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Research Article

Impact of Small-Scale Irrigation on Household Income in Central Ethiopia: Empirical Evidences from Walmara District

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ABSTRACT

Agricultural sector in Ethiopia is mainly characterized as traditional, subsistent and rainfed system which is highly susceptible to adverse effects of climate variabilities. Under such conditions, small-scale irrigation is recommended as the most effective way of improving agricultural production, productivity, income, food security and household wellbeing. This study was conducted with the objective of assessing the impact of small-scale irrigation on household income using the primary data collected from 220 households of Walmara district. Descriptive and econometric data analyses were executed. Logistic regression and PSM methods were used to measure the impact. The average treatment effect on the treated (ATT) result revealed that participation in irrigation significantly affected household income, and irrigator households get more gross income of Birr 22,161 than non-irrigators, and this result is statistically significant. Finally, sensitivity analysis was done, and the ATT is insensitive to unobserved bias up to 200%. Therefore, policy interventions focusing on installation of new small-scale irrigation schemes and fully utilization of the existing schemes are recommended for their direct contributions in improving household income, and indirect contribution in improving food security and national GDP, especially in erratic rainfall and drought-prone areas.

Key words: Impact, Small-scale irrigation, Income, PSM, Logit, Walmara

INTRODUCTION

Ethiopian economy is among the fast-growing economies of the world for the past two decades, and mainly dependent on agricultural sector that accounting for 33.3 percent of the GDP of the country, from which the majority of the share (64.8 percent) is from crop production sub sector (NBE 2019). Though the agricultural sector of the country is employing majority of the population, it is the least growing sector and mainly characterized by its traditional, subsistent, and rainfed farming system which is highly vulnerable to the adverse effects of climate variability and erratic rainfall patterns that resulting crop failure, famine, poverty, food insecurity and livelihood threats (Awulachew 2019; Feleke, *et al*., 2019; Muluneh, *et al*., 2017; Yihun 2015).

Ethiopia is the most populous country owning more than 110 million people (CSA 2019) and among the poorest countries of the world. The agricultural sector of the country is not growing with the pace that the population is growing and the sector could not sustainably satisfy the food demand of the overgrowing population ever-growing food demand of the country and more than 22 million people were under national poverty line during 2017 (UNDP 2018a).

Under erratic rainfall and climate variabilities, irrigation use is recommended by different scholars at different times for its contribution in improving household income (Zewdie, *et al*., 2019; Zewdie, *et al*., 2020; Mango, *et al*., 2018), improving the quality of life of the households (Gebrehiwot, *et al*., 2017, Zewdie, *et al*., 2019; Zewdie, *et al*., 2020;), contribution in poverty reduction (Hagos, *et al*., 2017, Adela, *et al*., 2019) and improving household food security status (Yigzaw, *et al*., 2019, Muleta, *et al*., 2021). Irrigation use is also reported to improve household livelihood by increasing income, food security status, poverty reduction, creating employment opportunities, fulfilling social needs, increasing agricultural production and productivity through diversification of crops grown, serving as a source of animal feed, enhanced health status due to accessibility of balanced diet and easy access to medication, reducing soil degradation, and contributing to household asset ownership (Asayehegn 2012).

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Ethiopia has immense water and land resources that can be taken as an opportunity for irrigation purpose. The total water potential from major rivers, lakes and groundwater for the country is estimated to be more than 239.19 billion cubic meters (BCM) i.e., 124.4 BCM from rivers, 84.79 BCM from lakes, and 30 BCM from groundwater (Ayalew 2018). The stated water resource has the potential to irrigate 3,800,733 hectares of land and also the country has an irrigable land potential of 5.3 million hectares, out of which 640,000 hectares were utilized (Awulachew and Ayana 2011).

In contrary to the irrigation potential of the country, 97 percent of cereal production in the country is using rainfed agriculture and this is because of technical, physical and economic challenges. In the recent years, Ethiopian government is making efforts to transform the agricultural sector from traditional and rain-fed agriculture to modern, technology intensive and mechanized, irrigated and market-oriented agriculture, with packages of post-harvest technologies (FAO and IFC 2015).

According to the information from Walmara district agriculture and rural development bureau (2020), the district has high potential of irrigation water and irrigable land. Out of 23 rural and 8 urban kebeles in the district, irrigation access exists in 20 rural and 4 urban kebeles, but in limited area coverage in 3 rural and 1 urban kebeles. The estimated irrigation potential of Walmara district is more than 9,055 hectares. In spite of this potential, the scientific information on the impact of irrigation on the livelihood of the community in the study area is limited. Therefore, this study was conducted to assess the impacts of small-scale irrigation on household income and contribute information for policy intervention, extension actions, and for future researches.

MATERIALS AND METHODS

Description of the study area

Walmara district is one of the districts of Finfinnee surrounding Oromia Special zone, Oromia, Ethiopia. The district is located at 34 km to the west of Addis Ababa and lies between 8°50'-9°15' N and 38°25'-38°45' E. The total area of the district is about 77,119 hectares (64984 hectares of cropland, 2442 hectares of grass land, 4329 hectares of forest land, 1404 hectares of wetland, 3790 hectares of settlement and 170 hectares of water body (Urgessa and Lemessa 2020). Majority part of the district (61 percent) is classified as highland and 39 percent is classified as mid-highland. The mean altitude of the district is 2400 meters above sea level, which is ranging from 2060 to 3380masl. The average annual rainfall of the district is 1,144 mm, ranging from 795 to 1300 mm. The temperature of the district ranges from 6 ºc to 24ºc with annual average of 14 ºc. According to the population projection report of CSA (2019), the total population of Walmara district was 112,498 (56,200 males and 56,298 female).

According to the information from the district office of agriculture and rural development, the farming system of the district is characterized as mixed, both crop and livestock production similar to other central highlands of the country. The major crops grown in the district during the main season are wheat, barley, tef, pulses, oilseeds, and potatoes. These are the major staple food crops in the study area. Similarly, potatoes, cabbages, tomatoes, carrots, and onions are the major vegetable crops grown during the off-season using irrigation.

Description of irrigation schemes in the district

There are different streams and rivers that are suitable for irrigation and can also be seen as an opportunity to the district, out of which Holeta river is the main. Walmara district has a long history in both traditional and modern irrigation schemes, and also has more than 9,055 hectares of irrigable land potential, out of which 7,580 hectares were cultivated yet. Different types of irrigation were implemented in the district and currently 828 hectares were cultivated using modern irrigation, 4,890 hectares were cultivated using traditional irrigation, 1,788 hectares were cultivated using motor pump, and 74 hectares were cultivated using wells and currently serving more than 2,163 households living in the district.

Walmara district is among the surplus producing and high irrigation potential districts of the Oromia region and it was chosen to be one of the districts of the second agricultural growths and transformation program (AGP II), and the construction of modern irrigation schemes are being undertaken in different kebeles by this program. This study addressed three kebeles having modern small-scale irrigation schemes (Talacoo, Barfata Tokkoffaa, and Bakakkaa & Qoree Oddoo), and one kebele having traditional irrigation scheme (Waajituu Harbuu). The irrigation schemes constructed by AGP II were summarized in Table 1.

Sampling procedure

A multi-stage sampling technique was the method used to select the required sample households. Walmara district was purposively selected first. Then, kebeles were classified into highland and mid-highland based on their ecology. In the third stage, kebeles in each ecology were stratified into irrigators and non-irrigators based on irrigation access. At the fourth stage, a total of four kebeles (two kebeles from each ecology) were randomly selected from those kebeles having access to irrigation. Finally, the representative sample households were selected using systematic random sampling technique.

The required sample size was determined using the rule of thumb. Based on this, the total sample size was 220 including 10 percent contingency. The sample size from sample kebeles were selected based on the proportional sampling method which is determined using the formula:

$$ni = \frac{(Ni)(n)}{\Sigma Ni} \quad (1)$$

Where ni - the sample to be selected from i^{th} kebele

Ni - the total population living in i^{th} kebele.

ΣNi - the summation of population living in selected four kebeles

n - total sample size for the district

Sources of data and method of collection

Primary and secondary data were used. The primary data were collected using structured and semi-structured questionnaires through interview. Secondary data were collected from records of district bureau of agriculture, published journals, records of kebele administration and etc.

Method of data analysis

Descriptive data analysis

Under the descriptive statistics, the included socio-economic, institutional and demographic variables were described and summarized using mean, percentage and standard deviation. T-test and chi-square tests were done to check the statistical significance of the continuous and dummy variables respectively. STATA V15.3 was the package used to analyze the collected data.

Econometric data analysis

To do econometric data analysis, participation in small-scale irrigation is used as a dummy dependent variable, and the propensity score was estimated using Logistic regression model. Propensity score is the probability of participation in irrigation given observed covariates, that will be used to match irrigation users and non-users in terms of annual household income. Functionally, the logistic regression model can be articulated as:

$$Pi = E(D=1|Xi) = \frac{1}{1+e^{-(\beta o+\beta iXi)}} \quad (2)$$

Equation 2 can be simplified as:

$$Pi = \frac{1}{1+e^{-Zi}} \quad (3)$$

Equation 3 is the probability of participating in small scale irrigation, and from this, the probability of non-participating in small scale irrigation can be expressed as equation 4 below:

$$1-Pi = \frac{1}{1+e^{Zi}} \quad (4)$$

Similarly, the odds ratio, i.e., the ratio of the probability of participation in irrigation to the probability of non-participation in irrigation can be expressed as:

$$\frac{Pi}{1-Pi} = \frac{1+e^{Zi}}{1+e^{-Zi}} = e^{Zi} \quad (5)$$

Taking the natural Logarithm of equation 4, we get:

$$Li = \ln\left[\frac{Pi}{1-Pi}\right] = \beta_o+\beta_1X_1+\beta_2X_2+\beta_3X_3+ \ldots + \beta_nX_n +U_i \quad (6)$$

Where: Pi - is probability of participation in irrigation
Li - is logarithm of the odds ratio
β_1 β_2 β_3 ……. β_n are the coefficients to be estimated
X_i - are the vectors of explanatory variables
Ui - is disturbance term

RESULTS AND DISCUSSION

Descriptive results

Descriptive Results of dummy variables

As presented in Table 3, from the total sample households, 16 percent were female-headed and 84 percent were male-headed households. Similarly, 11 percent and 89 percent of irrigator households were female and male-headed households respectively, while 20 percent and 80 percent of non-irrigator households were female and male-headed households respectively. From this result, the sex of the household head has positive relation with participation in small-scale irrigation and the chi-square test also showed that there is significant mean difference between irrigators and non-irrigators.

The result also revealed that 96 percent of irrigators and 86 percent of non-irrigator households have access to credit services. From this result, there was a positive and significant relation between household participation in irrigation and access to credit services. From this households having access to credit services are more likely to participate in irrigation. The chi-square test also showed that there is a significant relationship between access to credit services and participation in irrigation.

According to the result in the Table below, crop pests were occurred on the crop fields of 58 percent of irrigator and 44 percent of non-irrigators during the main season of 2019. This result is showing that households whose crop production affected by pests during the main season are more likely to participate in irrigation during the off-season. The chi-square test result is also proving that there is a significant relation between occurrence of crop pets and household participation in irrigation.

The result also revealed that 86 percent of non-irrigators and 87 percent of irrigators have access to extension contact. This indicates that access to extension contact is almost similar for both irrigators and non-irrigators. From the chi-square test, there was no significant relationship between access to extension contact and household participation in irrigation.

Descriptive results of continuous variables

The mean age for irrigators and non-irrigators were 42 and 45 years with standard deviations of 10.4 and 9.2, respectively; and the combined mean age was 43.9 years with a standard deviation of 9.9. This result indicates that older household heads are less irrigation users compared to the younger household heads. The t-test result also showed that the mean age is significantly different for irrigators and non-irrigators.

The mean livestock holding for irrigators and non-irrigators were 6.3 and 7.5 with the standard deviations of 3.7 and 4.1 while the combined mean was 7 with a standard deviation of 3.9. From this result, households having more livestock are less irrigation users. The t-test result also showed that the mean livestock holding for irrigators and non-irrigators was significantly different.

The result also revealed that distance from irrigation site also significantly related with household participation in irrigation. The mean irrigation distance for the sample household was 2.2 km with standard deviation of 0.8, while it was 1.9 and 2.3 kilometres with standard deviations of 0.8 and 0.7 for irrigators and non-irrigators, respectively. The t-test result also revealed that the mean distance from the irrigation site was significantly different for irrigator and non-irrigator households.

Family size also significantly related to households' decision to participate in small-scale irrigation. The mean family size for irrigators and non-irrigators were 4.9 and 4.4 with standard deviations of 2 and 1.8, while the combined mean for the sample households was 4.6 with a standard deviation of 1.9. The t-test result also showed that there is a significant mean difference between irrigation participants and non-participant households.

Table 1: Modern small-scale irrigation schemes in different kebeles of Walmara district

Kebeles	Irrigable land potential (ha)	Year Constructed	Number of beneficiary households		
			Male	Female	Total
Barfata Tokkoffaa	65	2008	125	27	152
Talacoo	94	2005	75	23	98
Duufaa	30	2007	339	68	407
Bakakkaa & Q/Oddoo	65	2004	107	14	121
Markos	106	2005	352	106	458
Walmaraa Cooqee	30	2007	103	29	132
Barfata Lammaffaa	130	2011	297	95	392
Dhohaa & Laaftoo	158	2011	120	33	153
Tulluu W/Daalachaa	150	2011	199	51	250

Source: Walmara district office of agriculture, and the construction year is in Ethiopian calendar.

Table 2: Total sample distribution over the selected *kebeles*

Name of *Kebeles*	Total HH	Total sample	Participant	Non-participant	Proportion
Talacoo	544	60	27	33	27.3%
Barfata Tokkoffaa	777	86	39	47	38.9%
Bakakkaa & Q/Oddoo	325	36	16	20	16.3%
Waajituu Harbuu	349	38	17	21	17.5%
Total	1995	220	99	121	100%

Source: District office of agriculture and own computation result.

Table 3: Descriptive results of dummy variables by participation in irrigation

Variables		Participation in irrigation						Chi-square
		No	%	Yes	%	Total	%	
Sex of the household head	Female	24	20	11	11	35	16	3.1*
	Male	97	80	88	89	185	84	
Access to credit services	No	17	14	4	4	21	10	6.3**
	Yes	104	86	95	96	199	90	
Occurrence of crop pests	No	68	56	42	42	110	50	4.13*
	Yes	53	44	57	58	110	50	
Access to extension contact	No	17	14	13	13	30	14	0.04
	Yes	104	86	86	87	190	86	

Source: Own household survey conducted during 2020: Note: * and ** shows the significance levels at 10% and 5%.

Table 4: Descriptive results of continuous variables by participation in irrigation

Variables	Irrigators		Non-irrigator		Combined		t-test
	mean	St.dev	mean	St.dev	mean	St.dev	
Age of head (years)	42.3	10.4	45.4	9.2	43.9	9.9	-2.5**
Education of head (years)	4.5	4.0	3.7	3.7	4.1	3.8	1.38
Dependency	0.9	.62	0.9	0.8	0.91	.71	-0.31
Livestock (TLU)	6.3	3.7	7.5	4.1	7.0	3.9	-2.2**
Family size (AE)	4.9	2.0	4.4	1.8	4.6	1.9	2.7**
Off-farm income in 1000 Bir	7.2	9.7	8.1	10.2	7.7	10.1	0.67
Market distance (KM)	5.2	2.3	5.5	2.1	5.4	2.2	-1.30
Irrigation distance (KM)	1.9	0.8	2.3	0.7	2.2	.8	-3.3***
Land owned (hectares)	1.7	1.2	1.4	1.2	1.5	1.2	2.3**

Source: Own household survey conducted during 2020. 1US dollar was equal to 29.5 Birr: Note: ** and *** shows the significance levels at 5% and 1%.

The mean land ownership were 1.7 and 1.4 hectares for irrigators and non-irrigators with standard deviation of 1.2 for both, while it was 1.5 hectares with standard deviation of 1.2. The t-test result also confirmed that the mean land holding showed significant difference for irrigators and non-irrigators.

Econometric results

To conduct econometric data analysis, propensity score matching (PSM) was the method used and logistic regression was the model used to estimate the propensity score. Participation in irrigation was used as dummy dependent variable and as independent variable, 13 variables were included. As stated in Bernard *et al.* (2008), conditional on the ability of propensity score to overcome potential sources of bias, program participants and non-participants become comparable.

The result of propensity score estimation presented in Table 5 showed that the model performed well since the overall fitness of the model was found to be significant at 1 percent. Moreover, the value of pseudo-R^2 is also fairly smaller (0.21), indicating that irrigators and non-irrigators are similar, and this similarity make easier to get good matches (Caliendo and Kopeinig 2008).

After the estimation of the propensity score, restricting the common support region was followed. Accordingly, 19 observations (16 from irrigators and 3 from non-irrigators) were rejected as they are out of the common support, and 201 observations (118 from non-irrigators and 83 from irrigators) were included in the matching.

Table 5: Logistic regression result of estimation of propensity scores

Variables	Coef.	St. Err.	Z value
Sex of the household head	1.286	0.497	2.580
Age of the head (years)	-0.069	0.021	-3.240
Education of the head (years)	0.052	0.044	1.190
Family size (AE)	0.425	0.112	3.800
Dependence ratio	-0.041	0.252	-0.160
Livestock holding (TLU)	-0.150	0.047	-3.230
Land owned (hectares.)	0.466	0.153	3.050
Distance of irrigation site (KM)	-0.493	0.222	-2.220
Off-farm income (Birr)	-0.000	0.000	-0.120
Occurrence of crop diseases	0.979	0.365	2.680
Access to extension contact	0.666	0.507	1.320
Market distance (KM)	-0.056	0.074	-0.750
Access to credit services	1.315	0.647	2.030
Constant	-1.025	1.541	-0.670
Logistic regression	Number of obs. = 220		Prob. > chi^2 = 0.000
Log likelihood = -118.2	LR chi2 (13) = 66.35		Pseudo R^2 = 0.2100

Source: Own household survey conducted during 2020.

Table 6: The joint significance table (the summary of the covariate balancing)

Sample	Ps R2	LR chi2	P>chi2	Mean Bias	Med Bias	B	R	%Var
Unmatched	0.216	65.27	0.000	23.8	27.7	117.7*	0.94	11
Matched	0.006	1.45	1.000	4.7	3.7	18.6	1.06	0

Source: Own household survey conducted during 2020.

Table 7: Estimation of the average treatment effect on the treated (ATT)

Variable	Sample	Treated	Controls	Difference	S. E (B.st)	T-stat
Gross Income	Unmatched	47403.1313	23706.686	23696.4454	3748.6169	6.32***
	ATT	41274.6988	19113.442	22161.2568	6359.3470	5.07***

Note: *** shows that the variable is significant at 1 percent probability level: B.st: Is the boot strapped standard deviation replicated .100 times.

In the matching process, radius matching with a band width of 0.1 was the chosen matching algorithm as it showed the best matching qualities compared to other methods, i.e., the mean bias of the test was 4.7, all the included covariates were balanced after matching done, and the value of pseudo R^2 after matching was 0.006 as presented in Table 6.

Since all the included covariates were balanced, estimation of the average treatment effect on the treated (ATT) was followed. As presented in Table 7, the average treatment effect on the treated measured in the households' gross income is significantly different for irrigators and non-irrigators, i.e., irrigator households are getting more gross income than that of non-irrigator households and this is significant at 1 percent.

To check the estimated average treatment effect on the treated (ATT) was the pure effect of participation in small scale irrigation, the sensitivity analysis was done. The result of the sensitivity analysis revealed that the estimated average treatment effect on the treated was not sensitive to unobserved bias up to 200%.

Therefore, the result in Table 7 was the pure effect of participation in small scale irrigation. This result is showing that irrigation user households on average earns more income amounting 22,161 Birr than non-irrigator households, and this difference is statistically significant at 1 percent.

Conclusion and Recommendation

This study was conducted with an objective of assessing the impact of small-scale irrigation on household income in Walmara district, Oromia, Ethiopia. A multi-stage sampling method was followed to randomly select 220 sample households from four representative *kebeles*. Logistic regression model and propensity score matching method were used for econometric data analysis. Logistic regression was employed to estimate the propensity score and different criteria like pseudo R^2, mean bias and the number of matched observations were used to assess the matching quality in matching treatments and controls. Accordingly, radius matching with band width of 0.1 was the matching algorithm with best matching quality. Finally, the estimation of the treatment effect on the treated (ATT) was followed and the result revealed that small scale irrigation has significant impact on household income and the income of irrigator households was significantly greater than that of non-irrigator households.

Based on the result of this research, participation in small scale irrigation can significantly improve household income. Therefore, agricultural policy interventions focusing on installation of new irrigation schemes; and fully utilization of the existing schemes are recommended for their direct contributions in improving household income; and indirect contribution in improving household food security status and national GDP; especially in erratic rainfall and drought-prone areas of the country.

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