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Socio-Economic Factors and Water Footprint in Smallholder Irrigation Schemes in Zimbabwe

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Abstract: Despite the need to grow crops with low water consumption needs, given the increasing water stress across many regions of the globe, assessments of crop water footprint (WFP) values have not received significant research attention in Zimbabwe. This unique study is the first of its kind to assess the mediation effect between socio-economic factors and crop WFP among smallholder irrigation schemes in Zimbabwe. A total of 317 farmers from three schemes in Midlands Province in Zimbabwe participated in this study. The following were the main findings in terms of the examined variables: (1) Schemes ($p < 0.01$), Gender ($p < 0.05$), and Maint ($p < 0.1$) all decreased WFP_Maize; (2) education showed a reduction effect on the link between scheme maintenance and WFP_Maize; (3) secondary education has a higher impact on the magnitude of Maint on WFP_Maize; and (4) Maint and WFP_Maize have a positive correlation. This study illustrates the interaction of socio-economic factors on WFP and has substantial implications for simultaneously addressing the sustainable consumption of water for crop production, food security, and malnutrition in a changing climate.

Keywords: interaction; moderation; water footprint; water stress

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1. Introduction

Globally, water scarcity is increasingly becoming a matter of major concern for stakeholders with an interest in environmental sustainability issues in the face of climate-induced water stress [1]. This is particularly true for the agricultural sector, which consumes a substantial amount of water in producing food [2] to feed the ever-increasing global population [3]. For instance, globally, about 86% of the freshwater supply is used for food production [4]. At the same time, agricultural productivity needs to increase by between 60 and 100% to meet the projected food demand by 2050 [3]. Worldwide, over 3.3 billion people live in climate hotspot regions [5]. These hotspots are dominantly in the semi-arid regions of Africa and Asia [6]. Thus, increased water stress in these regions threatens sustainable development since water is at the center of maintaining healthy ecosystems, human well-being, and socioeconomic development.

Generally, the total global extent of land area that is prone to drought will increase as the frequency and severity of drought conditions become more severe in the 21st century [5]. At the same time, several simulation models project an increase in water stress across many parts of the globe [5]. The impact of socio-economic development and climate change on water resources and the consequent water stress are less clearly understood [7,8]. Thus, there is an increasing need for the efficient utilization of the scarce water resources available. There is high confidence that the impacts of climate change-related extreme weather events on food security, nutrition, and livelihoods will be particularly acute and severe for small-scale food producers and people living in sub-Saharan Africa (SSA) [5]. There is already notable stress related to food production in SSA [5]. A 2 °C rise in temperatures will affect food availability and dietary quality by increasing nutrition-related diseases among undernourished people in the SSA region [9].

Global water use has risen at approximately 1% per year with the rising population, economic development, and shifting consumption patterns [10,11]. Concurrently, groundwater depletion doubled between 1960 and 2000, rising to 280 km^3 per year in 2000 [12]. Despite a predefined worldwide freshwater planetary boundary that is lower than 4000 km^3 per year, global water withdrawal from some sectors, agriculture included, has already surpassed the 4000 km^3/year threshold [13,14]. Climate change will increase the water stress in agriculture. The world is anticipated to face a 40% water deficit under a business-as-usual scenario, as the global average temperatures are projected to surpass pre-industrial levels by over 1.5 °C by the year 2050 [15]. Global water scarcity poses a significant challenge for climate adaptation, given that water mediates the majority of climate change impacts [10]. The situation in SSA is going to be dire under this projected level of climate change [16].

Freshwater is a finite and vulnerable resource, one that is essential for people's health, development, and the environment [17,18]. Widespread water scarcity and the pollution and depletion of freshwater resources are among the greatest challenges of the 21st century in relation to water [17]. This has perpetuated the loss of species that are dependent on water resources when ecosystems and soils degrade. Population growth and economic development are the major drivers of these growing water challenges [17]. Furthermore, climate change has affected water resources; as temperatures are getting warmer, rainfall patterns become erratic and the frequency of extreme weather events is on the rise. Humanity, the major water user, is responsible for continuously managing the environmental challenges related to freshwater resources.

There will be limited scope for raising the quantity of water used for irrigation, which accounts for 70% of global freshwater withdrawals, in the face of competing demands [19,20]. Irrigation water withdrawals are estimated to rise by 5.5% by 2050 to meet increasing food demands and global dietary changes [10,19]. Irrigated land accounts for 20% of total cultivated land, generating 40% of the world's agricultural output [10]. Increasing crop-water productivity can make a significant contribution to reducing the pressure on freshwater resources in the agricultural sector. The crop water footprint (WFP) is a good indicator when assessing the quantity of 'water used' to produce a single unit of a particular crop, including the resulting pollution created during its production [21]. Although there is significant variation in WFP across crops and regions [22], the highest share of the blue WFP occurs in arid and semi-arid regions [23].

The sustainable management of freshwater resources, one of the United Nations' Sustainable Development Goals (SDG 6) for human health and security, is an important part of the international agenda. Despite the crucial role of an integrated method for analyzing nutritional and water insecurity to inform adaptation planning-related studies and decision-making, especially in communal areas, these two issues are often overlooked [24]. Thus, further research and the application of novel tools are required to assess water use in smallholder farming systems to transform these food systems sustainably [14,25–27]. Our work will make an important contribution to the growing literature on assessing the interaction of socio-economic factors and WFP in smallholder farming systems. This research is most relevant in Zimbabwe, where, to the best of our knowledge [28,29], little effort has been made to link the agricultural WFP with socioeconomic factors. Hence, there is a need to explore the relationship between the interaction of socioeconomic factors and WFP to inform policy and practice on simultaneously addressing ecological sustainability, malnutrition, and water insecurity.

Despite the potential contribution of WFP to policy and practice in agricultural water management in a changing climate, the socioeconomic determinants of WFP in smallholder irrigation systems are poorly understood. This paper uses meteorological data from the Zimbabwe Meteorological Services Department, crop water usage data from the Department of Irrigation, and data from questionnaires and interviews to compute the WFP. The objective of the current study was to assess the relationship between the interaction of socioeconomic factors and WFP.

2. Materials and Methods

2.1. Study Site

Three smallholder irrigation schemes (SISs) in the Midlands Province of Zimbabwe were considered for this research. The first is the Exchange irrigation scheme on Zhombe communal land. Silobela, in Kwekwe District, is around 60 km northwest of Kwekwe town and 80 km northwest of the provincial town of Gweru [30]. It has 168.8 ha of irrigable area, with 982 farmers engaged in irrigation farming. The scheme is in Agro-ecological Zone 4, which is characterized by semi-arid climatic conditions with an average rainfall ranging from 450 to 650 mm [31]. The scheme was partly developed in 1973 and again in 1985 [32]. Irrigation water is drawn from the Exchange dam into its temporary storage.

The Insukamini irrigation scheme is the second project considered for this study. It is located in the Lower Gweru community, which is 46 km northwest of Gweru town. Insukamini has 125 farmers on a total irrigable area of 41 ha. Insukamini is also in Agro-ecological Zone 4, with an average annual rainfall ranging from 600 to 800 mm and temperatures averaging 16 °C [33]. The scheme was developed in 1988 by the Zimbabwean national government after DANIDA finished the construction of the Insukamini dam in 1986 [33]. The scheme draws its water from the Insukamini dam and is delivered gravitationally via a 1.6-kilometer-long open concrete canal.

The third is the Ruchanyu irrigation scheme in Shurugwi District; it is nearly 29 km southwest of Shurugwi town. The Ruchanyu irrigation scheme has 85 farmers who use a sprinkler irrigation technique on a total irrigable area of 27 ha. The Ruchanyu irrigation scheme is in Agro-ecological Zone 3, with average annual precipitation ranging from 650 to 850 mm and temperatures averaging 16 °C [34]. The scheme was developed in the early 1980s and pumps water from the Mutevekwi River [34].

2.2. Data Collection

Meteorological data for the period from 2000 to 2020 were obtained from the Thornhill meteorological station through the Zimbabwe Meteorological Services Department. Data regarding crop water requirements were sourced from the Department of Irrigation (DIRR). Questionnaire-based face-to-face interviews (Supplementary Materials) were used to collect data regarding the major crops grown, the water application rate, and crop yields, to address the objectives of this study. A pilot study was performed to determine and validate the questionnaire for the study. Random sampling was used to select the households to be interviewed, based on their homogeneity per scheme. Farmers were selected based on their age groups and gender, to ensure representative participation within each scheme. A sample size of 317 households was selected from the three schemes at a statistically significant level ($p \leq 5\%$). The focus group discussions (FGDs) were conducted with 10–15 household heads, who were randomly selected to help understand water use in SISs. We obtained expert information relating to water use and crop yields from the key informant interviews (KIIs). Data regarding standardized crop WFP and the nutritional density in crops were sourced from the literature [35–38].

2.3. Data Analysis

The computation of the blue WFP of crop production used in this paper was performed in line with the calculation framework of Hoekstra et al. [39]. The green WFP was excluded from this assessment; although it contributes to crop growth, it has a non-market value that is not easily quantified in terms of irrigated crops [7,8].

The calculation of blue WFP can be expressed as follows:

$$WFP_{blue,cropx} = \frac{CWU_{blue.cropx}}{Y}$$

where $WFP_{blue,cropx}$ represents the blue WFP of crop x (m^3/t), $CWU_{blue.cropx}$ represents the crop water use (m^3/ha) over the growing period, and Y represents yield (t/ha). In the case of this study, the water application rate per crop was used to determine crop water use. The observed yield obtained from the yield statistics was provided during questionnaire-based, face-to-face interviews of the scheme farmers. The crop water use was obtained from the KIIs.

Data were analyzed using SPSS version 27. Gender and irrigation scheme variables were used as covariates in the analysis of the moderation effects of maintenance (Maint) according to Age, and its association with WFP in this analysis. Linear regression analysis was used to estimate the association between Maint and Age [40]. The covariates and interaction items were analyzed concurrently.

Skewness and kurtosis show the normality of the data used in this study. The tolerances of Edu (0.407) and Maint (0.115) were far above 0.10. The VIF of Edu (2.455) and Maint (8.677) was below 10, showing no challenges of collinearity.

3. Results

The study findings show that majority of the household heads in this study were aged over 60 years (Table 1). The majority of the household heads were literate. Most of the household heads participate in scheme infrastructure maintenance.

Table 1. The sociodemographic variables.

Variable		**Overall**	
		Freq	**%**
Age	<20 years	3	0.9
	20–29 years	2	0.6
	30–39 years	3	0.9
	40–49 years	30	9.5
	50–59 years	85	26.8
	60–69 years	68	21.5
	70–79 years	83	26.2
	>80 years	43	13.6
Education	No education	31	9.8
	Primary	100	31.5
	Secondary	186	58.7
Participation in scheme infrastructure maintenance	Never	6	1.9
	Sometimes	60	18.9
	Always	251	79.2

Table 2 shows the crop yields and their related blue WFP. The table illustrates the finding that the cucumber crop has the highest yield (30.60 t/ha) and the lowest blue WFP (278.85 m^3/t), while sugar beans, with a lower yield of 1.04 t/ha, have the highest blue WFP of 6370.67 m^3/t.

Table 2. Yields and blue water footprints of the crops grown.

Crop	**N**	**Yield (Std Dev) (t/ha)**	**Min (t/ha)**	**Max (t/ha)**	**Water Footprint (Std Dev) (m^3/t)**	**Min (t/ha)**	**Max (t/ha)**
Maize	271	5.58 (3.21)	0.75	9.00	1911.07 (1427.71)	282.33	11,293.33
Okra	1	10.00			782.39		
Cucumber	3	30.60 (3.12)	27.00	32.40	278.85 (30.19)	261.42	313.70
Squash	1	2.77			3061.45		
Cabbage	29	13.40 (6.14)	1	30	1136.15 (1684.29)	282.33	8470.00
Wheat	11	5.43 (1.50)	2.5	7.50	1683.76 (738.76)	978.26	3388.00
Onions	11	6.68 (4.62)	1.00	15.00	2511.50 (2630.31)	562.50	8470.00
Sugar beans	81	1.04 (1.08)	0.00	1.70	6370.67 (3469.08)	3125.00	22,586.67

A zero-order latent correlation calculation was performed to determine the extent of correlation between the variables of Gender, Maint, and WFP_Maize. Table 3 shows that Maint is strongly and positively correlated with WFP_Maize. Meanwhile, Edu positively correlates with Maint.

Table 3. Correlation among the variables.

	Scheme	Gender	Age	Edu	Maint	WFP_Maize
Scheme	1					
Gender	0.017	1				
Age	−0.121 *	0.056	1			
Edu	0.143 *	0.185	−0.502	1		
Maint	0.038	0.103	0.023	−0.109 *	1	
WFP_Maize	0.242	0.078	0.051	0.018	0.240 **	1
SD			12.78	3.14	22.04	
Min			18	0	0	
Mux			87	17	200	

Note: **—$p \leq 0.01$; *—$p \leq 0.05$.

Moderation Analysis

A moderated regression analysis of the effect of Edu on the interaction between Maint and WFP_Maize is shown in Table 4. Edu does not have a direct effect on WFP_Maize (Table 4). Covariates, which include Scheme (B = 6.995, $p < 0.01$) and Gender (B = 3.4184, $p < 0.05$), were significantly and positively related to WFP_Maize.

Table 4. Predictors of WFP_Maize.

Variables	B	Std. Error	Beta	t
Scheme	6.995 **	185.992	0.234	3.761
Gender	3.418 *	193.318	0.113	1.768
Edu	15.923	39.330	0.034	0.405
Maint	2.825 *	13.756	0.037	0.205
Maint_edu	−2.849 *	1.679	−0.314	−1.697

Note: **—$p \leq 0.01$; *—$p \leq 0.05$.

The regression lines between Maint and WFP_Maize were drawn in relation to the farmers' levels of education (no education, primary education, and secondary education). Figure 1 shows that Edu has a reduction effect on Maint. These high levels of Edu reduce the impact of Maint on WFP_Maize. The magnitude of the reduction effect of Edu in the link between Maint and WFP_Maize increases with the rising level of Edu (Figure 1).

The regression lines between Maint and WFP_Maize were drawn in relation to the farmers' levels of education (no education, primary education, and secondary education). Figure 1 shows that Edu has a reduction effect on Maint. The high levels of Edu reduce the impact of Maint on WFP_Maize. The magnitude of the reduction of WFP-Maize decreases with the increase in the level of education.

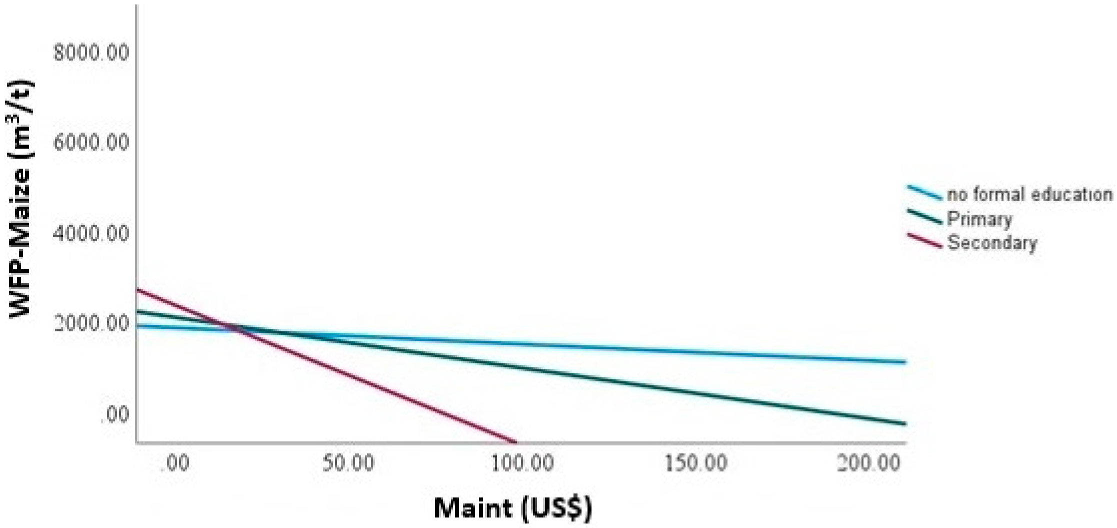

Figure 1. The interaction of Edu and Maint.

4. Discussion

Our research assesses the socioeconomic factors of agriculture in Zimbabwe. Their linkage with WFP in SISs addresses a very pertinent topic in the field of sustainability in agriculture and human well-being. The study aims to understand how the interaction of socioeconomic factors can be used to improve water efficiency, food, and nutrition security, and support sustaining environments in SISs and in the local communities. Assessing these links highlights an effective way to maximize water usage by improving nutrient access in rural communities. The mediation effect of these socioeconomic factors will enable researchers to improve the WFP under a given set of factors. This helps to improve water use in crop production, while ensuring that fresh water is available for other competing uses, thereby improving human and environmental health.

Yield and Water Footprint

Generally, the WFPs of the crops grown by the farmers in this study were higher than the standard global WFP reported by Mekonnen and Hoekstra [23]. Relative to the WFPs of the crops under study, their average yield was below the average of the region (Table 1). Although the global average WFP set by Mekonnen and Hoekstra was computed using the statistics from the 1996 to 2005 data, the average WFP for all crops in this study was higher than their average projected WFP, due to their relatively lower yield. Previous studies have compared global and local WFP estimates [41], revealing variation between the two estimates. Therefore, WFP is critically compromised by crop yields. The results from this study support findings in South Africa that beans have the highest WFP. According to Sokolow et al., [14] and Hoekstra et al. [39], pulses have a relatively higher WFP compared to other crops. However, the WFP of beans in this study was higher than that projected by Mekonnen and Hoekstra [23] and by Sokolow, Kennedy, and Attwood [14]. Cucumber has a lower WFP, although it is much higher than the WFP projected by Mekonnen and Hoekstra [23] and by Sokolow, Kennedy, and Attwood [14]. The low yield attained by smallholder farmers was attributed to a higher WFP, given that WFP has an inverse relationship with yield [18,33]. Increased evapotranspiration, due to the higher temperatures associated with climate change, may contribute to the increased WFPs of crops [14,42]. According to Hunter, Smith, Schipanski, Atwood, and Mortensen [3], agricultural management practices influence WFP. The adoption of agriculture management practices, such as mulching and reduced tillage, is crucial for retaining or increasing the soil's organic matter. This has positive effects on the soil's water-holding capacity while decreasing the evaporation rate [14]. However, according to the KII and FGDs, the majority of farmers did not use such practices.

Given that the WFP is directly linked to yield, the best way to improve water-use efficiency is to develop strategies to improve water productivity, which also depends on numerous variables. According to Sokolow, Kennedy, and Attwood, crop yields can be influenced by numerous factors, including water availability, nutrient supply, crop variety, access to agricultural inputs, and pest and disease prevalence. Sokolow, Kennedy, and Attwood [14] further stressed that WFP could be influenced by effective nutrient, water, and soil management, as determined by agricultural management, climatic and soil factors. Furthermore, the dilapidated state of some canals has resulted in increased runoff and leakages. However, the common pooled-resource nature of SISs makes it notoriously difficult to address these challenges [43]. Climate variability and change could have added an extra burden to the functionality of these socioecological systems, which already have mixed performance, making it impossible to address such factors.

This study adds to the body of literature by establishing the contribution of the interaction of factors on WFP. This study mainly finds that: (1) Edu negatively correlates with Maint; (2) Maint negatively correlates with WFP_Maize; (3) Edu negatively and significantly moderates the relationship between Maint and WFP_Maize.

The study indicates the strong variation of WFP_Maize between farmers in different schemes, whereby farmers in Exchange have a lower WFP_Maize, while those in Ruchanyu have a high WFP. Previous studies have reported a spatial variation of WFP at local, regional [44], and global scales [39,45]. Understanding the spatial variation of WFP is essential to comprehending the production and consumption perspectives [46], water return on investment [47], and water investment options [48] in each specific area. Therefore, farmers in Ruchanyu need more sustainable investments to improve their WFP.

Gender equality, which is highly emphasized in SDG5, is important in WFP assessment [49]. Our results indicate that male farmers have a higher WFP compared to their female counterparts (Table 4). As is consistent with our findings, several studies [50–52] have shown that the WFP of male farmers is comparatively higher than that of their female counterparts. In contrast to our findings, Alqahtani et al. [53] found no significant differences between male and female farmers in terms of WFP. Women are the primary users and managers of ensuring water resources in their communities; hence, their experience and knowledge need to be recognized and factored into future development projects [54]. According to the findings regarding gender, women are more concerned about environmental issues that harm their families and communities [55]. However, this relationship was more pronounced when it came to water use, with men being less concerned about water conservation than their female counterparts. This could be because, in the local society, women are more concerned about saving water than males because it is the woman's responsibility to meet her family's fundamental human needs, particularly in terms of preparing food, washing clothes, and cleaning [56]. Water access is important for women's empowerment since it has an impact on their access to education, health, income, and safety [57]. However, men make the decisions regarding water resource management and development at both the local and national levels, while women work to provide enough water for their domestic needs. This relationship shows that the participation of women in designing, planning, managing, implementing, monitoring, decision-making, and evaluating the use and exploitation of water resources at all levels is fundamental [57].

Furthermore, this study found that farmers who contribute more money toward maintenance positively contribute to high WFP. The results from the study conflict with the findings that optimized scheme maintenance bridges the failure and utility of users [58]. Maintenance is important for conditioning the existing scheme infrastructure to ensure that it functions efficiently. However, people who contribute more to scheme maintenance may claim exclusive rights to access irrigation water, compared to those who contribute less money.

This study shows that Edu negatively moderated the link between Maint and WFP_Maize. This means that Edu has a reduction effect on the impact of Maint on WFP_Maize. Among the schemes, most of the scheme farmers are formally educated, averaging nine years in formal education. Therefore, they are able to employ water-saving initiatives. According to Moyo et al., educated scheme farmers practice a pluralistic extension system; hence, they are able to cope better with technological advancement and will improve water use efficiency. Higher education levels widen the farmers' access to knowledge and investment opportunities. Therefore, even if the irrigation scheme receives insufficient irrigation water, it can still cope with the changes. Particularly in the case of farmers with secondary education, Maint is recognized as valuable. In this case, for farmers with higher levels of Maint, their WFP_Maize will be much lower than those farmers who contribute less to maintenance. However, the magnitude of this impact decreased with the decrease in the level of Edu. This means that when Edu is high, Maint can help to lower WFP_Maize. Hence, the positive link between Maint and WFP_Maize is reduced by high Edu. The findings from this study are in contrast to those of Pang et al. [59], who indicated that education is positively related to WFP.

Education and cognitive skills are thought to alter an individual's ability to acquire and remember information. The variable of education has been positively associated with WFP. Farmers with secondary education were found to show a greater reduction in WFP with a unit increase in maintenance (Figure 1). Fortunately, the schemes under study are dominated by farmers who have received secondary education (Table 1). Farmers with secondary education were found to be more likely to have a lower WFP, with an increase in maintenance of the scheme's infrastructure. Farmers with a higher level of education are thought to have stronger cognition abilities, allowing them to contribute more to scheme infrastructure maintenance and upkeep, thus enhancing the WFP. Thus, the positive relationship between the interaction of WFP, maintenance, and education is as expected.

Despite the growing literature on WFPs [14,42,51,52], little is known about the interaction of socioeconomic factors with WFPs. This study surpasses the previous WFP studies that do not consider this innovation. Given that the WFP is attributable to many factors, the contribution of socioeconomic factors requires rigorous scientific inquiry.

The link between education, maintenance, and WFP may vary spatially, temporally, and across crops. This study shows that education is essential for improving the WFP among scheme farmers. This research confirms the positive contribution of education to WFP. Education has been recently characterized as an instrument that will lower the WFP across human communities [60–62]. Therefore, it is essential to encourage educated farmers to participate in irrigation farming, to improve their WFP in the face of climate change.

5. Conclusions

This study shows the mediating effect of education on the link between maintenance and WFP_Maize among smallholder irrigation schemes. This study confirms that education has a reduction effect on the relationship between maintenance and WFP_Maize. Specifically, farmers who attain secondary education and contribute more toward scheme maintenance have the lowest WFP_Maize value. Thus, education has a crucial role to play in improving water-use efficiency. To our knowledge, this study is among other groundbreaking studies to assess mediation effects on WFP, specifically the effects of education and maintenance. It also positively contributes to showing the importance of the interaction of numerous factors to determine the nature of their link with WFP. Hence, broadening the study temporally, especially in the long term, will substantially impact WFP. The WFPs used in this study were estimates from KII, which could either be lower or higher than the actual WFPs of the crops grown; therefore, further rigorous scientific inquiry will be required to assess the WFPs of the major crops grown in the SISs of Zimbabwe.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/w14132101/s1, Questionnaire for The governance-institutions nexus in water manage-ment for climate change adaptation in smallholder ir-rigation schemes in Zimbabwe.

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