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Double-edge effects of small-scale irrigation on small-holder vegetable farmers' income in Gurara dam, Nigeria

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Abstract

This study examined the dual effects of the Gurara Irrigation Scheme on the income and livelihood diversification of smallholder vegetable farmers in Kaduna State, Nigeria. A multi-stage sampling procedure was used to select 188 irrigation beneficiaries and 202 non-beneficiaries across twelve communities. Primary data were collected through structured questionnaires, and the analysis employed descriptive statistics, Simpson's Index of Diversity (SID), and Propensity Score Matching (PSM) to assess the impact of irrigation on household income and livelihood patterns. The results revealed a clear contrast in livelihood strategies between the two groups. Non-beneficiaries exhibited significantly higher livelihood diversification, with a mean SID of 0.64 compared to 0.22 for beneficiaries. While 74.07% of non-beneficiaries engaged in high-diversity income portfolios, 59.88% of beneficiaries concentrated on low-diversity livelihoods, primarily irrigated vegetable farming. This suggests a trade-off between specialization and resilience. Income impact analysis using four PSM algorithms showed that irrigation significantly enhanced income, with the Average Treatment Effect on the Treated (ATT) ranging from ₦941,652.90 to ₦1,031,595.00 annually. These findings confirmed that while irrigation improves income, it may also reduce livelihood flexibility and increase exposure to market or climate-related shocks. The study concludes that for irrigation schemes to sustainably improve rural livelihoods, complementary policies must promote off-farm opportunities and diversification, ensuring both income enhancement and economic resilience for smallholder farmers.

***Keywords:** Gurara dam, welfare, income diversity, impact, Nigeria*

Introduction

Agriculture remains a key driver of rural livelihoods and economic development in Nigeria, with smallholder farmers playing a dominant role in food production. However, the sector is heavily reliant on rainfall, making it vulnerable to climatic uncertainties, especially in the arid and semi-arid regions. As rainfall patterns become increasingly unpredictable due to climate change, small-scale irrigation has emerged as a vital intervention to stabilize food production, extend the farming season, and improve farmers' incomes (Adeoye et al., 2020; IFPRI, 2023).

Small-scale irrigation schemes have been promoted as a means of intensifying production systems and transforming

subsistence agriculture into a more commercial, market-oriented model. Through improved water access, these schemes allow farmers to engage in dry-season cultivation, particularly of high-value crops like vegetables, which can significantly boost farm income. Previous studies have shown that irrigation access can lead to increased crop yields, employment opportunities, and overall rural development (Biosaline Agriculture Center, 2021; Asfaw & Demeke, 2021).

However, the introduction of irrigation also has broader socio-economic implications that go beyond income generation. There is growing evidence suggesting that access to irrigation may influence how farmers allocate their labor and time, particularly in relation to other income-generating activities. While irrigation can enhance specialization and income from farming, it may simultaneously reduce livelihood diversification—an important risk-coping strategy in rural areas (Ellis, 2000; Gebrehiwot & Gebrewahid, 2016). Farmers who rely heavily on irrigated farming may become more exposed to market and production shocks, such as price volatility, pest outbreaks, or climate-induced water shortages, which could undermine their economic resilience. On the other hand, farmers without access to irrigation may adopt broader livelihood strategies, combining farming with off-farm and non-farm activities to spread risk and stabilize household income (Asefa & Tadesse, 2023; Barrett et al., 2001).

The Gurara Irrigation Scheme in Kaduna State represents a significant government investment aimed at promoting dry-season vegetable production among smallholder farmers. The scheme offers an opportunity to assess not only the income-related benefits of irrigation but also its influence on livelihood patterns and economic behavior. Understanding these dynamics is crucial, especially in contexts where irrigation is expected to play a pivotal role in agricultural transformation and rural poverty reduction.

This study seeks to contribute empirical evidence to the ongoing debate on the dual impact of irrigation. It aims to: (i) describe the socio-economic characteristics of vegetable farmers in the study area; (ii) assess and compare the total income derived from various livelihood activities among irrigation beneficiaries and non-beneficiaries; and (iii) evaluate the effect of the Gurara Irrigation Scheme on smallholder farmers' income. By examining both the opportunities and trade-offs associated with irrigation access. The study will inform more inclusive and balanced policy interventions that promote agricultural productivity while safeguarding the economic resilience of rural households.

Materials and Methods

Description of the Study Area

This study was carried out in Kachia and Kagarko Local Government Areas of Kaduna State, located in Nigeria's North-West zone. Kaduna State spans a rolling plateau interlaced by rivers—including the Gurara River, which feeds into the Niger—and is characterized by distinct wet and dry seasons that make irrigation essential for year-round vegetable production (Kaduna State Government, 2012).

The Gurara Irrigation Project, a federal government initiative, currently supplies water to about 6,000 ha of smallholder and commercial farms in these LGAs using a motorized pivot system. Though originally designed to serve up to 20,000 ha with multiple irrigation technologies, the scheme now relies primarily on its 29 km steel pipeline and 100,000 m³ reservoir to support dry-season

farming (Federal Ministry of Water Resources, FMWR 2012; Federal Ministry of Agriculture and Rural Development, 2014).

These settings provide the backdrop for evaluating how access to reliable irrigation water affects both farm incomes and the breadth of livelihood activities among smallholder vegetable growers.

Sampling Procedure and Sampling Size

A multi-stage sampling technique was employed in this study to select the respondents for the study as demonstrated in Table 1. The first stage involved the purposive selection of Kachia and Kagarko Local Government Areas (LGAs) of Kaduna State where Gurara irrigation facility is domiciled. The second stage involved a random selection of two (2) districts each from the two LGAs. It entailed selecting (i) one district each randomly that are users of the irrigation facilities of the dam, while the other district consists of non-beneficiary of the dam in each LGA. In the third stage, three communities from each of the four districts were randomly selected; giving twelve (12) communities in all. In the fourth stage, total number of farming households, in each community were collected with the help of their community heads and extension personnel, and at the final stage, a total of 188 and 202 respondents were randomly selected from a sample frame of 355 and 408 farming households using Yamane's (1967), formula to calculate the sample size of beneficiary and non-beneficiary of Gurara dam based on assumption of 95% confidence level.

The Yamane formula adopted is expressed as follows:

$$n = \frac{N}{1+N(e)^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots (8)$$

1+N (e)^2

Where: n= Sample size; N=Sample frame (population); e = Confidence level assumed to be 0.05 and 1 = constant value. In equation 9 a & b, the beneficiary and non-beneficiary is calculated thus,

$$n_1 \text{ (Beneficiary)} = \frac{355}{1+355(0.05)^2} = \frac{188}{1.8875} = \frac{188}{1.8875} \times 100 = 52.96\%$$

$$n_2 \text{ (Non Beneficiary)} = \frac{408}{1+408(0.05)^2} = \frac{202}{2.02} = \frac{202}{2.02} \times 100 = 49.51\% \quad \ldots\ldots (9)$$

Primary data was used for this study. The data was collected through a structured questionnaire and interviews schedule within the 2023 cropping season. Data generated from the study were analyzed using both descriptive and inferential statistics.

Descriptive statistics such as frequencies, mean, standard deviation were used to achieve Socio-economics characteristics of the respondent, and Livelihood Diversification Patterns Among Beneficiaries and Non-Beneficiaries**.** The Simpson Index of Diversity (SID) is used to determine the level of income diversity among farmers such as Gurara irrigation farmers' income. It takes into consideration both the number of livelihood sources as well as how evenly the distributions of the income were between the different sources (Oluwatusin & Sekumade, 2020). Simpson index was used to measure objective (ii) that is, to assess the total income from the livelihood activities of Gurara farmers. That is the number of income sources or the level of income diversification from Gurara dam earnings. A value of one indicates complete dependence on a single income source while a value of 1/s represents perfectly equal earnings across income sources, where they are different.

Table 1: Distribution of selected farming households in the study area

LGAs	District	Communities	Sample frame	Sample size
		Beneficiary		**52.96%**
Kachia	Bishini	Kigwali	59	31
		Saminaka	63	33
		Atara	57	30
Kagarko	Kushe	Kushe Makaranta	69	37
		Kasangwe	54	29
		Dogwa	53	28
		Sub-total	355	188
		Non-beneficiary		**49.51%**
Kachia	Ariko	Dutse	78	39
		Anfani	61	30
		Koron-sofua	73	36
Kagarko	Janjala	Iddo	66	33
	non-beneficiary	Gidan Sani	55	27
		Sabon Janjala	75	37
		Sub-total	408	202
Total			763	

Source: Reconnaissance Field Survey, June 2023

Data Collection Method

The SID model is expressed in this study in equation 8:

$SID = 1 - \sum_{i=1}^{n} P_i^2$ …… …… (10)

(Bernard *et al.*, 2014; Femi & Adelomo, 2016)

Where: SID= Simpsons Index of Diversity, n=number of income sources, Pi= Proportion of income coming from the source i.

Explicitly, the SID is expressed in equation 12 as:

$$SID = 1 - \sum_{i=1}^{19}\left(\left(\frac{afi}{thi}\right)^2 + \left(\frac{wti}{thi}\right)^2 + \left(\frac{fnri}{thi}\right)^2 + \left(\frac{cbi}{thi}\right)^2 + \left(\frac{csri}{thi}\right)^2 + \left(\frac{smi}{thi}\right)^2 + \left(\frac{cpi}{thi}\right)^2 + \left(\frac{lpi}{thi}\right)^2 + \left(\frac{aoi}{thi}\right)^2 + \left(\frac{bkhi}{thi}\right)^2 + \left(\frac{awli}{thi}\right)^2 + \left(\frac{wci}{thi}\right)^2 + \left(\frac{cai}{thi}\right)^2 + \left(\frac{cri}{thi}\right)^2 + \left(\frac{nfwi}{thi}\right)^2 + \left(\frac{rgi}{thi}\right)^2 + \left(\frac{hgi}{thi}\right)^2 + \left(\frac{ti}{thi}\right)^2 + \left(\frac{pti}{thi}\right)^2\right) \text{ ……..(11)}$$

Where: Where: *thi* is total household income (Naira, ₦), n= number of household heads, engaging in each activity (persons), acm_i = actual crop main income from Gurara dam, (Naira, ₦), wt_i = water transport income (Naira, ₦), fn_i = fish net making and repairs income (Naira, ₦), cb_i = canoe building income (Naira, ₦), ce_i = canoe engine services and repairs income, (Naira, ₦), mpi = fish marketing and processing income (Naira, ₦), cp_i = crop production income apr from Gurara dam (Naira, ₦), lp_i = livestock and poultry income (Naira, ₦), ao_i = agric. input and output processing, sales and marketing (Naira, ₦), bh_i = Bee keeping and bee hunting income (Naira, ₦), wl_i = agricultural wage labour income (Naira,₦), wd_i = wood carving income (Naira, ₦), ca_i = carpentry and other artisans income (Naira, ₦), cm_i = commercial motorcycle income (Naira, ₦), nf_i = non-farm wage income (Naira, ₦), rg_i = remittance and gifts (Naira, ₦), hgi = hunting and gathering income (Naira, ₦), ti =teaching income (Naira, ₦), pti =petty trading income (Naira, ₦).

Propensity Score Matching (PSM) was employed in this study to determine the impact of the Gurara Irrigation Scheme on the income and profitability of vegetable

crop farmers. PSM is a widely used quasi-experimental method that controls for selection bias in observational studies by matching treatment and control units based on the probability of receiving treatment given a set of observed characteristics (Rosenbaum & Rubin, 1983).

The propensity score is defined as the probability that a unit (e.g., household or farmer) receives the treatment (i.e., participation in the irrigation scheme), conditional on a set of observed covariates. It is typically estimated using a binary logit or probit model, where the dependent variable takes the value of 1 for participants (beneficiaries) and 0 for non-participants (non-beneficiaries). The covariates used in the model are those that influence the probability of participation but are not themselves influenced by the intervention.

Mathematically, the propensity score $P(X)$ is expressed as:

$P(X) = Pr(P = 1|X = x_i)$

where X represents the vector of observed characteristics (Pufahl & Weiss, 2009).

After estimating the propensity scores, matching was performed using four algorithms: Nearest Neighbor, Radius, Kernel, and Stratification Matching. These methods pair each treated unit with one or more control units with similar propensity scores, thus creating a counterfactual that mimics randomization. The most common evaluation parameter used is the Average Treatment Effect on the Treated (ATT), which captures the average difference in outcomes between treated and matched untreated units:

$ATT = E(Y_1 - Y_0|P = 1)$

Where: ATT = Average Treatment Effect on the Treated, Y_1 = Outcome for participants (treated group), Y_0 = Outcome for non-participants (control group), E = Expectation function, P = Probability of treatment

A positive value of ATT suggests that participation in the Gurara Irrigation Scheme had a positive impact on farmers' income or productivity, while a negative value would suggest otherwise.

In recent developments, Covariate Balancing Propensity Score (CBPS) techniques, which ensure covariates are better balanced before matching, have also been applied to improve the reliability of causal inference in non-experimental settings (Imai & Ratkovic, 2014). However, for this study, traditional PSM algorithms were deemed sufficient to achieve determine the impact of the Gurara Irrigation Scheme on the selected vegetable farmers.

Results and Discussion

Socio-economic characteristics of the respondents

The socio-economic characteristics of respondents by participation in the Gurara Irrigation Scheme is presented in Table 2. The results showed that vegetable farming is dominated by males and individuals in their active years, with mean ages of 45 and 46 years for beneficiaries and non-beneficiaries, respectively. Both groups had high literacy levels, with over 91% having formal education. Household sizes were slightly larger among beneficiaries (mean = 10), and they also had more farming experience (9.61 years vs. 7.43 years). Although non-beneficiaries cultivated slightly larger plots (1–5 ha), beneficiaries had greater access to extension services (93.09%), training (92.55%), and cooperative membership (71.28%). These findings suggest that participation in the scheme enhances access to institutional support, which may improve productivity and livelihoods.

Table 2: Socio-economic characteristics of the respondents

	Variable	Beneficiary (%)	Non-Beneficiary (%)
Age	20-30 years	90.4	91.5
	Mean ± Std dev	45 ± 9.41	46 ± 9.67
Gender	Male	73.26	71.50
Education	Formal education	91.5	93.0
Marital status	Married	88.83	88.50
Household size	5 persons and above	88.65	83.25
	Mean ± Std dev	10 ± 4.64	9 ± 4.76
Farming experience	Mean	9.61	7.43
Farm size	1-5 hectares	29.26	39.50
Cooperative membership	Yes	71.28	56.50
Extension visits	Yes	93.09	26.0
Training participation	Yes	92.55	19.00

Source: Field Survey 2024

Livelihood Diversification Patterns Among Beneficiaries and Non-Beneficiaries

Table 3 presents the distribution of livelihood diversification activities among beneficiaries and non-beneficiaries of the Gurara Irrigation Scheme. The results indicate that non-beneficiaries engage in a broader range of income-generating activities compared to beneficiaries, suggesting a higher level of livelihood diversification. This reflects an adaptive strategy to mitigate the risks and uncertainties associated with rainfed agriculture. In contrast, beneficiaries appear to concentrate their efforts on irrigation-based vegetable farming, likely due to the stability and profitability offered by access to water.

Crop production remains the principal activity for non-beneficiaries, with 90.10% involved, compared to only 20.32% of beneficiaries. This highlights the reliance of non-beneficiaries on seasonal rainfed farming, which often necessitates diversification to other income streams. In contrast, the beneficiaries' reduced dependence on seasonal crops may be attributed to continuous irrigation-supported farming.

Fisheries-based activities, including fish marketing, processing, and net making, are significantly more prevalent among non-beneficiaries. Specifically, 68.81% of non-beneficiaries are involved in fish-related activities, compared to 37.97% of beneficiaries, while fishnet making and repair engage 48.51% of non-beneficiaries versus 9.63% of beneficiaries. These activities serve as important alternative livelihoods for those lacking access to irrigation.

Interestingly, teaching emerges as a major non-farm income source for beneficiaries (28.88%) relative to non-beneficiaries (18.32%), suggesting that the income stability from irrigation may enable beneficiaries to pursue off-farm employment with higher barriers to entry. Commercial riding (motorcycle taxi services) is more common among non-beneficiaries (17.33%) than beneficiaries (8.02%), reinforcing the broader livelihood base of the former.

Livestock and poultry farming further differentiate the two groups. While 60.40% of non-beneficiaries engage in these activities, only 1.60% of beneficiaries do so—indicating that those without irrigation support tend to diversify into livestock as a resilience mechanism. Other informal sector

activities such as petty trading, canoe services, water transport, and hunting are also more prominent among non-beneficiaries.

These findings are consistent with prior studies by Ellis (2000) and Chalchisa (2021), who assert that rural households diversify livelihoods primarily as a risk management strategy. Similarly, Amare & Balana (2023) and FAO (2022) observe that access to irrigation reduces the necessity for diversification, allowing households to specialize in high-return agricultural activities.

Table 3: Distribution of livelihood diversification activities of the Gurara Irrigation vegetable farmers.

Livelihood Activities	Beneficiary (%)	Beneficiary (%)
Crop production	20.32	90.10
Agricultural product processing	4.28	17.33
Agricultural wage labour	2.67	8.42
Canoe building	1.60	6.44
Livestock poultry	1.60	60.40
Carpentry & other artisans	0.00	4.46
Fish marketing processing income	37.97	68.81
Teaching	28.88	18.32
Beekeeping bee hunting	0.00	1.98
Petty trading	0.00	13.37
Commercial rider	8.02	17.33
Hunting and gathering	0.00	15.84
Fishnet making repairs	9.63	48.51
Canoe services repair	1.07	21.78
Water transport	2.67	13.86
Remittance /gifts	0.00	1.49

Source: Field Survey 2024

Distribution of livelihood diversity index

Table 4 presents the distribution of the livelihood diversity index among beneficiaries and non-beneficiaries of the Gurara Irrigation Scheme. The results reveal a striking contrast in livelihood diversification between the two groups. Non-beneficiaries exhibit significantly higher livelihood diversification than beneficiaries, with a mean diversity index of 0.64 compared to 0.22 for beneficiaries. This suggests that non-beneficiaries, lacking irrigation access, diversify their income sources more extensively to mitigate risks and ensure financial stability. A substantial 74.07% of non-beneficiaries fall into the high-diversity category (0.68–1.00), whereas only 7.56% of beneficiaries achieve this level of diversification. Conversely, a majority (59.88%) of beneficiaries exhibit low livelihood diversity (0.02–0.33), compared to only 10.65% of non-beneficiaries in this category. This disparity indicates that irrigation beneficiaries are more specialized in a single dominant livelihood activity—vegetable farming—while non-beneficiaries engage in multiple income-generating activities to buffer against uncertainties associated with rainfed agriculture.

Moderate livelihood diversity (0.34–0.67) is observed among 32.56% of beneficiaries and 15.28% of non-beneficiaries. This middle category suggests that while some beneficiaries diversify their income streams, the extent is still lower than that of non-beneficiaries. The lower diversity among beneficiaries aligns with the expectation that irrigation provides a stable and profitable source of income, reducing the necessity for diversification.

These findings aligned with previous research on livelihood diversification and rural economies. Ellis (2000), Barrett *et al.,* (2001) and Musumba *et al.,* (2021) highlight that rural households often engage in multiple livelihood activities to spread risk, particularly in environments where agricultural productivity is uncertain. Similarly, Babatunde and Qaim (2010) found that access to irrigation reduces the need for livelihood diversification, as it enables higher productivity and profitability in a single agricultural enterprise. This is further supported by Asfaw et al. (2019), who demonstrated that irrigation beneficiaries often exhibit lower diversity indices due to their reliance on irrigation-enabled crop production.

Table 4: Distribution of livelihood diversity index

		Beneficiary		Non-Beneficiary	
Livelihood Diversity	**RANGE**	**Freq.**	**Percent**	**Freq**	**Percent**
Low diversity	**0.02–0.33**	103	59.88	23	10.65
Moderate diversity	**0.34–0.67**	56	32.56	33	15.28
High diversity	**0.68–1.00**	13	7.56	160	74.07
Mean		0.22		0.64	
		172	100	216	100

Source: Field Survey 2024

Total income from various livelihood sources

The total income from various livelihood sources in objective two, which also highlights the diverse income streams available to vegetable farming households in the Gurara irrigation area is as shown in Table 5. Crop production stands out as the primary income source, contributing ₦1,186,496.89, which accounts for 52.22% of the total household income. This significant share underscores the critical role that crop farming, supported by the irrigation scheme, plays in the economic well-being of these households. Other agricultural-related activities, such as agricultural input-output processing and marketing, add another substantial portion of income at ₦413,867.44 (18.22%), indicating that post-farming activities are also important contributors to household livelihoods.

Several other non-agricultural activities also generate income for these households. For instance, carpentry and other artisan skills contribute ₦63,500, which is approximately 2.79% of total income. Additionally, agricultural wage labor provides ₦93,045.45, accounting for 4.10% of the household's income. These results suggest that households engage in diverse activities to supplement their agricultural earnings, relying on both farm and non-farm income sources to enhance their overall economic stability.

Table 5: Total income from households per annum

Livelihood Source	Average Income (N)	Percentage
Crop production	1186496.89	52.22
Agricultural product processing	413867.44	18.22
Agricultural wage labour	93045.45	4.1
Canoe building	75937.50	3.34
Livestock poultry	67264.00	2.96
Carpentry other artisan	63500.00	2.79
Teaching	49043.96	2.16
Beekeeping bee hunting	47500.00	2.09
Petty trading	43266.67	1.9
Commercial rider /okada/keke	42240.00	1.86
Hunting and gathering	41500.00	1.83
Fishnet making repairs	33935.34	1.49
Canoe services repair	28521.74	1.26
Water transport	19060.61	0.84
Remittance /gifts	5000.00	0.22
Total	**2271917.70**	**100.00**

Source: Field Survey 2024

Smaller income contributions come from activities such as fish marketing and processing (₦61,738.10), petty trading (₦43,266.67), and commercial riding (₦42,240.00). While these activities contribute smaller amounts to total household income, their presence highlights the resilience strategies households employ. Beekeeping, hunting, and remittance form smaller yet critical additional sources of income, collectively adding up to a more diverse income portfolio that helps households cope with economic challenges and improve their livelihood sustainability (Adeyemo, 2024).

Distribution of farmers base on the impact of vegetable crop farmers income.

Table 6 presents the estimated impact of the Gurara Irrigation Scheme on the income of vegetable crop farmers, as evaluated through four Propensity Score Matching (PSM) methods: Nearest Neighbor, Radius, Kernel, and Stratification. The results provide compelling evidence that participation in the irrigation scheme significantly increases farmers' income, as demonstrated by the Average Treatment Effect on the Treated (ATT) across all matching algorithms.

The ATT values indicate that, on average, beneficiary farmers earned between ₦941,652.90 and ₦1,031,595.00 more annually than their non-beneficiary counterparts. The Nearest Neighbor matching method yielded the highest ATT (₦1,031,595.00), followed closely by the Stratification (₦1,006,393.00), Radius (₦978,799.40), and Kernel (₦941,652.90) approaches. These positive and statistically significant ATT values (*** at 1% level) reflect the substantial economic benefits associated with access to irrigated vegetable farming.

The corresponding standard errors for these estimates, ranging from ₦132,497.80 to ₦141,628.20, are relatively low compared to the ATT values, further reinforcing the reliability of the results. The t-values, which range from 6.91 to 7.74 across the methods, are all well above conventional critical values, indicating

strong statistical significance and high confidence in the results.

Moreover, the control group (non-beneficiaries) consistently shows a mean income of ₦351,512.50 across all methods, while the treated group (beneficiaries) earns between ₦1,348,902.50 and ₦1,357,906.06. This wide income differential clearly underscores the transformative effect of the Gurara Irrigation Scheme on the livelihood of its beneficiaries.

These findings are consistent with prior studies emphasizing the income-enhancing role of irrigation in smallholder agriculture. For example, Abdulai, & Huffman (2021) and Tesfaye & Tiruneh, (2022) demonstrated that irrigation projects in sub-Saharan Africa significantly increase farm incomes by improving productivity and enabling multiple cropping. Similarly, Bacha & Shibru (2023) found that access to agricultural technologies, including irrigation, substantially boosts the welfare of rural households in Nigeria.

Table 6: Distribution of farmers base on the impact of vegetable crop farmers income.

Parameters	Nearest_neighbor	Radius	Kernel	Stratification
ATT	1031595.00 ***	978799.4 ***	941652.9 ***	1006393 ***
SE	133234.20	141628.2	132519.2	132497.8
Treated	1383107.00	134902.5	1357906.06	1357906.0
Control	351512.5	370225.35	351512.5	351512.5
T-value	7.74	6.91	7.11	7.60

Source: Field Survey 2024

Conclusion and Recommendations

The findings of this study underscore the dual impact of small-scale irrigation on smallholder vegetable farmers in the Gurara Dam area. On one hand, participation in the irrigation scheme significantly improved farmers' income, as evidenced by the higher Average Treatment Effect (ATT) across all matching algorithms. Beneficiaries also had greater access to agricultural extension services, training, and cooperative networks, which facilitated better knowledge transfer, input access, and adoption of improved technologies—factors that directly contributed to enhanced farm productivity and profitability.

On the other hand, the study revealed a notable reduction in livelihood diversity among irrigation beneficiaries compared to non-beneficiaries. This suggests an overreliance on vegetable farming as the primary income source, which may expose these farmers to heightened vulnerability from price volatility, pest outbreaks, and climate-related risks. In contrast, non-beneficiaries, though earning lower incomes, maintained more diversified income streams, which can serve as buffers during shocks.

The contrasting outcomes point to the need for integrated rural development strategies that expand access to irrigation while encouraging complementary livelihood opportunities. Policymakers should prioritize inclusive training, support for cooperative formation, and diversification of income sources even among irrigation participants. Strengthening the resilience of smallholder farmers requires balancing income gains from irrigation with risk management through diversified livelihood portfolios.

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