compared with the values in the flow diagram provided by Davis and Shirtliff manual (2010) (Appendix 6).

Plate 3.1. Pressure gauge along the pipeline.

Head losses along the hosepipes were calculated using Hazen Williams equation (equation 3.2).

$$Hf_{100} = \frac{K * \left(\frac{Q}{C}\right)^{1.852}}{D^{4.84}} \qquad 3.2$$

where Hf_{100} – friction losses over a 100 m distance (m), K – Constant $1.22 * 10^{12}$, for metric units, Q – Flow (l/s), C – Coefficient of retardation based on type of pipe material (C = 140 for plastic), D – Inside diameter (mm).

Head loss computation due to fittings was evaluated using the design manuals shown in Appendix 12, 13 and 14. The calculated headlosses were compared with the optimal design head loss and from FAO, 2002 the ratio of the headloss due to fittings should not exceed 10% of the sum of total head losses due to pipes, hosepipes and suction lift head.

3.6.3 Measurement of water discharge from PVC pipes

Water discharge from the PVC pipes was measured using a bucket of known volume and a stopwatch (Plate 3.2). This was done for the 10 sample farms where irrigation was practiced in the study area.

Plate 3.2. Water discharge measurements in a Tomato plantation.

The length of the pipeline was measured prior to water discharge measurements.

The pipe discharges were compared with the optimal design values outlined in the design manuals (Allen, 1977, Appendix 10).

3.6.4 Pump working efficiency

3.6.4.1 Pump engine speed measurement

To measure the rotating speed of the pump, a tachometer was used. First, calibration of the tachometer was done. Using the tractor PTO set at a speed of 540 rpm, the pointer of the hand held tachometer was placed at the rotating shaft and the revolutions per minute read. The ratio between the known PTO speed and reading from the tachometer was calculated. The calculated ratio (1.073) was then multiplied by the readings obtained by the tachometer to obtain precise results. The tachometer was subsequently used to measure pumps speed (rpm) in the field. Several readings were obtained for each rotating speed of the pump and for the 10 different pumps considered and an average value computed. A wide range of pumps were being used by farmers and 3 pump sets were randomly selected (Honda-5, Koshin-3 and Robin -2 (Appendix 4)) and studied. Pump efficiencies were calculated by first evaluating the pump specific speed from equation 3.3. The pump speed was measured using a hand held tachometer (Plate 3.6) at different levels of acceleration while the discharge and head were measured using a bucket and a quickset level respectively. The results of the calculations were read in the graph shown in Appendix 5.

$$N_s = N\left[\frac{Q^{0.5}}{H^{0.75}}\right] \qquad 3.3$$

where N_S –pump specific speed (rpm), N – Pump speed (RPM), Q- Discharge (L/min), H – Total dynamic head (m)

Plate 3.3. Measurement of pump speed using a hand held tachometer.

The computed pumps efficiency were compared with the set standards (FAO, 2002), to check if the pumps operated within the required range.

3.6.5 Power requirement determination

Pump power requirements for the 10 irrigation setups was calculated from equation 3.4.

$$power\,(KW) = \frac{Q * H}{360 * Ep} * 1.2 \qquad 3.4.$$

where: power (KW) = Power requirements, Q = Discharge (m^3/hr), H = Head (m), Ep = Pump efficiency, 360 = Conversion factor for metric units and 1.2=20% derating (allowance for losses in transferring the power to the pump (FAO, 2002)).

Converting kW to horsepower, a factor of 1.34 was multiplied by the power (kW).

3.7. Economic analysis of pumped irrigation systems

3.7.1 Gross margin analysis

80 smallholder farmers practicing pumped irrigated agriculture and growing horticultural crops were considered in evaluation of the gross margin analysis. Questionnaire (Appendix 3) administered to each of the 80 farmers helped gather information needed to compute the gross margin analysis. Information regarding prices of different agricultural inputs was obtained from the local retail shops where farmers bought them. A total of 38 farmers growing French beans, 26 growing tomatoes and 16 growing water melons were considered in the gross margin analysis. Two cropping season were considered with the first one in February to April and the second one beginning from May to July 2009. Random sampling of the farmers was done to select only those who grew similar crop variety of each type in order to minimize on crop variation.

The computation of gross margin analysis entailed evaluation of quantity produced by the farmers and from the price estimates based on the current market value, the total returns were calculated. On the other hand, all the variable costs were analyzed and the difference of the total income and the total variable cost yielded gross margin analysis. In evaluation of the gross margin analysis, a fixed farm size of $^{1}/_{8}$th of an acre (31.6m x 15.8m) was considered for each farmer. The values obtained were projected to 1 hectare of land hence giving the gross margin analysis in Kenya shillings per hectare (Ksh/ha). Average values of gross margin analysis for each crop type in each season were put in a table format.

3.7.2 Benefit cost ratio analysis

3.7.2.1 Income benefit calculation

Income from horticultural crops production was determined based on the land size instead of per capita as given in Renwick et al, (2007), since the benefit depends on the land productivity. The information on annual income from Tomatoes, Water melons and French beans production, and cultivated land size were collected from the household interviews conducted. Income from the three crops considered was evaluated per season and the results projected on a yearly basis to obtain the annual income.

3.7.2.2 Calculation of the total operating costs

The operating costs of producing Tomatoes, Water melons and French beans which included labour costs, input costs and harvesting costs were obtained from the questionnaire administered to the farmers. The operating costs which were calculated per each season were projected on a yearly basis to obtain the annual operating costs.

3.7.2.3 Evaluation of the benefit cost ratio

Evaluation of the benefit cost ratio was done by dividing the total returns and the total operating costs based on equation 2.3 for each of the crops considered. Same data used in evaluation of the gross margin analysis was used to compute the benefit cost ratio and the estimates were based on two crop growing seasons. Average values for each of the cases considered were calculated and the results were put in a table format for easy comparison.

3.7.3 Overall seasonal energy cost

The overall seasonal energy cost for the 10 sample farms growing French beans, tomatoes and water melons was done considering two growing seasons. The overall seasonal energy cost was calculated from equation 2.6 while the cost of fuel was determined from the local market rate at the time of data collection. Overall seasonal energy demand was computed from equation 2.7. Determination of average pump discharge rate was measured using a bucket of known volume and a stop watch and was done at different pump running speed while total dynamic head was done following equation 3.1. Fuel consumption rates of different pumps were measured by connecting a pipette directly to the carburetor as shown in plate 3.4 and it was done at the optimal pump running speed.

All the measuments taken were averaged to obtain representative values.

Plate 3.4. A pipette being used in fuel use determination.

An average value of 95% for fuel efficiency was used while the power unit efficiency for petrol pumps used was 10% and for diesel engines it was 25%. Evaluation of fuel consumption was based on the recommendations of FAO 1992 and was 0.09L/Kwh for diesel and 0.11 L/Kwh for petrol. The value of transmission efficiency for the pumps used was 100% since they were directly coupled to the engine. The ratio of overall seasonal energy cost to the total cost of production for French beans, Tomatoes and Watermelons was calculated and presented in percentage form. The results were then tabulated for easier comparison.

3.8 calculating water use efficiencies of pumped irrigation systems

Observational study of the water conveyance and application methods used in the two study areas was done and the main issues regarding water usage noted. The questionnaire administered to the farming community also highlighted some of the constraints regarding water use and water conservation methods used.

Detailed field measurement of water conveyance and application losses was done in the 10 sample farms.

3.8.1. Measurement of seepage losses in the canals.

Parshall flumes were used in measurement of water flow in the canals for the 5 sample farms considered and before any field measurements were taken, the Parshall flumes were first calibrated as follows;

3.8.1.1 Calibration process of the Parshall flume

Figure 3.2 shows the dimensions of the Parshall flume (Armfield, England) used in measurement of water discharge in the canals.

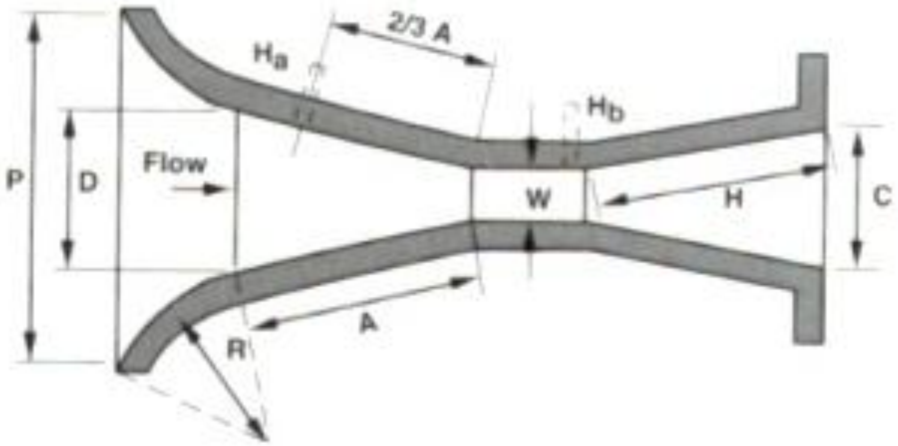

Figure 3.2. Plan view of the Parshall flume used

where W (throat width) = 2.5cm, H_a (upstream height), H_b (downstream height), Depth of the flume =27cm, Total length of the flume = 71cm, D = 16cm, C = 9.3cm, P= 35cm, A = 35.5cm, H = 20cm.

Calibration was carried out in the hydraulics laboratory in BEED, Jomo Kenyatta University of Agriculture and Technology. The Parshall flume was placed inside the open channel apparatus as shown in plate 3.5 and water discharge was measured with a calibrated 90^0 V- notch.

Plate 3.5. Calibration process for the Parshall flume.

The head, h (m), on the Parshall flume was measured at varying discharge rates of the v-notch. The coefficient of discharge (K) for the V-notch was evaluated from equation 3.5.

$$K = 81.2 + \frac{0.24}{H}(8.4 + \frac{12}{\sqrt{D}})(\frac{H}{B} - 0.09)^2 \qquad 3.5$$

where B – Width of the waterway, (m), D – Depth of the ‘’V’’ notch from the bottom of the waterway, (m), H – Water head on the V- notch, (m).

Q - Flow rate (m^3/min) on the V-notch was calculated from equation 3.6.

$$Q = K H^{5/2} \qquad 3.6$$

The values of the discharge, Q for the V-notch versus the recorded upstream head, h_a on the Parshall flume aided in the generation of the calibration curve (figure 4.9) resulting to equation 3.7.

$$Q = 4.9952 h_a^{1.5919}, R^2 = 0.9996 \qquad 3.7$$

where, Q = Discharge (m^3/min), h_a- Upstream depth in the Parshall flume (m).

3.8.1.2 Water flow measurements in the canals

The two calibrated Parshall flumes were set at specified distances along the canals as shown in plate 3.6.

Plate 3.6. Water flow measurement using Parshall flumes in a canal.

The upstream head was recorded for both of the flumes at the same time. This procedure was repeated for several hours at an interval of 30 minutes and for several days when irrigation was carried out. Average values of seepage rate were computed by calculating the differences of water flow in the two flumes using equation 2.19 and based on the schematic layout shown in figure 3.3. This assessment was done for five sample farms in Kithimani area of Yatta division. The calibrated flumes equation 3.7 was hence used to compute the discharge on each Parshall flume.

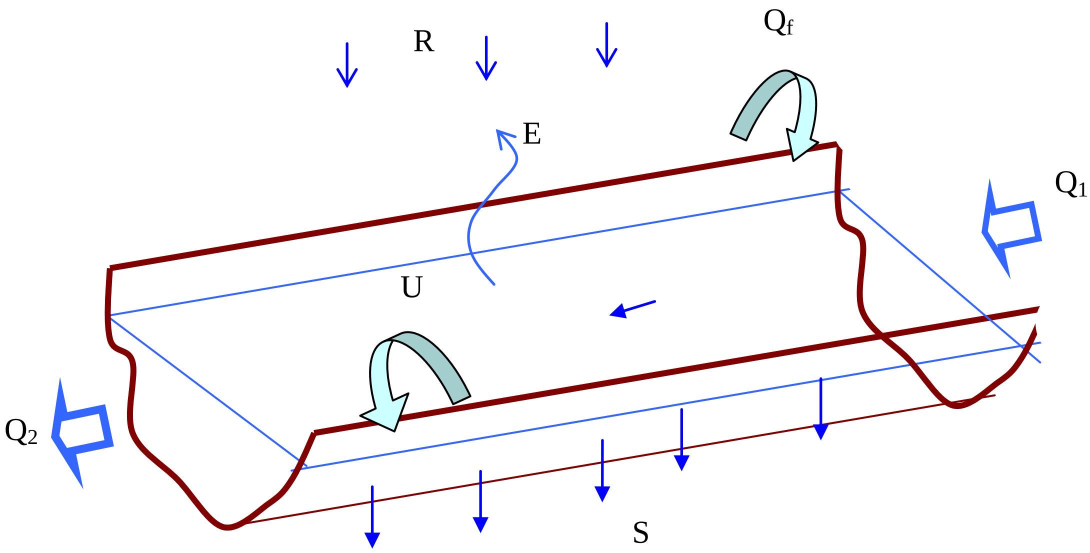

Figure 3.3. Schematic representation of water balance in a canal.

Where s is the seepage, Q_1 and Q_2 is water that enters the reach and one that leaves the reach respectively, R is the rainfall, Q_f is flow that enters the reach from external sources and U is overflowing water that leaves the reach.

NB// during the time of the project, there was no runoff, hence Q_F and U were zero.

The features of the canals in the five farms are shown in Table 3.5.

Table 3.5 Experimental set up to evaluate conveyance losses on the sub canals.

Farms	**Sub canal bottom width (m)**	**Length of sub canal considered (m)**	**Soil texture**
F1	0.30	50	Sandy loam
F2	0.40	30	Sandy clay
F3	0.40	50	Sandy clay
F4	0.30	25	Loam
F5	0.35	40	Sandy loam

Note/ the shape of the canals were rectangular.

Water conveyance efficiency was evaluated from equation 2.18 for all the 5 sub canals.

3.8.2. Assessment of water application efficiency

10 experimental sites each measuring 5m by 5 m were set in the 10 sample farms in the study areas. In the 10 farms, 3 farms were under French beans, 3 with Tomatoes and 3 with Baby corns and only 1 farm was grown with Water melons. Detailed study was done in the experimental sites to investigate net irrigation requirement for the four different crops grown by the farmers. The amount of water applied at each irrigation in each experimental site was also measured. The process was repeated every time irrigation was done up to the time the crops were ready for harvesting. This was done for two crop growing seasons. Crop characteristics were monitored such as the height and rooting depth at various crop growth stages. Weather data was acquired from

metrological station in Thika (KARI research station) and in National Youth Service (NYS) in Yatta division.

3.8.2.1. Measurement of soil moisture

Soil moisture was measured using calibrated tensiometers placed at the root zone of the specified crop. The tensiometers used were of Terada type (DIK- 3120, Japan) and during calibration they were installed in the experimental plots as described by (Smajstrla and Pitts, 1997). The calibration entailed placing soil from the experimental sites in a bucket that had holes on all sides to allow free movement of water both longitudinally and laterally. Composite samples of the soil were collected from the experimental plots and mixed thoroughly. The soil was initially saturated with water. The gravimetric moisture contents were measured as the soil dried up. The soil samples were saturated again and the process repeated three times such that for a given soil tension three values of soil moisture were obtained. The values of soil tension were plotted against soil moisture and a calibration curve developed as shown in figure 4.11.

Measurement of water stored in the soil in the 10 sample farms entailed placing tensiometers at the centre of all the plots in the experimental sites as shown in plate 3.7 and soil moisture recorded everyday at 9.00 a.m. The tensiometers were placed at a depth of 15 cm from the soil surface.

Plate 3.7. Tensiometer measures soil water tension in a French bean plantation.

The tension readings on the tensiometers were converted to soil moisture in millimeters.

3.8.2.2. Evaluation of the net irrigation requirement

The first step was to evaluate the net irrigation requirement from the field balance equation 2.9. One year weather data to evaluate crop evapotranspiration such as Pan coefficient and evaporation, wind speed and mean minimum relative humidity were obtained from the nearest metrological station. Crop parameters such as crop height, rooting depth were measured during the crop growing period.

Soil parameters including availability coefficient (AC (%)) were read from table 2.3 and available water storage capacity (AWSC) was evaluated using the pF Meter (H-1400PF, Japan). The procedure for evaluating the available water storage capacity of the soil entailed collection of composite soil samples taken from each of the 10 experimental sites and analyzed in the BEED laboratory by measuring the water potential. Standard procedure was used in evaluation of the available water storage capacity. The difference between the permanent wilting point and field capacity gave the available water storage capacity of the soil (Brouwer et al, 1985; Werner, 1993). Percent moisture content was computed for all tensions and the results of these versus pF values plotted to obtain the pF curve as shown in figure 4.10. The pF values for permanent wilting point and field capacity were 4.2 and 2.5 respectively (FAO, 1985). The effective rainfall was calculated from equation 2.13 based on the weather data collected, soil and crop parameters obtained from metrological station and in the field respectively.

Water application efficiency for the different crops considered was evaluated from equation 2.17.

3.9 Development of an ideal pumped irrigation system

In development of an ideal pumped irrigation system, three options were considered as follows;

I. Open channel system (pump- pipes – sub canal - furrow).

II. Closed pipe system (Pump – pipes – hosepipe - furrow).

III. Sprinkler irrigation system (Pump – pipes - sprinklers).

The following general assumptions were made;

- One acre square field located near the water source (river).
- Crop irrigated was assumed to be vegetables with a crop water requirement of 6mm/day.
- Irrigation interval was considered to be 3.5 days for options I and II.
- Farm elevation varied from 0, 5, 10 and 15m.
- Irrigation efficiency was considered to be 70% and the sprinkler distribution uniformity coefficient was assumed to be 0.7.
- Average irrigation time was taken to be 7 hours per day for options I and II.
- Suction lift was fixed at 3 metres head.
- Pump efficiency was 60% which is the ideal pump as recommended (FAO, 2002).
- All the pipes used for options I, II and III were assumed to be of uPVC material of class 4.

The technical specification of the sprinklers selected and are available in the Kenyan market is as outlined in table 3.6 and other assumptions made were as follows;

- Irrigation interval was considered to be 7 days for option III.

➢ Area irrigated daily, 667m^2,

Table 3.6. Technical specifications for the sprinklers - 322 Dual Nozzle;

Nozzle (mm)	Pressure (kg/cm^2)	Discharge (m^3/hr)	Diameter (m)	Precipitation (mm/h)/spacing (m)		
				10x10	10x12	12x12
2.8x2.5	2.1	0.73	20	7.1	5.9	4.9

Other features and specifications of the sprinklers are;

- Heavy duty metal impact sprinklers, ½ ‘’ male or ¾’’ female.
- Full circle
- Uniform precipitation rate
- Durable, heavy-duty all brass construction
- Total dependable sand and dust protection sleeve for reliable operation and durability.

➢ Crop irrigated - vegetables, crop water requirement = 6 mm/day.

- Rooting depth = 60 cm

- Crop factor = 0.9.

➢ Soil type; Clay loam, with good surface structure,

- Assumed water intake rate of the soil = 8mm/hr.

- Half storage capacity of the soil = 8 – 11 mm/hr.

➢ Friction losses due to – fittings = 1m

➢ Suction pipe friction losses = 0.5m

➢ Couplers = 1m.

➢ Headloses for mainline and lateral line were computed thus;

Mainline

Assuming a 63mm inch pipe of class 4 with a total length of 53m and a flow rate of 1.22l/s, the headloss was read from the flow diagram (Appendix 6).

Lateral line

Assuming a 50mm inch pipe of class 4 with a total length of 53m and a flow rate of 0.61l/s, the headloss was read from the flow diagram (Appendix 6).

3.9.1. Ideal design for options I and II

For options I and II, the farm layout was divided into 3 blocks each irrigated twice per week.

The first step in development of the ideal irrigation system design was computation of the pump flow rate and power requirement.

Scheme water requirement, Q (L/s) was computed from equation 2.24 and values converted to m^3/hr.

The pump power required was computed from equation 3.4.

The total dynamic head was computed from the normal equation as shown in equation 3.1.

The headlosses for the PVC pipes, hosepipes and fittings were read from the respective normographs (Appendices 6, 7, 8 and 9).

3.9.2. Design for the sprinkler irrigation system (option III).

The layout of the sprinkler irrigation design is shown in figure 3.4.

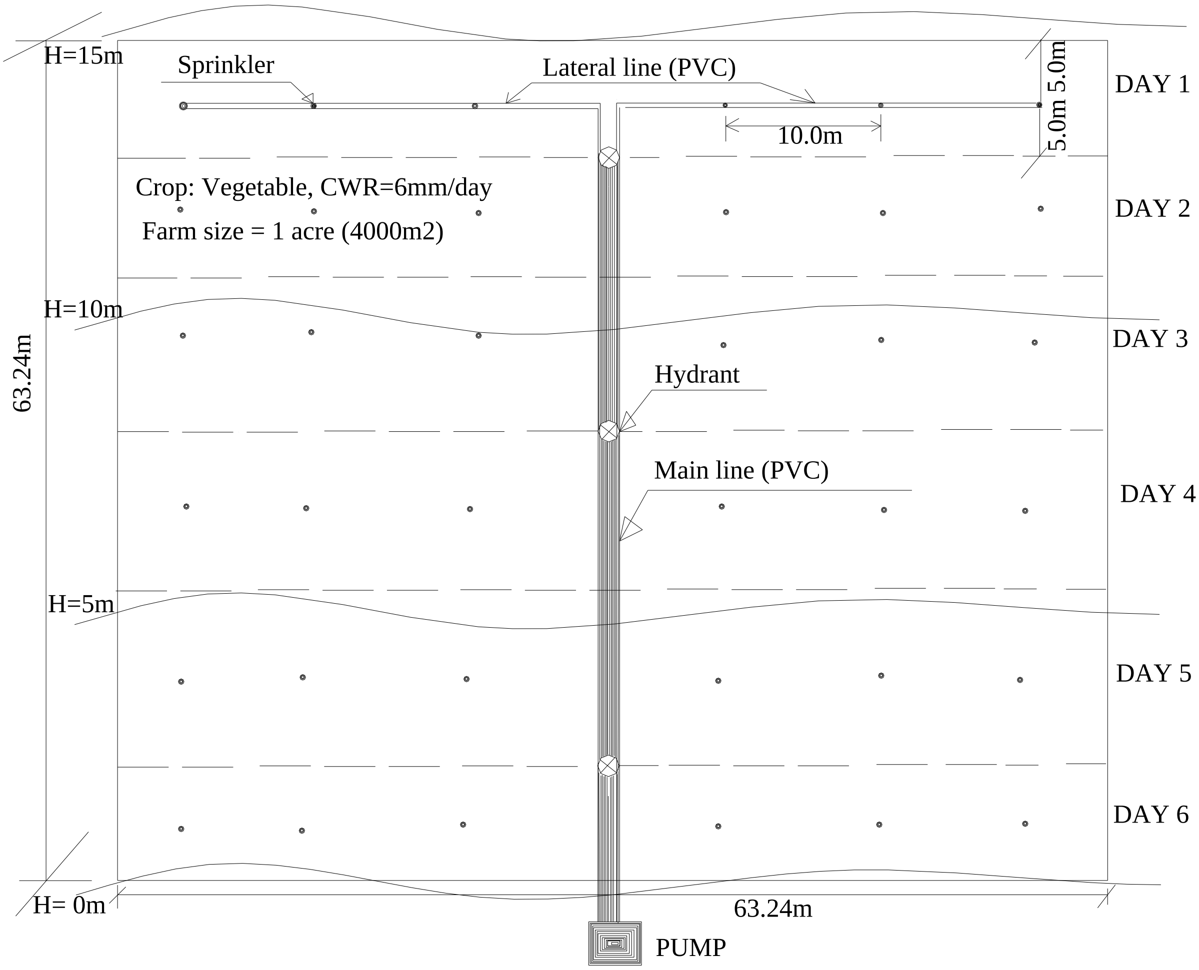

Figure 3.4. Layout of pumped sprinkler irrigation system

1. Water application rate of the sprinklers was computed from equation 2.22 and was compared with the water intake rate of the soil.
2. Number of hours of irrigation per week was computed from equation 2.23.
3. Easily available moisture for the soil considered was found to be 48mm – 60mm.
4. Water application rate for one block was computed from equation 2.25.
5. Number of sprinklers required was computed from equation 2.26.

6. Required capacity of the pump and the pump power required was calculated from equation 2.27 and 3.4 respectively. The size of the main line was hence selected from the flow diagram for uPVC pipes as shown in Appendix 6. It was ensured that the size of the mainline was adequate to meet the required flow as well as minimize on the head losses.

The total dynamic head was computed from equation 3.1 and table 3.7 shows the calculated heads.

Table 3.7. Different calculated heads

Elevation head (m)	Suction head (m)	Working pressure (m)	Friction head (m)	Total head (m)
0	3	21	20.4	44.4
5	3	21	20.4	49.4
10	3	21	20.4	54.4
15	3	21	20.4	59.4

The head losses for the mainline and lateral lines were read From the flow diagram for Upvc pressure pipes shown in Appendix 6, while the head losses of the fittings was read from the respective tables as shown in appendices 7, 8 And 9.

CHAPTER 4

4.0 RESULTS AND DISCUSSION

4.1 Overview of the results and discussion

This section presents the results as well as the discussions of the study to evaluate the technical performance and agricultural water use for smallholder pumped irrigation systems. The results highlight the agricultural activities practiced by 80 smallholder farmers in Kakuzi and Yatta divisions. This mainly includes the crops grown, irrigation methods used, pumping technologies adopted as well as the challenges facing the farmers.

Detailed description of the performance of the smallholder pumped irrigation systems is also highlighted. The performance of the pumping devices used as well as the conveyance mechanisms is highlighted. Pump efficiency and power requirements and pipe head losses are discussed in detail. Agricultural water use efficiency for smallholder pumped irrigation systems is discussed. An economic evaluation of smallholder pumped irrigation systems done is presented and the viability of this farming enterprise discussed. Finally an ideal irrigation system design is presented that can be used to guide smallholder farmers in their choice of appropriate components matching their farm enterprises.

4.2 Smallholder agricultural activities in yatta and kakuzi divisions

From the preliminary survey done in the two study areas, smallholder farming dominated the agricultural sector with majority of the farmers practicing irrigated horticultural farming. Most of the horticultural crops are grown for both local and export market. The basic information of the agricultural practices from the two districts as obtained from the two representative locations is presented in Table 4.1. The two study locations i.e. Mitubiri location and Kithimani sub location are in Thika and Yatta districts respectively. From table 4.1, horticultural crops dominated the two study sites owing to the favorable climatic conditions, rich water bodies and soil types. Subsistence farming is also carried out in the two areas particularly during the rain periods. Mitubiri location is served by a network of rivers used by farmers to irrigate their horticultural crops while the Yatta furrow with its main intake from River Thika is the main source of water for farmers in Mitubiri sub location.

Table 4.1. Agricultural related site specific findings in the two study areas.

	Mitubiri location	**Kithimani sub location**
Crops grown	Water melons, French beans, Baby corns, Vegetables, Bananas, Tomatoes, Mangoes and Subsistence crops (maize, beans, potatoes).	Water melons, French beans, Baby corns, Vegetables, Bananas, Tomatoes, Mangoes and Subsistence crops (maize, beans, cassava).
Main water Sources	River Thika, Kabuku, Samuru, seasonal streams and springs	Yatta furrow and river Thika
Soil types	Sandy clay, Sandy loam, Loam.	Sandy clay, Sandy loam, Loam
Climatic conditions	Arid and semi arid zone with low rainfall, high temperatures and high evaporation rates.	Arid and semi arid zone with low rainfall, high temperatures and high evaporation rates.

4.2.1 Irrigation practices in Yatta and Thika districts

Smallholder farmers practice irrigated agriculture in the two study areas with some practicing pump fed system while others use gravity fed systems. From the questionnaire administered to the farmers in Mitubiri location and Kithimani sub location, over 80% of the respondents practice supplemental irrigation to their crops during the dry periods particularly March to August. Majority of the smallholder farmers surveyed use furrow irrigation. Fewer farmers used basin, sprinkler and bucket (hand watering) irrigation methods. No farmer was found to use drip irrigation in the study area. Figure 4.1 shows the methods of irrigation used by farmers in the two study areas.

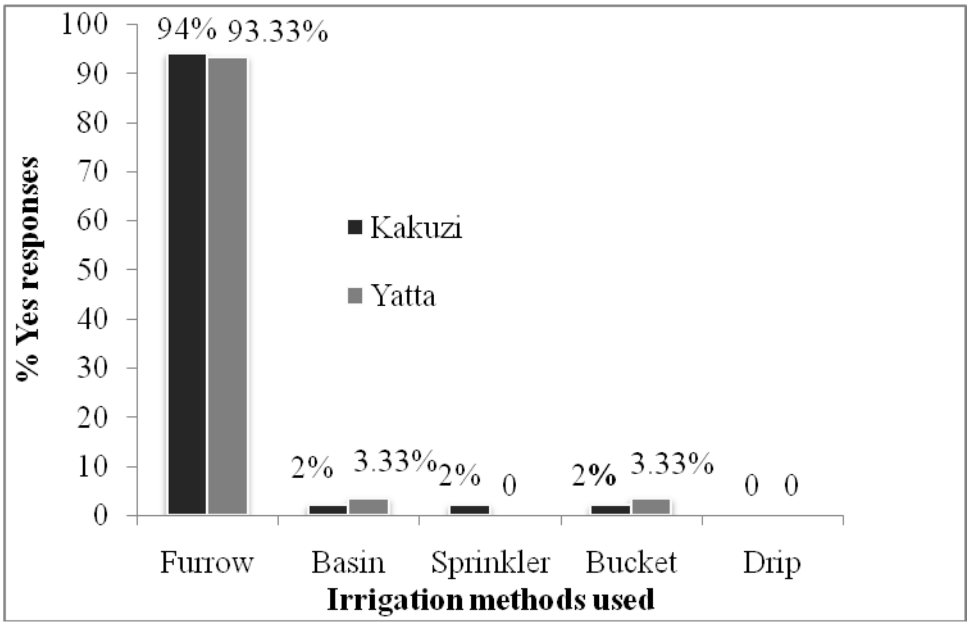

Figure 4.1. Irrigation methods used by smallholder farmers in Mitubiri location and Kithimani sub location.

From the findings, it was concluded that there was low adoption of modern irrigation technologies by farmers. Few farmers used sprinkler irrigation in their farms while majority continued to rely on furrow irrigation method which apparently has low water use efficiency (Hayrettin, Filiz and Ali, 2008). The survey also found out that different onfarm irrigation set ups were being used in the two areas (Table 4.2). A large percentage of the farmers pumped water using small motorized pumps and conveyed it through pipes and then applied it directly in the furrows. The result shows that simple irrigation setups were being used by the farmers which they could probably understand and afford.

Table 4.2. On farm irrigation setups used by smallholder farmers.

On farm irrigation set up	No. of respondents	Percentage
A) Pump-pipes-sprinklers	1	1.3
B) Pump-pipes – hosepipe – furrow	52	65
C) Pump – pipe –sub canal - furrow	8	10
D) Pipe- sub canal – furrow	15	18.7
E) Bucket	2	2.5
F) Pump – pipe – hosepipe – basin	2	2.5
Total	**80**	**100%**

4.2.2 Sources of information in purchasing irrigation equipments

Figure 4.2 shows different sources of information on where to purchase the irrigation equipments needed by farmers in the study areas. 60% of the farmers get information on where to purchase the irrigation equipments from other farmers who have experience in using them.

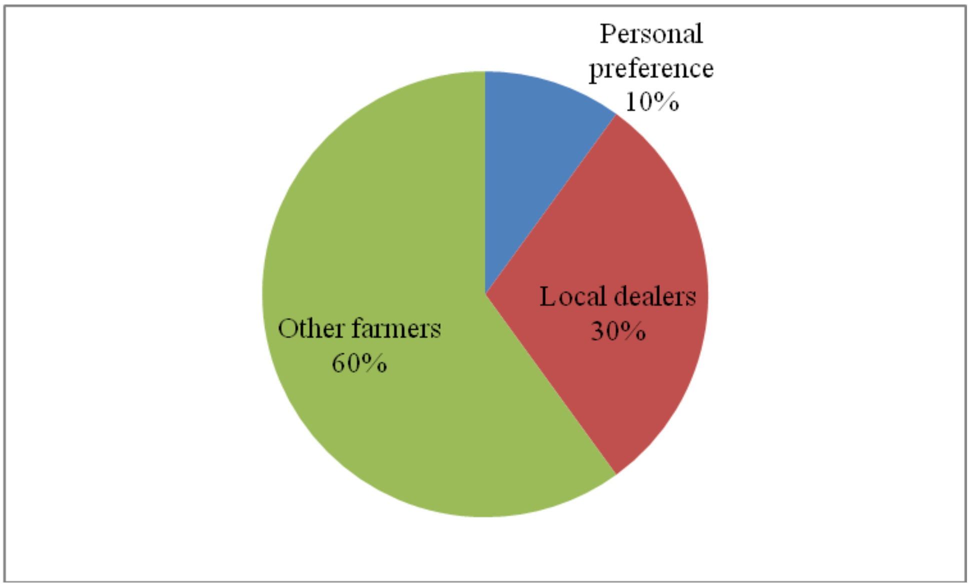

Figure 4.2. Source of information in purchasing irrigation equipment.

Further information revealed that the farmers depended on past experiences while purchasing irrigation equipments with apparent lack of information from irrigation personnel's or engineers in the two areas. This therefore indicates that there was no engineering approach that was adopted in selection, design and operation of the irrigation equipments. It was also found that the local dealers who sell the irrigation equipments provided information on equipments to use without prior considerations of the engineering concept. The government as well as the private sectors is called upon to offer technical advice regarding irrigation system component selection, design and operation. This in return would result to farmers using the right irrigation components and also design and operate them optimally to ensure sustainable use and minimized operational costs of running them.

4.2.3 Limitations of pumped irrigated smallholder agriculture

Several factors were found to have a negative influence in smallholder irrigated agriculture. Figure 4.3 shows in percentage the different costs that have a big influence on pumped irrigated agriculture as cited by respondents in Mitubiri location and Kithimani sublocation.

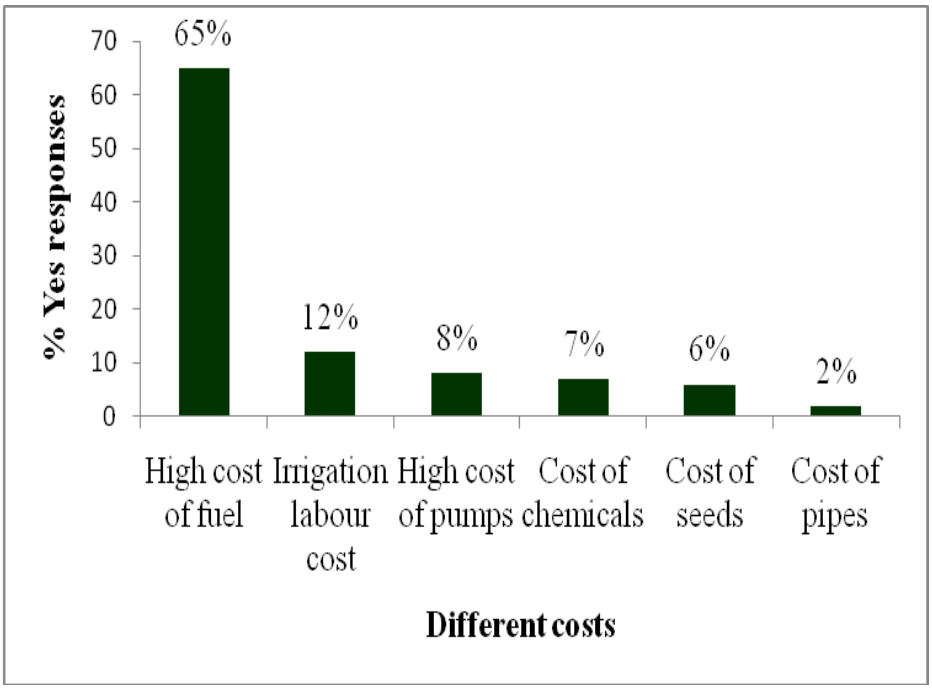

Figure 4.3. Limitations of smallholder pumped irrigation systems.

High cost of fuel as cited by 65 % of the respondents was found to be the most limiting factor in pumped irrigated agriculture. With the current global energy crisis, fuel costs are deemed to increase and irrigated agriculture may even become more costly. Alternative sources of energy that does not rely on fossil fuels should hence be introduced to counteract increased need for use of these fossil fuels.

4.2.4 Crops irrigated

The crops commonly irrigated in the two study areas are shown in Table 4.3.

Table 4.3. Percentage of smallholder farmers irrigating different crops in Mitubiri and Kithimani areas.

Area	French Beans	Tomatoes	Water melon	Baby corns	Cabbages	Onions	Kales
Mitubiri location	18	10	4	5	6	3	4
Kithimani sub Location	7	7	4	6	3	1	2

French beans were irrigated by majority of smallholder farmers in the two study areas. The second crop in popularity was Tomatoes. Both French beans and Tomatoes played an important economic role in the agricultural sector of the two areas. Over 90% of French beans produced is exported while Tomatoes is sold particularly in the local markets and generally in large town centers. Due to the high demand of these two products, farmers have intensified their production through irrigation.

4.2.5 Factors used to determine irrigation timing

Table 4.4 shows the factors used by the farmers to indicate when they should irrigate.

Table 4.4. Factors used to indicate irrigation timing.

Time to irrigate	% of respondents
Assessing the crop appearance (signs of withering)	30
Set date for irrigation	15
Soil feel/ appearance	5
Weather conditions (e.g. temperature, rainfall)	10
Availability of irrigation equipments	40

The factors in Table 4.4 roughly guided the farmers on when to irrigate. 60% of the farmers surveyed did not own a pump meaning that they depended on leasing it from other farmers with its availability not guaranteed. Factors of crop appearance also prompted some of the farmers on when to irrigate. No modern monitoring tests that guided farmers on the right time to irrigate their crops were found. In addition, the farmers do not have proper techniques/water monitoring devices resulting to either over irrigation or under irrigation.

4.2.6 Challenges facing smallholder pump fed agriculture

Main challenges cited by smallholder farmers practicing pumped irrigated agriculture were poor markets for their produce, water shortages during crop production, lack of technical advice during irrigation system component selection, design and operation, high cost of inputs among others. Some of the challenges cited are shown in figure 4.4.

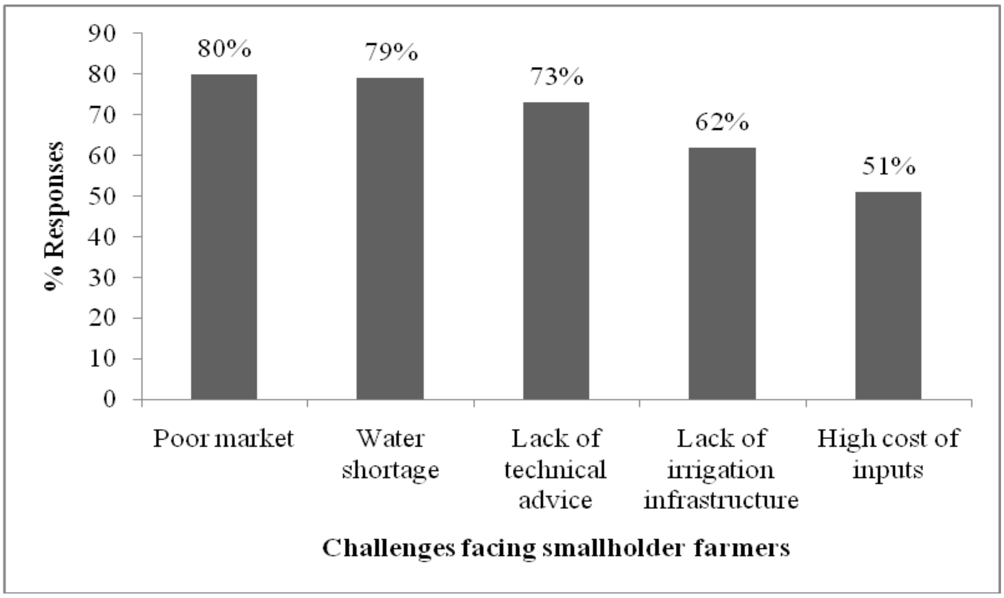

Figure 4.4. Challenges facing smallholder farmers.

Technical advice regarding irrigation equipment selection, design and operation was generally lacking in the two study areas. Inadequate technical capacity affecting farmers' organization and participation was also common. Poor market particularly the local market for horticultural crops posed a major problem for most smallholder farmers as indicated by 80% of the respondents. This was further aggravated by unreliable market prices and middlemen who offer low prices for the produce. Water shortage during times of high demand of the horticultural crops was prominent in the study areas. To cope up with these challenges, farmers should always ensure that they have proper information regarding the market and market prices of their commodities before venturing into production. More experienced technical personnel should always be available and at farmers disposal. The government should hence ensure that it avails technical people to work with and through the farmers. Ways of reducing costs of inputs such as subsidies should be offered by the government to the farmers to reduce the cost of production.

4.3 technical evaluation of smallholder pumped irrigation systems

4.3.1 Pumping systems used in the 10 farms.

Different types, makes and models of pumps were found in the two study areas and detailed specifications of the pumps used by the 10 farmers are shown in Appendix 7. All the pumps used in the 10 farms were small motorized centrifugal pumps run by petrol and ranging from 4.0 to 6.6 horsepower. The total head for the different pumps ranged from 28 to 32m while the discharge rate varied from 31.2 m^3/hr to 66m^3/hr. The pumps had varied inlet and outlet diameters ranging from 37.5mm to 75mm respectively. The detailed technical specifications of the pumps assessed are shown in appendix 4.

4.3.2 Water discharge measurement from the pipes

The diameters as well as the length of the pipes used in the 10 farm setups are shown in table 3.4. Different sizes and diameters of pipes were used in the 10 farm setups. An evaluation of pipe discharge rate in each farm was done and the values compared with the optimal pipe discharge as shown in Table 4.5.

Table 4.5. Average measured and optimal pipe discharge rate.

Farm	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
Measured pipe discharge (L/s)	3.0	5.3	2.2	6.7	12.4	2.8	6.9	0.2	5.6	1.5
Optimal pipe discharge (L/s)	2.8	2.8	1.3	6.2	11.9	2.6	5.7	3.2	4.1	2.5

The optimal pipe flow rate was based on the pipe diameter, type of pipe and farm gradient. All these parameters were measured for all the 10 experimental farms in the two study areas. The flow rate in the pipes should not exceed a certain design limit in order to ensure that the head loss is minimized as much as possible.

The values for the optimal discharge rates were read from the tables for the hydraulic design of pipes (Appendix 10).

In 6 farm setups, the measured flow rates in the pipes exceeded the design flow. Only pipes used in 4 farm setups met the optimal operation range. Excessive water flow exceeding the design flow rates results to an introduction of design stress on the pipeline. The effect can be worsened if temperature of the fluid being conveyed rises.

4.3.3 Energy losses during pumping

4.3.3.1 Frictional head losses in the PVC conveyance pipeline

Figure 4.5 shows the results of the measured pipe head losses and the optimal pipe head losses read from the pipes product manual. In each of the 10 farms, measured head losses were different due to differences in water flow rates, pipe sizes, pipe length and types of fittings used in the 10 farms,

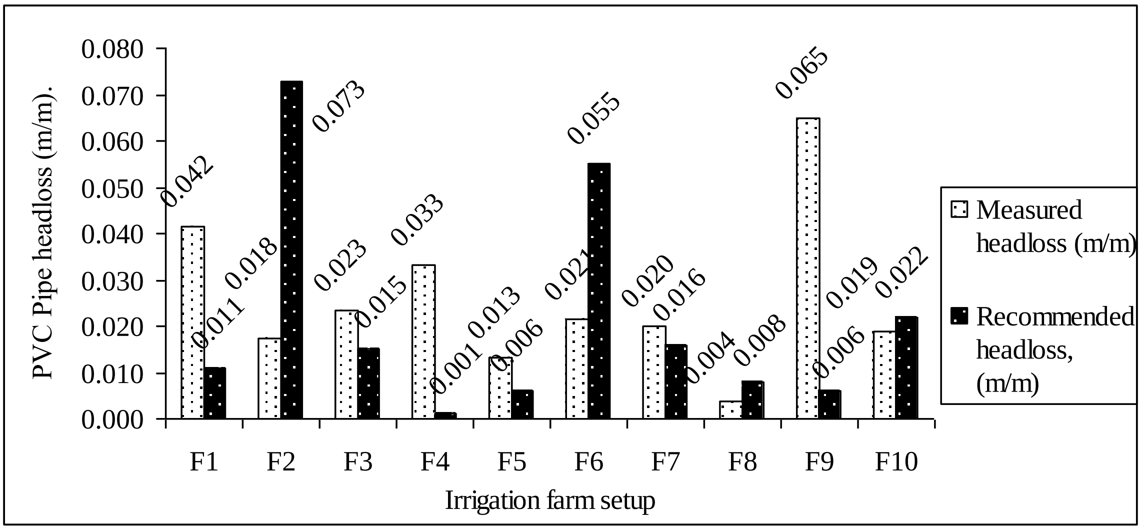

Figure 4.5. Pipe head losses for different on farm designs.

Farm irrigation setups F1, F3, F4, F5, F7 and F9 representing 60% of all the irrigation setup evaluated had the measured pipe head losses exceeding the design pipe head loss limit. The remaining farms (F2, F6, F8, and F10) representing about 40% had the measured pipe head loss within the design head loss range. The effect of increased head losses results to introduction of design stress on the piping material with subsequent reduction in pipeline lifespan. It is recommended that the selection of the required pipeline should be based on the required flow rates and farm conditions.

In the 6 farm setups, farmers did not first consider the requirement before selecting the appropriate pipe sizes. This in effect led to higher measured head losses exceeding the design head losses.

4.3.3.2 Hosepipe head losses determination

The frictional and shock head losses for five irrigation systems using drag hosepipe are presented in Table 4.6.

Table 4.6. Hosepipe head loss for 5 irrigation setup.

Farm setup	F6	F7	F8	F9	F10
Hosepipe diameter (inches)	1	1	1	1.5	1
Hosepipe length (m)	20	15	15	6	6
Calculated hosepipe head loss (m)	3.3	2.7	0.1	0.6	0.3

For the 5 farm setups with hosepipes connected to pipes, it was found out that different sizes of hosepipes (diameters, length) showed differences in head loss. Farms 8,9,10 had the head loss due to the hosepipe being less than 1m while farm 6 and 7 had head losses due to the hosepipes exceeding 2m. Water flow velocity in the hosepipes used in farm setups 6 and 7 were higher as compared to the other 3 farm setups. This led to higher hosepipe head losses in farm setups 6 and 7.

4.3.3.3 Head losses due to fittings

The evaluated values for the head losses due to fittings in the 10 irrigation setups are presented in Table 4.7. The design ratio of head loss due to fittings versus combined head losses due to hosepipe, PVC pipes and suction lift should not exceed 10 %.

Table 4.7. Ratio of head loss due to fittings versus total head losses due to hosepipe, PVC pipes and suction lift.

Farms	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
Type of fitting	Reducer	Tee	Reducer	Tee	Reducer	Tee	Tee	Tee	Reducer	Reducer
Sizes of fittings (inches)	2’’-1.5’’	2’’	2’’-1’’	1.5’’	2’’-1.5’’	2’’-1’’	2’’-1’’	1.5’’-1’’	1.5’’-1’’	1.5’’-1’’
HLx (m)	2.3	3.2	2.9	2.5	2.8	19.2	16.5	4.1	3.6	3.9
HLfittings (m)	0.1	0.1	0.1	0.1	0.1	0.4	0.4	0.9	0.1	0.2
R *100 %	5.7	4.4	4.9	4.4	4.3	1.8	2.5	20.9	1.3	5.1

where $HL_{fittings}$ is the head loss due to the fittings, HL_x (m) is the total combination of suction head lift, PVC pipe head losses and hosepipe head loss and $R = \frac{HL_{fittings}}{HL_x}$.

The ratios (R) for the 9 irrigation setups were within the 10% recommended range, while farm 8 had the ratio exceeding 10%. Farm 8 had the highest ratio (R) due to low water flow velocity which led to reduced hosepipe and PVC pipe head losses. It is appropriate for the farmers to know the effects of wrong sizes of fittings in the irrigation system and its effect on energy uses for pumping.

4.3.4 Pumps efficiencies

The results showed that most pumps operated below the manufacturers rated optimal design efficiency of 60% or higher (FAO, 1992). Mostly, the operating efficiency of centrifugal pumps ranges from 40% to 80% hence a pump operating at 60% efficiency is considered to be operating within its optimal range. Of the 10 pumps assessed, P1, P2, P3, P4 and P5 (all of Honda family) slightly showed higher operating efficiencies as compared to P6 and P7 (Koshin type) and P8 and P10 (Robin type). Figure 4.6 shows the graph of pump efficiency for the 10 pumps assessed. The Robin type of pumps had the lowest operating efficiencies.

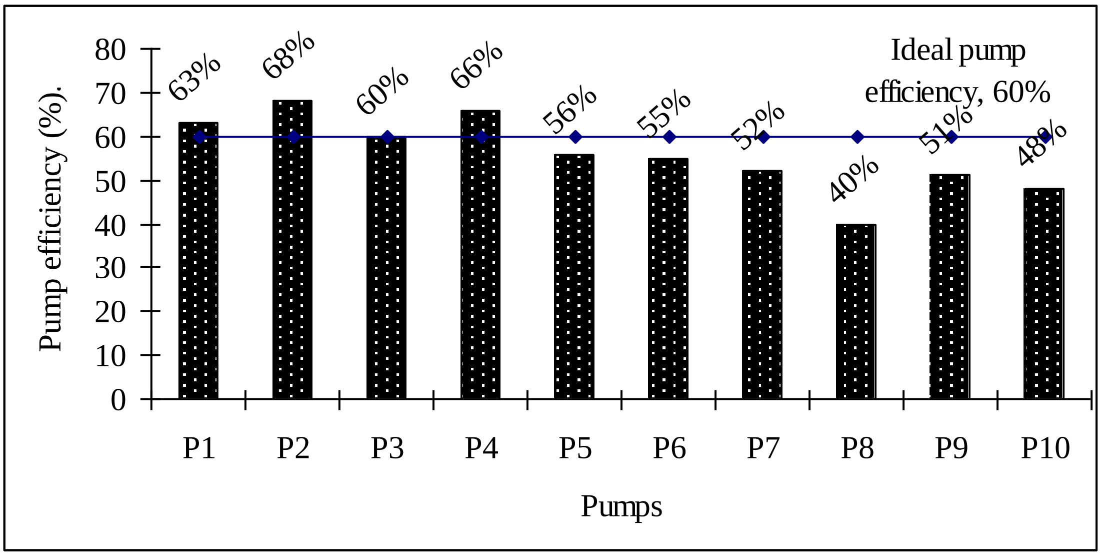

Figure 4.6. Efficiencies of different pumps used by smallholder farmers.

Pump efficiency is a factor of many components such as pump specific speed, water discharge rate, rotating speed of the pump impeller and total dynamic head. Several factors that affect pump efficiency are pump over sizing, throttling valves operation, pump operating conditions among other factors. The right size of the pump should be selected based on the field parameters available. Matching the pump to the right field condition further ensures that it is operated at optimal range hence in effect results to improved pump efficiency. In all the 10 farm setups considered, oversized pumps were being used as opposed to the need for less powered pumps (table 4.11). Further investigation on relationship between pumps age versus efficiency showed that pumps age did not affect its efficiency (Table 4.8). Some old pumps had a higher efficiency than the new pumps. Several factors that could have contributed to this anomaly were either repair or maintenance, pumps make and model as well as proper operation of the pumps.

Table 4.8. Pump age versus efficiency.

Pump	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
Pump age (years)	3	7	9	10	12	5	8	5	6	10
Pump efficiency (%)	63	68	60	66	56	55	52	40	51	48

Proper pump selection by matching it to the right field conditions and operation would ensure that it operates at a higher efficiency with long periods of operations with no major problems experienced.

4.3.5. Water power and fuel used in irrigation

From the results of water power against fuel use, 4 pumps (P1, P3, P4 and P10) consumed very little fuel while generating moderate water power. Pumps 2, 5,6,7,8 and 9 used more fuel and generated low water power. The comparison of water power versus fuel used for the 10 pumps is shown in Table 4.9.

Table 4.9. Water power versus fuel used.

Pump	Fuel used (L/hr)	Water power (kW)
P1	0.96±0.14	0.18
P2	2.41±0.09	0.54
P3	1.26±0.10	0.14
P4	0.60±0.11	0.24
P5	1.44±0.13	0.26
P6	1.12±0.11	0.70
P7	1.45±0.12	0.63
P8	2.65±0.08	0.14
P9	1.36±0.15	0.15
P10	0.87±0.14	0.14

Mean ± STDEV

4.3.6 Pump power requirement

Power requirements for each of the 10 farm setups was calculated based on each farm parameters such as farm elevation, water pumping point, water conveyance distance, optimal pump discharge rate and ideal pump operating efficiency. Table 4.10 shows the calculated values of total dynamic heads for each of the 10 farms that aided in pump power computation.

Table 4.10. Total dynamic head in the experimental plots.

Farm	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
Static Suction lift, m	1.8	2.5	2.2	2.3	2.4	1.2	1.5	1.7	1.3	2.1
PVC pipe HL, m	0.5	0.7	0.7	0.2	0.4	8.0	9.7	2.3	1.7	1.5
Hose HL, m	-	-	-	-	-	10.0	5.3	0.1	0.6	0.3
Fittings HL, m	0.1	0.1	0.1	0.1	0.1	0.4	0.4	0.9	0.1	0.2
Static delivery head, m	1.5	5.0	1.0	1.0	6.0	3.5	3.0	6.5	4.5	4.0
Operating head, m	2.4	2.0	2.4	1.6	2.1	2.2	2.0	2.3	1.6	1.3
Total dynamic head, m	6.3	10.3	6.4	5.2	11.0	24.3	21.9	13.8	9.8	9.4

The calculated pump power for each of the 10 farm setups is shown in table 4.11.

The results show that pump power in the range of 0.3 horsepower upto 1.3 horsepower was ideal in the 10 farm setups considered. A comparison of the calculated pump power and the power rated on the pumps being used shows a big difference i.e farmers used pumps which had a higher power rating than required. The effect of using an oversized pump is high initial cost of purchasing the pump and high operation costs due to fuel use. A survey of the availability of low powered pumps in the Kenyan market showed their inexistence and this offers a chance for further exploration and development of these pumps.

Table 4.11. Power requirements for the 10 irrigation setups assessed.

Farm setup	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
Computed pump horsepower (Hp)	0.3	0.8	0.2	0.4	0.5	1.3	1.2	0.4	0.3	0.3
Rated pump horsepower (Hp) used	5.5	5.5	5.5	6.6	5.5	5.5	5.5	4.0	4.0	4.0

4.3.7 Gross margin analysis and Benefit – Cost ratio of three different crops under smallholder pumped irrigation systems

Gross margin analysis of three different crops i.e. Tomatoes, French beans and Water melons was done. Two crop growing season was considered and only one variety of each crop was considered during the analysis and farmers adopted the same crop spacing for each of the crop considered. The benefit cost analysis of the three different crops was computed considering two crop growing season. Table 4.12 shows the average values for production per hectare versus net returns for each of the crops considered as well as the computed benefit cost ratio.

Table 4.12. Gross margin analysis and Benefit - Cost Ratio for the three commonly grown crops per ha for season 1 and 2 for the year 2009 in Mitubiri location and Kithimani sub location.

Season	**Season 1 (February to April 2009)**			**Season 2 (May to July 2009)**		
No. of Farmers considered (N)	**N= 38**	**N= 26**	**N= 16**	**N= 38**	**N= 26**	**N= 16**
Crop planted	French beans	Tomatoes	Water Melon	French beans	Tomatoes	Water Melon
Variety	Samantha	Monset F1	Charles Graton hybrid	Samantha	Monset F1	Charles Graton hybrid
Total marketable yield (kgs)	11,841.66	101,210	21000	10,350	98,300	19,573
Price per kg (Ksh)	40	20	20	35	20	20
Total sales (Ksh)	473,660	2,024,200	420,000	362,250	1,966,000	391,460
Costs (Ksh)						
Labour costs						
Spraying	13900	10600	7200	12100	9450	6749
Ploughing	13800	5250	10000	11500	6250	8900
Harrowing and furrow Making	5533.34	3,000	5100	5623	2,750	4,239
Planting	4533.34	3,500	900	3992	3301	1000
Irrigation	39,000	50,000	22400	41,400	48,000	23,400
Topdressing and fertilizer Application	5200	4400	1000	6300	4300	1300
Weeding	4480	6345	4000	4300	6290	4600
Input costs						
Seeds	42793.4	31920	6240	3992.6	33950	7100
Fuel	32766.6	37,680	31,920	31876.5	40,647	33,799
Fertilizers	10540	31,900	16000	9667	29,600	17,000
Top dressing fertilizers	10540	15,700	30500	9600	13,600	33000
Chemicals	12971.66	20,2392.5	15300	10478.45	19,300.5	16510
Harvesting costs	63506.6	305,937.5	15,750	64475.66	280,609.5	14,560
Total operating costs (Ksh)	258820	708,625	166,310	215,305.21	498,048	172,157
Net benefit	214,840	1,655,575	253,690	146,944.80	1,719,952	219,303
Benefit/Cost ratio	1.8	2.9	2.5	1.7	3.9	2.3

From table 4.12, it can be seen that the mean income from Tomatoes, Water melons and French beans was 1,687,764 Ksh/ha, 236,497 Ksh/ha and 180,892Ksh/ha respectively on season basis. Annual income from Tomatoes, Water melons and French beans was 5,063,291Ksh/ha, 709,490Ksh/ha and 723,569.60 Ksh/ha. Tomatoes gave the highest returns of the three crops considered in the two seasons respectively. Water melon on the other hand emerged second and French beans were third in terms of financial returns on season basis. Annually, Tomatoes gave more while French beans and Water melons were second and third respectively.

The computed benefit-cost ratio for the three crops was greater than 1 indicating a profitable investment. Tomatoes had the highest benefit cost ratio for the two seasons considered followed by water melons and then French beans. It can therefore be concluded that smallholder pumped irrigation systems is a profitable investment.

A survey of the most preffered crops by smallholder farmers showed that French beans was highly preferred than the other two crops despite having lower returns. The reason why farmers preferred French beans over the others was due to the export market demand rather than for local market. The farmers highlighted that export market was more reliable as compared to local market. This indicates that crop production for export market still plays a significant role. Despite the numerous challenges faced while exporting the produce such as exploitation from the middlemen and at times lack of price awareness for the produce, farmers still gave it more emphasis.

The most limiting cost in producing the three crops was found to be fuel cost followed by harvesting costs and then topdressing fertilizer. This indicates the need for the farmers to monitor the fuel used during irrigation and ways of minimizing its use sought. Having the right size of the pump that matches the farm condition and one with high fuel use efficiency, right amount of water pumped matching crop water needs and right operation and maintenance of the irrigation equipments are among the major factors that should be considered to ensure more returns on investment for pumped irrigated agriculture.

4.3.8 Evaluation of overall seasonal energy cost (OSEC)

The OSEC for the crops whose gross margin analysis was done was evaluated. The values for the OSEC versus total cost of production (TCP) are shown in Table 4.19. The ratio of OSEC to TCP is also indicated in table 4.13.

Table 4.13. Comparison of OSEC to Total Cost of Production (TCP) in percent

	1st season			**2nd season**		
Crop	**OSEC (Ksh/ha)**	**TCP (Ksh/ha)**	**OSEC to TCP (%)**	**OSEC (Ksh/ha)**	**TCP (Ksh/ha)**	**OSEC to TCP (%)**
French beans	175,000	258,820	68	131,336	215,305.20	61
Water melons	94,796.70	166,310	57	89,521.50	172,157	52
Tomatoes	318,881.30	708,625	45	254,004.50	498,048	51

From table 4.13, over half of the total cost of production was found to result from energy used for pumping water during irrigation. OSEC is a function of different factors combined such as pump operating efficiency, fuel consumption rate of the pump, cost of fuel, volume of water pumped during irrigation, total dynamic head, transmission efficiency and power unit efficiency. In order to reduce the overall seasonal energy cost for any farming enterprise, all the above factors must be ensured to operate at optimal range. This reduced overall seasonal energy cost would subsequently result to increased net benefit of the farming enterprise.

In summary, smallholder pumped irrigated agriculture was found to be generally profitable and with a benefit cost ratio of greater than 1 for all the considered cases, it was hence beneficial. Significant improvement in income level, food security and employment creation seemed to be promoted by use of irrigated agriculture and with proper design.

4.4 Water use efficiency for smallholder pumped irrigation systems

4.4.1 Water conveyance and application methods commonly used by the farmers in the study area.

Before any detailed assessment of water use efficiency for smallholder pumped irrigation systems, the soil texture in the study sites was established and from the delineated map of the study area with soil overlaid in it as shown in figure 4.7 and 4.8 further description of the soil was enhanced (Appendix 1).

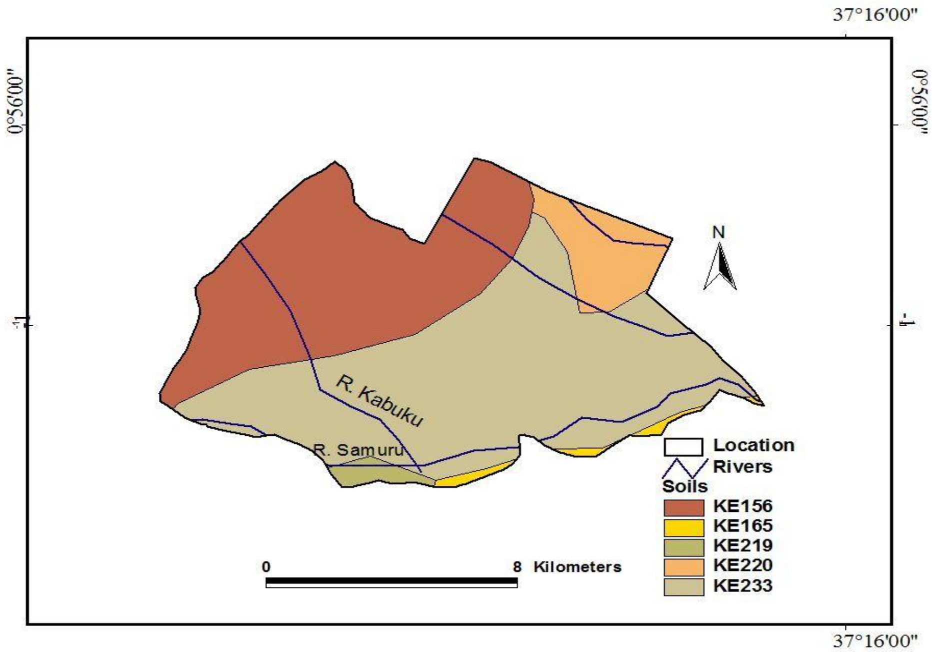

Figure 4.7. Mitubiri location showing rivers and soils of the area.

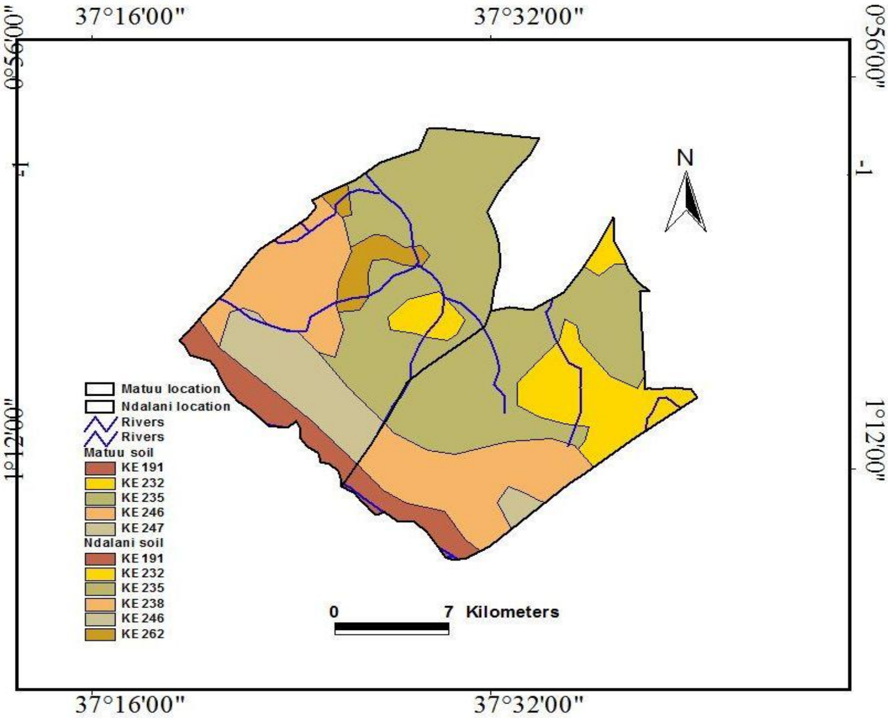

Figure 4.8. Kithimani sub location soil map.

Some of the most commonly used water conveyance and application methods used by smallholder farmers in the study area are shown in Plates 4.1, 4.2 and 4.3. The study revealed that 93.7% of the studied population used furrow irrigation methods while 1.3%, 2.5% and 2.5% used sprinkler, basin and bucket (hand watering) respectively. There was no drip irrigation in use in the study area.

Plate 4.1 (Water delivery in sub canal) and 4.2 (PVC pipe for water conveyance & drag hose for water application

Plate 4.3. Use of drag hose in water application

4.4.2 Issues regarding water usage in smallholder irrigated agriculture

An assessment of water problems experienced during crop production showed that 65% of the respondents experienced water shortages when the demand for horticultural produce both for local and export market was high. The two areas being in the ASAL regions, dependence on water from some of the seasonal rivers (Samuru and Yatta furrow) renders crop production throughout the year impossible unless augmented with irrigation. Over abstraction by upstream users due to unregulated water use observed could also further lead to lack of water for the downstream farmers. River Thika and

Kabuku which traverse through Mitubiri location were both permanent and assured crop production throughout the growing season. The residents in Kithimani sub location served by Yatta furrow which is seasonal only grew horticultural crops when there was water flow in the furrow.

From the sample population studied, only 5% of the farmers interviewed had acquired water permits while the remaining 95% didn't have. This is an indication that cases of unregulated water use and high abstraction rate by smallholder farmers could possibly occur leading to decreased river flows or possible drying up.

4.4.3 Water losses

4.4.3.1 Water losses during conveyance

Table 4.15 shows the detailed description of the 10 sample farms where detailed study on water use efficiency was done. In Kithimani sub location, the studied farmers pumped water from the Yatta furrow and channeled it through sub canals to their farms.

Water discharge rate along the sub canals were measured using the calibrated Parshall flume. The measured values for the Parshall flume shown in Table 4.14 aided in calibration process to generate the calibration curve shown in figure 4.9.

Table 4.14. Parshall flume readings during calibration.

B	D	H	K	Q	H
0.12	0.285	0.063	90.9	0.09	0.08
0.14	0.285	0.072	90.1	0.13	0.1
0.19	0.285	0.097	89.1	0.26	0.155
0.22	0.285	0.1156	89.1	0.40	0.207
0.23	0.285	0.1204	88.9	0.45	0.22

where B – Width of the waterway, (m), D – Depth of the ''V'' notch from the bottom of the waterway, (m), H – Water head on the V- notch, (m), K – Coefficient of discharge

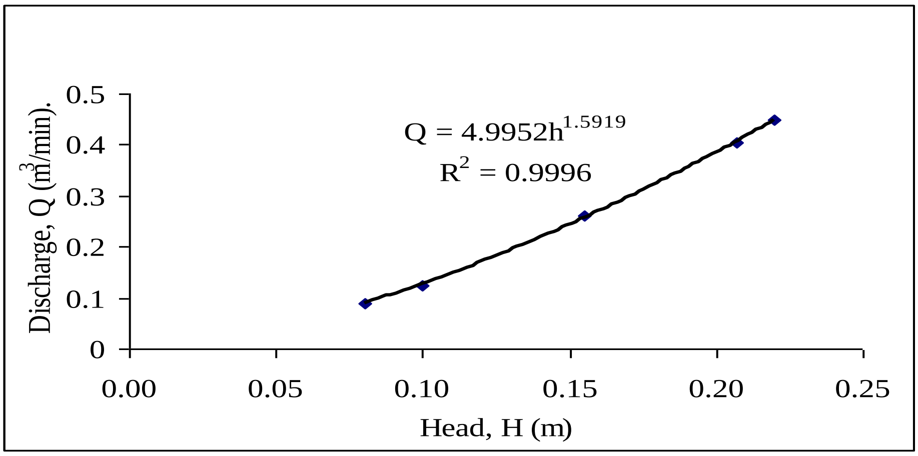

Figure 4.9. Calibration curve of the Parshall flume.

The generated equation 3.7 as shown in figure 4.9 aided in calculation of the water discharge rate along the Parshall flume and subsequent water conveyance losses in the subcanals as shown in table 4.15. Regression analysis of discharge (Q) and head (h) yielded a relationship given by equation 3.7 with high correlation coefficient of (R^2 = 0.9996).

Table 4.15. Detailed description of the experimental sites.

Farmer	Crop grown	Soil texture	Water source	Experimental plot size (m^2)	Pump model	Pump horsepower	Water delivery Mechanism	Water application Mechanism
F1	Maize	Sandy loam	Yatta furrow	25	Honda	5.5	Pipe/canal	Sub canal
F2	Maize	Clay	‘’	25	Mitsubishi	5.5	Pipe/canal	Sub canal
F3	Tomatoes	Loam	‘’	25	ETQ178F	6.6	Pipe/canal	Sub canal
F4	Tomatoes	Sandy loam	‘’	25	Robin	5.5	Pipe/canal	Sub canal
F5	Maize	Clay	‘’	25	Robin	5.5	Pipe/canal	Sub canal
F6	W/melon	Clay	R.Samuru	25	Koshin	4.0	PVC Pipe	Hose Pipe
F7	Tomatoes	Clay loam	R.Samuru	25	Koshin	4.0	PVC Pipe	Hose Pipe
F8	F/beans	clay Loam	R.Kabuku	25	Honda	5.5	PVC Pipe	Hose Pipe
F9	F/beans	Loam	R.Samuru	25	Koshin	4.0	PVC Pipe	Hose Pipe
F10	F/beans	Loam	R.Kabuku	25	Honda	5.5	PVC Pipe	Hose pipe

Water losses during conveyance carried out in 5 sample farms in Kithimani sub location of Yatta district is shown in table 4.16. These sites had different soil types as shown in figures 4.7 and 4.8.

Table 4.16. Water conveyance losses in 5 sample farms in Kithimani sub location of Yatta district.

Farms	Soil texture	Sub canal length (m)	Sub canal width (m)	Conveyance losses ($m^3/m^2/hr$)	Average irrigation duration (hrs) per irrigation	Conveyance loss/irrigation for whole canal length (m^3)	Conveyance efficiency (%)
F1	Sandy loam	50.00	0.30	0.11	5.60	9.24	73.74±5.93
F2	Sandy clay	30.00	0.40	0.07	7.10	5.96	87.40±3.43
F3	Sandy clay	50.00	0.40	0.08	7.40	11.84	77.90±5.52
F4	Loam	25.00	0.30	0.12	4.00	3.6	90.74±3.32
F5	Sandy loam	40.00	0.35	0.12	7.25	12.18	77.30±9.24
					average water lost/irrigation	8.56	81.42%

Mean ± STDEV

The results shown in table 4.16 indicates that the average water conveyance efficiency was 81.42%. This was particularly high with only very little water being lost through seepage. The differences in soil structural formation seemed to have less effect on water seepage losses.

4.4.1.2 Water losses during application

Water losses during application was computed for 10 irrigation setups growing horticultural crops. The available water storage capacity (mm/m) for different soils were determined from the generated pF curves shown in Figure 4.10 and the results are shown in Table 4.17. The pF curve shows the pF values versus volumetric moisture content that were derived.

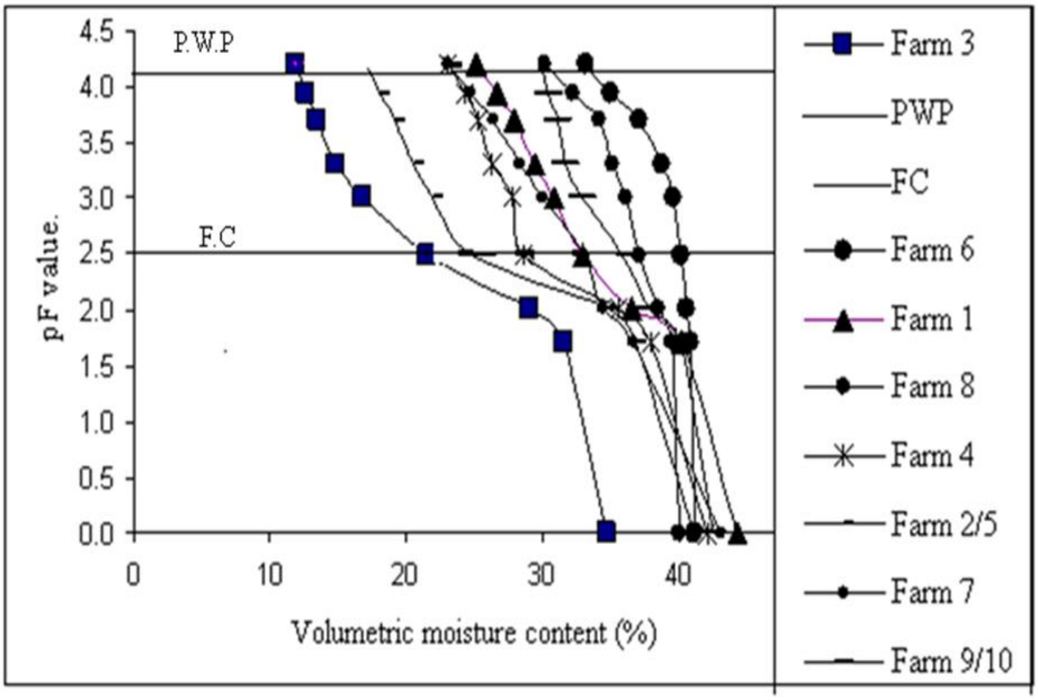

Figure 4.10. pF values versus gravimetric moisture content

Table 4.17. Available water storage capacity (AWSC), (mm/m) determined for the different soil samples from the experimental sites.

Soil sample	1	2	3	4	5	6	7	8
AWSC (%)	7.0	6.9	5.6	6.0	9.9	7.8	7.8	9.5
AWSC (mm/m)	70	69	56	60	99	78	78	95
Farmer setup	F8	F6	F4	F9/F10	F7	F2/F5	F1	F3

The soil moisture in the 10 sample farms was measured using calibrated tensiometers inserted at 15cm depth. The calibration curve developed and aided in computation of soil moisture content is shown in figure 4.11.

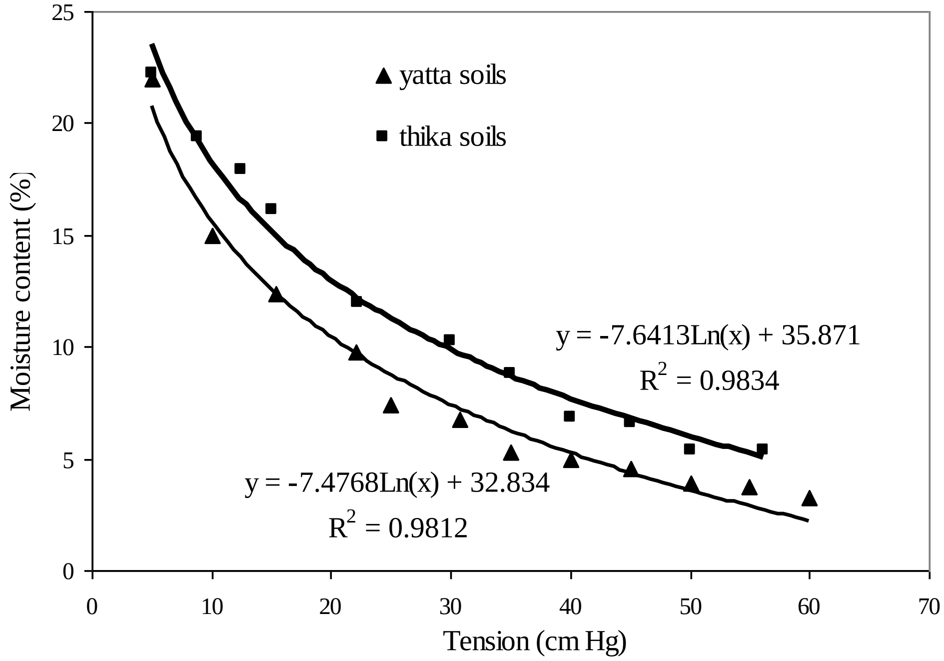

Figure 4.11. Calibration curve for soils in Yatta and Kakuzi divisions.

The relationship between tension in cm Hg units and gravimetric moisture content as a percentage is given in equation 4.1 and 4.2 respectively:

$y = -7.48\ln(x) + 32.83$ (for soils in Yatta district) 4.1

$y = -7.64\ln(x) + 35.871$ (for soils in Thika district) 4.2

where y = volumetric moisture content (%), x = soil tension (cm Hg)

The coefficient of correlation (R^2) for data obtained in this calibration of the tensiometers was 0.9834 and 0.9812 for soils in Thika district and Yatta district respectively which are high correlation.

Table 4.18 shows the average amount of water applied at different crop growth stages per every irrigation in the study sites.

Table 4.18. Average amount of water applied at different crop growth stages per every irrigation.

Farm	Crop Spacing (cm)	Furrow size		Total furrow	Water applied at different crop growth stages per irrigation, (mm)		
		Length, (m)	Width, (m)	Area (m^2)	Initial	Development	Late
F1	30*50	2010	0.15	301.5	130±5	125±2.8	70±3.3
F2	30*45	6690	0.2	1338	75±6.5	80±3.7	65±5.1
F3	45*60	1667	0.3	500	50±6.6	120±2.1	82±4.5
F4	45*60	16667	0.3	500	56±5.4	76±4.0	68±2.6
F5	30*45	2223	0.25	556	43±7.3	110±5.4	55.8±5.3
F6	70*160	625	0.45	281	29.5±4.1	46.3±3.3	59±2.9
F7	45*60	5000	0.25	1250	37±3.3	32±4.1	36±4.4
F8	5*30	6667	0.15	1000	33±2.5	30±2.4	44±2.2
F9	5*30	3333	0.14	467	55±2.7	81.8±4.4	62±3.0
F10	5*45	6667	0.16	1067	51±4.4	113±5.0	108±2.0

Mean ± STDEV

The irrigation interval for baby corns was found to be 7days in all the cases considered while that of Watermelon, Tomatoes and French beans were 4 days per week respectively. The application efficiency results for the different crops at different crop growth stages are shown in Table 4.19.

Table 4.19. Mean values for water application efficiency for the entire crop growing period.

Crop	Percent mean value for water application efficiency for different crops
Baby corns	19.5±4.1
French beans	25.4±9.3
Tomatoes	26.3±14.1
Water melon	30.0±6.3
Average	**25.5**

Mean ± STDEV

On average, it can be noted that water application efficiency is quite low hence high water losses during crop production. The results indicated that farmers over irrigated their crops hence loosing much water either through infiltration or deep percolation. Apart from the occurrence of environmental degradation such as rise in soil salinity levels, water logging, soil erosion and imbalances in the ecosystem as a result of water misuse, other negative effects that would arise are high operating costs of the irrigation systems. Every litre of water pumped means some fuel used and subsequent cost incurred. Excess water pumped hence means more fuel used than would be envisaged and extra cost of hiring irrigation labour. The extra time wasted running the pump in the long run amounts to increased pump depreciation rate and decreased operational life of the pump. The overall result of inefficient water use during irrigation therefore culminates to rise in cost of production leading to any farming enterprise becoming unprofitable or only marginally profitable.

4.4.4 Water conservation methods used

Figure 4.12 shows the water conservation methods used by farmers in the two study areas. Out of the 80 farmers studied, 22% of them adopted mixed cropping with the result of exposing very little land to open sun hence reduces effects of surface water evaporation. Only 17% of the farmers surveyed practiced conservation agriculture with the most common methods found being zero tillage, mulching and intensive use of herbicides. Use of organic manures as represented by 30% of the farmers also ensured that water was being conserved at farm level. Organic manure increases water holding capacity of the soil while boosting the soil fertility.

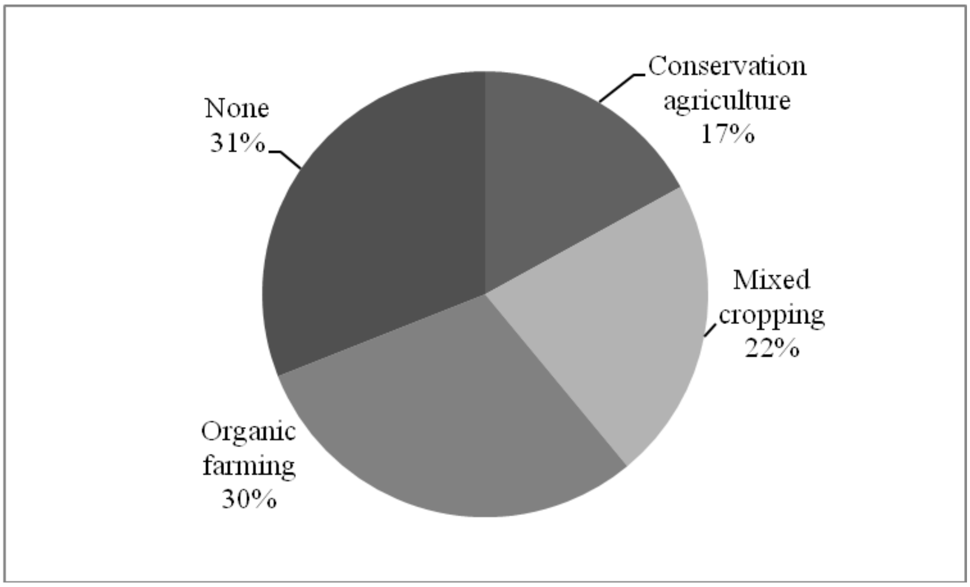

Figure 4.12. Water conservation methods used at farm level in the study areas.

4.5 developed optimal design for smallholder irrigation system

The results of the computed pump power required for the three irrigation systems considered under different elevations are shown in tables 4.20, 4.22 and 4.25.

4.5.1 Open irrigation system

The open irrigation system design included use of a pump connected to pipes conveying water to sub canals and then to furrow system.

Table 4.20. Calculated Pump power required for different elevations.

Elevation (m)	Q (m^3/hr)	T.D.H	Ep (%)	Pump Power (Kw)	Pump Power (hp)
0	9.72	13.5	60	0.729	1.0
5	9.72	18.5	60	0.999	1.4
10	9.72	23.5	60	1.269	1.7
15	9.72	28.5	60	1.539	2.1

With an assumed optimum pump efficiency of 60%, the pump horsepower under different farm elevations varied from 1.0hp for an elevation of 0 metres to 2.1hp for an elevation of 15m. During the study, the most common pumps available in the market ranged from 4.0 to 6.5 horsepower. This means that availability of low powered pumps was not currently guaranteed with the farmer still relying on only available pumps. Pump inlet and outlet diameters was considered to be 36mm for all the farm elevations considered to guarantee the water flow requirements. This hence prompted the selection of pipes of similar size. PVC types of pipes of class B which are generally available in the market were selected for the optimal irrigation system design.

Table 4.21 summarizes the requirements for the ideal design for an open irrigation system under different elevations.

Table 4.21. Optimal design for an open irrigation system.

Elevation (m)	Specification									Remarks
	Pump				Delivery pipes			Suction pipe		
	Type	Horse power	Discharge Rate, Q (m^3/hr)	Type	class	Diameter (mm)	No. of Pipes	Length (m)	Diameter (inches)	
0	Centrifugal	1	9.72	PVC	B	36	12	3	1.5	Low pressure pump required Allowable pipe flow rate =1.5m/s
5	Centrifugal	1.4	9.72	PVC	B	36	12	3	1.5	Low pressure pump required Allowable pipe flow rate =1.5m/s
10	Centrifugal	1.7	9.72	PVC	B	36	12	3	1.5	Low pressure pump required Allowable pipe flow rate =1.5m/s
15	Centrifugal	2.1	9.72	PVC	B	36	12	3	1.5	Low pressure pump required Allowable pipe flow rate =1.5m/s

With the farm elevations provided, a suitable pump can be selected as well as the pipes required in terms of size and quantity for water delivery. The irrigation components can be selected from table 4.25.

4.5.2 Closed irrigation system

This irrigation design included use of a pump connected to pipes conveying water to a hosepipe and then applied to furrow system. From the study area, 65% of the smallholder farmers interviewed used this system. The calculated pump power required for different elevations are shown in table 4.22.

Table 4.22. Calculated Pump power required for different elevations.

Elevation (m)	Q (m^3/hr)	T.D.H (m)	Ep (%)	Pump Power (Kw)	Pump Power (hp)
0	9.72	10.67	60	0.50922	0.7
5	9.72	15.67	60	0.77922	1.1
10	9.72	20.67	60	1.04922	1.4
15	9.72	25.67	60	1.31922	1.8

With an assumed optimum pump efficiency of 60%, the pump horsepower under different farm elevations varied from 0.7 for an elevation of 0 metres to 1.8 for an elevation of 15m. During the study, the most common pumps available in the market ranged from 4.0 to 6.5 horsepower. This means that availability of low powered pumps was not currently guaranteed with the farmer still relying on only available pumps. Pump inlet and outlet diameters was considered to be 36mm for all the farm elevations considered to guarantee the water flow requirements. This hence prompted the selection of pipes of similar size. PVC types of pipes of class B which are generally available in the market were selected for the optimal irrigation system design. Table 4.23 summarizes the requirements for the ideal design for a closed irrigation system under different elevations.

Table 4.23. Ideal design for a closed irrigation system

Elevation (m)	Specification									Remarks
		Pump		Delivery pipes				Suction pipe		
	Type	Horsepower	Discharge rate (m^3/hr)	Type	class	Diameter (mm)	No. of Pipes	Length(m)	Diameter (inches)	
0	Centrifugal	0.7	9.72	PVC	B	36	10	3	1.5	Low pressure pump required Allowable pipe flow rate =1.5m/s
5	Centrifugal	1.1	9.72	PVC	B	36	10	3	1.5	Low pressure pump required Allowable pipe flow rate =1.5m/s
10	Centrifugal	1.4	9.72	PVC	B	36	10	3	1.5	Low pressure pump required Allowable pipe flow rate =1.5m/s
15	Centrifugal	1.8	9.72	PVC	B	36	10	3	1.5	Low pressure pump required Allowable pipe flow rate =1.5m/s

Irrigation components (pumps and pipes) can be selected from table 4.26. The determining factor for component selection is the elevation head.

4.5.3 Sprinkler irrigation system

The computed results for the sprinkler irrigation system are shown in table 4.24 while the pump power required for different elevations are shown in table 4.25. The result shows that pumps of lower horsepower were most ideal in operating these irrigation systems. This further indicated that they were also applicable under different farm elevations.

Table 4.24. Computed results for the sprinkler irrigation system

Item	Calculated value
Water application rate	7.3 mm/hr
Number of hours of irrigation per week	7.4 hours
Scheme water requirement	1.34 l/s
Easily available moisture	48mm – 60 mm
Application rate for one block	46.8mm
Number of sprinklers required	6
Required capacity of the pump and the mainline	1.22 l/s

Table 4.25. Different head and calculated Pump power required for different elevations.

Elevation (m)	Suction head (m)	Sprinkler headloss (m)	Friction headloss (m)					T.D.H (m)	Pump Power required (hp)
			Suction headloss	Main pipeline	Lateral line	Couplers	Fittings		
0	3	21	0.5	2.7	2.8	1	1	32	1.23
5	3	21	0.5	2.7	2.8	1	1	37	1.42
10	3	21	0.5	2.7	2.8	1	1	42	1.61
15	3	21	0.5	2.7	2.8	1	1	47	1.80

Table 4.25 summarizes the requirements for the ideal design for a sprinkler irrigation system under different elevations.

The summary of the ideal design options for sprinkler irrigation system for 1 acre plot for varying elevations of o% to 15% is presented in table 4.26.

Table 4.26. Ideal design for a sprinkler irrigation system.

Elevation (m)	Specification										Fittings	Remarks
	Pump			Delivery pipes					Suction pipe			
	Type	Horse power	Discharge rate (m^3/hr)	Type	class	Diameter (mm) Mainline	Diameter (mm) Lateral line	No. of Pipes	Length (m)	Diameter (inches)		
0	Centrifugal	1.23	1.73	uPVC	4	63	50	9-Main line and 9 lateral	3	2	6 Sprinklers; nozzles: Size= 2.8*2.5mm, Pressure = 2.1kg/m^2 Couplers; 6 pieces, 1 ½ " diameter Risers: 1m length, ½ ’’ diameter	Low pressure sprinklers required. Low pressure pump required.
5	Centrifugal	1.42	1.76	uPVC	4	63	50	9-Main line and 9 lateral	3	2	6 Sprinklers; nozzles: Size=2.8*2.5mm , Pressure = 2.1kg/m^2 Couplers; 6 pieces, 1½ " diameter Risers: 1m length, ½ ’’ diameter	Low pressure sprinklers required. Low pressure pump required.
10	Centrifugal	1.61	1.79	uPVC	4	63	50	9-Main line and 9 lateral	3	2	6 Sprinklers; nozzles: Size= 2.8*2.5mm, Pressure = 2.1kg/m^2 Couplers; 6 pieces, 1 ½ " diameter Risers: 1m length, ½ ’’ diameter	Low pressure sprinklers required. Low pressure pump required.
15	Centrifugal	1.80	1.82	uPVC	4	63	50	9-Main line and 9 lateral	3	2	6 Sprinklers; nozzles: Size=2.8*2.5mm , Pressure = 2.1kg/m^2 Couplers; 6 pieces, 1 ½ " Diameter Risers: 1m length, ½ ’’ diameter	Low pressure sprinklers required. Low pressure pump required.

With an assumed optimal pump efficiency of 60%, the pump horsepower under different farm elevations varied from 1.23 for an elevation of 0 metres to 1.80 for an elevation of 15m. By determining the elevation of the farm, suitable pump with an optimal horsepower can easily be got from table 4.26. The number as well as the sizes of pipes required and sprinkler specifications and accessories can also be read from table 4.26. Smallholder farmers with farms having elevations not exceeding 15m can significantly benefit from the findings recorded in table 4.26 without the need of hiring an engineer to do the design for their farms.

Despite the need for the low powered centrifugal pumps, their availability in the Kenyan market was not guaranteed with the most common ones ranging from 4.0 to 6.5 horsepower. This hinders smallholder farmers in getting the right pump that matches their field condition. The more the power a pump has, the more the fuel use on one hand and the less the portability they are.

Several specifications of sprinklers exists in the market ranging from mini, micro, medium and high pressure sprinklers. Medium sprinklers were selected with a specified pressure of 2.1 kg/m^2 and a nozzle size of 2.8 x 2.5 mm.

The farm layout shown in figure 3.4 would also guide the farmer in layout of the system components and ensures that the farmer fully understands the design suitable for the farm.

CHAPTER 5

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The increased uptake of smallholder pumped irrigated agriculture has offered a multiple of solutions for many small holder farmers in producing food for domestic use and excess for market as well as job creation. Pump fed irrigated agriculture results to more food production and bigger land coverage than the normal use of traditional methods such as bucket irrigation.

This study found out an increased uptake of pumping technologies in Kakuzi and Yatta divisions with increased irrigation of horticultural crops. The two areas being in the semi arid zone, rain fed agriculture is unreliable and unless augmented by irrigated agriculture, food shortage would be experienced. The study found out that over 80% of the studied population practiced supplemental irrigation. Pumping of water from the river and channeling it using pipes and later applying it by drag hose to well made furrows was widely practiced by over 94% of the farmers assessed.

Small motorized pumps with horsepower ranging from 4.0 to 6.6 were widely used by the farmers and an assessment of their operating efficiency showed that 60% operated below their optimal efficiency range. An evaluation of power requirement for pumping water in the 10 farm setups considered showed that all the pumps used were oversized i.e. their power ratings was more than what was required. uPVC pipes were commonly used in water conveyance. Energy losses in the water conveyance pipes showed that 60% of the systems evaluated had head losses exceeding the design range. Poor performance of smallholder irrigated agriculture could be attributed to a number of issues with the most common one being lack of technical assistance during irrigation system component selection, design and operation.

The gross margin analysis of pumped irrigated agriculture showed high returns from horticultural crop production. The three crops considered i.e. Tomatoes, Water melons and French beans all had high returns per hectare of land though the returns from each crop were different. The Benefit Cost Ratio (BCR) calculation also shows the smallholder pumped irrigated agriculture to be beneficial as the BCR value obtained is higher than one, as any project whose BCR value is higher than one is taken as a good investment. Despite high returns from irrigated horticultural production, poor markets for the produce fetching low prices was very common as cited by 80% of the studied population. High energy costs (fuel) further aggravated the situation as indicated by 65% of the respondents. The calculations showed that over half of the total cost of production resulted from energy use.

A study on water use efficiency for smallholder irrigated agriculture showed that water application efficiency was quite low with a mean of 19.5% to 30% while water conveyance was quite high being 81.42%. A survey of measures taken to reduce water losses at farm level showed laxity on government side in regulating water use with only 5% of the studied population having water permits. On the other hand, lack of technical assistance for the farmers to guide them on irrigation scheduling and right amount of water to apply was also common. Due to the low water use efficiency, water shortages could have resulted and 79% of the respondents experienced water shortage during critical growth periods of the crops.

With an aim of making smallholder irrigated agriculture to be profitable, an ideal design kit was developed for 1 acre plot with varying heads ranging from 0% to 15%. The ideal design kit showed that less powered pumps in the range of 0.7 to 2.1 horsepower which were not available in the Kenyan market were more suitable for smallholder irrigated agriculture.

In conclusion, smallholder pumped irrigated agriculture is a viable investment with high returns on investments. They guarantees increased food production as well as increased land under production with high productivity per unit area of land. With increase in population, increase in food supply is needed while the increasing pressure on land and water resources, modern irrigation technologies needs to be promoted. Despite the many challenges faced by farmers practicing pump fed irrigated agriculture, it was found to be a worthwhile investment.

5.2 Recommendations

1. Irrigated agriculture being a multi purposed project, it requires expertise in many fields, including technical, marketing and training packages. Hence human resources development should be focused accordingly. Trainings and exposure visits for the concerned and responsible government, NGOS's and private institutions should be stepped up.
2. As pumped irrigated agriculture is still a new concept to many, there is a necessity of more awareness and knowledge sharing programmes at local, regional and national level. Hence creating knowledge sharing platform on smallholder irrigated agriculture is recommended.
3. Monitoring visits from the experts should be conducted regularly in areas where smallholder pumped irrigated agriculture is practiced so that farmers can share their problems and challenges with them. This will further help the users towards good production.
4. Potential water conservation opportunities (like Rain water harvesting etc) at the local level to meet increased water demand or to prevent from potential risk of source dry up should be explored and promoted accordingly.
5. Clearly defined policies regarding water use for agricultural production are needed as guidelines for farmers and key stakeholders in the agricultural sector. Water tariffs and permits need to be strengthened to reduce on water withdrawals and subsequent water losses.

6. Due to the unavailability of less powered pumps (horsepower less than 2) in the Kenyan market, a research should be carried out to assess their suitability as well as their applicability during irrigation.
7. Further study on the effect of introduction of water tariffs and permits on agricultural water use efficiency need to be carried out.
8. A large sample size of pumps should be studied to establish their performance.

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APPENDICES

Appendix 1.The major soils of Mitubiri location and their characteristics.

Soil type	Description	Soil characteristics	Where found
KE 233	nito-rhodic FERRALSOLS	Well drained, very deep, dark red, very friable clay	Mitubiri, Kititu
KE156	eutric NITISOLS; with nito-chromic CAMBISOLS and chromic* ACRISOLS, partly pisofferic or petro ferric phase)	well drained, extremely deep, dusky red to dark reddish brown, friable clay; with inclusions of well drained, moderately deep, dark red to dark reddish brown, friable clay over rock, pisoferric or petroferric material	Samuru, Mitubiri
KE219	eutric FLUVISOLS	well drained to imperfectly drained, very deep, brown to dark brown, friable, micaceous, slightly calcareous, sandy loam to clay loam; in places with a saline-sodic deeper subsoil	
KE220	Pellic VERTISOLS, stony phase and partly saline phase	imperfectly drained , very deep, dark grey to black, firm to very firm, bouldery and stony, cracking clay; in places with a calcareous, slightly saline deeper subsoil	Mitubiri

Appendix 2.The major soils of Matuu location and their characteristics.

Soil type	Description	Soil characteristics	Where found
KE246	ferralic ARENOSOLS; with ferralo-chromic/orthic LUVISOLS	complex of well drained, deep to very deep, reddish brown to dark yellowish brown soils of varying consistence and texture; in places gravelly and stratified	
KE235	Nito-rhodic FERRALSOLS and chromic CAMBISOLS, lithic and/ or bouldery phase).	complex of well drained, shallow to very deep, dark red, friable clay,; in many places rocky and bouldery	Ndalani Matuu Kinyaata
KE191	ferralo-chromic*/orthic/ferric ACRISOLS; with LUVISOLS and FERRALSOLS).	well drained, moderately deep to very deep, dark reddish brown to dark yellowish brown, friable to firm, sandy clay to clay; in many places with a topsoil of loamy sand to sandy loam	Ndalani Matuu Kinyaata
KE238	(rhodic and orthic FERRALSOLS) with ferralo-chromic */orthic/ferric ACRISOLS).	well drained, moderately deep to deep, dark red to yellowish red, friable, sandy clay loam to clay	Ndalani

Appendix 2. The major soils of Matuu location and their characteristics (continued).

KE232	pellic VERTISOLS;	complex of well drained	Ndalani

	with verto-eutric NITISOLS, verto-eutric PLANOSOLS and orthic SOLONETZ, partly lithic phase).	to imperfectly drained, shallow to very deep, dark red to black, friable to firm, cracking clay; in places sodic	Matuu Kinyaata

Source: MOA (1998)

Appendix 3. Questionnaire for survey on socio-economic status of smallholder farmers in Mitubiri location and Kithimani sub location.

Form 1: farm identification

Farm ID	
District	
Division	
Location	
Sub location	
Village	
Farm northing	
Farm easting	

Form 2: Background information

Name of key respondent (informant)

Household head: ☐ M ☐F 3. Age of household head

4. Household head marital status

☐Single ☐widow(er) ☐separated ☐married spouse present ☐married spouse absent

5. Family size 6. Number of family members staying in the farm

7. What is the staple food?

8. Number of months the staple food is able to feed the family

Form 3: agricultural activities

1. List of different crops grown in your farm

2. Do you maintain farm records for all your activities? Circle ☐ yes ☐ no

3. Which are the most preferred crops grown in your farm for income generation?

4. What are the different varieties planted for the above crops?

5. Where do you buy your inputs i.e. seeds, fertilizers, chemicals, fuel e.t.c?

6. How much transport costs do you incur while sourcing for these inputs?

7. Where do you sell the produce from your farm?

8. What is the acreages covered by each crop planted?

9. What is the total production from your farm for the crops planted?

10. What is the price per kilogramme of your farm produce?

11. What tillage method do you practice during land preparation? Circle

☐Hand digging ☐jembe/ fork/hoe ☐tractor ☐animal drawn plough ☐panga

☐Minimum/zero tillage ☐spraying with herbicides

12. What is the cost of ploughing an acre of land considering the method you use?

13. Do you do bush clearing? Circle ☐yes ☐no

14. What is the cost of bush clearing?

15. Which planting methods do you use? Tick as appropriate, ☐ panga, ☐ stick

☐Mechanized system

16. What is the cost of planting one acre considering the method used?

17. Which method of planting do you use in your farm? Circle, ☐furrow ☐basin

☐Planting holes ☐zai pits.

18. What is the cost of weeding an acre of land?

19. Do you spray your crops with suitable chemicals? Circle, ☐ yes ☐no

20. At what stage of crop development do you spray each chemical?

21. What is the cost of spraying an acre of land?

22. What is the spraying device used? Circle

☐Knapsack ☐branches ☐any other, specify.

23. What is the mixing ratio of the chemicals used with water?

24. What is the area that can be covered by one knapsack?

25. What is the cost of chemicals sprayed?

26. Which methods of harvesting do you use in your farm? ☐Hand picking, ☐machine

27. What is the cost of harvesting one kilogramme of the crops grown?

28. What is the cost per kilogramme of seeds planted in your farm?

29. How much seed do you plant per acre of land?

30. Do you apply fertilizers in your farm? Circle, ☐yes ☐no

31. What type of fertilizer do you use?

☐DAP ☐TSP ☐NPK ☐CAN ☐ any other

32. What is the application rate of the fertilizer used per acre of land?

33. What is the cost of fertilizer used per kilogramme?

34. What is the cost of transporting your produce to the market?

Form 4. Irrigation practices

35. Do you irrigate your crops?

36. What method of water application do you use? ☐Furrow, ☐basin, ☐pits

37. What is the labour cost incurred in irrigating one acre of land considering the method of irrigation used?

38. How often do irrigate your farm? Circle, ☐once a week, ☐ twice a week, ☐, thrice a week ☐ any other- specify.

39. What is the method of irrigation used in your farm? Circle, ☐bucket, ☐sprinkler ☐ drip, ☐hosepipe.

40. What is the irrigation set up used in your farm?

☐Pump-pipes-sprinklers ☐ pump-pipes – hosepipe – furrow ☐Pump – pipe – furrow ☐ pump- pipes – hosepipe – basin ☐ pump- pipes– basin ☐ Pipe- canal – furrow

☐Bucket ☐ Drip

41. What type of pump do you use?

42. What type of fuel do you use? Circle, ☐paraffin ☐petrol ☐diesel ☐any other

43. When do you replace the used engine oil from your pump? Circle ☐after two weeks

☐After three weeks ☐after one month ☐any other, specify.

44. Where do you buy the irrigation inventories?

45. How do you decide which type of irrigation equipment to buy?

46. What is the most limiting factor in irrigated agriculture?

☐Fuel ☐seeds ☐chemicals ☐ pumps ☐pipes ☐hosepipe ☐labour

47. Do you have any water saving technologies in you farm? Circle

☐Mulching ☐conservation agriculture ☐mixed cropping ☐use of organic manure.

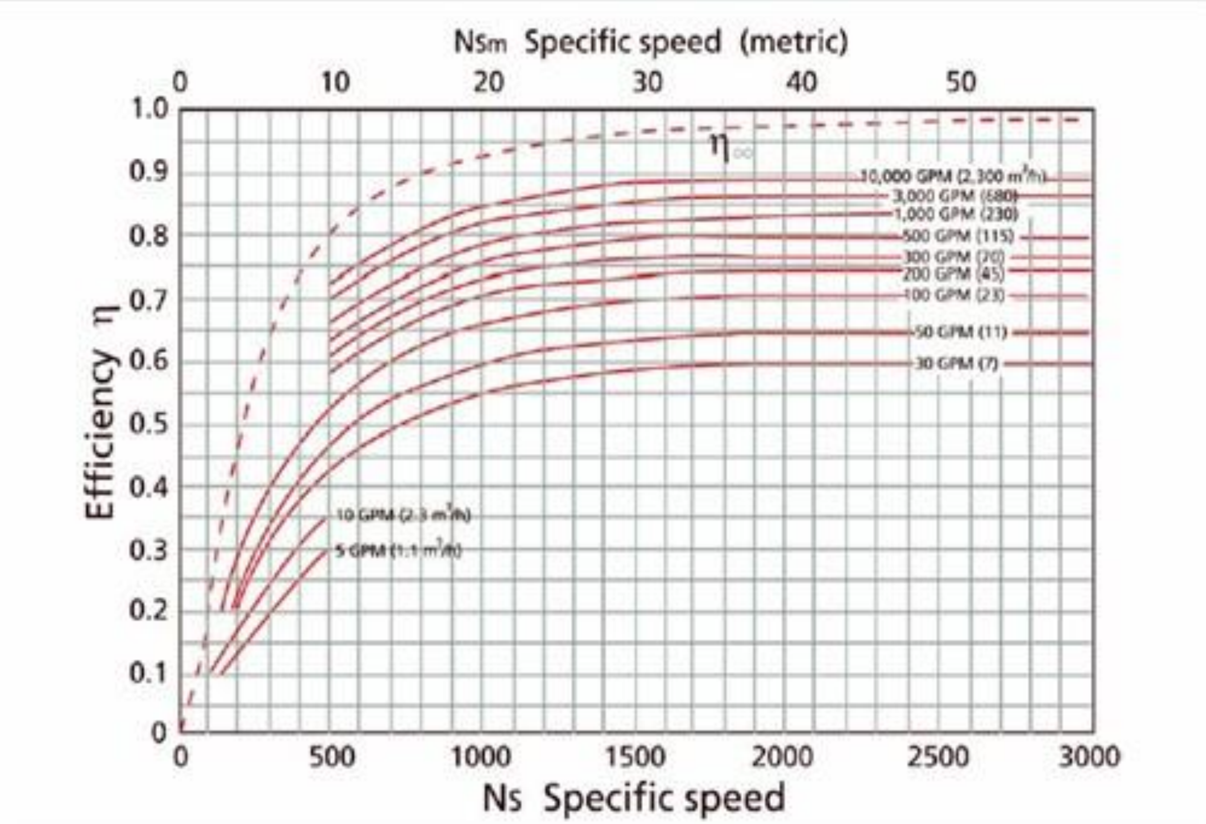
Appendix 4. Technical specifications of pumps found in the field (specifications in English units).

Pumps	Model	Pump Make	Horse power	Suction ø	Discharge ø	Maximum suction	Total	Pump Speed	Maximum capacity	Origin	fuel consumption
				(inches)	(inches)	Head (m)	Head (ft)	(RPM)	L/min		rate, (L/hr)
F1	BX30	Honda -GX160	5.5	3.0	3.0	8.0	92.4	3600	1100	Japan	1.25
F2		Honda	5.5	3.0	3.0	8.0	-	4000	-	Japan	1.25
F4	DP3C-4	Honda	6.6	3.0	3.0	14.5	82.0	3600	-	China	1.50
F8	PTG205	Robin	5.5	2.0	2.0	8.0	105.0	3600	520	Japan	1.25
F10	PTG205	Robin	5.5	2.0	2.0	8.0	105.0	3600	520	Japan	1.25
F6		Koshin	4.0	1.5	1.5	6.0	-	3600		Japan	0.90
F7		Koshin	4.0	1.5	1.5	6.0	-	3600		Japan	0.90
F3	SCR-80HX	Honda	5.5	3.0	3.0	8.0	105.0	3600	1000	Japan	1.25
F9		Koshin	4.0	1.5	1.5	7.0		3600		Japan	0.90
F5	SCR-80HX	Honda	5.5	3.0	3.0	8.0	105.0	3600	1000	Japan	1.25

Source (Davis and Shirtliff and Honda Atlas Power Products (pvt) ltd. (HAPPL)

Note: The fuel consumption rate of the pumps are the values when the pump is operated at full throttle.

Appendix 5. The graph of pump efficiency showing the pump specific speed.



Appendix 6. Friction loss tables for PVC and GI pipes of different classes and sizes.

DAVIS & SHIRTLIFF PRODUCT MANUAL: TECHNICAL REFERENCE

TABLE 1: PVC AND GI FRICTION LOSS TABLES

HEAD LOSS IN METRES PER 100m FOR DIFFERENT CLASSES OF PVCAND GI PIPES

Flow (m³/h)	¾"			1"			1¼"			1½"				2"				2½"				3"				
	PVC		GI	PVC		GI	PVC		GI	PVC			GI	PVC			GI	PVC			GI	PVC				GI
1	D	E		D	E		D	E		C	D	E		C	D	E		C	D	E		B	C	D	E	
1.5	2.4	3.2	8.0			1.9			1.5																	
2	5.0	6.8	17.8	1.6	2.2	4.2			2.6																	
2.5	8.6	11.5	31.9	2.8	3.8	7.5	1.3	1.8	3.9				1.5													
3	12.9	17.4	49.8	4.2	5.7	11.6	2.0	2.7	5.7				2.3													
3.5	19.0	25.8	71.7	6.2	8.4	17.7	2.7	3.7	8.0	1.2	1.4	1.9	3.3													
4				8.5	11.6	25.2	3.5	4.7	10.3	1.5	1.8	2.4	4.3				1.0									
5				10.8	14.8	32.7	4.9	6.7	15.5	2.2	2.6	3.5	6.3				1.5									
6				15.5	21.3	50.5	6.9	9.3	21.7	3.1	3.6	4.9	9.0	1.0	1.2	1.6	2.1									
7				21.6	29.6	72.7	9.2	12.5	29.3	4.1	4.7	6.5	12.3	1.4	1.6	2.2	2.9									
8				28.8	41.8	98.9	11.5	15.6	38.8	5.1	5.9	8.1	15.6	1.7	2.0	2.7	3.7				1.2					
9							14.4	19.6	49.1	6.4	7.5	10.2	20.0	2.1	2.5	3.4	4.7				1.6					
10							17.5	23.8	60.7	7.8	9.0	12.4	24.6	2.6	3.0	4.1	5.8				1.9					
12								33.3	87.4	10.8	12.6	17.3	35.3	3.6	4.2	5.8	8.4	1.2	1.4	1.9	2.7					1.1
14										14.3	13.9	22.9	48.3	4.8	5.6	7.6	11.5	1.6	1.8	2.5	3.7					1.5
16										18.3	25.9	29.3	63.0	6.1	7.2	9.8	16.2	2.0	2.3	3.2	5.0					2.0
18														7.6	8.9	14.4	20.9	2.5	2.9	4.0	6.3	1.0	1.0	1.3	1.8	2.5
20														9.2	10.8	18.7	25.6	3.0	3.5	4.9	7.6	1.2	1.4	1.6	2.2	3.1

Flow (m³/h)					2"				2½"				3"					4"					6"			
					PVC			GI	PVC			GI	PVC				GI	PVC				GI	PVC			GI
					C	D	E		C	D	E		B	C	D	E		B	C	D	E		B	C	D	
20					9.2	10.8	18.7	25.6	3.0	3.5	4.9	7.6	1.2	1.4	1.6	2.2	3.1									
25					13.9	16.2	28.7	37.3	4.5	5.3	7.4	12.0	1.8	2.1	2.4	3.3	4.8					1.1				
30									6.4	7.5	10.4	17.2	2.5	2.9	3.4	4.7	6.9					1.7				
35									8.5	9.9	13.8	23.2	3.4	3.8	4.5	6.2	9.3	1.0	1.1	1.3	1.8	2.3				
40									10.9	12.5	17.7	30.3	4.3	4.9	5.8	8.0	12.2	1.2	1.4	1.7	2.3	2.9				
45									13.6	16.3	22.0	38.2	5.4	6.1	7.2	9.9	15.4	1.5	1.8	2.1	2.9	3.7				
50														7.5	9.2	12.0	19.0	1.9	2.2	2.5	3.5	4.6				
60														10.7	13.1	17.2	27.6	2.7	3.1	3.6	5.0	6.5				
70														14.3	17.8	23.0	37.3	3.6	4.1	4.8	6.7	8.8				1.2
80														17.8	23.3	28.8	48.7	4.5	5.2	6.1	8.4	11.5				1.5
90																		5.6	6.5	7.6	10.9	14.6				1.9
100																		6.8	7.9	9.2	13.5	18.0	1.0	1.2	1.4	2.4
120																		9.5	11.0	13.6	19.5	25.9	1.4	1.7	1.9	3.4
140																							1.9	2.2	2.6	4.7
160																							2.4	2.8	3.3	6.3
180																							3.0	3.5	4.1	7.9
200																							3.6	4.2	5.0	9.5
225																							4.5	5.3	6.2	11.4
250																							5.5	6.4	7.8	15.0

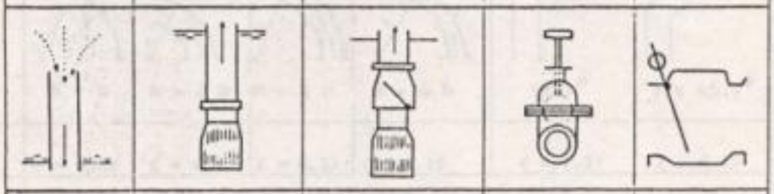
Source; Davis and Shirtliff manual, 2010.

Appendix 7. Head losses for different pipe connectors/fittings (expansions and contractions).

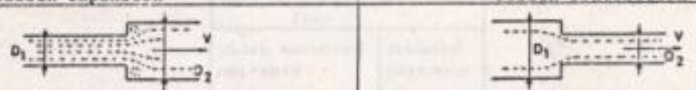
Table 3-1 Head losses in fittings

$H = \xi \frac{v^2}{2g}$ (m)

v m/s	a: entrance of suction pipe	b: suction pipe with strainer	c: suction pipe with strainer and foot-valve	d: gate valve	e: non-return valve
	ξ = 1.50	ξ = 1.75	ξ = 3.25	ξ = 0.20	ξ = 1.50
	$H = \xi \frac{v^2}{2g}$ (m)				
0.20	-	-	0.01	-	-
0.40	0.01	0.01	0.03	-	0.01
0.60	0.03	0.03	0.06	-	0.03
0.80	0.05	0.06	0.11	0.01	0.05
1.00	0.08	0.09	0.17	0.01	0.08
1.25	0.12	0.14	0.26	0.02	0.12
1.50	0.17	0.20	0.37	0.02	0.17
1.75	0.23	0.27	0.51	0.03	0.23
2.00	0.31	0.36	0.66	0.04	0.31
2.50	0.48	0.56	1.04	0.06	0.48
3.00	0.69	0.80	1.49	0.09	0.69



v m/s	f: Sudden expansion					g: Sudden contraction				
	$D_2:D_1=2$	$D_2:D_1=1.8$	$D_2:D_1=1.6$	$D_2:D_1=1.4$	$D_2:D_1=1.2$	$D_2:D_1=0.5$	$D_2:D_1=0.6$	$D_2:D_1=0.7$	$D_2:D_1=0.8$	$D_2:D_1=0.9$
	ξ = 9.00	ξ = 5.0[illegible]	ξ = 2.44	ξ = 0.92	ξ = 0.19	ξ = 0.36	ξ = 0.31	ξ = 0.24	ξ = 0.17	ξ = 0.09
	$H = \xi \frac{v^2}{2g}$ (m)									
0.20	0.018	0.010	0.005	0.002	-	0.001	0.001	-	-	-
0.40	0.073	0.041	0.020	0.008	0.002	0.003	0.003	0.002	0.001	0.001
0.60	0.165	0.092	0.045	0.017	0.003	0.007	0.006	0.004	0.003	0.002
0.80	0.294	0.164	0.080	0.030	0.006	0.012	0.010	0.008	0.006	0.003
1.00	0.459	0.256	0.124	0.047	0.010	0.018	0.016	0.012	0.009	0.005
1.25	0.717	0.400	0.194	0.073	0.015	0.029	0.025	0.019	0.014	0.007
1.50	1.032	0.576	0.280	0.106	0.022	0.041	0.036	0.028	0.019	0.010
1.75	1.405	0.784	0.381	0.144	0.030	0.056	0.048	0.037	0.027	0.014
2.00	1.835	1.023	0.497	0.188	0.039	0.074	0.063	0.049	0.035	0.018
2.50	2.867	1.599	0.777	0.293	0.061	0.115	0.100	0.076	0.054	0.029
3.00	4.128	2.303	1.119	0.422	0.087	0.165	0.142	0.110	0.078	0.041



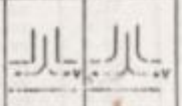
Source; Lenselink, 1987

Appendix 8. Head losses for different pipe connectors/fittings (tees and bends).

Table 3-2 Head losses in fittings

	h				i	
	Sweep elbows				square elbows	
						
	R = D	R = 2 D	R = 3 D	R = 6 D	90.-°	2 x 45.-°
	ζ = 0.52	ζ = 0.29	ζ = 0.25	ζ = 0.18	ζ = 1.27	ζ = 0.45
v m/s	$H = \zeta \frac{v^2}{2g}$ (m)					
0.20	-	-	-	-	-	-
0.40	-	-	-	-	0.01	-
0.60	0.01	0.01	-	-	0.02	0.01
0.80	0.02	0.01	0.01	0.01	0.04	0.01
1.00	0.03	0.01	0.01	0.01	0.06	0.02
1.25	0.04	0.02	0.02	0.01	0.10	0.04
1.50	0.06	0.03	0.03	0.02	0.14	0.05
1.75	0.08	0.05	0.04	0.03	0.20	0.07
2.00	0.11	0.06	0.05	0.04	0.26	0.09
2.50	0.16	0.09	0.08	0.06	0.40	0.15
3.00	0.24	0.13	0.11	0.08	0.58	0.21

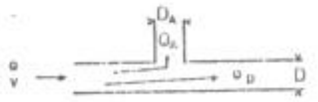
k

	tees	
	sharp cornered entrance	rounded entrance
		
v m/s	ζ = 1.30	ζ = 0.87
0.2	-	-
0.4	0.01	0.01
0.6	0.02	0.02
0.8	0.04	0.03
1.0	0.07	0.05
1.25	0.10	0.07
1.50	0.15	0.10
1.75	0.20	0.14
2.00	0.27	0.17
2.50	0.41	0.28
3.00	0.60	0.40

Source; Lenselink, 1987

Appendix 9. Head losses for different pipe connectors/fittings (tee connectors).

Table 3-3 Head losses in fittings



	tees 1			tees 1			
	$\frac{Q_D}{Q} = 1.0$	$\frac{Q_D}{Q} = 0.5$	$\frac{Q_D}{Q} = 0.2$	$\frac{Q_A}{Q} = 0.2$	$\frac{Q_A}{Q} = 0.5$	$\frac{Q_A}{Q} = 0.8$	$\frac{Q_A}{Q} = 1.0$
	$D_A = D$			$D_A = D$			
	$\zeta = 0.0$	$\zeta = 0.0$	$\zeta = 0.21$	$\zeta = 0.87$	$\zeta = 0.87$	$\zeta = 1.00$	$\zeta = 1.27$
v m/s	$H = \zeta \frac{v^2}{2g}$ (m)						
0.20	-	-	-	-	-	-	-
0.40	-	-	-	0.01	0.01	0.01	0.01
0.60	-	-	-	0.02	0.02	0.02	0.02
0.80	-	-	0.01	0.03	0.03	0.03	0.04
1.00	-	-	0.01	0.04	0.04	0.06	0.06
1.25	-	-	0.02	0.07	0.07	0.09	0.10
1.50	-	-	0.02	0.10	0.10	0.12	0.14
1.75	-	-	0.03	0.14	0.14	0.18	0.20
2.00	-	-	0.04	0.18	0.18	0.22	0.26
2.50	-	-	0.06	0.28	0.28	0.34	0.40
3.00	-	-	0.10	0.40	0.40	0.50	0.58
	$D_A = 0.58\ D$			$D_A = 0.58\ D$			
	$\zeta = 0.0$	$\zeta = 0.0$	$\zeta = 0.2$	$\zeta = 1.5$	$\zeta = 3.2$	$\zeta = 7.2$	
	$H = \zeta \frac{v^2}{2g}$ (m)						
0.20	-	-	-	-	0.01	0.01	
0.40	-	-	-	0.01	0.03	0.06	
0.60	-	-	-	0.03	0.06	0.13	
0.80	-	-	0.01	0.05	0.10	0.23	
1.00	-	-	0.01	0.08	0.16	0.37	
1.25	-	-	0.02	0.12	0.25	0.57	
1.50	-	-	0.02	0.17	0.37	0.83	
1.75	-	-	0.03	0.23	0.50	1.12	
2.00	-	-	0.04	0.31	0.65	1.47	
2.50	-	-	0.06	0.48	1.02	2.29	
3.00	-	-	0.09	0.69	1.47	3.30	
	$D_A = 0.35\ D$			$D_A = 0.35\ D$			
	$\zeta = 0.0$	$\zeta = 0.1$	$\zeta = 0.2$	$\zeta = 3.0$	$\zeta = 13.8$	$\zeta = 31.3$	
v m/s	$H = \zeta \frac{v^2}{2g}$ (m)						
0.20	-	-	-	0.01	0.03	0.06	
0.40	-	-	-	0.02	0.11	0.25	
0.60	-	-	-	0.05	0.25	0.57	
0.80	-	-	0.01	0.10	0.45	1.02	
1.00	-	0.01	0.01	0.15	0.70	1.59	
1.25	-	0.01	0.02	0.24	1.10	2.49	
1.50	-	0.01	0.02	0.34	1.58	3.59	
1.75	-	0.02	0.03	0.47	2.15	4.88	
2.00	-	0.02	0.04	0.61	2.81	6.38	
2.50	-	0.03	0.06	0.96	4.39	9.95	
3.00	-	0.05	0.09	1.38	6.33	14.37	

Source; Lenselink, 1987

Appendix 10. Table of hydraulic design of pipes.

k_s = 0.060 mm.
i = 0.004 to 0.1

ie hydraulic gradient =
1 in 250 to 1 in 10

Water (or sewage) at 15 °C;
full bore conditions.

Velocities in m/s
discharges in l/s

4 continued

Gradient	Pipe diameters in mm: 50	75	80	100	125	150	175	200	225	250	275	300
0.02000	0.878	1.152	1.202	1.392	1.609	1.809	1.997	2.173	2.341	2.502	2.656	2.805
1/ 50	1.724	5.090	6.044	10.932	19.745	31.973	48.023	68.276	93.092	122.810	157.755	198.239
0.02200	0.924	1.212	1.265	1.464	1.692	1.902	2.099	2.284	2.460	2.629	2.791	2.946
1/ 45	1.815	5.355	6.358	11.497	20.761	33.610	50.475	71.754	97.824	129.041	165.747	208.266
0.02400	0.969	1.269	1.325	1.533	1.771	1.991	2.196	2.390	2.574	2.750	2.919	3.082
1/ 42	1.902	5.608	6.658	12.038	21.732	35.177	52.820	75.080	102.348	134.999	173.386	217.853
0.02600	1.011	1.325	1.382	1.599	1.847	2.076	2.290	2.491	2.683	2.867	3.043	3.212
1/ 38	1.985	5.852	6.947	12.557	22.664	36.680	55.071	78.271	106.690	140.715	180.717	227.051
0.02800	1.052	1.378	1.437	1.662	1.920	2.158	2.380	2.589	2.788	2.979	3.161	3.337
1/ 36	2.066	6.086	7.224	13.056	23.562	38.128	57.238	81.344	110.870	146.218	187.774	235.908
0.03000	1.092	1.429	1.491	1.724	1.991	2.237	2.467	2.684	2.890	3.087	3.276	3.458
1/ 33	2.144	6.313	7.493	13.539	24.428	39.525	59.330	84.310	114.904	151.530	194.586	244.452
0.03200	1.130	1.478	1.542	1.783	2.059	2.313	2.551	2.775	2.988	3.192	3.387	3.575
1/ 31	2.219	6.532	7.753	14.006	25.267	40.877	61.354	87.180	118.808	156.670	201.176	252.720
0.03400	1.167	1.527	1.592	1.841	2.125	2.387	2.632	2.864	3.083	3.293	3.495	3.689
1/ 29	2.292	6.744	8.005	14.459	26.080	42.189	63.317	89.962	122.593	161.652	207.565	260.736
0.03600	1.203	1.573	1.641	1.897	2.190	2.459	2.712	2.950	3.176	3.392	3.599	3.799
1/ 28	2.363	6.951	8.249	14.899	26.871	43.462	65.223	92.665	126.269	166.492	213.770	268.521
0.03800	1.238	1.619	1.689	1.952	2.252	2.530	2.789	3.033	3.266	3.488	3.701	3.906
1/ 26	2.432	7.152	8.488	15.327	27.639	44.702	67.078	95.294	129.845	171.200	219.807	276.095
0.04000	1.273	1.663	1.735	2.005	2.313	2.598	2.864	3.115	3.353	3.581	3.800	4.010
1/ 25	2.499	7.348	8.720	15.744	28.388	45.909	68.885	97.856	133.329	175.787	225.688	283.473
0.04200	1.306	1.706	1.780	2.056	2.373	2.665	2.937	3.194	3.439	3.672	3.896	4.112
1/ 24	2.565	7.539	8.946	16.152	29.119	47.087	70.648	100.355	136.728	180.261	231.424	290.670
0.04400	1.339	1.749	1.824	2.107	2.431	2.730	3.009	3.272	3.522	3.761	3.991	4.212
1/ 23	2.629	7.726	9.168	16.549	29.833	48.238	72.370	102.796	140.048	184.631	237.027	297.699
0.04600	1.371	1.790	1.867	2.157	2.488	2.793	3.079	3.348	3.604	3.848	4.083	4.309
1/ 22	2.691	7.908	9.384	16.938	30.531	49.363	74.054	105.183	143.293	188.903	242.505	304.571
0.04800	1.402	1.831	1.909	2.205	2.544	2.856	3.147	3.422	3.684	3.933	4.173	4.404
1/ 21	2.753	8.087	9.596	17.319	31.215	50.464	75.702	107.518	146.470	193.084	247.866	311.297
0.05000	1.433	1.870	1.950	2.253	2.598	2.917	3.214	3.495	3.762	4.017	4.262	4.497
1/ 20	2.813	8.262	9.804	17.692	31.884	51.543	77.316	109.806	149.581	197.180	253.117	317.884
0.05500	1.507	1.966	2.050	2.367	2.730	3.064	3.377	3.671	3.951	4.219	4.475	4.722
1/ 18	2.959	8.686	10.305	18.593	33.502	54.150	81.217	115.335	157.100	207.077	265.805	333.801
0.06000	1.578	2.058	2.146	2.477	2.856	3.205	3.532	3.839	4.132	4.411	4.679	4.938
1/ 17	3.098	9.091	10.785	19.455	35.048	56.642	84.946	120.620	164.286	216.536	277.931	349.013
0.06500	1.646	2.146	2.237	2.582	2.977	3.341	3.680	4.001	4.305	4.596	4.875	5.144
1/ 15	3.232	9.480	11.246	20.282	36.532	59.033	88.523	125.690	171.181	225.610	289.565	363.607
0.07000	1.711	2.230	2.325	2.684	3.093	3.471	3.824	4.156	4.472	4.774	5.064	5.343
1/ 14	3.360	9.854	11.689	21.078	37.961	61.335	91.967	130.570	177.816	234.344	300.762	377.652
0.07500	1.775	2.312	2.411	2.782	3.206	3.597	3.962	4.306	4.633	4.946	5.246	5.534
1/ 13	3.485	10.215	12.117	21.847	39.340	63.557	95.290	135.279	184.220	242.773	311.567	391.206
0.08000	1.836	2.391	2.493	2.876	3.314	3.718	4.095	4.451	4.789	5.112	5.422	5.720
1/ 13	3.605	10.565	12.531	22.591	40.674	65.706	98.505	139.836	190.416	250.927	322.020	404.318
0.08500	1.895	2.468	2.573	2.968	3.420	3.836	4.225	4.592	4.940	5.273	5.592	5.900
1/ 12	3.722	10.904	12.933	23.312	41.967	67.789	101.622	144.252	196.421	258.831	332.152	417.027
0.09000	1.953	2.543	2.650	3.057	3.522	3.951	4.351	4.728	5.087	5.429	5.758	6.074
1/ 11	3.835	11.233	13.323	24.012	43.224	69.813	104.649	148.542	202.253	266.506	341.991	429.370
0.09500	2.009	2.615	2.726	3.144	3.622	4.062	4.473	4.861	5.229	5.581	5.919	6.244
1/ 11	3.945	11.553	13.702	24.693	44.446	71.782	107.594	152.714	207.926	273.972	351.562	441.375
0.10000	2.064	2.686	2.800	3.229	3.719	4.171	4.592	4.990	5.368	5.729	6.076	6.410
1/ 10	4.053	11.865	14.072	25.357	45.636	73.699	110.462	156.779	213.452	281.246	360.886	453.070
Coefficient for part-full pipes:	60	90	100	120	150	200	200	250	250	300	350	350

Source; Tables for the hydraullic design of pipes manual, 1977

Appendix 11. Photo story.

Plate 7.1. Pump discharge measurement.

Plate 7.2. Water application measurement.

Plate7.3. Gravity fed in field system.

Plate7.4. Water application using drag hose.

Plate 7.5. Conveyance loss in a leaking Pipe.

Plate 7.6. A siphoning pipe abstracting water illegally from the Yatta furrow into the field with no metering device.

Plate 7.7. Water being conveyed through a sandy sub canal with the source from Yatta furrow feeding the downstream farms probably result to high seepage rates.