2022-10-29

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https://doi.org/10.3390/w14213459

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Assessment of Variation in Marginal Productivity Value of Water in Paddy Farming Systems in Times of Water Stress

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Abstract: Global projections show that increases in agriculture water productivity (AWP) by 30 and 60% in rain-fed and irrigated agriculture, respectively, are required to ensure food security in the period 2000–2025. In sub-Saharan Africa, attempts to understand AWP has seen a lamping of input values which paints an unrealistic picture of AWP. We employed the residual imputation method to isolate the marginal productivity value of water in six paddy farming systems viz. the conventional transplant and flooding system (CTFS), the system of rice intensification (SRI), and the Kilombero Plantation Limited (KPL) mechanized system. Findings showed that AWP for rainfed CTFS is 0.39 kg/m^3 or 0.003 US$/m^3, irrigated CTFS (0.30 kg/m^3 or 0.002 US$/m^3), rainfed SRI (0.68 kg/m^3 or 0.08 US$/m^3), irrigated SRI (0.52 kg/m^3 or 0.06 US$/m^3), rainfed KPL (0.33 kg/m^3 or 0.05 US$/m^3), and irrigated KPL (0.68 kg/m^3 or 0.11 US$/m^3). This shows that rainfed systems have good AWP, especially physical ones. We recommend a rollout of rainfed SRI to secure local food security and downstream ecosystem services. In addition, groupings of farmers will assist in optimizing resources, stabilizing markets, and prices for the better economic value of water (US$/m^3). Adoption of SRI will require intensive demonstration that needs public financing. In addition, revamping the KPL off-taker arrangement with small-holder farmers could also be a good PPP anchor.

Keywords: agriculture productivity; climate adaptation; water value; hydro-economics; water productivity

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Citation: Sigalla, O.Z.; Kadigi, R.M.J.; Selemani, J.R. Assessment of Variation in Marginal Productivity Value of Water in Paddy Farming Systems in Times of Water Stress. *Water* **2022**, *14*, 3459. https://doi.org/10.3390/w14213459

Academic Editor: Arturo Alvino

Received: 21 August 2022
Accepted: 24 October 2022
Published: 29 October 2022

1. Introduction

1.1. Background and Concepts

Globally, irrigation farming is known to be a water-intensive, consuming up to 70% of the world's total consumptive water uses [1,2]. At this global scale, about 324 million ha under irrigation is anticipated to increase by 34% in 2030 [3]. However, by the same period, water to support the subsector will only increase by 14% [3], which requires more efforts to improve agricultural water productivity (AWP). In these statistics, Africa, with only 5.8% of cultivated land under irrigation, has the worst irrigation efficiency numbers at an average of only 60% [4]. This water use status is synonymous to most parts of Tanzania where irrigation water demand is among the top three major water-using sectors (but the leading one amongst the consumptive uses), i.e., ecosystem 66%, hydropower 17%, irrigation 14%, domestic 2%, industries 0.6%, and livestock 0.5% [5]. Furthermore, Tanzania is reported to have agriculture water use efficiency as low as 15% in small-scale farming with unlined canals, which form the majority of the farming population [6,7]. However, there is scant data and information to back up the claim of low water use efficiency of physical water productivity in small-holder irrigation systems.

On the part of AWP, there is a general consensus that when it is not well considered, farming can impair catchment performance in relation to equitable water uses with other sectors [8,9]. Water productivity (WP), in general, is defined as the physical quantity or economic value of a product derived from the use of a given quantity of water [10]. Increasing WP to attain higher output or value per drop of water used is essential in mitigating water scarcity [8,9]. Global projections indicate that increment in WP while maintaining the expansion of irrigated areas will cut half of the long-term rise in global water requirements for a food supply that will ensure the food security of the population expected by the year 2050 [11]. Further, in order to meet the food security of 2025, the projected increases in WP by 30% and 60% in rain-fed and irrigated agriculture, respectively, are required. [12,13]. However, this entails multiple actions including choice of variety, irrigation technology, field-level water management, land management, and efficient utilization of inputs, including labor, fertilizer, and machinery [14,15]. Each improvement requires more capital that farmers will have to invest in adapting against the stresses (climatic or anthropogenic), affecting gross margins, AWP, and hence the feasibility of the proposed intervention.

This study focused on paddy farming in the Kilombero river catchment (KRC) and assessed the mechanized plantations operated by Kilombero Plantations Limited (KPL) and the small-holder farming practices viz. conventional transplanting and flooding systems (CTFS) and the system of rice intensification (SRI) to understand how AWP varies across the different farming practice. While KPL deploys state-of-the-art technology from modern pumping systems and overhead sprinklers to farming technology, harvest equipment, and value addition, the small-holder farmers represent the subsistence agricultural economy of most farmers in Tanzania and sub-Sahara Africa. On the one hand, CTFS entails the using basic hand hoes, family labor, and no or very limited use of fertilizer or pesticides, and irrigation is not through improved canals that attract water user fees [16]. On the other, SRI is described as an agroecological farming approach that is geared towards increasing the yield of rice production per unit size of the farm. It has been demonstrated to be a water-efficient and labor-intensive method that uses younger seedlings, singly spaced and typically hand weeded with special tools [16]. It promotes root systems and increases the abundance and diversity of soil organisms [17].

Different scholars have attempted to study AWP of different paddy farming systems in Tanzania, e.g., [17–19]. However, they did not attempt to isolate the value of water as one of the many production inputs whose total value was under consideration in calculating economic water productivity. Some, for instance, [18] acknowledged this fact and suggested a more realistic methodology that would consider the role of other production inputs. Where they have isolated different production inputs, farming as a whole or paddy as a crop has been considered in general terms. This was picked by [20,21], who studied the same but did not study all the types of paddy farming practices in isolation to study their uniqueness. Understanding of AWP in wetter ecoregions and encompassing all paddy systems can add better information in adaptive water allocation. Therefore, the current study focuses on isolating the marginal value of water for all the paddy farming systems to suggest best practice and tradeoffs considering the level of poverty in these rural settings. The residual imputation method was employed to single out the value of water as an unknown claimant, as was discussed in [20,22,23]. This avoided the lamping of production inputs, as pointed out in [18], where a change in the net income method was used. Furthermore, our study also considered the stressed years to understand the value of water in stressed conditions. The dependable rainfall methodology was adopted where the probability of exceedance of rainfall value at P80 was used as the base of isolating drier years from normal and wetter ones at P50 and P20, respectively; see also [24,25].

As such, the research considered the three main hypotheses:

(a) Because the rainfed system is applied at the wettest time (soil water saturation at its maximum), water applied is at the lowest. Hence, these systems will have higher physical water productivity (kg/m^3).

(b) Since SRI is labor intensive, it will attract more operational costs and hence attracts lower economic water productivity USD/m^3 attributable to low SRI adaptability.
(c) Irrigation augmentation has a significant leap in harvests and hence better AWP for all systems of paddy farming.

1.2. General Climate of Kilombero River Catchment

KRC experiences a subhumid tropical climate [26] with annual mean temperatures between 24 °C in the valley and about 17 °C in the higher altitudes [26]. Although with high spatial and temporal variability, the mean annual precipitation ranges between 1200 and 1400 mm [27]. The mountainous area receives up to 2100 mm of precipitation, whereas the expansive lower-laying Kilombero valley plain receives about 1100 mm [26,28]. The general rainfall pattern is divided into a dry season that runs from June to November and a rainy season lasting between November and May. The latter can further be divided into short rains from November to January and long rains from March to May [26]. However, the interannual variability is high [29] and the reliability of long rains is much more pronounced [28]. Owing to the fact that some parts of Kilombero catchment experiences only the long rains, the whole catchment is characterized by a unimodal to bimodal rainfall distribution, depending on the year and the specific area [27,29].

1.3. Social Economic Profile of Kilombero River Catchment

Based on the national household census of 2012, the Kilombero River Catchment (KRC) hosts 412,320 people, out of which 50.3% are females and 49.7% males, and is generally characterized by households composed of 4–5 family members [30]. The census also indicated that about 50% of the population was under the age of 20 years while 75% were below the age of 40 years [31], signifying a good number of family workforce. Cultural communities have age groups that are linked with decision making in families, including farm inheritance. Furthermore, there are statutory organs from the village, ward, and division to the district level that oversee the allocation of water and farms/land. Other structures include community associations related to water allocation and revolving funds, e.g., merry-go-rounds and other forms of informal groupings supporting their livelihood improvements. Merry-go-rounds are local money landing scheme that individuals (mostly women) engage in alternating rounds (mostly weakly) where each individual pays same amount to a first recipient and continuously until a complete round to the last member.

KRC is central to the southern agricultural growth corridor of Tanzania (SAGCOT) and forms one of its six clusters: Rufiji, Kilombero, Ihemi, Mbarali, Ludewa, and Sumbawanga [32,33]. It constitutes one of the most productive and ecologically important wetlands in Tanzania, i.e., the Kibasira wetland, whose floodplain supports several large-scale agricultural investments that already engages smallholders in out-grower schemes for sugar, rice, and teak production. Last mile infrastructures such as roads and electricity are only reliable up to Ifakara, the major population center, and the TAZARA railway passes close by many of the communities and farms in the corridor. However, last-mile infrastructure in the cluster is generally poor and limits market access for smallholders and new investors. The same elevates transportation costs and inhibits knowledge transfer and agricultural inputs to farmers.

The Kilombero floodplain, which is the center for most economic activities in the study area, is becoming increasingly more degraded in with time due to an influx of crop producers and grazers [34]. This experience increases conflicts that were never there. There is little enforcement capacity to address these conflicts, to the detriment of wildlife, fisheries, and long-term human livelihoods. In a similar vein, the expansion of smallholder agriculture (and to a lesser extent, commercial farming) has interfered with several key wildlife corridors that once connected the Udzungwa Mountains to the Kilombero floodplain and Selous Game Reserve [35,36]. With time, these expansions of human activities are expected to increase levels of human-wildlife conflict while reducing game populations in the Selous and Udzungwa protected areas. The Kilombero Valley has good soils suited to a variety of agricultural uses. This is attributed to reasons for the majority of the population (85% to 90% in some districts) engaging in agriculture. Other livelihood activities are small-scale businesses and elementary occupations, but all are based directly or indirectly on exploiting natural resources [34,35].

There is considerable inequality in the catchment communities, with large disparities in household assets, domestic services, household income, and household expenditure [31]. About one-third of the population in rural areas and one-fifth of the population in urban areas fall below the basic needs poverty line; that is, they have an income below TZS 36,500 per month per adult [31]. Other scholars, such as [34], have identified wealth categories based on farm size owned by communities in and outside the wetland. They categorized ownership of up to 2.1 ha, 2.8 ha, and above 5.5 ha of a farm in the wetland to be poor, medium, and wealthy farmers, respectively. In addition, categories in dryland included farm sizes of about 0.2 ha, 0.6 ha, and above 0.7 ha as poor, medium, and wealthy farmers, respectively.

2. Materials and Methods

2.1. Description of the Study Area

The study was carried out in the Kilombero River Catchment (KRC) extending between longitudes 34°00′ E–37°20′ E and latitudes 07°40′ S–10°00′ S and covers an area of approximately 40,000 km^2 [31] (Figure 1). It constitutes an important part (Table 1) of Tanzania's largest hydrologic basin and leading food basket, i.e., the Rufiji River Basin (RRB), spreading across 177,420 km^2 (about 20% of Tanzania). KRC is the most important catchment in respect of river flow to RRB (Table 1), agricultural potential, energy production, and natural resources [37].

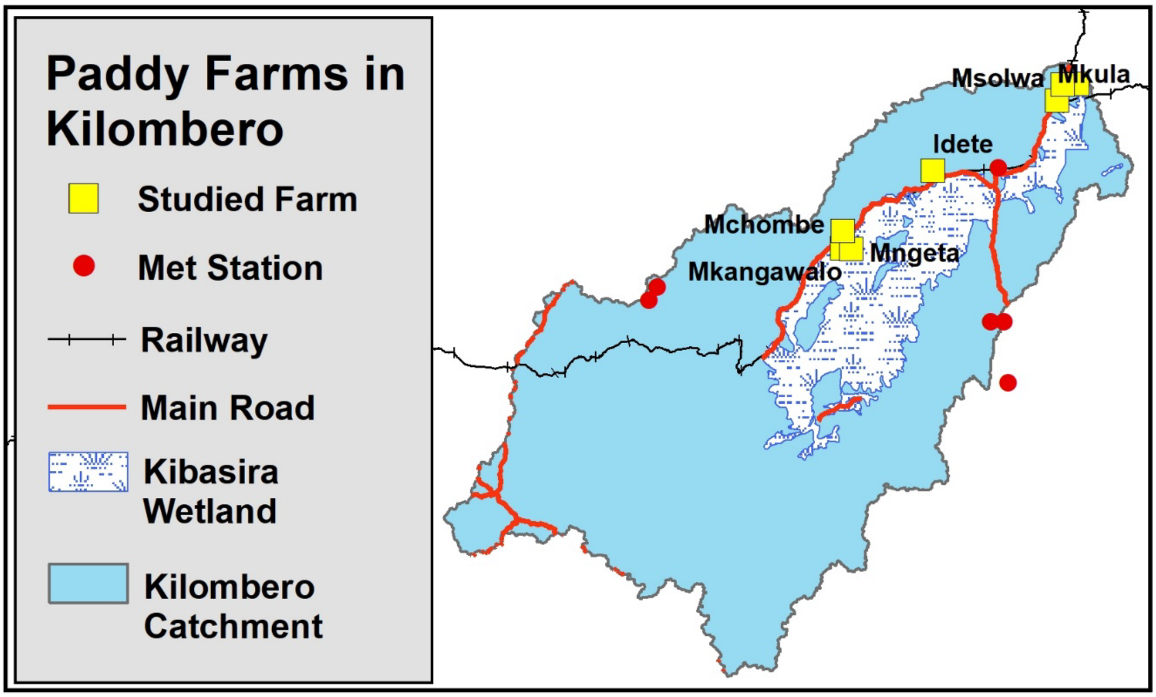

Figure 1. Map of Kilombero River Catchment illustrating surveyed sites (villages and KPL farm).

The catchment borders the Udzungwa Mountains ranges to the north-western border of the catchment. The mountain rises to an elevation of 2576 m.a.m.s.l forming an important climate driver. To the south-eastern are the Mbarika Mountains reaching up to 1516 m.a.m.s.l, and the Mahenge escarpment forms the north-eastern border of KRC (the topographical cross-section in Figure 2 illustrates). The large part of the basin floor is characterized by the presence of the Kibasila wetland with 7967 km^2, which was designated as a Ramsar site in 2002 (http://www.ramsar.org accessed on 12 July 2022). The valley constitutes part of the famous East African Rift Valley System resulting from Pliocene faulting [38].

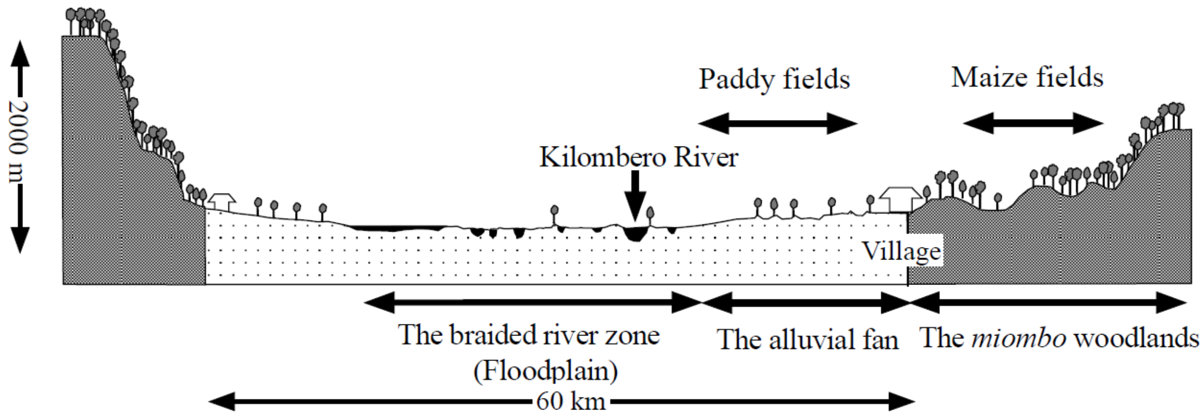

Figure 2. Cross-section of the Kilombero River Catchment adopted from [40].

Table 1. Attributes of the Kilombero river catchment—source [39].

No.	Sub Basins	Catchment Area	% of Drainage Area	% of Annual Runoff
1	Great Ruaha	85,554	47	15
2	Kilombero	40,430	23	62
3	Luwegu	26,300	15	18
4	Rufiji	27,160	15	5
5	Total	183,791	100	100

2.2. Data Collection and Analysis Methods

2.2.1. Determination of Stressed/Drier Years

The study intended to assess agricultural water productivity (AWP) during times of stressed, drier years. As such, isolation of dryer, normal, and wetter years was paramount. In this regard, arithmetic means for the six (6) weather stations in the catchment (Figure 1) with daily observed data (1933–2019) were calculated. Gap filling between and within stations was performed using long-term averages for years/stations with continuous data. Following that, a dry, normal, and wet year were determined at a probability of exceedance P80, P50, and P20, respectively (Figure 3). With reference to Equation (1), as also considered by [24,25], the values for each month of these years were calculated as summarized in Table 2, and the characteristic rainfall pattern is illustrated in Figure 4. The dry year rainfall data were then used in CROPWAT 8.0 to obtain the crop water requirements or crop evapotranspiration (ETc). These CROPWAT data for dry years were taken for further calculations (ref. Section 2.2.2) as a conservative value useful to study times of stress.

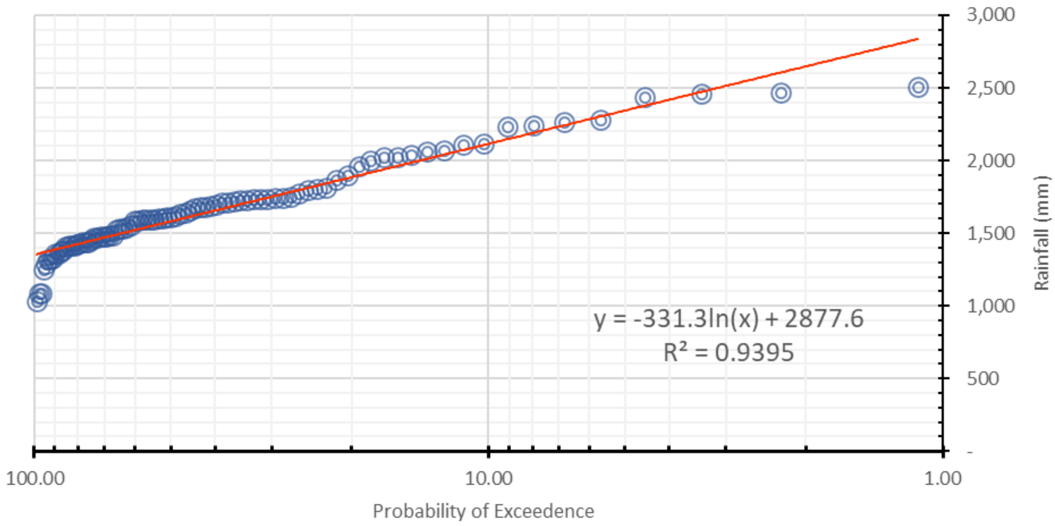

Figure 3. Dependable rainfall in Kilombero river catchment.

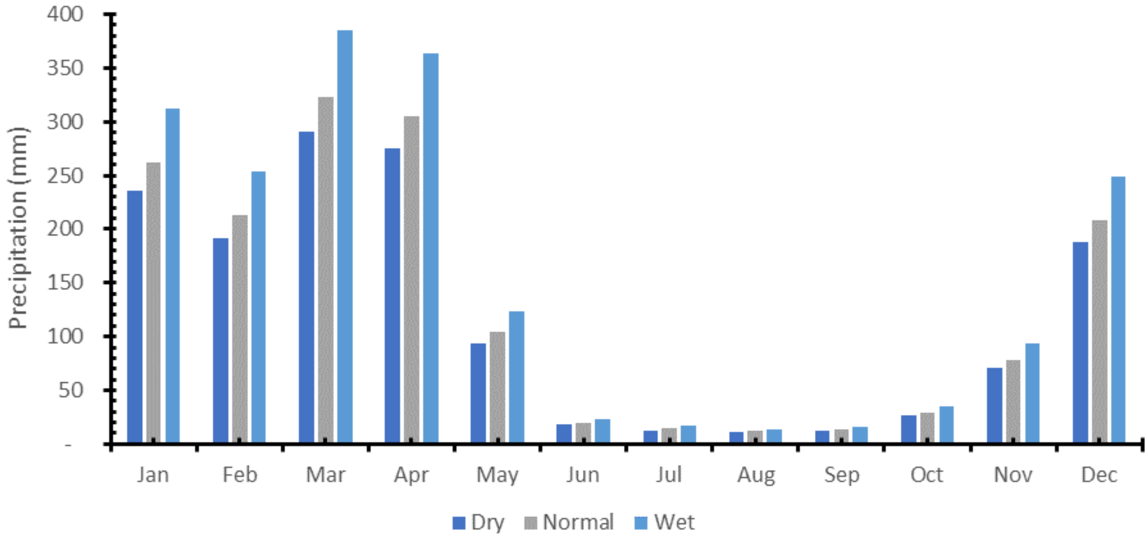

Figure 4. Monthly rainfall characteristics based on arithmetic mean between 1933–2019.

Table 2. Summary of monthly rainfall values for dry, normal, and wet years.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Dry	235.74	191.90	291.10	274.90	93.68	17.83	12.94	10.69	12.14	26.41	70.44	188.03
Normal	261.48	212.85	322.89	304.92	103.91	19.78	14.36	11.86	13.46	29.29	78.14	208.56
Wet	311.67	253.72	384.88	363.45	123.85	23.58	17.11	14.13	16.05	34.92	93.14	248.60

$$Pi(d/n/w) = Piav\frac{P(d/n/w)}{Pav} \quad (1)$$

where:

Pi(d/n/w) = monthly rainfall for dry, normal, or wet year (calculated individually)
Piav = Mean monthly rainfall for month
P(d/n/w) = Yearly rainfall at 80%/50/20% probability of exceedance
Pav = Average yearly rainfall.

2.2.2. Productivity Value of Water

(a) Physical Water Productivity

Physical water productivity (PWP), sometimes referred to by others as water use efficiency is defined as the quantity of yield (Y) derived from the use of a given quantity of water [10] and was calculated using Equations (2) and (3). The latter was used to estimate actual PWP in the irrigated system, while the former was calculated to get an ideal value that improvement of water productivity should aim to achieve.

$$PWPr = \frac{Y}{ETc} \tag{2}$$

$$PWPi = \frac{Y}{P + I} \tag{3}$$

where: Y is yield in Kg/ha, P is precipitation in mm, I is irrigation water in mm, and ETc is crop evapotranspiration in mm.

On the irrigation water use, the study made use of the permitted volume as issued by Rufiji Basin Water Board (RBWB). Irrigation schemes that were considered in this study are illustrated in Figure 5. The average permitted volume was taken to be the gross irrigation water used in these farms. This was guided by an assessment conducted by RBWB, which is the competent statutory organ who indicated that the variance between permitted and actual water use is less than 10% in KRC [41]. This is attributed to the fact that the study area is one of the areas receiving better rains in the larger Rufiji River Basin [39]. In addition, the area is not yet highly developed (e.g., accessibility) to attract many investments. Moreover, farming is generally concentrating around the wetland where soils are moist; hence, there is not much departure from permits [41]. The water use in the KPL mechanized system was based on their real-time irrigation system monitoring. However, the split between SRI and CTFS was based on questionnaire responses on farmers' experience, where 60% water serving was adopted for SRI. This agrees well with other researchers on comparing water uptake between CTFS and SRI [17,19]. The methodology for qualitative data collected by questionnaire responses is adopted from a parallel study by authors [42] submitted for publication.

All three water use components were then modeled through CROPWAT 8.0 developed by FAO, which is considered a dependable rainfall method that is recommended in these wetter areas following Equations (4) and (5) [43,44]. Input data for CROPWAT included temperature (Tmax and Tmin) in °C, humidity expressed in %, wind speed (km/day), and sunshine in hours. These data were obtained from the Tanzania Meteorological Authority (TMA) and downloaded from satellite sources. Additional soil data were collected at the Kilombero Agricultural Training and Research Institute (KATRI). The yield data was adopted from a parallel study by authors [42] and submitted for publication.

$$P_{eff} = 0.6P - 10 \; for \; P_{month} \leq 70 \text{ mm} \tag{4}$$

$$P_{eff} = 0.8P - 24 \; for \; P_{month} > 70 \text{ mm} \tag{5}$$

where P is precipitation.

(b) Economic Value of Water

The Economic Value of Water (EVW) or economic productivity value of water was calculated using the Residual Imputation Approach, which entailed the identification of the unknown incremental contribution of an input after isolating the known inputs from the value of the total output. The derivation of the 'residual' value of water in this approach was based on two principal postulates as discussed in [20,22,23]:

1. Competitive Equilibrium: This requires that the prices of all resources be equated to returns at the margin. "Profit-maximizing" producers are assumed to add productive

inputs up until the point when the value marginal products (VMPs) are equal to opportunity costs or "value" of the inputs.

2. The total value of product (TVP) can be divided into shares so that each resource is paid according to its value marginal product (VMP), and the TVP is thereby completely exhausted.

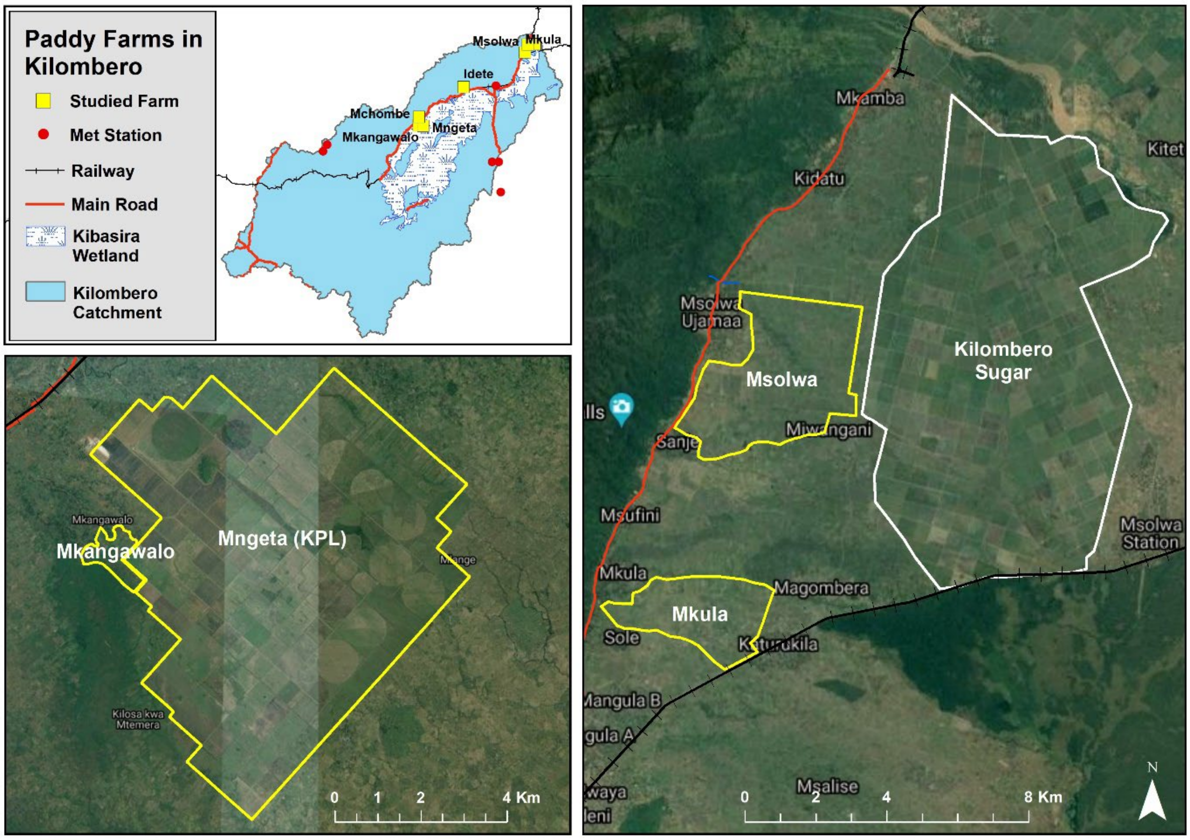

Figure 5. The spatial illustration of some of the sampled farms in the study area. Map shows only those large enough for illustration.

For instance, in the agricultural production process, in our case, paddy output (*Y*) is produced by the following factors of production: capital (*C*), labor (*L*), and other natural resources [e.g., land (*R*) and irrigation water (*W*)]. The production function can be written as Equation (6) below:

$$Y = f(C,\ L,\ R, W) \tag{6}$$

By the second postulate, it then follows that:

$$TVP_Y = (VMP_c \times Q_c) + (VMP_L \times Q_L) + (VMP_R \times Q_R) + (VMP_W \times Q_W) \tag{7}$$

where, *TVP* represents the total value of product, *Y*; *VMP* represents the value marginal product of resource *i*; and Q is the quantity of resource *i*. The first postulate, which asserts that value *P* of product *i* is represented by $P_i = MPV_i$, permits the substitution of P_i into Equation (6) Equation and rearrangement of the same Equation as follows:

$$TVPY - [(P_c \times Q_c) + (P_L \times Q_L) + (P_R \times Q_R)] = P_W \times Q_W \tag{8}$$

On the assumption that all variables in Equation (8) are known except P_W, that expression can be solved for that unknown to impute the value (shadow price) of the residual claimant, (water) P_W, as in Equation (9):

$$P_W = \{TVP_Y - [(P_c \times Q_c) + (P_L \times Q_L) + (P_R \times Q_R)]\}/Q_W \tag{9}$$

As pointed out, the residual imputation approach offers the capability to derive the value of water isolated from other production inputs, thereby giving a more realistic picture of its value. Approaches such as a change in net income as employed by [45,46] Equations (10) and (11) below tends to lump all as production inputs and hence blot the value of water.

$$AW_v = (NVO_w - NVO_{wo})/W \tag{10}$$

$$NVOx = GVO_x - C_x \tag{11}$$

where:

AW_v = Mean value of water in monetary units
W = Amount of consumed water in m^3 or liters
NVO_w = Net output value with water
NVO_{wo} = Net value of output without water
GVO_x = Gross output value
C_x = Summed Cost of production.

3. Results

3.1. Physical Water Productivity

Table 3 summarizes the results for water usage, the ideal and real physical water productivity (PWP) in kg/m^3. Farm harvests in Kg/ha are adopted from the authors' parallel study, as summarized in Table 4. The comparison shows that, although irrigated systems had slightly better harvests (Table 4), they have slightly lower PWP (in small-holder farms), which may only explain the need for improvements in water conveyance systems in small-holder farms (Figure 6). Furthermore, Figure 6 illustrates a comparison of the real PWP for all farming systems to indicate the best performance in the study area. This show that, except for irrigated KPL, SRI practice performs better across the board. The better PWP results for SRI may be attributable to the fact that small-holder farms are much closer to the wetland and, thereby, need even less water for farming and that actual SRI harvests per ha are higher than the rest (Table 4). This collaborates well with an observation by the agriculture department in the Kilombero District Council, who indicated a similar experience. *"It's a common experience by farmers to block flowing water to enter their plots during rainy season. This is even more practiced by farmers practicing SRI where water serving is above 50% of normal flooding practice. This is because, most of the time, soils water saturation is above field capacity around these wetland areas"*.

Table 3. Descriptive statistics for physical water productivity (PWP) in all farming systems.

N	Farming Systems	ETc (mm)	Water Use (m^3/ha)	MIN	Q1	Q2	Q3	MAX	Mean	Ideal PWP
				PWP (kg/m^3)						
1	CTFS Rainfed	687.7	10,313	0.07	0.22	0.31	0.61	0.79	0.39	0.59
2	CTFS Irrigated	630.9	14,542	0.17	0.18	0.34	0.40	0.45	0.30	0.70
3	SRI Rainfed	687.7	10,313	0.41	0.46	0.68	0.90	0.95	0.68	1.02

Table 3. *Cont.*

N	Farming Systems	ETc (mm)	Water Use (m^3/ha)	MIN	Q1	Q2	Q3	MAX	Mean	Ideal PWP
				PWP (kg/m^3)						
4	SRI Irrigated	630.9	14,542	0.40	0.42	0.50	0.62	0.68	0.52	1.19
5	KPL Rainfed	687.7	10,313	0.22	0.24	0.32	0.44	0.48	0.33	0.50
6	KPL Irrigated	630.9	6495	0.42	0.56	0.67	0.76	1.09	0.68	0.70

Table 4. Descriptive statistics for paddy harvests in the study area. Source: [42].

N	Farming Systems	Avrg. Farm Size (ha)	Mean	MIN	Q1	Q2	Q3	MAX
			All Values Are in Kg/ha					
1	CTFS Rainfed	1.58	4058	682	2302	3240	6309	8184
2	CTFS Irrigated	0.65	4410	2450	2613	4900	5880	6533
3	SRI Rainfed	1.22	7025	4215	4740	7020	9310	9830
4	SRI Irrigated	0.73	7516	5869	6100	7259	8958	9884
5	KPL Rainfed	2003.7	3429	2230	2470	3250	4520	4920
6	KPL Irrigated	1404.3	4445	2740	3640	4380	4960	7060

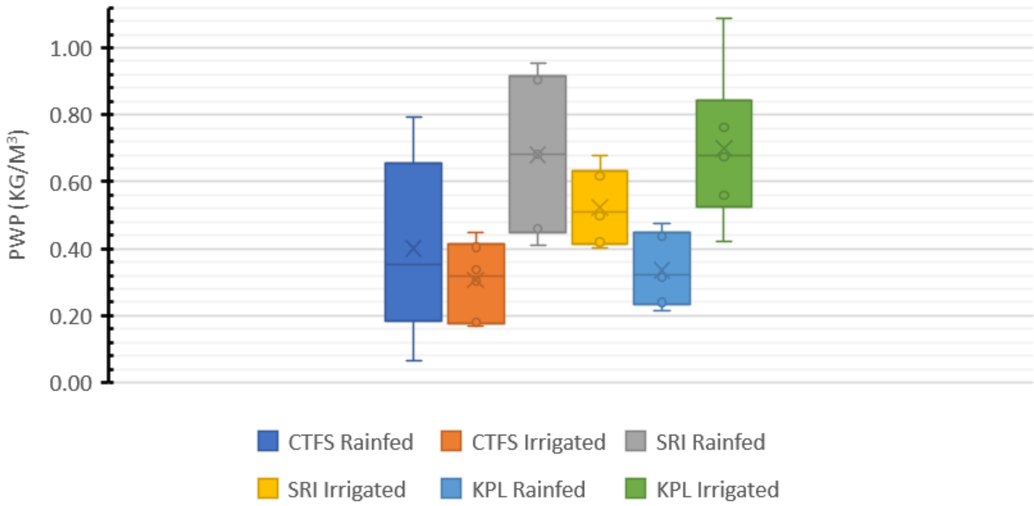

Figure 6. Physical water productivity across all the farming practices.

3.2. Economic Value of Water

The economic value of water (EVW), also referred to by others as economic water productivity in US$/$m^3$, was calculated using the residual imputation method (discussed in Section 2.2.2 (b), which helped to single out the imputed marginal economic value of water [20,22,23]. Results are summarized in Table 5, and comparisons across farming systems are illustrated in Figures 7 and 8 for paddy and rice, respectively. These results show that, although KPL harvests less per ha of farming, they record higher EVW due to efficient water use and better prices by the investor as compared to small-holder farms. However, KPL did not share sensitive operational costs such as salaries and statutory taxes, which could lower their EVW. Furthermore, it is shown that some of the small-holder players record negative EVW, which is also attributed to the loss of rice due to poor milling processes, poor practice on water usage, and weak market mechanisms. This agrees well with comments from a KPL production department technician who said, *"Most smallholder out growers lose most of the rice due to poor pre preparation and milling machines. On average they make 1 Ton of rice from 1.5 Tons or more of paddy while our average rate is 1.23 Tons of paddy for 1 ton of rice which is one of the best in Tanzania"*.

Table 5. Summary of descriptive economic value of water with other inputs of production.

N	Farming Systems		MIN	Q1	Q2	Q3	MAX	Mean	Water Use m^3/ha	Land	Labor	Capital
			All EVW Are in US$/$m^3$							Input Values in US$/ha		
1	CTFS Rainfed	Paddy	−0.08	−0.04	−0.02	0.06	0.11	0.003	10,313	107.75	653.10	282.84
		Rice	−0.08	−0.02	0.04	0.16	0.27	0.06				
2	CTFS Irrigated	Paddy	−0.03	−0.03	0.01	0.03	0.04	0.002	14,542	111.77	769.91	253.35
		Rice	−0.03	−0.02	0.03	0.05	0.062	0.02				
3	SRI Rainfed	Paddy	−0.02	−0.01	0.04	0.10	0.11	0.08	10,313	161.34	838.40	285.57
		Rice	0.003	0.03	0.12	0.22	0.355	0.13				
4	SRI Irrigated	Paddy	0.03	0.03	0.06	0.09	0.11	0.06	14,542	188.23	830.59	274.82
		Rice	0.05	0.05	0.08	0.12	0.14	0.09				
5	KPL Rainfed	Paddy	0.02	0.03	0.05	0.08	0.09	0.05	10,313		334.48	
		Rice	0.04	0.05	0.08	0.12	0.14	0.08				
6	KPL Irrigated	Paddy	0.04	0.08	0.11	0.14	0.22	0.11	6495		495.28	
		Rice	0.09	0.14	0.19	0.22	0.35	0.19				

Notes: Land, labor, and capital are calculated from Table 6 and analyzed from questionnaires. KPL values were lamped together.

Table 6. Average annual value of input of production, based on 1 ha of farming.

N	Farming Inputs	Irrigated SRI	Rainfed SRI	Irrigated CTFS	Rainfed CTFS
A. Land Input					
1	Renting a farm	188.23	161.34	111.77	107.75
Sub Total A		188.23	161.34	111.77	107.75
B. Labor Inputs					
2	Farm Clearing	53.78	43.02	35.65	32.65
3	Ploughing	64.54	64.54	56.85	59.54
4	Blocks preparation	53.93	53.78	37.65	32.27
5	Nursery preparations	26.89	26.86	21.51	13.44
6	Watering the farm	48.40	-	43.02	-
7	Field leveling	80.67	72.60	63.66	64.54
8	Uprooting seedlings	37.65	43.02	26.39	24.20
9	Rice transplanting	86.40	86.05	58.02	59.54
10	Weeding with chemicals	64.54	96.80	64.43	53.35
11	2nd Weeding manual	59.16	75.29	59.16	48.40
12	Bird control	86.05	69.91	53.78	-
13	Harvesting	46.25	64.54	64.54	80.67
14	Threshing	89.81	93.04	103.79	127.52
15	Winnowing	32.54	48.94	81.48	57.01
Sub Total B		830.59	838.40	769.91	653.10
C. Capital Inputs					
16	Seeds	16.13	13.60	19.41	14.03
17	Initiation fertilizer	13.44	35.33	14.68	33.40
18	Pesticides/Insecticides	6.45	5.92	8.07	5.38

Table 6. *Cont.*

N	Farming Inputs	Irrigated SRI	Rainfed SRI	Irrigated CTFS	Rainfed CTFS
19	Weeding chemicals	29.58	30.65	29.58	34.96
20	Boosting fertilizer	91.43	40.33	21.51	14.99
21	Pesticides/Insecticides	6.45	5.92	8.07	5.38
22	Panicle initiation fertilizer	5.93	5.38	27.27	14.99
23	Transportation costs	70.99	116.16	82.82	127.46
24	Storage	34.42	32.27	41.95	32.27
Sub Total C		275	286	253	283
Grant Total Paddy		1293.64	1285.30	1135.02	1043.70
Grant Total Rice		1387.76	1374.04	1236.13	1232.46

Notes: All values are converted to USD with a rate of TZS 2297.39 for 1 USD at Bank of Tanzania (BoT) rates (https://www.bot.go.tz/ accessed on 5 January 2021).

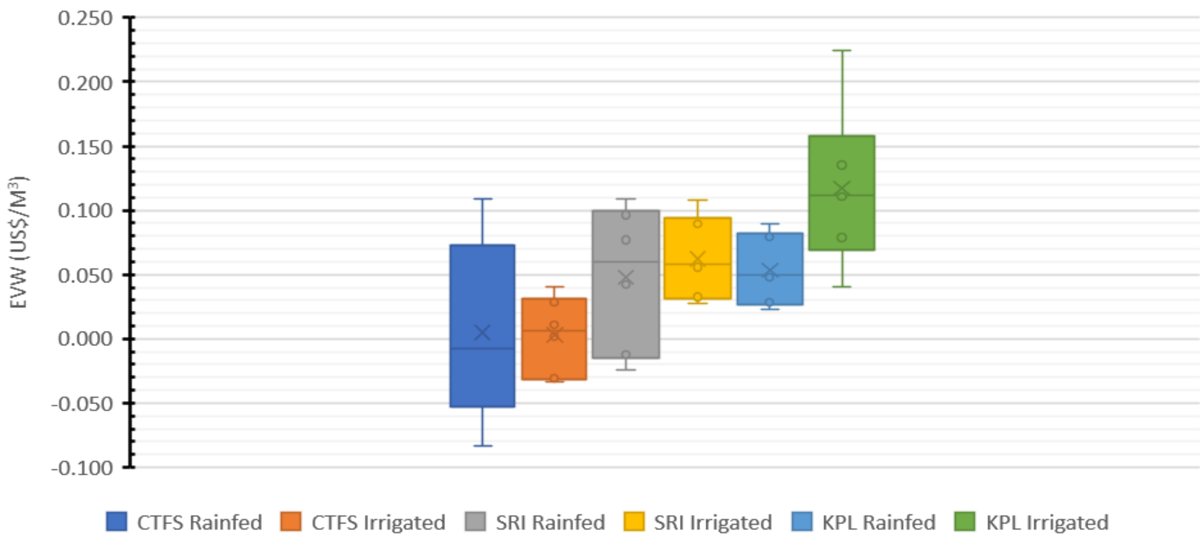

Figure 7. Comparison of the economic value of water for paddy in all the six farming systems.

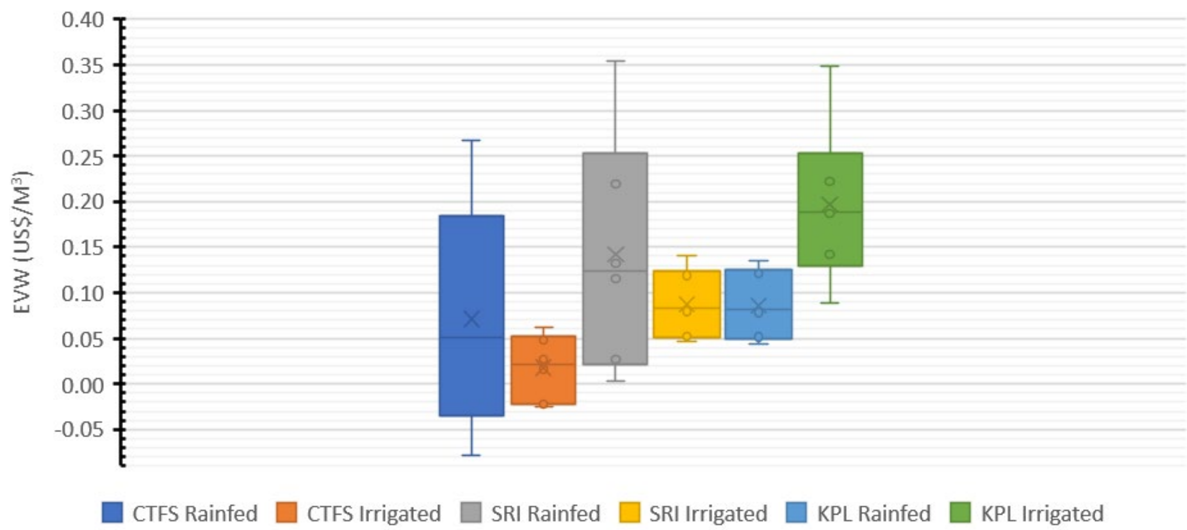

Figure 8. Comparison of the economic value of water for rice in all the six farming systems.

3.3. Comparison of Study Water Productivity with Other Parts

The obtained results for water productivity have been compared with the rest of Tanzania to understand how Kilombero catchment fairs (Table 7). This has also been compared with average rainfalls linked with site soil moisture and hence water uptake and productivity. According to this, while the study area has a high PWP, it depicts a low EWP. The former may be attributable to the fact that water consumption in the study area is low since it is situated in a high rainfall belt with numerous perennial rivers and hence moist soils for a good part of the season. In addition, farms in Kilombero fetch better harvests than the national average for similar practices (Table 8). Other paddy-farming tropical countries such as India recorded similar PWP, e.g., 0.24 to 0.57 kg/m^3 in paddy-farming states, while Punjab, West Bengal, and Assam were relatively high (more than 0.50 kg/m^3) but low in Bihar, Madhya Pradesh, and Karnataka with PWP of 0.28, 0.25, and 0.24 kg/m^3, respectively [47]. Furthermore, since EWP is sensitive to paddy prices, the low EWP can be explained by the low prices of agricultural goods due to the lack of good markets in Kilombero, where the accessibility network is just recently being upgraded to tarmac.

Table 7. Comparison of water productivity values for paddy in Tanzania.

N	Water Productivity	Area (Region/Catchment)	Research Source	Received Rainfall (mm)
1	0.30–0.68 kg/m^3 0.002–0.11 US$/m^3	Study area in Kilombero catchment	current study	1200–1400
2	0.85 kg/m^3 0.23 US$/ m^3		[21]	
2	0.15–0.51 kg/m^3	Arusha in Kikuletwa Catchment	[19]	590–1460
3	0.17–0.22 kg/m^3 0.02–0.8 US$/m^3	Usangu in Great Ruaha catchment	[20]	669
4	0.126–0.265 kg/m^3 0.01–0.04 US$/m^3		[18]	669
5	0.14–0.47 kg/m^3	Morogoro in Wami Catchment	[17]	669

Table 8. Comparison of harvests between KRC and National Average. Comparison of current study and others [48,49].

N	Practice	Practice Countrywide	KRC Harvest (Tons/ha)	Countrywide Harvest (Tons/ha)
1	Rainfed CTFS	Rainfed traditional system	4.058	1–1.8
2	Irrigated CTFS	Traditionally Irrigated	4.410	1–2
3	Rainfed SRI	Improved Traditional	7.025	4
4	Irrigated SRI		7.516	6
5	Rainfed KPL	Mechanized/High Inputs/Modern varieties	3.429	2–6
6	Irrigated KPL		4.445	

4. Discussion

4.1. Climate Characteristics

The analysis of wet, normal, and dry years agrees well with other scholars who indicated that the study area exhibits a subhumid tropical climate with good precipitation

(1200–1400 mm) [27], with the mountainous area receiving up to 2100 mm precipitation, whereas the expansive lower laying Kilombero valley plain receives about 1100 mm [26,28]. These rainfall characteristics, coupled with the existence of an expansive Kibasira wetland and numerous perennial rivers with maximum protection of river mouth (at national part status), are attributed to better moisture around many paddy farms. At times of peak rainfall, farmers are known to raise riverbanks and farm boundaries to block flowing waters. This is especially the case for those who practice SRI in wet seasons, where they also farm much earlier to avoid too much water. The combined effect of the higher harvests and moisture levels causes the study area to have low water usage and hence higher productivity values compared to other parts of Tanzania. The relatively cooler temperatures, i.e., between 24 °C in the valley and about 17 °C in the mountainous areas, also add to this advantage where evaporation is low [26].

Since there is a climate section explaining how climatic factors contributed to variation in PWP and EVW within the six studied sites, we can include the overall contribution of climatic factors to low/high PWP and EVW in Kilombero compared to other sites.

4.2. Productivity Value of Water

The system of rice intensification (SRI) has recorded better values of physical water productivity (PWP) as well as the economic value of water (EVW) compared to other practices in the study area. This is due to low water uptake by SRI supported by even better soil moisture in these wetland areas. The high EVW can be attributed to the SRI farmers starting earlier to avoid floods and, hence, becoming the first ones to sell before markets are saturated. In addition, the PWP values for all farming practices in Kilombero are higher than in other parts of Tanzania, which is attributable to high harvests per ha (almost twice as much) and similar or low water uptake due to favorable climates [26–28] and better availability of moisture even during times of stress compared to most parts of Tanzania and some parts of sub-Saharan Africa [48–50]. However, due to a lack of communication network and hence limited markets, the EVW in the study area is lower than in other parts of Tanzania, with good road and railway networks. Furthermore, although there is a consistent leap in harvests in the irrigated system, it records lower PWP. This is linked to low water abstraction in the rainfed system (only a small amount of water for nursery and rotavating), hence slightly higher PWP.

5. Conclusions

The study has assessed agricultural water productivity (AWP) values for paddy farming in terms of both physical (kg/m^3) and economic (US$/m^3). This has been done across the two mechanized farming practices by KPL and four small-holder farming systems (i.e., CTFS and SRI). It has been demonstrated that SRI systems fetch better AWP due to high yields and low water uses. In addition, it has been found that irrigation does not have a substantial leap in harvests in these wetland areas. Hence, rainfed systems score better values, especially SRI, providing a plural benefit that includes downstream ecosystem integrity. Furthermore, due to early planting in rainfed SRI, farmers secure competitive market prices in early harvests hence better economic water productivity (EWP).

It has also been found that stable prices and well-controlled water usage for the KPL system cause better AWP despite their low harvests per ha. Lastly, it has been shown that (a) rainfed farming fetches real PWP closer to the ideal one. This means that, in the irrigated system, there is more room for improvements to curb losses that cause higher volumes of water to reach field capacity, especially as it is practiced in the dry season (b), where there is naturally a general leap in EWP when value addition to rice is exercised across the board.

Based on these, the following operational and policy recommendations are provided:

1. Farmers should be trained and encouraged to practice SRI (especially rainfed ones), which secures better AWP and serves more for downstream uses, reducing water use conflicts and sustaining the ecosystem. Since self-adoption has been too slow, policymakers need to allocate enough budget for an adequate time of demonstration

and design rewarding schemes for efficient systems while also exercising law enforcement for inefficient ones. In addition, large-scale offtakes such as KPL present a good mechanism to anchor a PPP model with a caveat for efficient systems only.

2. Government interventions are strongly recommended to support value addition from paddy to rice. This will not only secure higher EWP but also add multiplier effects on employment, branding of products, and statutory revenue through taxes and levies.
3. Although KPL harvest less even in comparison with the poorest small-holder practice (i.e., CTFS), they fetch better and stable markets, which means better EWP. Corporative authorities through the district council should facilitate appropriate groupings of the disintegrated small-holder farmers. This will help them to have better price bargaining power and market influence.
4. Since rainfed systems fetched better AWP even closer to the ideal one, it is recommended to reassess the mushrooming investments in irrigation infrastructure. This is especially meaningful in the face of big downstream flagship projects, e.g., Nyerere Hydro-Power Plant (HEP) and other needs further downstream, including the Rufiji River Delta ecosystem. Similar rivers, e.g., Great Ruaha, are seriously impaired due to these misaligned interventions to the detriment of the ecosystem in Ruaha National Park, HEP in Mtera and Kidatu, and others further downstream.
5. In order to further finetune the AWP, it is also recommended to carry out long-term physical measurements of water flows to different farming systems and calculate the investment cost, including the depreciating/appreciating value of long-term assets such as land, equipment, etc.

Author Contributions: Conceptualization and methodology, O.Z.S. and R.M.J.K.; formal analysis, investigation, resources, data curation, and writing—original draft preparation, O.Z.S.; writing—review and editing, O.Z.S., R.M.J.K., and J.R.S.; supervision, R.M.J.K. and J.R.S. All authors have read and agreed to the published version of the manuscript.

Funding: Field data collection was supported by the Climate Research for Development (CR4D) Project—Tanzania. African Academy of Science (AAS) through CR4D project, grant number CR4D-19-07.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Not applicable.

Acknowledgments: The authors are greatly indebted to the generosity accorded for free data access by Rufiji Basin Water Board (RBWB), Kilombero Agricultural Training and Research Institute (KATRI), Ifakara District Council, and Kilombero Plantations Ltd. (KPL).

Conflicts of Interest: The authors declare no conflict of interest.

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