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Determining the Economic Value of Irrigation Water in Kerio Valley Basin (Kenya) by Residual Value Method

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Abstract
This paper presents an application of the residual value technique to determine the disaggregated economic value of irrigation water used across crops at the basin level for the Kerio valley basin Kenya. A multistage sampling method was used to select a representative sample of 216 smallholder irrigation farmers. Data was collected using a structured questionnaire administered to the small holder farmers, additional data on irrigation water requirements was obtained from FAO, CROPWAT 8.0 and CLIMWAT 2.0 (2013) database. The average residual value in the basin is Ksh 6.17 per M^3. Results for the economic values of irrigation water are Ksh/ M^3 20.85, 14.87, 4.3, 11.28, 1.25, 0.3 for field food crops; green grams, maize, millet, sorghum, cassava and cowpeas are respectively. Similarly for the fruit trees bananas, mangoes and lemons, the economic value of irrigation water are Ksh/M^3 1.36, 0.90, 0.45 respectively Green grams and maize had the highest values for the ratios of apparent productivity and residual value and cowpeas and lemons the lowest. The results shows that at crop level water values estimated for field crops are generally higher compared to fruit trees. This means that there is greater potential in field crops than fruit trees in the basin.
Keywords: Irrigated agriculture, apparent productivity, value of water, residual value method

1.0 Introduction

Water is one of the most important natural resources and is a key component to prosperity and wealth (Arbues *et al.,* 2003). However, globally water is becoming increasingly scarce, especially in developing countries (Amer, 2004). The growing population, rising incomes and urbanization are increasing the demand for fresh water. This upward trend in demand calls for efficient water allocation among competing uses. Irrigated agriculture is currently the biggest user of global water supply accounting for approximately 70 percent of fresh water abstraction in the world (FAO-COAG, 2007). In addition, it is projected that irrigated land in developing countries will increase by 27 percent in the next 20 years (World Bank, 2008). Irrigated agriculture is the only option that can enhance food production in rain deficit regions. With climatic changes experienced in most regions of the World, irrigated agriculture is increasingly facing uncertainty about the quantity and regularity of water supply (UNESCO-WWAP, 2009). According to FAO, (2007), climate change will account for 20 percent of global increases in water scarcity. In order to bridge the water deficit and adapt to climate change there is a need to allocate water in production among crops which utilize less water while at the same time generating more yields. The food-water consumption relationship is measured in terms of water productivity. Water productivity or yield per unit of water for a farmer means getting more crops per drop of irrigation water; it is a vital parameter to assess the performance of smallholder irrigated agriculture (FAO, 2003). It can be defined at different spatial scales such as plant, field, farm, scheme, sub-basin, and basin or regional scales. Bos *et al.* (2005) defines water productivity at the farm level in terms of economic benefit in relation to irrigation water supply. According to Cook *et al.* (2006), estimates of water productivity have two basic uses: firstly as a diagnostic tool to identify the level of water use efficiency of a system under study and secondly to provide insight into the opportunities for better management towards increased water productivity at the scale under consideration. Several models have been developed by researchers to describe the relation between crop production and water use. Hanks (1974) linearly related yields (Y_{act}) to transpiration (T_{act}) with maximum attainable yields (Y_{max}) under maximum transpiration (T_{max}). FAO research paper 33 on yield response to water (Doorenbos and Kassam, 1979) provided a simple method to assess the impact of crop water on yield reduction for more than 25 crops. Water stress is determined as the difference between actual evapotranspiration (ET_{act}) and the evapo-transpiration when crop requirements are met (ET_{max}).These are linearly related to crop yield (Y_{act}) under certain conditions, and maximum yields (Y_{max}) under optimal conditions (Stewart *et al.,* 1977). FAO introduced the Aqua crop toolbox in 2009, it is a crop water productivity model that simulates the yield response to water and is particularly suited to function under water scarce conditions (Steduto *et al*., 2009).

1.2 Residual imputation model

Residual imputation model also known as residual value method (RVM) is a technique used to value water productivity where water is used as an intermediate input into production. Crop production is a dynamic process in which decisions about inputs are made sequentially. Farmers require field level information on the soil-water plant relationship before making rational decisions on the best crops to grow given conditions of water scarcity.

In valuing water, very few studies have employed the residual imputation technique. Some of the studies which have employed this technique include Yokwe (2005) and Ashfaq and Saima (2005). Emad *et al.* (2012) estimated the average economic value of irrigation water for twelve crops in Jordan. The results showed that the weighted average of water value used in field crops were JD 0.44 and JD 1.23 for vegetable crops and JD 0.23 for fruit trees. The overall weighted average water value in irrigation is estimated with JD 0.51. With regard to individual crops, cucumbers had the highest water values with about JD 6.05, followed by string beans with JD 2.64, and sweet pepper with JD 2.54. Average economic values of irrigation water for wheat, rice, sugarcane and cotton were determined by Muhammad *et al.,* 2005 in Pakistan. The economic value of irrigation water for wheat, rice, sugarcane and cotton was Rs. 1.13, 0.63, 0.30 and 1.52, respectively. For the minor crops like potatoes, onions, and sunflower, the economic value of irrigation water was Rs. 6.60, 13.10, and 0.53, respectively. Yokwe (2005) investigated the productivity of water and its value in two smallholder irrigation schemes (Zanyokwe and Thabina) in South Africa using residual Valuation method. In both schemes, water value was estimated for a vegetable (cabbage, tomatoes and butternut) was found to be greater than water value for dry maize. At the farm level; and scheme level a comparison was made between gross margins per m^3 of water, WTP per m^3 and accounting cost per m^3 to estimate the relative value of water productivity. From the results the active farmers in Zanyokwe scheme had lower WTP per m^3 (R0.084) of water which was less than the gross margin.

1.3 Theoretical framework

1.3.1 Euler's theorem

Euler's theorem is a standard mathematical function that shows that if a production function involves constant returns to scale, the sum of the marginal products will actually add to the total product. Considering a production function $f(x_1... x_n)$ and suppose it is homogeneous of degree 1 (i.e. has "constant returns to scale"). Euler's theorem shows that if the price (in terms of units of output) of each input i is its "marginal product" $f'_i(x_1... x_n)$, then the total cost, namely $\sum_{i=1}^{n} x_i f'_i(x_1... x_n)$ is equal to the total output, namely $f(x_1... x_n)$.

$$\sum_i = 1^n x_i f_i^{'}(x_1......, x_n) = kf(x_1,....., x_n) \ \ for\ all\ (x_1,......., \ x_n) \ldots\ldots\ldots\ldots\ldots(6)$$

In this study the residual imputation model was applied to find out the average economic value of irrigation water used in production across major crops grown in Kerio valley basin. Considering a production function Y=f (x's) in which four factors of production namely) capital (K), labour (L), natural resources, such as land (R), and irrigation water (W).

$$Y = f(K, L, R, W) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(7)$$

Assuming production and prices are known and technology is constant. Py is the price of output; Px is the price of input under perfect information. And we assume the farmers' objective is to maximize production, the production function can be written as.

$$\pi = \sum_{j=1}^{n} P_{i^*} Y - \sum_{i=1}^{n} P_{x^*} X_i + P_w . Q_w \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

To find the conditions for optimal profits, take the first derivative of π with respect to x and set that equal to zero

$$d\,\pi/dx = Py.df(X)/dx - Px = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(9)$$

Therefore Py.dy/dx=Px or Py.MPx which means VMPx = Px

If all the inputs, including water are exchanged in a competitive market and employed in production process, the value of water will be

$$P_w . Q_w = P_y . Y - \sum_{i=1}^{n} Px_i . X_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(10)$$

The residual imputation model determines the incremental contribution of each input in the production process if appropriate prices can be assigned to all inputs except water. The residual obtained by subtracting the non-water input costs equals the gross margin and can be interpreted as the as the maximum amount the farmer would pay for water and still cover the cost of production . The residual calculation can be expressed as:

$$Pw^* = \frac{\left(\sum_{j=1}^{m} Y_j . P_j - \sum_{j=1}^{n} X_i . P_i\right)}{\sum Q_w} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(11)$$

2.0 Methodology

2.1 Study area

The study was undertaken in Elgeyo Marakwet County consisting of Marakwet East, Marakwet West, Keiyo North and Keiyo South constituencies. The County is located between longitude 35° 20′ and 35° 45′ East Longitude and 0° 10′ and 0° 20′ North Latitude. It Borders West Pokot County to the North, Baringo County to the East, Uasin-Gishu County to the West and Trans Nzoia County to the North West. It covers a total land area of 3,030 Km^2 and a population of 369,998 (KNBS, 2009) with an altitude ranging from 1000 m in Kerio valley to 3,350 meters above sea level in the highlands. The County receives a bimodal type of rainfall with long rains received in March through April and short rains starting from July to September. Mean annual rainfall ranges from 1000mm for the highlands and between 200mm to 800 mm in the dry low land. Temperatures in the Kerio valley basin are generally very high ranging from 10 ^{0}C in the Cherangany Hills and Tugen Hills, to maximum of 40 ^{0}C in the lower altitude areas. Evapo-transpiration is high in these zones due to the long dry periods. The County falls into three distinct topographical zones: The highland plateau (2500m-3500m) ideal for (forest, pyrethrum, tea, wool sheep, potatoes and dairy cattle); the Kerio Escarpment (1200m-2000m) and the Valley floor (300m-900m). Irrigation occurs along the 40 kilometers stretch of the Escarpment containing three major irrigation schemes: Arror, Chepsigot and Tot. Irrigation under these schemes is practiced mostly on small plots the major crops grown include: maize, millet, mangoes, sorghum, green grams, cassava and cowpeas. Untapped and underutilized crops which have high potential for production potential include: sisal, cotton and pyrethrum. The main challenge in crop production is climate variation with occasional severe droughts and heavy floods. The County is also endowed with other natural resources like indigenous forests and minerals such as fluorspar and oil prospecting is currently underway.

2.2 Data collection

The study used primary data collected using a structured questionnaire and administered to the smallholder irrigation farmers in the Kerio basin. Secondary data on irrigation, crop-water use and requirements' were obtained from the FAO *CLIMWAT* and *CROPWAT* software 2009.

2.3 Data analysis

In analyzing data, descriptive statistics including frequencies, percentages and means were used to describe the socioeconomic characteristics of the farmers. Residual imputation model was used to determine the average economic value of irrigation water used in production across major crops grown.

2.4 Econometric specification

Residual imputation model is the most common method applied to determine the shadow pricing of irrigation water and other producers' goods. The technique determines the contribution of each input to output in the production process. It assumes that if appropriate prices are assigned by market forces for all production inputs except one the remaining total value of product or residual which is water in this specific case, then its value can be imputed (Young 2005). The residual value of water is estimated even if water is a scarce resource and crops are irrigated with deficit or supplementary irrigation because water value is assigned the residual value once the remaining inputs get the opportunity or market cost.

The model expressed mathematically and by considering an agricultural production process in which four factors of production: capital (K), labour (L), natural resources, such as land (R), and irrigation water (W) produces a single product denoted Y.

$$Y = f(K, L, R, W) \qquad (23)$$

If we consider technology as constant, but all other factors variable except water, the total production value is:

$$TVP_Y = (VMP_k Q_k) + (VMP_L Q_L) + (VMP_R Q_R) + (VMP_W Q_W) \qquad (24)$$

Where *TVP* represents the total value of product *Y, VMP* represents value of marginal product of resource I, and Q is the quantity of resource i.

Assuming competitive factor and product markets and treating, prices as known constants. The first postulate which asserts that ($VMP_i = P_i$) permits substituting into (2) and by rearranging

$$TVP_Y - P_k Q_k + P_L Q_L + P_R Q_R = P_W Q_W \qquad (25)$$

Assuming that all variables in (1) are known except $P_{w,}$ the expression can be solved for that unknown to impute shadow price of water P_W^* as follows:

$$P_W^* = (TVP_Y - P_K Q_K + P_L Q_L + P_R Q_R) / Q_W \qquad (26)$$

The study undertook valuation of the residual value of water for nine major crops grown in the Kerio Valley basin. These crops together make up 90% of the total irrigated land area of the basin (KVDA, 2010). The crops included are maize, millet, cowpeas, green grams, cassava, bananas, mangoes, lemons and sorghum. Data available from FAO irrigation water use and crop water requirements for crops cultivated in different agro-ecological zones in Kenya guided the selection of these crops. FAO uses the Penman-Montheith methodology in calculating the crop water requirements. These data are available in the *CROPWAT* computer software, which uses data from *CLIMWAT* 2.0, which is a database of climatic data from weather stations globally. Farm budgets for each of these crops were developed. Gross margins calculations for each crop aided in imputing the value of water for these crops. All costs were on per acre basis, and converted to per hectare. These crop budgets were used to determine the price of water (Ksh/m^3). The costs of production were deducted from gross returns of each individual crop. These returns were further divided by the amount of water applied (m^3) in this case the irrigation crop water requirement.

3.0 Results and discussion

3.1 Table1. Socioeconomic characteristics of smallholder farmers (continuous variables).

Characteristics	Overall mean
Age (years)	40
Household size (members)	6
Total land ownership (acres)	3.6
Irrigated Land	2.25
Total livestock	29

The aggregated mean age of the sampled farmers was 40 years with a mean household size, composition, of six members. In terms of household asset ownership, the total land owned had a mean acreage of 3.6 cares with land utilized for irrigation having a mean acreage of 2.25 acres. Regarding livestock ownership mean number of total livestock owned was 29 as shown in Table 1 above.

Table 2: Gender, educational level and occupation status of farmers (categorical variables)

Characteristic of the farmer	Category	%
Gender	Male	66
	Female	34
Occupation status	Full-time farmers	58
	Salaried /employed	26
	Retired	1
	Casual laborer's	15
Education level	No education	13
	Primary	56
	secondary	18
	Tertiary/college	13

Analysis of farmers' categorical characteristics is presented in Table 2 above. Approximately 66% of the sampled farmers were male while 34% were female. Concerning occupation status and participation in farm activities the results indicate that 58% were full time farmers while 26%, 1% and 15% were employed, retired and casual laborers respectively. Regarding education level, 13% of farmers had no formal education, while 56% went to primary school, 18% secondary school and 13% attended tertiary institutions.

3.2 Water productivity

3.2. 1 The residual return to water

Farm budgets of eight crops namely; maize, millet, cowpeas, green grams, cassava, bananas, mangoes, lemons and sorghum were developed. Farm costs which include rent of land, labour, seed, fertilizer, pesticides, were all added up to arrive at total cost for each crop. The prices are determined by the farm gate or first point of sale transactions where farmers participate in their capacity as sellers of their own products. The gross margins are calculated for each crop in order to analyze the value of water of these crops. All costs were estimated on per acre basis then converted to per hectare Table 3 provides a summary of the crop budgets of the eight crops obtained from the sampled 216 smallholder farmers.

Table 3: Summary of crop budgets

Crop	Average total sales TVP (Ksh/Ha)	Average total cost Ksh/ha	Average Gross margin (Ksh/Ha)	Average total sales TVP Ksh/Acre	Average total cost Ksh/Acre	Average Gross margin Ksh/Acre
Maize	110,484	25,540	84,944	44,193	10,196	33,997
Millet	74,649	15,388	59,261	29,859	6,155	23,704
Cowpeas	6,945	4,461	2,484	2,778	1,785	993
Green grams	108,779	17,491	91,288	43,511	6,996	36,515
Cassava	52,350	23,200	29,150	20,940	9,280	11,660
Bananas	257,488	106,971	150,517	102,995	42,788	60,207
Mangoes	295,643	251,958	43,685	118,257	100,783	17,474
Lemons	141,368	98,277	43,091	56,547	39,311	17,236
Sorghum	74,981	19,535	55,446	29,992	7,814	22,178

Source: Survey data 2013

The results indicate the average gross margins for the different crop enterprises. From the results Bananas had the highest gross margin (Ksh 150,517) compared to other crops followed by green grams (Ksh 91,288), maize (Ksh 84,944), millet (Ksh 59,261), sorghum (Ksh 55,446), mangoes(Ksh 43,685), lemons (Ksh 43,091), cassava (Ksh 29,150) and cowpeas (Ksh 2,778) respectively in decreasing order. These crop budgets were utilized to determine the price of water (Ksh/m^3) through Residual Imputation Model. The costs of production were deducted from gross returns of each individual crop. These returns were further divided by the amount of water applied (m^3) in this case the irrigation crop water requirement. Irrigation crop water requirements for the various crops grown in the basin were obtained from the FAO Penman-Montheith methodology through the CROPWAT 8.0 windows program. The program uses data from CLIMWAT 2.0 which is a database of climatic data from weather stations globally. Table 6, provides a summary of the data at the farm crop level, which was used to evaluate the residual return to water (Kenya Shillings per m^3). The residual return to water was derived from the crop output with irrigation over the entire production period of one year.

Table 4: Water productivity ratios and residual value of irrigation water (2013)

Crop	Average total sales (Ksh/Ha)	Gross margin (Ksh/Ha)	Average water consumption m^3	Sales /water Ksh/m^3	Gross margin/water m^3	Residual value ksh/m^3
Maize	110,484	84,944	5,650	19.554	15.034	14.87
Millet	74,649	59,261	2,440	30.593	24.287	4.3
Cowpeas	6,945	2,484	4,582	1.515	0.5421	0.3
Green grams	108,779	91,288	1,115	97.559	81.872	20.85
Cassava	52,350	29,150	3,730	14.034	7.815	1.25
Banana	257,488	150,517	6,215	41.430	24.218	1.36
Mangoes	295,643	43,685	3,415	86.571	12.792	0.90
Lemons	141,368	43,091	4,600	30.732	9.367	0.45
sorghum	74,981	55,446	982	76.355	56.46	11.28

Source Author's own data; data for irrigation crop water requirement is obtained from FAO, CROPWAT 8.0 and CLIMWAT 2.0 (2013).

Through residual imputation model the economic values of irrigation water for the nine crops were estimated on per Ha per cubic meter basis. The economic value of irrigation water for field food crops; green grams, maize, millet, sorghum, cassava and cowpeas are Ksh 20.85, 14.87, 4.3, 11.28, 1.25, 0.3 respectively. Similarly for the fruit trees bananas, mangoes and lemons, the economic value of irrigation water are Ksh 1.36, 0.90, 0.45 respectively. Green grams and maize have the highest values for the ratios of apparent productivity and residual value and cowpeas and lemons the lowest. The results shows that at crop level water values estimated for field crops are generally higher compared to fruit trees. This means that there is greater potential in field crops than fruit trees.

4.0 CONCLUSIONS AND POLICY RECOMMENDATIONS

Results from the residual imputation model on the economic values of irrigation water for the nine crops estimated on per Ha per cubic meter basis are Ksh 20.85, 14.87, 4.3, 11.28, 1.25, 0.3 for field food crops; green grams, maize, millet, sorghum, cassava and cowpeas are respectively. Similarly for the fruit trees bananas, mangoes and lemons, the economic value of irrigation water are Ksh 1.36, 0.90, 0.45 respectively. Green grams and maize have the highest values for the ratios of apparent productivity and residual value and cowpeas and lemons the lowest. In light of the above conclusions this study Results from crop water productivity indicate that green grams and maize give high returns while utilizing less water farmers should be encouraged to grow more of green grams and maize in the river basin.

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