Evaluation of the Performance of Smallholder Pumped Irrigation Systems, in Arid and Semi-arid Areas of Kenya

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Abstract: A study was carried out to evaluate the performance of smallholder pumped irrigation systems with a view of comparing if the system operated within the designed optimal engineering standards. Different parameters studied were selection, design and operations of the irrigation systems with detailed analysis on energy uses for pumping (fuel use), efficiency of pumping devices as well as pump power required and energy losses (headlosses) during pumping. Semi structured questionnaires were administered to 80 smallholder farmers practicing pumped irrigated agriculture in Mitubiri location of Kakuzi division and Kithimani sub location of Yatta division, Kenya. An observational study was done to identify the irrigation methods used. Detailed study was done in 10 farms (5 in each study site) using pumped irrigated agriculture and water application through furrow irrigation system. 79 % of the farmers assessed used small motorized pumps run by petrol and diesel fuel and ranging from 4.0-6.5 horsepower. Water was pumped from nearby rivers and conveyed to their farms using closed conduits, open channels or a combination of both. Furrow irrigation method was widely used by 94% of the farmers studied in the two study areas. 60% of the irrigation setups using PVC pipes in water conveyance had the allowable water discharge within the design optimal range. The frictional head loss in the PVC pipes used exceeded the design limit for 60% of the irrigation systems while 90% of the irrigation setups used fittings whose resultant frictional head losses were within the desired optimal range. Of the 10 pumps evaluated, 6 of them operated below the optimal design efficiency level while fuel consumption rate of each pump varied. The study of the amount of fuel used to run the different pumps used in the 10 farm setups varied from one farm to the other. In some farms, mean fuel amount used to irrigate 1 hectare of land was in excess of 60L/ha while in other farm setups, fuel used was as low as 5L/ha. The varied fuel amounts used could be attributed to varied factors in each farm such as topographic elevations, water conveyance distance and different make and model of pump. An assessment of fuel consumption rate for each of the 10 pumps at similar operational speed was also different. Pumps age did not affect its efficiency. A comparison of the calculated pump power required and the power rated on the pumps being used showed a big difference indicating that the 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 as well as high operation costs due to high fuel use.

From the study, it was found that smallholder pumped irrigated agriculture despite showing tremendous increase in uptake faces numerous challenges ranging from components selection, design and use leading to poor performance.

Keywords—Irrigation Assessment, Field irrigation Evaluation, Smallholder pumped irrigation, Technical performance, Kenya.

1. Introduction

1.1 General

Irrigation has long been seen as an option to improve and sustain rural livelihoods by increasing crop production. It can reduce dependency on rain-fed agriculture in drought prone areas and increase cropping intensities in humid and tropical zones by `extending' the wet season and introducing effective means of water control (FAO, 2001). In Kenya, smallholder irrigated agriculture has been on the increase which was attributed to government intervention and NGO's funding with the notion that smallholder farming is generally more profitable than large scale ventures (Mbatia, 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).

Despite the increase and their apparent attractiveness in terms of potential productivity, smallholder irrigation systems are, however, not always as efficiently run as they could be. Most 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 high operating costs arising from high cost of fuel (Gay, 1994). The improper design of these irrigation systems have several consequences which can be classified as those affecting public health, waste of natural resources, water pollution, operator safety, and economic factors, including cost of irrigation, economic return from irrigation, and irrigation system life expectancy (Smajstrla et al., 1993).

It is due to the above findings that a study was commenced to evaluate pumped irrigation systems used by smallholder farmers by analyzing the system performance parameters with a view of comparing their performance with the optimal designed system. Design standards for pipes, pumps and other accessories used in irrigation have been developed inorder to guide the farmers during selection, design and operation of the systems.

1.2 Location of the study area

Two study areas with most smallholder farmers practising pumped irrigated agriculture were chosen. These are Kakuzi and Yatta divisions. Kakuzi division is located in Thika district of central province while Yatta division is located in Yatta district of Eastern province. Kakuzi division lies between longitudes of 36º 40'W, 37º 21'E and latitudes- $1^0 20^0$ N,-1^0,15^0S while Yatta division lies between longitudes of -0.8^{0}W,-1.27^{0}E and latitudes of 36.66^{0}N, 37.10^{0}S. Kakuzi division is approximately 5 km and 52 km from Thika and Nairobi town respectively while Yatta division is 45 km and 81 km from Thika town and Nairobi town respectively. Kakuzi and Yatta division are on the north east and eastern direction from Nairobi town respectively. Figure 1 shows the location of the study area.

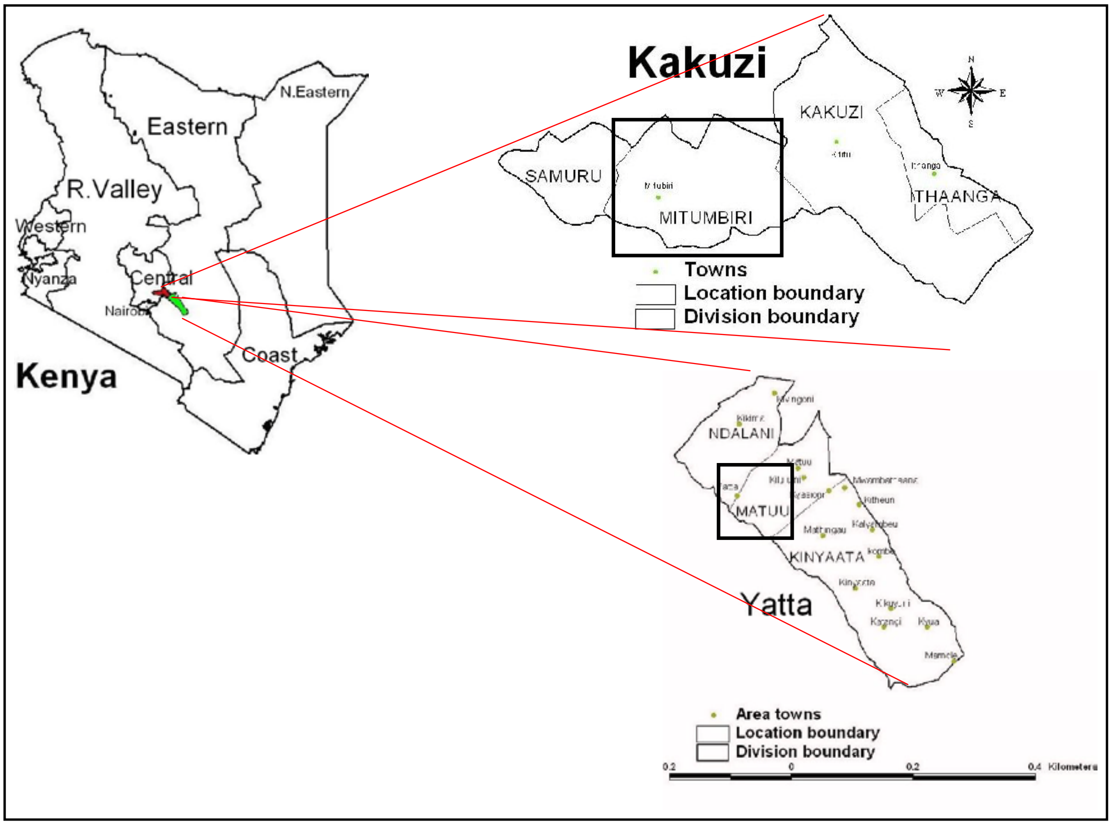

Figure1 Location maps of Kakuzi and Yatta division with area towns and location boundaries.

1.3 Hydrology and climate in the study area

The main water sources are Yatta canal and River Athi in Yatta division and Rivers Thika, Kabuku and Samuru in Kakuzi division. The climate in the two study areas is semi-arid with mean annual precipitation of 943 mm and 754 mm in Kakuzi and Yatta division respectively. Mean annual evaporation which is 1485 mm and 1625 mm in Kakuzi and Yatta division respectively, exceeds the mean annual rainfall of 943 mm and 754 mm respectively (MOALD, 1998).

2 Materials and method

2.1 Collection of technical and socio-economic data

Observational study in the two areas was done through transect walks along the riverine areas. Semi structured questionnaires developed were administered to 80 smallholder farmers along these rivers to obtain socio-economic data as well as technical information such as pumping systems used, irrigation systems used, equipments used as well as irrigated crops. Data on irrigation equipment selection and information regarding purchase of these equipments was also obtained. The data obtained from the questionnaire as well as the observational data were analyzed statistically using the statistical package SPSS pc + (SPSS Inc, 1993). The sample questionnaires used are shown in appendix 1.

2.2 Field experimental set up

Ten farms were identified, five in each study site where detailed analysis of the farm and irrigation set-up practiced by the farmers was done. Participatory approach was used where the farmers were engaged during the entire study. Various parameters were identified such as the pumping system including the pumps, pipes and the irrigation fittings and accessories used. Irrigation methods used by the farmers were also identified in addition to water conveyance and application mechanism. Farm parameters such as farm area and slope were measured. Static delivery head was also measured using a quickset level and clinometer. The distance from the water source to furthest point of water application was also measured in each of the 10 farms.

2.3 Technical evaluation of irrigation setup

2.3.1 Water discharge measurement in conveyance pipes

Water discharge from PVC pipes connected to the ten pumps was measured using a bucket of known volume and a stopwatch. The measurement of water discharge from the pipes was done in consideration to the pumping head and conveyance distance in each farm setup. Total dynamic head was evaluated based on method recommended by FAO (1992). Water discharge measurements were taken during each irrigation and over the whole cropping season and average values were obtained. The recommended design optimal water discharge of the PVC pipes were read from the tables for the hydraulic design of pipes manual (Allen, 1977), which outlines water discharges at different farm gradients. A comparison of the measured and optimal water discharge values was done to check if water conveyance in the pipeline was within the required set design standards for PVC pipes as recommended by Allen (1977).

2.3.2 Assessment of pipe frictional and shock head loss

All the smallholder farmers in the assessment used PVC pipes of class B and of different sizes. The pipe frictional losses were determined using bourdon pressure gauges. One pressure gauge was set adjacent to the pump while the second pressure gauge was set at the furthest point along the pipe outlet. Water flow velocity on the upstream and downstream side were calculated by measuring the discharge and crossection area of the pipes used. Optimal pumping speed was ensured during the process of pressure measurement. The farm elevations were measured using a quickset level. The process was repeated severally and average values for pipe frictional and shock losses evaluated. Figure 2 illustrates the field setup.

Figure 2 Pressure determination along the pipeline

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Steady state energy equation as described by Cimbala and Cengel (2008), Munson et al., (1998) and Streeter et al., (1998) were equated to frictional head losses given by Hazen-Williams equation as described by Hammer (1998) and Mays (1999). Equation 1 was hence used to compute the head loss in the PVC pipes.

$$h_f + h_m = Z_1 - Z_2 + \frac{P_1 - P_2}{S} + \frac{V_1^{\,2} - V_2^{\,2}}{2g} \qquad (1)$$

where:
h_f and h_m is major and minor head losses respectively
P_1 and P_2 is upstream and downstream pressure respectively
V_1 and V_2 is upstream and downstream velocity respectively
Z_1 and Z_2 is upstream and downstream elevation respectively
S is weight density of water and g is acceleration due to gravity.

The pipe sizes used in each farm setup is shown in table 1.

Table 1 Sizes of pipes used

Farm	**F1**	**F2**	**F3**	**F4**	**F5**	**F6**	**F7**	**F8**	**F9**	**F10**
Pipe diameter, mm	37.5	37.5	37.5	75	63	37.5	63	37.5	37.5	50

The measured pipe head loss was compared with the optimal design pipe headlosses from the design manual (Davis and Shirtliff, 2001). In 5 farm setups where drag hose was used to apply water to the furrow as shown in figure 5, the headloss of the hosepipes used were evaluated using the Hazen-Williams relationship based on equation 2. Measurement was repeated several times during each irrigation and the average values computed.

$$Hf_{100} = \frac{K\left[Q/C\right]^{1.852}}{D^{4.87}} \qquad (2)$$

Where:
Hf_{100} = Friction losses over a 100 m distance (m)
K = Constant 1.22×10^{12}, Q = Flow (l/s)
C = Coefficient of roughness based on type of pipe material
D = Inside diameter (mm).

The value of C (unit-less) for PVC pipes used ranged from 140 – 150 (FAO, 2002).
Equation 2 gives the headloss for a 100m hose hence the equivalent headloss for the hosepipe length used by the farmer was calculated.

2.3.3 Determination of headloss due to fittings used in the irrigation setup

Different types and sizes of fittings as shown in table 2 were found to be used by the farmers. The diameter of the fittings was measured. The discharge on the outlet side of the fitting was measured and from the cross sectional area of the fitting, the velocity of water was computed. From the velocity and the ratio of the diameters, the headloss was finally read from the design manuals (Lenselink, 1987). 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 % (FAO, 1992).

Table 2 Types and sizes of fittings used in the 10 irrigation setups

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’’-0.5’’	1.5’’-1’’	1.5’’-1’’

2.3.4 Pump efficiency assessment

Operating efficiency for 10 pumps was evaluated by first measuring the optimal pump running speed. The pumping head at the highest point in the farm was used as the reference point and discharge from the pump through the pipes was measured at this point using a bucket of known volume and stopwatch. Pump speed was measured with a calibrated hand held tachometer held directly pointing at the pumps rotating axle. The pump specific speed was calculated from equation 3.

$$N_s\,(_{USgpm,\,ft}) = 0.861N\,\frac{Q^{0.5}}{H^{0.75}} \tag{3}$$

Where:
N_S –pump specific speed
N – Pump speed (RPM)
Q- Discharge (m^3/hr)
H – Total dynamic head (m).

The operating efficiency of the pump as a function of specific speed was then read off from figure 3 (Igor, 2007).

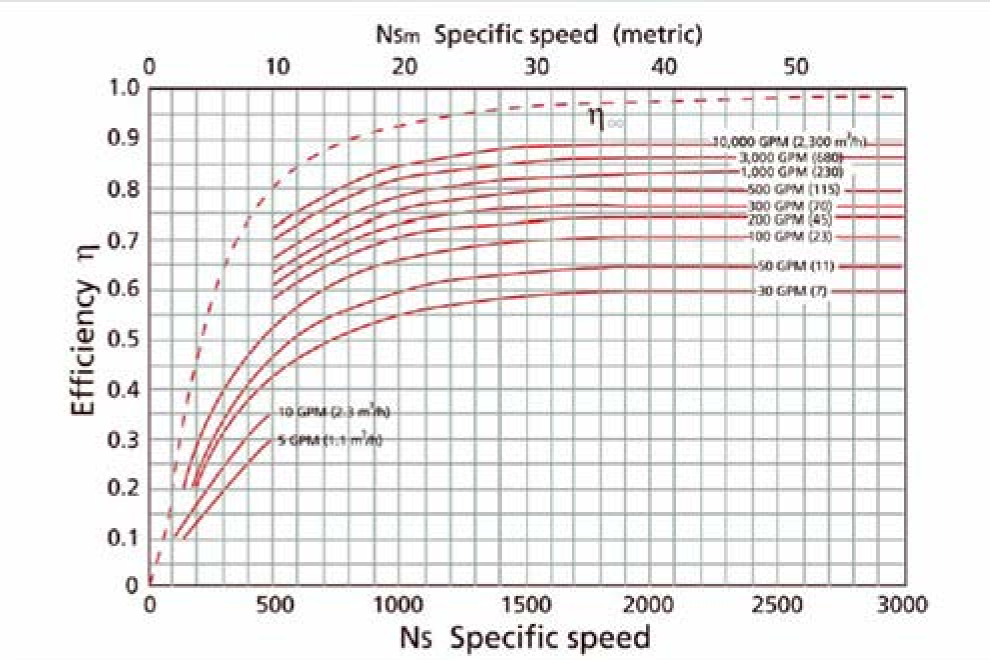

Figure 3 Efficiency values for pump with different specific speeds
(source: The Pump Handbook published by McGraw Hill, 2007).

2.3.5 Pump power requirement determination

Equation 4 was used to compute the pump power (in kW) requirements for the ten irrigation pumps setups.

$$power\,(KW) = \frac{Q * H}{360 * Ep} * 1.2 \qquad (4)$$

Where:
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).

Mean values of discharge Q were obtained by measuring the discharge during each irrigation over the entire cropping season. The total dynamic head, H was also evaluated for each of the farm considering the farthest point where water was delivered while ideal pump efficiency values as described by FAO (1992) were used.

2.3.6 Fuel consumption rate assessment

Fuel consumption rate for each of the 10 pumps used during irrigation was measured at different pump running speeds by connecting a transparent measuring pitot tube gauge with calibrations on the sides to the pump carburetor where the fuel decrease as the pump was being run was read off. This was repeated for several times during pump operation and at different pump running speeds and mean values thereafter computed.

3 Results and discussion

3.1 Technical and socio-economic results

3.1.1 Irrigation systems used in the study area

The percentages of the farmers using different methods of irrigation in the study area are shown in figure 4. From the findings, it was found out that very few farmers used the modern irrigation technologies such as drip and sprinkler in the study area. There was great preference for furrow irrigation in both sites.

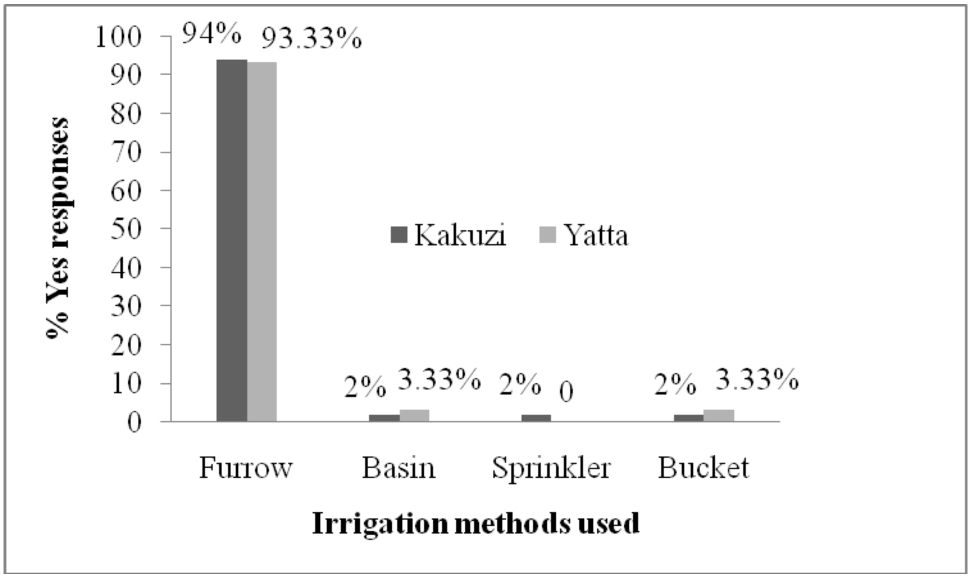

Figure 4 Percentages of farmers using different irrigation methods in the study area

A total of 80 irrigation setups were assessed. The setups were all different with each farmer selecting the components to suit their personal preferences. These combinations are presented in table 3.

Table 3 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	65.0
C) Pump – pipe –sub canal - furrow	8	10.0
D) Pipe- sub canal – furrow	15	18.8
E) Bucket	2	2.5
F) Pump – pipe – hosepipe – basin	2	2.5

Majority of the smallholder farmers could not afford the modern irrigation technologies such as drip and sprinkler due to their high cost and inadequate knowledge on system selection, design and operation. Majority of farmers preferred simple irrigation setups which were easier to design and use with the most common system being a connection of pump to the pipes and then apply water to the furrows. This method required no skilled labour to design and operate. Figure 5 shows the commonly used water conveyance and application methods used in the study area.

Figure 5 Water application using drag hose.

3.1.2 Description of irrigation components used

3.1.2.1 Pumps used in the 10 farm setups

Different types, makes and models of pumps were found in the study area and detailed specifications of the pumps used in the ten farm setups are shown in table 4.

Table 4 Pumps specifications

Farm	**Pump model**	**Pump make**	**Horse power**	**Suction diameter (mm)**	**Discharge diameter (mm)**	**Maximum suction head (m)**	**Total Head (m)**	**Optimal Speed (RPM)**
F1	BX30	Honda	5.5	75	75	8.0	28	3600
F2	No data	Mitsubishi	5.5	75	75	8.0		4000
F4	DP3C-4	ETQ178F	6.6	75	75	14.5	25	3600
F3	PTG205	Robin	5.5	63	63	8.0	32	3600
F5	PTG205	Robin	5.5	63	63	8.0	32	3600
F9	No data	Koshin	4.0	50	50	6.0		3600
F8	No data	Koshin	4.0	50	50	6.0		3600
F7	SCR-80HX	Honda	5.5	75	75	8.0	32	3600
F10	No data	Koshin	4.0	50	50	7.0		3600
F6	SCR-80HX	Honda	5.5	75	75	8.0	32	3600

Source (Davis and Shirtliff, 2001)

3.1.2.2 Pipes and fittings used in water conveyance and application

In the study area, most farmers preferred using PVC pipes of different classes and sizes. The most commonly used type of PVC pipe is class B which was used by farmers in the 10 farm setups. Different types and sizes of fittings were used by farmers in the study area. The most common fittings used in the 10 farm setups were TEE connectors and Reducers.

3.1.3. Sources of information in purchasing irrigation equipments

Different sources of information on where to purchase the irrigation equipments in the two study areas are shown in figure 6.

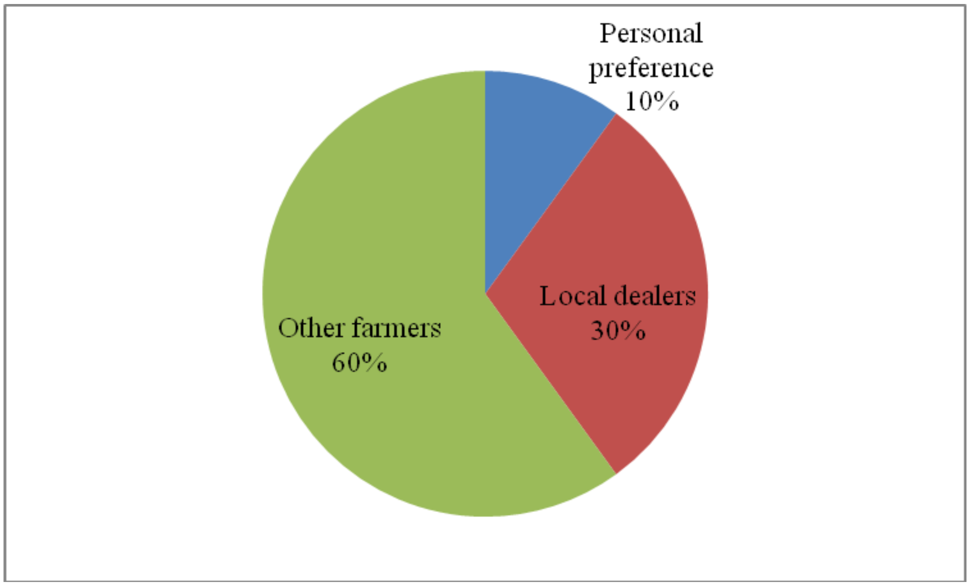

Figure 6 Source of information in purchasing and installation of irrigation equipment.

It can be concluded that sound technical advice from engineers or technicians was not sought in the selection and installation of the irrigation systems. Majority of farmers got information from other farmers indicating that knowledge transfer from farmer to farmer plays a significant role in smallholder pumped irrigation systems.

3.2 Technical evaluation of irrigation system components

3.2.1 Water discharge in the PVC pipes

Figure 7 shows the comparison of measured discharge versus the recommended water discharge from the PVC pipes used. The optimal design water discharge from the PVC pipes is given for different farm gradients hence the farm gradients in the 10 farm setups was considered in comparison of the measured and design optimal water discharge. In the 10 farm setups, different sizes of farms were irrigated by the farmers but 1 acre (4000 m^2) piece of land was considered for comparison purposes.

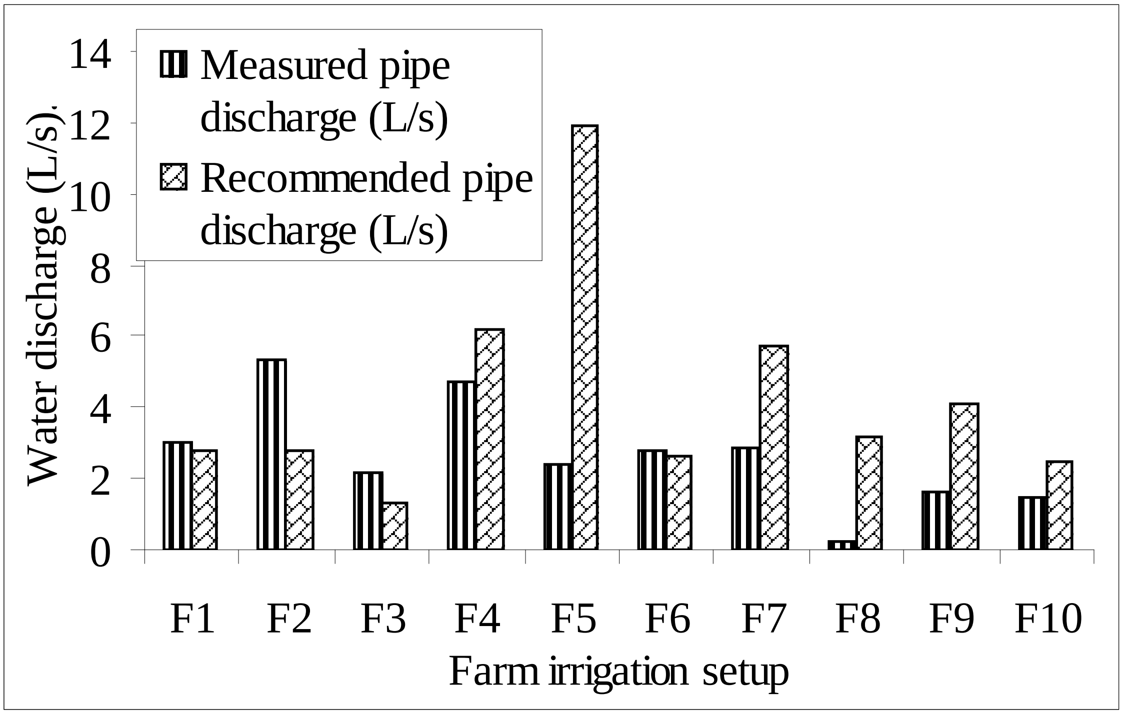

Figure 7 PVC pipe water discharge for 10 farm irrigation setup

From figure 7, the field measured water discharge exceeded the optimal design water discharge for the irrigation set-ups 1, 2, 3 and 6 while the field measured water discharge was within the recommended range for farms 4, 5,7,8,9 and 10. This analysis shows that approximately 60% of the smallholder farmers have their irrigation setups operating within the required optimal design discharge range for the PVC pipes. In 6 farm setups (F1, F2, F3, F6, F8 and F9) with less diameter pipes as shown in table 1, the discharge measured from the pipes varied from 0.6l/s to 5.7l/s while farm setups (F4, F5, F7 and F10) with bigger diameter pipes, the discharge varied from 1.8l/s to 5l/s. It is therefore possible to conclude that the pipe size did not have any effect on water discharge rate. The probable cause of varied water discharge in the different farm setups using different sizes of pipes could be attributed to varied pump operating speed for each of the farm setups.

3.2.2 Energy losses during pumping

3.2.2.1 Pipe frictional head losses

Figure 8 shows the comparison of measured and design pipe head losses in each of the 10 farm setups. Pipes exhibit different head losses due to several parameters such as water flow rate, pipe size, farm elevation and pump running speed.
A comparison of different parameters such as pipe size, water flow rate, pipe head losses, farm elevation and pump operating speed was done as shown in table 5.

Table 5 Comparison of water flow rate, pipe size and head loss, farm elevation and pump operating speed

Farm	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
Farm elevation, m	18	24	12	22	10	16	17	14	11	9
Pipe size, mm	37.5	37.5	37.5	75	63	37.5	63	37.5	37.5	50
Pipe flow rate, Q (L/S)	3	5.7	2	5	2.2	2.7	2.7	0.6	1.85	1.80
Pump operating speed, RPM	2300	2500	2150	2400	2100	2200	2250	2000	2050	2100
Measured pipe head loss, m/m	0.042	0.032	0.017	0.033	0.013	0.02	0.035	0.004	0.025	0.1019

In farms with high elevations (F1, F2, F4 and F7), pumps were operated at high speed in order to deliver the required flow and this subsequently resulted to high pipe head losses as indicated in table 6. It was also found that water flow rate in the pipes was not affected by the size of pipe as indicated in table 6 Water flow rate was also found to be proportional to the resulting pipe head losses. The main contributing factor of pipe head losses was found to be pump operating speed and farm elevation which also resulted to high flow rate.
The ten irrigation systems had different sizes and lengths of pipes used and the measured water discharge was also different. This resulted to variances in pipe frictional headlosses.

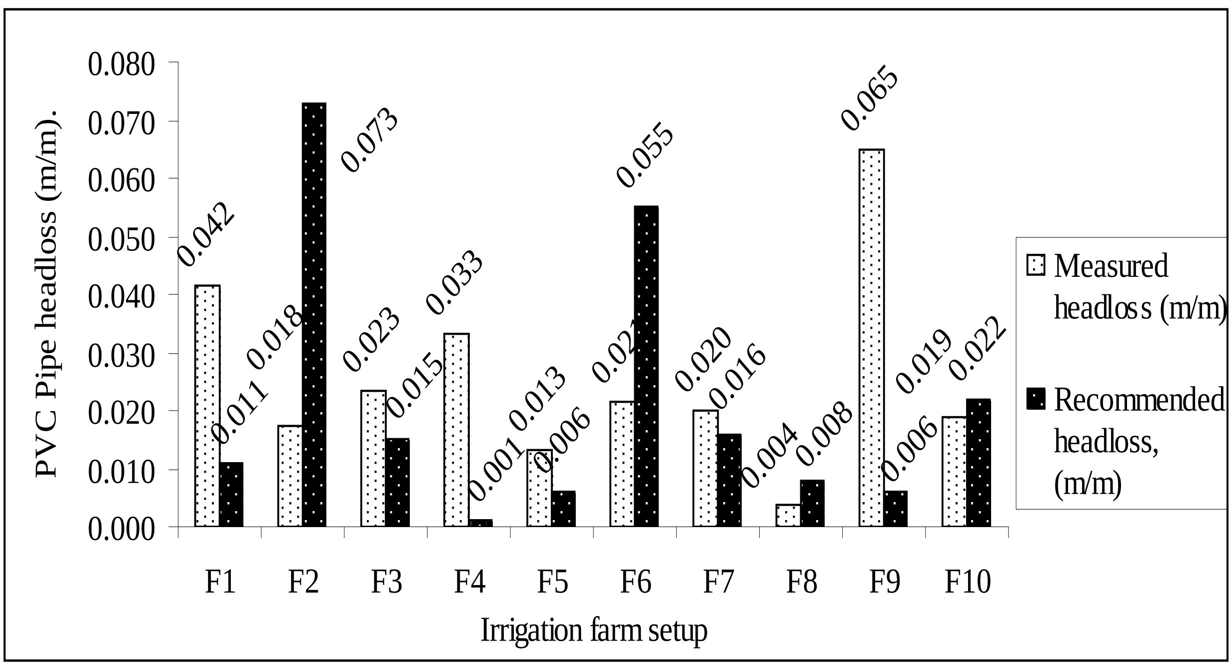

Figure 8 Pipe head losses for different on farm designs.

The recommended pipe headlosses was based on farm elevation, pipe size and water flow velocity in each system as described by Allen (1977). In farms, F1, F3, F4, F5, F7, F9, the measured pipe headloss exceeded the recommended pipe headloss while in farms F2, F6, F8, F10 the measured pipe headloss within the design

headloss. 60% of the farm setups had measured pipe headlosses exceeding the optimal pipe headloss while 40% had the measured pipe headloss within the design headloss limit.
The measured frictional and shock headlosses for the hosepipes used in the five irrigation systems are presented in table 6.

Table 6 Hosepipe headloss for 5 irrigation setup

FARM	F6	F7	F8	F9	F10
Hosepipe head loss (m)	10.0	5.3	0.1	1.0	0.3
Hosepipe length (m)	30	17	7	9	7
Hosepipe diameter (inches)	0.5	0.5	0.5	1	1.5
Water flow rate (L/s)	2.7	2.7	0.6	1.85	1.80

For Farms 8, 9, and 10, the headloss due to the hosepipe was less than 1m while farm 6 and 7 had head losses due to the hosepipes exceeding 5m. For the 5 farm setups with hosepipes connected to pipes, it was found out that different sizes of hosepipes (diameters, length) showed differences in headloss. The headloss variance was also caused by water flow velocity in the system. The longer the hosepipe used as well as the lesser the diameter of hosepipe used, the higher the resulting headloss in the system.

3.2.2.2 Head losses due to fittings used in the irrigation systems

The evaluated values for the head losses due to fittings in the 10 irrigation setups are presented in table 9. It is recommended that the ratio of headloss due to fittings versus sum of head losses due to hosepipe, PVC pipes and suction lift combined should not exceed 10 % (FAO 2002).

Table 7 Ratio of headloss due to fittings versus sum of total head losses due to hosepipe, PVC pipes and suction lift

Irrigation farm setup	HLx (m)	HLfittings (m)	$\frac{HL_x * 100}{HL_{fittings}}$
F1	2.29	0.13	5.7
F2	3.2	0.14	4.4
F3	2.85	0.14	4.9
F4	2.5	0.11	4.4
F5	2.8	0.12	4.3
F6	19.2	0.35	1.8
F7	16.5	0.413	2.5
F8	4.12	0.86	20.9
F9	3.63	0.049	1.3
F10	3.93	0.2	5.1

Where $HL_{fittings}$ is the headloss resulting from the fittings and HL_x (m) is the total combination of suction head lift, PVC pipe head losses and hosepipe head loss.

The ratio of headloss for the 9 irrigation setups was found to be within the recommended range while only one farm setup (F8), was the ratio exceeding 10% probably due to the greater reduction as compared to the others used in the other farm setups. Hence it is recommended that fittings with less reductions or expansions should always be used in any farm setup.

3.2.3 Pumps working efficiencies

The results shown in figure 9 indicate that most pumps operated below the manufacturers optimal design efficiency range of 60% (FAO, 1992). A pump running at optimum head and speed should have an efficiency of 40% to 80% (FAO, 1992). Of the 10 pumps assessed, 6 of them operated below the optimal design efficiency range. Figure 9 shows the graph of pump efficiency for the 10 pumps assessed.

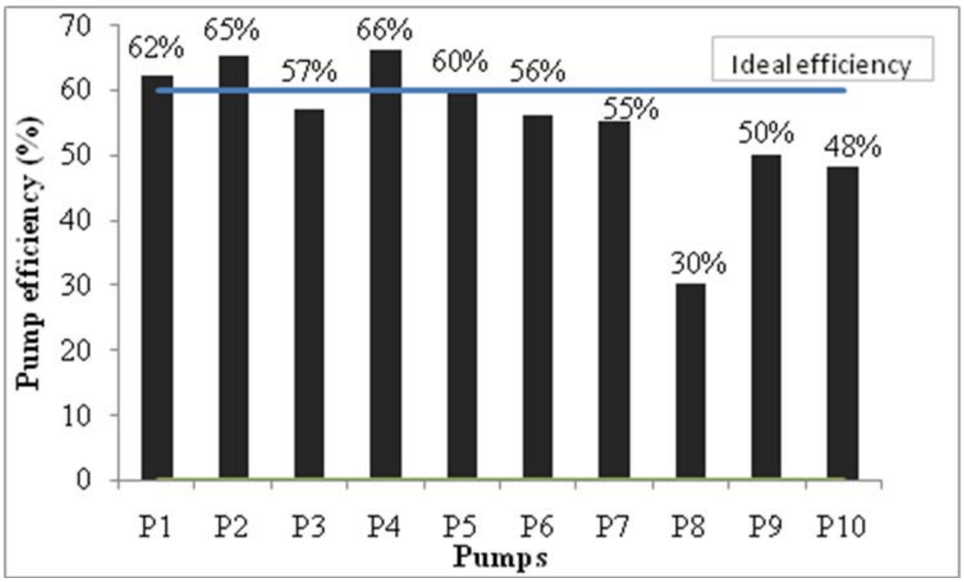

Figure 9 Pump efficiency for 10 pumps used by smallholder farmers.

Many pumps are not run at optimum head and speed, and so their efficiency could be much lower as shown by FAO (1992). Further investigation on relationship between pumps age versus efficiency showed that pumps age did not affect its efficiency (fig 10). Some old pumps had a higher efficiency than the new pumps. Several factors that could contribute to this anomaly are repair and maintenance, pumps make and model as well as proper operation of the pumps.

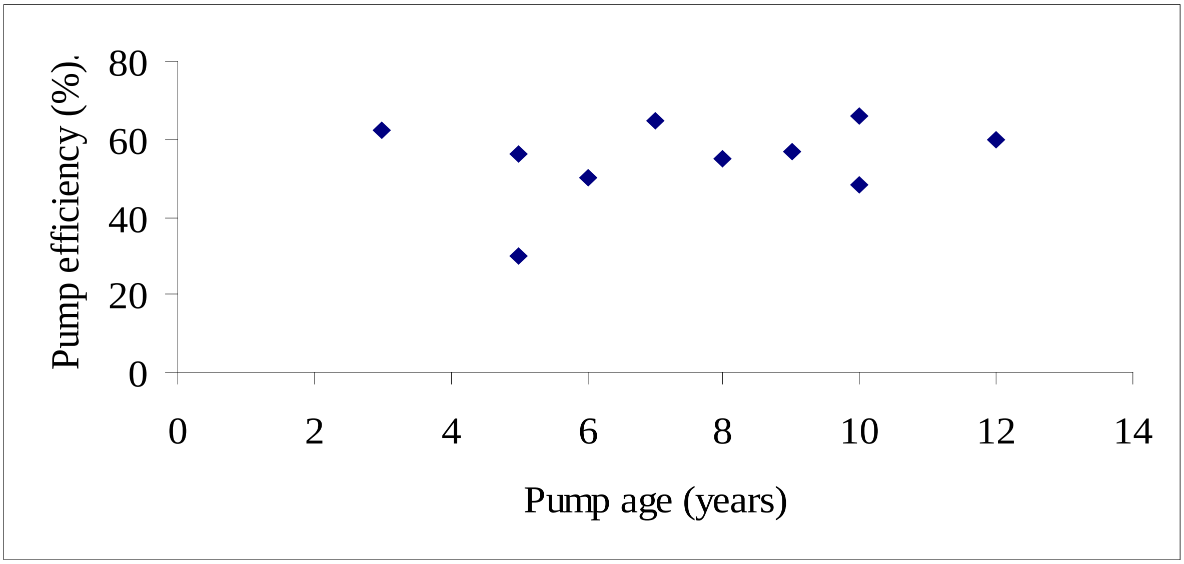

Figure 10 Variation of pump efficiency with age

3.2.4 Pumps power requirements

The computed pump power versus rated pump power for each of the 10 farm setups is shown in table 8. A comparison of the computed pump power versus rated pump power for all the 10 pumps considered was found to vary significantly. All the 10 pumps used in each of the farm setup had higher power rating than actually was needed. The effect of using a pump with higher power rating than required is seen in the capital as well as operational costs. The cost of purchasing a higher rated pump is high as compared to a less powered pump and the operational cost (fuel use) also varies proportionally to the pump power rating.
Matching the right pump to the field condition is hence important before making the final decision of purchasing a pump.

Table 8 Power requirements for the 10 irrigation setups

Pumps	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9**	**P10**
Computed pump power (kW)	0.23	0.78	0.19	0.30	0.44	1.39	1.27	0.10	0.30	0.30
Rated pump power (kW)	4.10	4.10	4.10	4.93	4.10	4.10	4.10	2.99	2.99	2.99

3.2.5 Total dynamic head

The total dynamic head for the 10 irrigation set ups as calculated from equation 1.3 is shown in table 9.

Table 9 Total dynamic head in the experimental plots

Irrigation Setup	PVC pipe length (m)	Suction Lift (m)	PVC pipe headloss (m)	Hose Headloss (m)	Fittings Headloss (m)	Elevation Height (m)	Total Dynamic Head (m)
F1	12	1.8	0.49		0.13	1.5	3.9
F2	40	2.5	0.70		0.14	1.0	4.0
F3	30	2.2	0.65		0.14	1.0	4.0
F4	6	2.3	0.20		0.11	1.0	3.6
F5	30	2.4	0.40		0.12	6.0	8.9
F6	100	1.2	8.00	9.97	0.35	3.5	23.0
F7	60	1.5	9.74	5.30	0.41	3.0	20.0
F8	78	1.7	2.32	0.10	0.86	6.5	11.5
F9	20	1.3	1.73	0.60	0.05	4.5	8.2
F10	104	2.1	1.50	0.33	0.20	4.0	8.1

The table indicates that 3 farms lied between 1-4 m while 4 farms were between 4.1-10m and the remaining 3 farms had the total dynamic head exceeding 10m. The differences in farm elevations were as a result of different field parameters and irrigation system setup and this hence leads to differences in energy requirements during pumping. It is therefore necessary to select irrigation system equipments based on individual farm parameters in order to optimize the irrigation system and reduce unnecessary costs.

3.2.6 Energy uses for pumping

3.2.6.1 Fuel consumption rate of pumps

Fuel consumption rates for 10 pumps considered were evaluated by measuring the fuel consumption rate at different pump running speeds. The running speed of the pump was found to have a big influence on fuel use. Figures 11 and 12 indicate the fuel use versus running speed of the different pumps assessed.

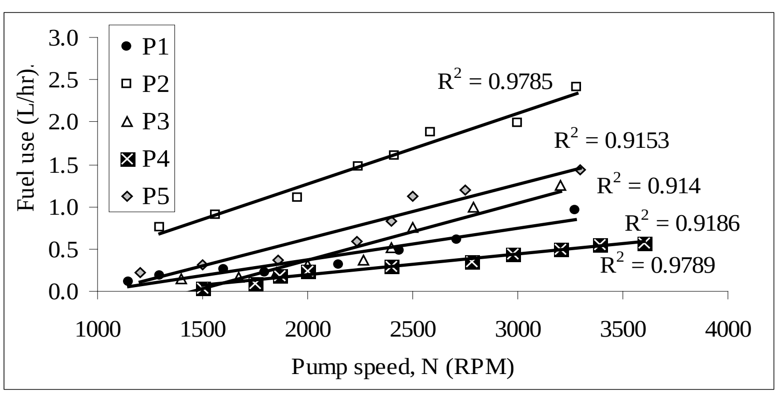

Figure11 Fuel use versus pump speed for different pumps in Kithimani sub location.

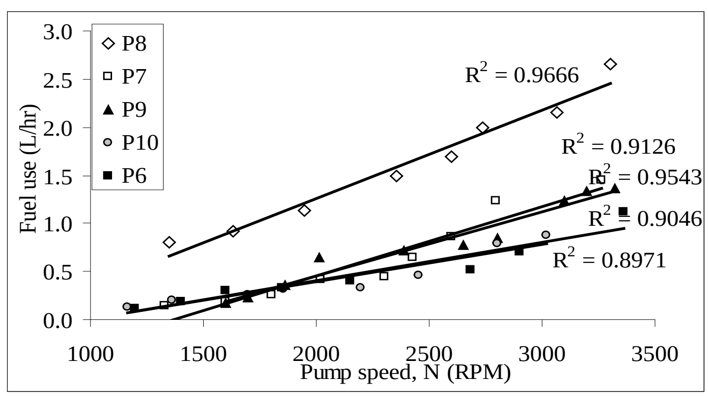

Figure12 Fuel use versus pump speed for different pumps in Mitubiri location

A regression analysis indicated that the fuel consumption rate of the pump depended heavily on the pump running speed. The relation is actually linear with coefficient of determination (R^2) for the pumps lying between 0.72 to 0.98.

3.2.6.2 Fuel usage and its corresponding costs in irrigation.

Figure 13 shows the relationship between the fuel used in litres per hectare per irrigation for the 10 farms considered.

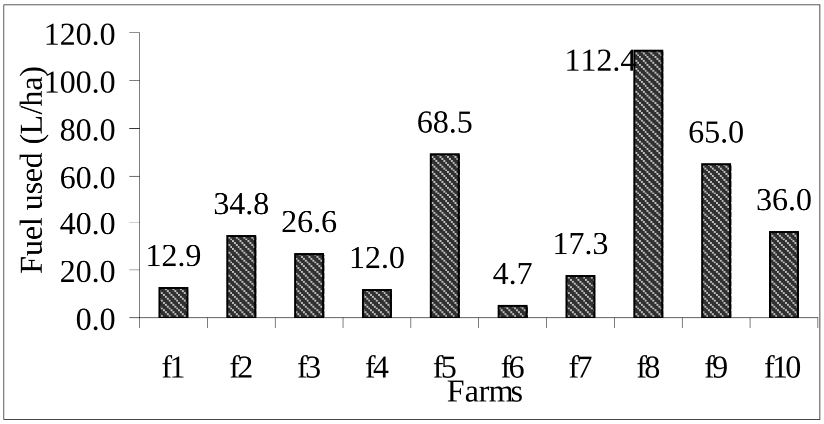

Figure13 Mean fuel used per irrigation event (L/ha) in the 10 farms.

Table 10 classifies the irrigation systems in terms of fuel consumption during irrigation.

Table 10 Classification of fuel used during irrigation

Fuel use range (L/ha/irrigation)	Farm irrigation setup	Farm irrigation setup (%)
<5	F6	10
5.1-10	-	-
10.1-20	F1,F4,F7	30
20.1-40	F2,F3,F10	30
40.1-60	-	-
>60	F5,F8,F9	30

From figure 12, the 10 farms considered showed wide variation in the amount of fuel used while irrigating 1 hectare of land. Only one farm irrigation setup used less than 5 litres per hectare during irrigation while 30% of the farm irrigation setups used between 10.1 to 20 litres and a further 30% of the farm irrigation setups used greater than 60 litres per hectare during irrigation. This shows a wide variation in fuel use in irrigating the 10 farms and the possible causes of this variation could be due to several factors such as use of different pumps with differences in fuel consumption rate, different headlosses in the irrigation systems, differences in farm elevations, applying wrong amounts of water among others. This led to wide variation in fuel cost used (figure 14). During the time of study, 1 litre of petrol fuel was valued at 75Ksh while diesel fuel was 69Ksh.

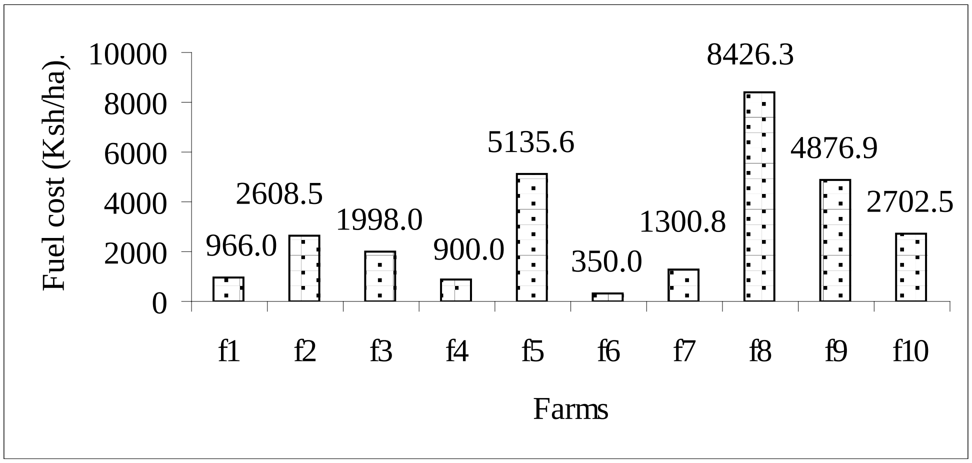

Figure14 Fuel cost per irrigation (Ksh/ha)

4 Conclusions and recommendation

From the study, it was found that there was high uptake of pumped irrigated agriculture by smallholder farmers in the arid and semi arid regions of Kenya with traditional methods of water application still dominating. 94% and 93% of the interviewed farmers in Kakuzi and Yatta division used furrow irrigation systems respectively. Low uptake of modern water application technologies was very common with only 1.3 % of the smallholder farmers in Mitubiri location of Kakuzi division using sprinkler irrigation methods and non used drip systems in the two study areas. Simple irrigation setups were used by majority of the farmers interviewed with poor system matching to the field as well as performance. Farmers apparently did not seek professional advice during irrigation system selection, design and operation with most of them getting information from other farmers.

During water conveyance, all the farmers used PVC pipes and 60% of the smallholder farmers had their irrigation setups operating within the required optimal pipe discharge range. The remaining 40% had the measured water flow rates exceeding the optimal design water flow rates.

Based on analysis of pipe head losses, 60% of the systems evaluated exceeded the design limit. Several factors causing high headlosses was found to be varying water flow rates in the pipes caused by different pump operating speed, farm elevations and different pipe sizes. Delivering water at higher elevations requires operating the pump at a much higher speed and the effect of this is increased flow rates with increased pipe headlosses. Headlosses is also proportional to the pipe size. It is therefore important to match the pipes required to the field condition as well as operating the system at the required optimal range. 90% of the irrigation setups showed that fittings used were within the desired range.

Of the 10 pumps assessed, 4 had an efficiency of more than 60 % (recommended optimal range) while 6 worked below the recommended range. This poor performance could be attributed to either lack of proper matching of the pumps with the farm conditions i.e. the head and poor system operation resulting to higher discharge of water. Some older pumps were found to have higher efficiencies than new pumps; an indication that pumps servicing was done despite their age and optimal pump operation range.

The 10 pumps assessed showed variances in fuel consumption rate with 60% of the pumps consuming more than 20 litres of fuel per hectare of land and only 10% used less than 5litres per hectare. This wide variation of fuel use could result to some farms having higher operational costs resulting to low profit margin. The system inefficiency could be attributed to use of faulty pumps, over or under irrigation or poor pump operating range.

It is therefore important for the farmer to know the right operating range of the pump and that the pump does not exceed the recommended fuel consumption range.
It is greatly recommended that routine check ups of the whole irrigation system be done on a set time frame to ensure that it operates within the desired level. This will ensure long term sustainability of the irrigation system without unnecessary high operating costs and system lifespan ensured. These routine check ups include among others pumps operating efficiency, energy uses (fuel consumption rate), water discharge and energy losses during conveyance. Proper selection of the irrigation system components should be done with the farmer involving the area engineers who are better versed with irrigation system design. Capacity building of the farmers at farm level should also be embraced by the relevant government sectors if smallholder pumped irrigation is to remain the top cream of development.

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Appendix 1 Questionnaire for survey on socio-economic status of smallholder farmers in Mitubiri location and Kithimani sublocation.

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?

Form 4. Irrigation practices
1. Do you irrigate your crops?
2. What method of water application do you use? ☐Furrow, ☐basin, ☐pits
3. What is the labour cost incurred in irrigating one acre of land considering the method of irrigation used?
4. How often do irrigate your farm? Circle, ☐once a week, ☐ twice a week, ☐, thrice a week ☐ any other-specify.
5. What is the method of irrigation used in your farm? Circle, ☐bucket, ☐sprinkler ☐drip, ☐hosepipe.
6. 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
7. What type of pump do you use?
8. What type of fuel do you use? Circle, ☐paraffin ☐petrol ☐diesel ☐any other
9. When do you replace the used engine oil from your pump? Circle ☐after two weeks
☐After three weeks ☐after one month ☐any other, specify.
10. Where do you buy the irrigation inventories?
11. How do you decide which type of irrigation equipment to buy?

12. What is the most limiting factor in irrigated agriculture?
☐Fuel ☐seeds ☐chemicals ☐ pumps ☐pipes ☐hosepipe ☐labour