Farm water use efficiency assessment for smallholder pumped irrigation systems in the arid and semi-arid areas of Kenya

S. N. Kang’au, P. G. Home, J. M. Gathenya

(*Biomechanical and Environmental Engineering Department, Faculty of Engineering, Jomo Kenyatta University of Agriculture and Technology, Nairobi, Kenya*)

Abstract: Water use efficiency for irrigated agriculture still remains low. This presents a risky trend in the near future due to diminishing water resources as well as rising population demanding increased food supplies. The objective of the study was to investigate pumped irrigation methods used by smallholder farmers in the arid and semi-arid land environments as well as assess the water use efficiency during crop production under usual farmer management. The study was carried out in Mitubiri location of Kakuzi division and Kithimani sub location of Yatta division, Kenya. Observational study during the field transect walks in the study sites identified methods of irrigation used by the smallholder farmers, water conveyance as well as application methods and the soil physical properties. Questionnaires were developed and administered to 80 farmers in order to find out the socio-economic status of the people and the agricultural practices carried out. A detailed study was carried out in 10 experimental plots set in the study areas. Water losses during conveyance and application were assessed in the experimental plots. Of the five farms where water conveyance was through secondary canals, the mean water conveyance efficiency was found to be 81.4%. Water application efficiency in the ten blocks under different crops grown i.e. baby corns (*Zea mays* L.), French beans (*Phaseolus vulgaris* L), tomatoes *(Lycopersicon esculentum L)* and water melon *(citrullus lanatus)* in the months of April to July 2009 was assessed. On average, water application efficiency ranged from 19.5% to 30 % for the crops assessed which was far below the recommended range of 65% for surface irrigation methods. The study hence shows that there is a need to improve water use efficiency in smallholder irrigated agriculture in order to conserve water and ensure no shortages of water during the times of high water demand.

Keywords: application efficiency, conveyance efficiency, on farm water use efficiency, Kenya

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1 Introduction

1.1 General

With continuous population and economic growth, water resources have become increasingly scarce in many countries and regions of the world. Food production is the largest water user and is directly constrained by water scarcity (Yang et al., 2006). One of the main factors that limits further expansion of food production for the increasing population will be water (Rosegrant, Cai and Cline, 2002; Playan and Mateos, 2006; Yang et al., 2006; Falkenmark, 2007). Although water is scarce, there are many ways of using it more efficiently, or making each drop of water more productive (Rosegrant , Cai and Cline, 2002). Falkenmark (2007) suggested three options for capturing the additional water needed to meet the requirements of future food production: (1) increasing water productivity by reducing losses, (2) improving the use of rainfall and expanding rain-fed agriculture, and (3) pursuing virtual water options (Allan, 1997; WWC, 2004; Hoekstra and Hung, 2005; Hoekstra and Chapagain, 2007).

In Kenya, irrigated agriculture has been on the increase with the most challenging factor being shortage of water as well as market availability, instability and

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Corresponding author: Stanley Njenga Kang'au, E-mail: staninjek@yahoo.com

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; Kulecho and Weatherhead, 2006)

It is due to the above concerns that a study was conducted to evaluate the farm water use efficiency for smallholder pumped irrigation systems growing horticultural crops in the arid and semi-arid areas of Kenya.

1.2 Study area

1.2.1 Location of the study area

Two study areas, i.e. Mitubiri location and Kithimani sublocation were chosen as the study sites where smallholder farmers practiced pumped irrigation systems. Kakuzi division is located in Thika district of Central Province while Yatta division is located in Yatta district of Eastern province, Kenya. Kakuzi division lies between longitudes of 36^0 40’’W, 37^0, 21^0E and latitudes -1^0, 20^0 N, -1^0, 15^0S while Yatta division lies between longitudes of -0.8^0W, -1.27^0E and latitudes of 36.66^0N, 37.10^0S. 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 northeast and eastern direction from Nairobi town respectively. The location of the study area is presented in Figure 1.

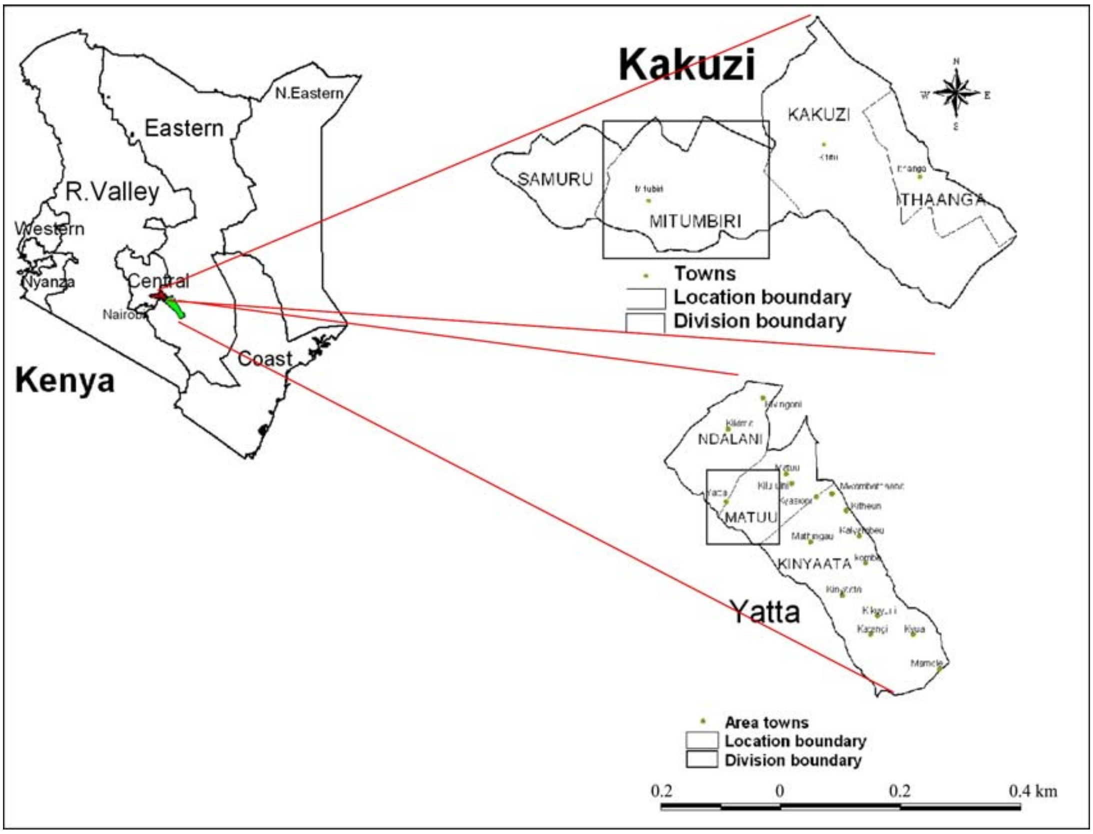


Figure 1 Location maps of Kakuzi and Yatta division with area towns and location boundaries

1.2.2 Population density

The population density of Yatta division is approximately 152 persons/km^2 (Frederick, Lutta and Samuel, 2000) while that of kakuzi division, it is approximately 149 persons/km^2 (Robinson, Thomas and Catherine, 2005).

1.2.3 Water resources

The available water resource in Yatta division is the Yatta canal (popularly called ‘‘Yatta furrow’’) with its intake in Thika River at Mavoloni area. Yatta canal 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. Its envisaged coverage would be 60 kilometers but it covers a distance of approximately 40 kilometers from the intake point due to increased water use, losses and misuses (MOA, 2009). The available water resources in Kakuzi division are rivers, streams, springs and shallow wells. River Thika and Kabuku are the main water resources for the division since they are permanent while river Samuru is seasonal and highly polluted. Other springs such as Kasioni in Ithanga location play a key role in water supply to the residents.

1.2.4 Climatic conditions

Rainfall patterns in parts of Eastern province exhibit distinct bimodal distribution. The first rains fall between mid-March and the end of May and are locally known as the long rains. The second rains, the short rains, are received between mid October and the 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%. Temperature ranges between 17-24℃. Evapo-transpiration rates are high, with mean annual values being 1625mm and exceeding the amount of rainfall most of the year except November (Fredrick et al., 2000). Kakuzi division rainfall distribution is bimodal with peaks from March to May (long rains), and October to December (short rains). Annual rainfall varies from about 800 mm at an altitude of about 1525m above sea level (ASL). The temperatures are high at the lower altitudes ranging from 25℃ to 30℃ but reduces to between 18 and 20℃ towards the higher altitudes of 3,500 m ASL. Mean annual evapo-transpiration which is 1,485 mm and 1,625 mm in Kakuzi and Yatta division respectively exceeds the rainfall (MOALD, 1998).

1.2.5 Soils

The soils of Kakuzi division are well drained, very deep, dark red, very friable clay (nito-rhodic Ferralsols) with inclusions of well drained, moderately deep, dark red to dark reddish brown, friable clay over rock, pisoferric or petro ferric material (eutric NITISOLS; with nito-chromic CAMBISOLS and chromic ACRISOLS, partly pisofferic or petroferric phase). The soils of Yatta division are developed from undifferentiated basement system rocks thus Acrisols, with Luvisols and Ferralsols. They are composed of well drained, moderately deep to deep, dark red to dark reddish brown, friable to firm, sandy clay to clay with topsoil of loamy sand to sandy loam in most places (Agumba, 1985).

1.2.6 Agricultural activities

Irrigated agriculture dominates the two areas due to unreliability of the rainfall. Few farmers practice subsistence agriculture during the short rain period and later on switch to irrigation. Only those farmers near the water sources benefit greatly as they practice supplemental irrigation to their crops. Crops grown in the study area include diverse horticultural crops, subsistence crops such as maize and beans and in some parts perennial crops such as coffee and fruits. Pump fed agriculture is widely practiced by the residents in the two study areas.

2 Materials and methods

2.1 Collection of technical and socio-economic data

Transect walks in the two study sites identified the agricultural activities of the farming community, the irrigation methods used as well as the socio-economic status of the people. questionnaire (Appendix 1) were used to gather socio-economic data in the study areas. The questionnaire detailed the socio-economic status of the people, crops irrigated by the farming community, technical information such as irrigation methods used (water abstraction technologies, conveyance and application methods), irrigation equipments used, i.e. pumps, pipes, hosepipes and other fittings. Data on irrigation practices including mode of operation of irrigation set-ups, on farm designs used by the farmers and farmers' decision on irrigation scheduling were collected. The questionnaires also detailed information on farmers' decision on how much water to apply per irrigation and to different crops at different growth stages. A total of 80 farmers were interviewed, 50 in Kakuzi and 30 in Yatta division.

2.2 Field experimental set up

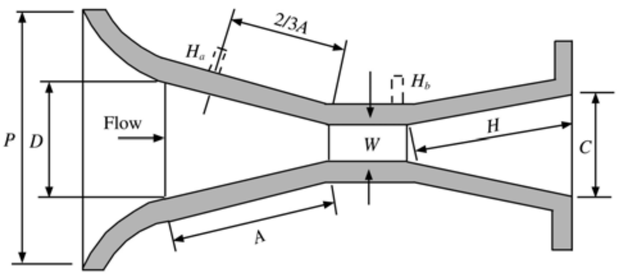
Ten farms were identified with five of them in each study site where detailed analysis of the farm and irrigation practices by the farmers was done. Participatory approach was used where the farmers were engaged during the entire study. Various parameters were identified such as the water pumping system used including the pumps and water delivery mechanisms such as pipes and sub canals. Irrigation methods used by the farmers were also identified including water conveyance and application methods. Farm parameters such as farm dimensions and size were measured, the distances from the water source to field was also measured. In the 5 farms in Kithimani sub location, water was pumped using motorized pumps and then conveyed to the farm using sub canals while in Mitubiri location, pumps were used to pump water and then conveyed using pipes and thereafter water was applied to the fields using hosepipes. Conveyance efficiency was evaluated for the 5 farms in Kithimani sub location while application efficiency was evaluated in all the 10 farms. Crops grown in the study areas were baby corns (*Zea mays* L.), French beans (*Phaseolus vulgaris* L), tomatoes *(Lycopersicon esculentum L)* and water melon *(citrullus lanatus).*

2.3 Calculating water use efficiencies of pumped irrigation systems

In the 10 sample farms, water application losses was evaluated while in 5 farms where water conveyance was through secondary canals, water losses due to seepage was assessed.

2.3.1 Measurement of seepage losses in the secondary canals

Calibrated Parshall flumes were used to measure seepage losses in the secondary canals. Figure 2 shows the dimensions of the Parshall flume (Armfield, England) used in measurement of water discharge in the secondary canals.



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

Figure 2 Plan view of the Parshall flume used

The Parshall flumes were first calibrated before any field measurements were taken. Calibration was carried out in hydraulics laboratory in Jomo Kenyatta University of Agriculture and Technology. The Parshall flume was placed inside the open channel apparatus and water discharge was measured with a 90^0 V- notch as shown in plate 1.

The head, *h* (m), on the Parshall flume was measured at varying discharge rates of the V-notch and the measured values are shown in Table 1.

Table 1 Values recorded during calibration of the Parshall flume

B	*D*	*H*	*K*	*Q*	*h*
0.1	0.29	0.063	90.85	0.091	0.08
0.1	0.29	0.072	90.09	0.125	0.1
0.2	0.29	0.097	89.13	0.261	0.16
0.2	0.29	0.116	89.13	0.405	0.21
0.2	0.29	0.12	89.00	0.448	0.22

Note: *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 given by Equation (1).

$$K = 81.2 + \frac{0.24}{H} + (8.4 + \frac{12}{\sqrt{D}})(\frac{H}{B} - 0.09)^2 \quad (1)$$

The flow rate *Q* (m^3/min) on the V-notch was given by Equation (2).

$$Q = Kh^{5/2} \quad (2)$$

where, *h* is the upstream depth in the Parshall flume in metres.

Plate 1 Calibration process for the Parshall flume

A calibration curve of the Parshall flume was generated by the flume upstream depth versus the computed discharge of the flume as is shown in Figure 3.

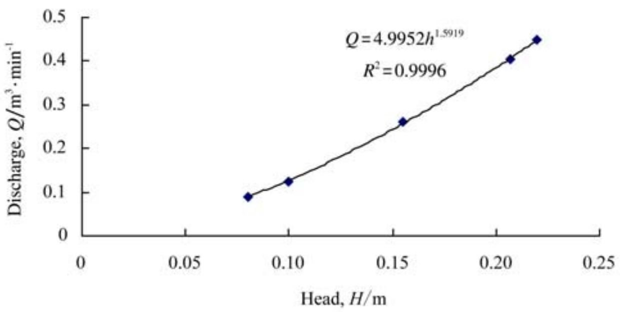


Figure 3 Calibration curve of the Parshall flume

Regression analysis of discharge (Q) and head (H) yielded a relationship given by Equation (3) with high correlation coefficient of R^2 = 0.9996. Discharge in the flumes was calculated from Equation (3). In measurement of water conveyance efficiency in the secondary canals, two calibrated Parshall flumes were set at specified distance along the secondary canal as is shown in Plate 2.

$$Q = 4.9952h^{1.5919}, \quad R^2 = 0.9996 \tag{3}$$

Plate 2 Water flow measurement using a Parshall flume in a sub 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 min in order to get the average values of seepage rate. This assessment was done for five farms in Kithimani area of Yatta division. The procedure was repeated during the whole cropping period to get the best results.

Equation (3) was then used to compute the discharge on each Parshall flume. Finally seepage loss was computed using the inflow-outflow method (Tyagi et al., 2005) as is shown in Equation (4) while conveyance efficiency was then computed from Equation (5) (Michael, 1983).

$$S = Q_1 + R - Q_2 - Q_f - U \tag{4}$$

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; U = flow rate diverted to the reach, m^3; E= daily evaporation, m^3.

$$E_c = {Q_2}/{Q_1} \times 100 \tag{5}$$

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.

2.3.2 Assessment of water application efficiency

Ten experimental sites each measuring 5 m by 5 m were set in the ten farms in the study areas. Crops grown in the 10 farms were French beans, tomatoes, baby corns and water melon. Detailed study was done in the experimental sites to investigate crop water requirement for the 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. Crop characteristics such as the height and root depth at various growth stages were monitored.

Weather data was acquired from meteorological station in Thika (KARI research station) and in National Youth Service (NYS) in Yatta division.

Soil moisture in each of the 10 experimental sites was measured using a calibrated Tensio meter (Terada type, DIK-3120, Japan). Calibration was carried out at the soil laboratory in BEED, Jomo Kenyatta University of Agriculture and Technology. The calibration process entailed placing soil from the experimental sites in a bucket that had holes in 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 samples were initially saturated with water. The corresponding gravimetric moisture content values 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 and a mean was calculated. The values of soil tension were plotted against soil moisture and a calibration curve was developed as is shown in Figure 4.

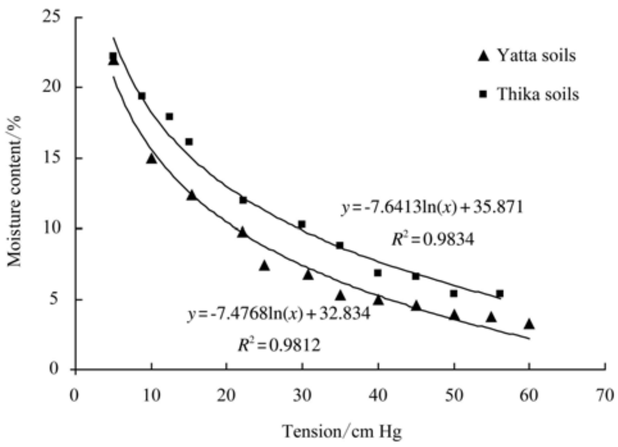


Figure 4 Calibration curve for the tensiometers

The coefficient of correlation (R^2) for data obtained in this calibration of the Tensio meters was 0.9834 and 0.9812 for soils in Kakuzi division and Yatta division, respectively, which is a high correlation. The soil moisture at the centre of all the plots in the field experimental sites was measured using Tensio meters everyday at 9:00 a.m. The Tensio meters were placed at a depth of 15 cm from the top. Equations (6) and (7) were used to convert tension readings to moisture content.

The relationship between tension in cm Hg units and volumetric moisture content as a percentage is given as:

$$y = -7.64\ln(x) + 35.871,\ R^2 = 0.9834$$

(for soils in Mitubiri location of Thika district) (6)

$$y = -7.47\ln(x) + 32.834,\ R^2 = 0.9812$$

(for soils in Kithimani sub location of Yatta district) (7)

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

2.3.2.1 Evaluation of net irrigation requirement

The first step was to evaluate the net irrigation requirement from the field balance Equation (8) (FAO, 2002).

$$IR_n = ETC - (Pe - Ge + Wb) + LR \tag{8}$$

where, IR_n = Net irrigation requirement, mm; ET_c = 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 irrigation period, mm; LR = Leaching requirement, mm

High water tables are rare and as a result groundwater contribution to crop water requirements was ignored as well as the leaching requirements. As a rule, the leaching requirement is normally ignored when estimating irrigation requirements for smallholder farmers (FAO, 2002).

ETc was calculated from Equation (9).

$$ETc = ETo \times Kc_{adj} \tag{9}$$

where, ETo is reference crop Evapo-transpiration given by Equation (10).

$$ETo = Kpan \times Epan \tag{10}$$

where, $Kpan$ is pan coefficient used which was obtained from the meteorological stations. The obtained Kpan values for Yatta and Kakuzi division was 0.75; $Epan$ is the pan evaporation which were obtained from the meteorological stations in the two study areas.

The adjusted value for crop coefficient (Kc_{adj}) was determined from Equation (11) as is described by Allen et al., 1998.

$$Kc_{adj} = Kc(table) + (0.04(U_2 - 2) - (0.004(RH\min - 45)) \times \left(\frac{h}{3}\right)^{0.3} \tag{11}$$

where, Kc = values for the crops studied were obtained from the tables (FAO, 2002), Kc was evaluated at each crop growth stage; U_2 = mean wind speed at 2 m high; $RH_{\min}$ = mean daily minimum relative humidity; h = field measurements of appropriate crop height.

Secondly, the effective rainfall for each of the study sites was calculated from Equation (12) (USDA, 1970).

$$Pe = SF \times \left[0.70917\left(P_m/25.4\right)^{0.82416} - 0.11556\right] \times 10^{0.000955ETC}. \tag{12}$$

where, SF is the soil water storage factor which was calculated from Equation (13); P_m is the average monthly precipitation, mm from the nearest rainfall station in the study areas

$$SF = 0.5317 + 0.295164\left(\frac{D}{25.4}\right) - 0.057697\left(D/25.4\right)^2 + 0.003804\left(D/25.4\right)^3 \tag{13}$$

where, D is the maximum soil water deficit calculated from Equation (14).

$$D = MSWD = SWS \times p(\%) \quad (14)$$

where, SWS is the soil water storage given by Equation (15); p is the soil water depletion fraction for no stress for different crops whose value of 5.5 was used in computation according to Allen et al.,1998.

$$SWS = RD \times AWSC \quad (15)$$

where, RD is the crop rooting depth, which was estimated by measuring the lengths at different crop growth stages.

2.3.2.2 Evaluation of available water storage capacity (AWSC)

Eight composite soil samples were obtained from eight different farms of the 10 farms considered. Three farms were close to each other hence one representative soil sample was used. The soil samples were analyzed in the BEED laboratory by measuring the water potential using the PF Meter (H-1400.PF, Japan). Standard procedure for evaluating the available water storage capacity in the soil samples was used. Percent moisture content was computed for all tensions and the results of these versus pF values plotted to obtain the pF curve. Figure 5 shows the soil water characteristics of soils from different farms

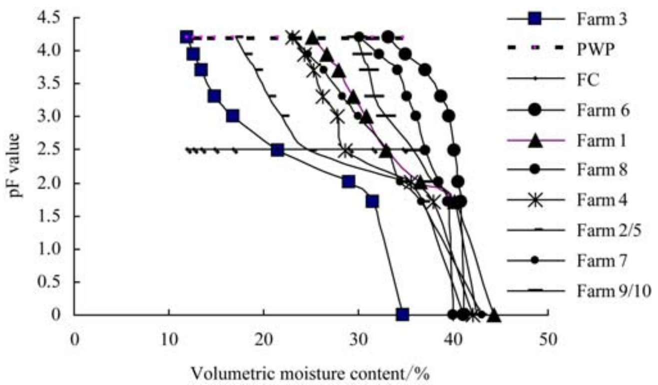


Figure 5 Pf values versus volumetric moisture content

The values for permanent wilting point and field capacity were taken as 4.2 and 2.5 respectively (FAO, 1985).

2.3.2.3 Water application loss assessment

Water application losses at different crop growth stages were evaluated from Equation (16);

$$\text{Water application losses} = Q - IRn \quad (16)$$

where, Q is water application rate measured in mm which was measured in the experimental block using a bucket of known volume and a stopwatch and IRn is net irrigation requirements.

The application efficiency was calculated from Equation (17) (Michael, 1983).

$$E_a = {W_s}/{W_f} \times 100 \quad (17)$$

where, E_a = water application efficiency, %; W_s = water stored in the root zone of the plants; W_f = water delivered to the field (at the field supply channel).

2.4 Statistical data analysis

The data obtained from the questionnaire administered to 80 farmers as well as the observational data were analyzed statistically using the statistical package SPSS pc + (SPSS Inc., 1993).

3 Results and discussion

3.1 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. Table 2 summarizes the findings from the two study areas.

Table 2 Agricultural activities and environmental concerns in the study area

	Mitubiri location of Thika district	Kithimani sub location of Yatta district
Crops grown	water melons, French beans, baby corns, Vegetables, Bananas, Tomatoes, Mangoes, and subsistence crops.	water melons, French beans, vegetables, baby corns, bananas, tomatoes, Baby corns, Vegetables, Bananas, Tomatoes, Mangoes and subsistence crops
Environmental concerns	Water pollution, water use efficiency, evaporation losses.	Soil erosion, illegal abstractions, seepage losses, water contamination, evaporation losses.
Main water users	Small holder farmers, few large scale farmers, Few large scale farmers.	Small holder farmers, few large scale farmers
Natural Vegetation	Indigenous trees	Shrub land dominates the area

3.2 Irrigation practices in the two study areas

The percentages of the farmers using different methods of irrigation in the study area are shown in Figure 6. Very few farmers used modern irrigation technologies in the study area. This would be due to lack of advice on appropriate technologies available or financial limitations to obtain modern equipments for irrigation.

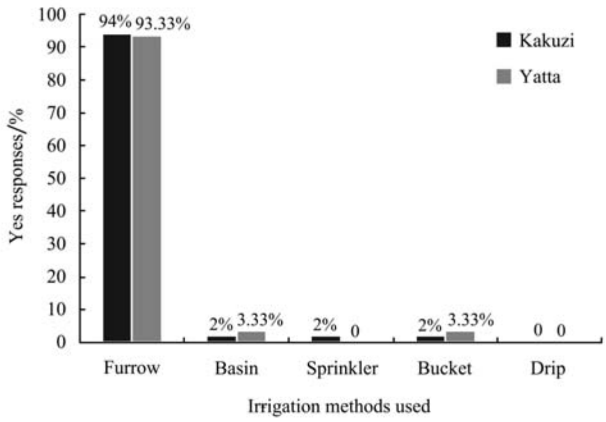


Figure 6 Smallholder irrigation methods used in the study sites

From an observational study, it was found out that different farm irrigation set ups were being used in the two areas. A majority of smallholder farmers in the study areas used small motorized pumps with 97.5% owning petrol pumps and 2.5% had diesel engine pumps. The farmers using diesel powered pumps gave the reason as the high cost of buying the diesel pumps as compared to petrol pumps. It was also found out that several factors dictated the scheduling of irrigation for most farmers as is shown in Table 3.

Table 3 Factors influencing irrigation scheduling practiced by smallholder farmers

Time to irrigate	Respondents/%
Assessing the crop performance	30
Set date for irrigation	15
Soil feel tests	5
Weather conditions	10
Availability of irrigation equipments	40

This shows that smallholder farmers do not have proper monitoring tests that would guide them on when to irrigate. An investigation of how much water the smallholder farmers uses during irrigation showed that they do not have proper techniques/water metering devices, Hence could result in over irrigation or under irrigation could be prevalent. Only 5 % of the farmers interviewed had water permits indicating that the rest of the population abstracted water for irrigation illegally. Lack of proper water use control mechanism such as water permits also would mean that farmers would either over irrigate their farms leading to low water use efficiency. Other effects attributed to over abstraction of water for irrigation would be reduced water flow in the rivers and streams and possible drying up of the sources. The water conservation methods used in the study areas are shown in Figure 7.

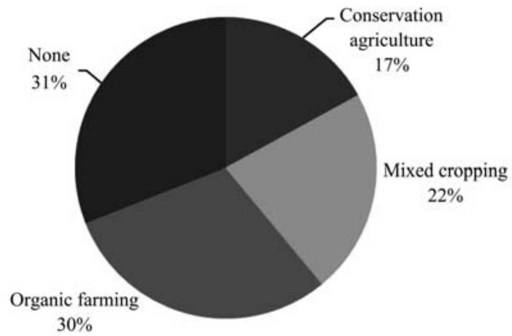


Figure 7 Water conservation methods used by smallholder farmers in the study area

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.

3.3 Crops irrigated

Crops commonly irrigated in the two study areas are shown in Table 4 while Table 5 shows the methods of irrigation used in relation to the crops grown.

Table 4 Percentage of farmers growing various crops under irrigation in the study areas

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

Table 5 Methods of irrigation used

Irrigation method used	Furrow	Basin	Sprinkler	Bucket	Drip	Total
No. of farmers	75	2	1	2	0	80

From Tables 4 and 5, in the study area, 1 farmer grew baby corn under sprinkler irrigation method while 2 farmers used basin irrigation method to grow tomatoes and 2 farmers grew French beans using bucket irrigation method. The remaining 75 farmers growing different crops used furrow irrigation method.

3.4 Water availability related problems

An assessment of water problems experienced during crop production showed that 65% of the respondents cited that great water shortages occurred when the demand for horticultural produce both for local and export market was high. This was further aggravated by the dry conditions during these periods. An observational study showed that river flows were lowest during the months of January to March. Further assessment indicated more problems that could result in water shortages such as over abstraction by upstream users and low rainfall levels which was cited by 65% and 30% of the respondents respectively. A water survey in the two areas revealed that River Thika and Kabuku were both permanent while Yatta furrow and River Samuru are seasonal and highly polluted.

3.5 Water conveyance efficiencies for different sub canals

To calculate the seepage losses in 5 secondary canals in five farms in the study area, the values shown in Table 6 were used. The results of the mean conveyance losses in the 5 sub canals are also shown in the table.

Table 6 Measured mean parameters for values used in calculation of water seepage losses

Farm	Upstream flume 1		Downstream flume 2		Evaporation loss/mm	Canal dimensions /m^2	Pan evaporation /$m^3 \cdot hr^{-1}$	Seepage loss /$m^3 \cdot m^{-2} \cdot hr^{-1}$	Mean seepage losses/%
	H1/m	Q1/$m^3 \cdot hr^{-1}$	H2/m	Q2/$m^3 \cdot hr^{-1}$					
F1	0.1	7.67	0.08	5.38	9	15	0.01	0.15	73.7
F2	0.12	10.25	0.1	7.67	14	12	0.01	0.21	87.4
F3	0.102	7.92	0.08	5.38	37	20	0.03	0.13	77.89
F4	0.134	12.22	0.12	10.25	3	8	0.01	0.25	90.7
F5	0.12	10.15	0.10	7.67	14	14	0,01	0.18	77.3

In the five farms, water was pumped to sub canals for delivery to the irrigable field. During water conveyance, seepage losses occurred in the sub canals and not all water diverted from the main canal reached the field. The result in Table 6 indicates some significant amount of water lost through seepage in the sub canals. Due to differences in soil types and period of water conveyance in the 5 farms, different values of seepage losses were found.

3.6 Water losses during application

In evaluating water losses during application for different crops considered in the study area, the following parameters shown in Table 7 were calculated. Four months were considered during the growth period of the four crops.

Table 7 Mean estimated parameters for different crops grown in the study area in the year 2009

Estimated parameter	Observation months															
	April				May				June				July			
	B	T	F	W	B	T	F	W	B	T	F	W	B	T	F	W
Ep/mm · day^{-1}	11	11	11	11	8	8	8	8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8
Kp (Dimensionless)	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
ETo/mm · day^{-1}	8.25	8.25	8.25	8.25	6.0	6.0	6.0	6.0	5.25	5.25	5.25	5.25	6.5	6.5	6.5	6.5
Kc (Dimensionless)	1.15	1.15	0.5	0.4	1.05	1.15	1.05	1.0	1.05	0.8	0.9	0.6	1.05	0.8	1.05	0.7
ETc/mm · day^{-1}	4.46	4.50	1.03	2.7	3.24	5.27	2.82	2.6	3.94	4.0	2.31	2.7	3.70	2.50	2.40	2.69
Pe/mm · day^{-1}	0.40	0.35	0.50	0.40	0.30	0.32	0.40	0.40	0.3	0.45	0.4	0.44	0.35	0.30	0.3	0.40
AWSC/mm	78	78	78	78	70	70	70	70	60	60	60	60	78	78	78	78
SWS/mm	35.1	25.5	7.7	8.5	49.9	23.3	16.8	34.5	46.8	9.9	7.8	27.8	47	35.8	19.8	30.1
P	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
SF/mm	0.71	0.6	0.58	0.66	0.77	0.65	0.62	0.56	0.67	0.6	0.6	0.63	0.76	0.70	0.64	0.65
RHmin/%	58.5	58.5	58.5	58.5	45	45	45	45	60	60	60	60	62	62	62	62
U_2	0.5	0.5	0.5	0.5	0.69	0.69	0.69	0.69	0.66	0.66	0.66	0.66	2.56	2.56	2.56	2.56

Note: B- baby corns; T- tomatoes; F- French beans;W-water melon

Table 8 shows the computed values for water application efficiency for different crops assessed.

Water was lost by infiltration due to over application of water to the crops during irrigation.

Table 8 Mean values for infiltration water losses for the entire crop growing period

Crop	No. of farms	Percent mean value for water losses by infiltration for different crops
Baby corns	1	19.5
French beans	3	25.4
Tomatoes	3	26.3
Water melon	3	30.0

On average, it can be noted that water application efficiency is quite low hence high water losses occurs during crop production. In the study sites, all the 10 farms used furrow irrigation methods where farmers applied water using drag hose system. The use of drag hose results in the irrigator not accurately applying the right amount of water due to lack of appropriate measuring devices. Matching of crop water needs to the amount of water applied requires detailed technical evaluation and knowledge which is not common with smallholder farmers who only irrigates their crops based on estimation methods. In the study area, Watermelon had the highest water application efficiency followed by tomatoes with the baby corns having least water application efficiency.

4 Conclusions and recommendations

Irrigated agriculture still plays a key role in the agricultural sector in producing food for the growing population. This increased uptake of irrigated agriculture was noted in the two study areas where farmers heavily grew horticultural crops for local and export market. Most farmers have adopted water pumping though traditional methods of water application still predominates this sector. It can be concluded that continuous use of traditional water application methods led to low water application efficiency which was averaged at 25.5% in the 10 farms studied.

Lack of use of water control devices such as water meter could have resulted to the water misuse as was noted in the study area as well as lack of farmers capacity building on water management issues. This presents a worrying trend in the agricultural sector considering the diminishing water resources and the ever increasing need for the scarce commodity by different sectors. Farmers should embrace modern irrigation technologies in order to increase the irrigation efficiency. Water conveyance efficiency in the study areas had a mean of 81.4% which was quite high though more improvements should be embraced to ensure even least loss of water become possible.

The study recommends detailed study of water use at farm level considering a large sample size as well as seek means of improving its use. Other methods of estimating crop Evapo-transpiration should be used in the study to assess if changes would occur in evaluating water use efficiency.

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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?
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