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Do Public Works Investments in Watershed Rehabilitation and Small-Scale Irrigation Improve Nutrition and Resilience?

Evidence from Bureau for Humanitarian Assistance Interventions in Support of Ethiopia's Productive Safety Net Program

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Abstract

Between 2017 and 2021, the Bureau for Humanitarian Assistance (BHA) of the United States Agency for International Development supported public works in the areas of watershed rehabilitation and small-scale irrigation under Ethiopia's Productive Safety Net Program (PSNP). The investments aimed to improve food security and nutrition and to increase the resilience capacities of households through improved natural resource systems and asset development. However, there is little evidence about how these water-related investments supported household food security, nutritional outcomes, and resilience. This study used a mixed-methods approach to fill some of these knowledge gaps. Econometric results show that households in BHA intervention areas had smaller food gaps, and this association is statistically significant. Similarly, households that adopted small-scale irrigation and water harvesting techniques on their own plots show significantly better nutritional outcomes than those that did not. The results further suggest that in general the households in BHA areas are more resilient than those in non-BHA *woredas*. However, higher resilience capacities are associated with agricultural water management on own plots rather than with public works in communal lands. Thus, if household security, nutrition and resilience are key goals of program interventions, then programs need to grow intentionality in developing assets, and particularly irrigation.

Keywords: Ethiopia, Public works, Watershed rehabilitation, Small-scale irrigation, Food security, Nutrition, Resilience

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1. INTRODUCTION

Launched in 2005, Ethiopia's Productive Safety Net Program (PSNP) harmonizes the delivery of donor support to vulnerable populations that are experiencing chronic food insecurity and climate induced shocks. PSNP investments aim to improve food consumption and nutrition security, while also protecting and developing assets for sustaining stable access to food in the medium- to longer-term. PSNP differentiates between two types of beneficiaries: (1) households with no able-bodied members, which receive direct support in the form of cash or in-kind transfers; and (2) public works (PW) beneficiaries, who receive payments for labor contributions. PW activities are generally located within walking distance of target beneficiary households; this avoids both the costs and risks of migration and enables participants to continue to manage their farms and other activities. Key PW programs include watershed rehabilitation such as soil and water conservation (SWC) activities to reduce soil erosion and control runoff; rehabilitation of existing irrigation schemes; construction of new and typically small-scale irrigation[1] (SSI) schemes; and social infrastructure such as schools, health centers, farmer training centers, drinking water sources, roads, and bridges. According to the World Bank (2013), SWC comprised about 60 percent of the PSNP's PW sub-projects.

Several past studies have documented the impacts of PSNP on a range of outcome areas, for instance, Gilligan et al., (2009a; 2009b) on food security, productive investments, ownership of non-farm businesses and use of modern agricultural technologies; Hoddinott et al. (2012) on food security and assets buildings; Berhane et al. (2014) on household food security (measured in food gaps), asset protection, and asset building; Debela et al. (2015) on child nutrition; Berhane et al. (2017) on children's schooling, labor, and nutrition; Bahru et al. (2020) on household food security and child nutrition; and Tadesse and Zeleke (2022) on food security and asset accumulation.

Gilligan et al. (2009a) assessed the impacts of PSNP (after 18 months of its operation) and other complementary food security interventions[2] on a set of outcome areas including household food security, productive investments, use of modern farming techniques, participation in non-farm business activities, and asset accumulation. They found weak impacts of the PSNP alone in its first year partly due to delays and underpayment of transfers but found positive impacts on household food security, productive investments, use of modern agricultural technologies, and ownership of non-farm businesses for households which accessed both the PSNP and other complementary food security support packages. Gilligan et al. (2009b) evaluated the impact of the PSNP on food security and assets from 2006–2008 and further tested the differential impacts by estimating the average impacts to all households, to households which received high levels of transfers, and incremental impacts on households which received complementary transfers. They found modest average impacts of PSNP on food security and livestock holdings, but greater impacts

[1] Small-scale irrigation can be defined as an irrigation system practiced on small plots using a level of technology that a small-scale producer can effectively control, operate, and maintain.

[2] These included 'access to credit; assistance in obtaining livestock, small stock, or bees; tools; seeds; and assistance with irrigation or water-harvesting schemes, soil conservation, and improvements in pastureland.' Berhane et al. (2014, p.4)

on asset accumulation for higher level transfer recipients and households accessed both the PSNP and complementary interventions.

Hoddinott et al. (2012) assessed the relative impacts of PSNP transfers alone and the bundled PNSP and other food security/asset building interventions for the period 2006–2010 and obtained similar findings to that of Gilligan et al. (2009a). While PNSP plus access to other complementary food security and asset building packages resulted in considerable improvements in the use of agricultural inputs and improved agricultural productivity; the PSNP program alone had no effect on agricultural input use or productivity and limited impact on agricultural investments.

Using a three round longitudinal survey data collected in 2006, 2008, and 2010 and difference-in-difference and matching methods of evaluation, (Berhane et al., 2014) estimated the impacts of PSNP on a range of outcomes including food security, asset protection, and asset building. Their findings show that a household's food security and asset holdings increase as the number of years of PW participation increases, indicating that the intensity of participation in the program or bundling of SNP with other interventions matter on the magnitude of the estimated impacts. These results align with the evidence provided in Gilligan et al. (2009a) that show weak impacts of the PSNP alone in its first year but strong impacts if PSNP is bundled with other food security interventions

Using survey data from Northern Ethiopia and an exogenous switching regression mode, Debela et al. (2015) assessed the impacts of PSNP on nutritional outcomes (weight-for-height Z-scores) of children aged under 5 years. Their findings indicate that children in households participating in the PSNP had higher weight-for-height Z-scores than those of children in non-participating households. Contrary to Debela et al.'s finding, Berhane et al. (2017) did not find evidence on the effects of PSNP on reducing chronic or acute under nutrition. Berhane et al. highlighted the plausible explanation for their findings: most mothers in their study neither contacted health extension workers nor received information on good feeding practices. In a related study on the impacts PNSP on child nutrition, Bahru et al. (2020) used a Young Lives[3] cohort panel dataset from the four major regions in Ethiopia (Amhara, Oromia, Southern Nations Nationalities and People, and Tigray). As with Berhane et al. (2017), this study also found that participation in PSNP has not improved child dietary diversity and child anthropometry. These findings on child nutrition outcomes may imply the need for bundling of PSNP with other interventions such as heath extension services to observe improvement in child nutritional outcomes.

As indicated above, most past studies focus either on assessment of PSNP alone or jointly with other complementary food security programs or asset accumulation interventions. To the best of our knowledge, assessment of PW investments specifically targeting watershed rehabilitation and small-scale irrigation were not missing from this literature. Between 2017 and 2021, the Bureau for Humanitarian Assistance (BHA) of the United States Agency for International Development (USAID) invested in PW activities focused on watershed rehabilitation and, to a lesser extent, on small-scale irrigation (SSI) in the Amhara, Oromia, and Tigray regions. While USAID had been supporting PSNP in these areas prior to 2017, this paper is focused on understanding the effects of investments after 2017 on household food security,

[3] Young Lives is a collaborative research project coordinated from the Department of International Development at the University of Oxford.

nutrition, and resilience to shocks. While BHA PSNP activities directly support the environmental sustainability, climate resilience, food security, and nutrition goals of the government of Ethiopia and BHA, the extent (how much and how significantly) the PW components focused on watershed rehabilitation and small-scale irrigation support these goals is not known. The present study aims to fill this gap by focusing on BHA PW investments in watershed rehabilitation and SSI on household food security, nutrition, and the resilience capacities of vulnerable households.

The remainder of the paper is structured as follows. Section 2 provides the methodological details of the study including conceptual framework, data, study design, and empirical approaches to econometric models. Key insights from the qualitative research and descriptive quantitative results are presented in sections 3 and 4, respectively. Section 5 presents the key findings from the econometric estimations. The last section concludes with policy recommendations.

2. METHODOLOGY AND DATA

2.1 Conceptual framework

The conceptual framework underlying the pathways to impacts in this study draws on Feed the Future's Innovation Lab for Small-Scale Irrigation (ILSSI) research and the Phase 4 Ethiopia's PSNP and DFSA theories of change (Starr, 2019), which highlight the pathways and linkages between water-related investments under PSNP and key BHA target outcomes of food security, nutrition, and resilience to shocks (Fig. 1). The framework provides a guide for the quantitative and qualitative analysis of the study.

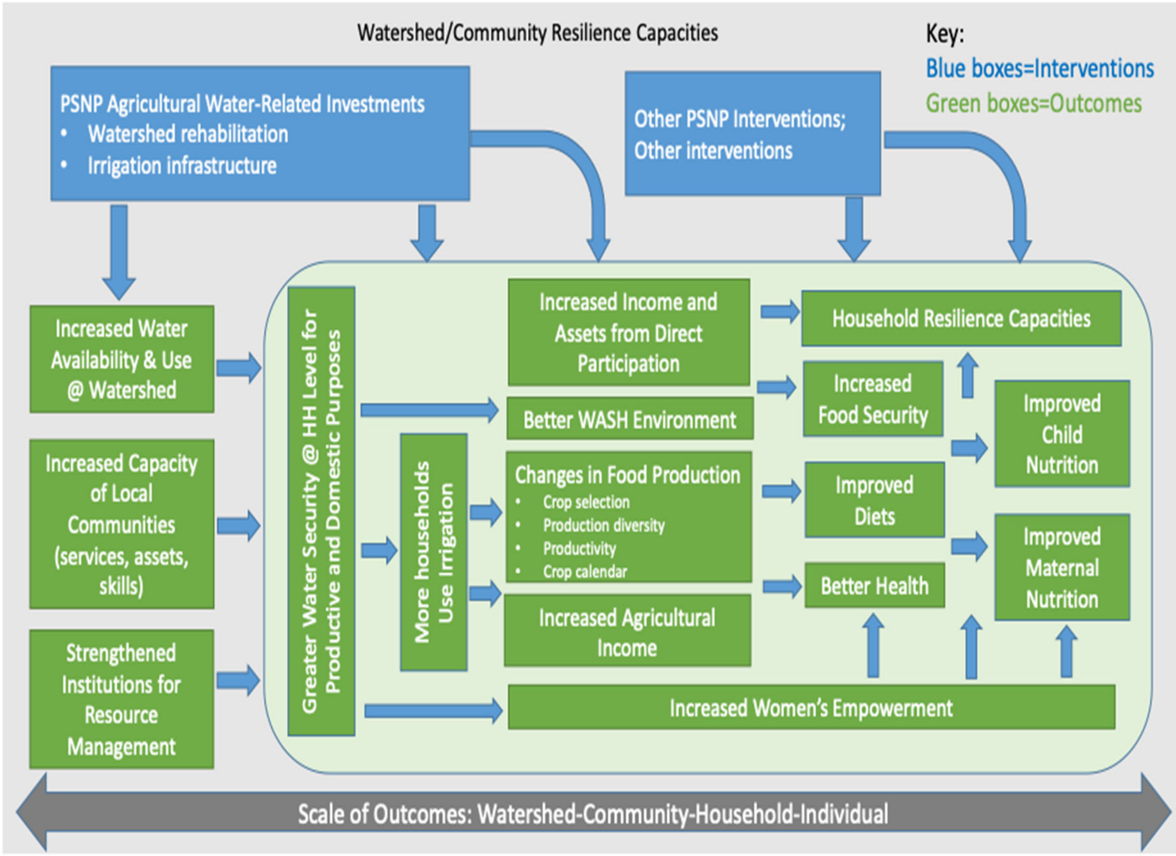

Figure 1. Conceptual framework

Source: Adapted from Starr (2019).

Note: PSNP = Productive Safety Net Program; HH = household; WASH = Water, Sanitation and Hygiene.

The conceptual diagram highlights that PSNP interventions focused on public works and watershed rehabilitation support specific watershed, community, household, and individual resilience capacities. These are mediated via improved water availability and use at the watershed level, increased capacity of local communities, and strengthened institutions for natural resource management. The resulting potential household- and individual-level impacts include greater water security at the household level for both productive and domestic purposes. Participation in PSNP PW and watershed rehabilitation can result in increased productive uses such as irrigation but can also lead to an improved water, sanitation, and hygiene (WASH) environment as well as increased income and assets. Women's empowerment can be improved through reductions in the amount of time they spend fetching water as well as potentially improved control over irrigation assets, enhanced decision-making power over irrigated land and increased participation in institutions associated with irrigation. Together with changes in food production from PW and watershed interventions, household resilience capacities and nutrition can be improved. We note that there are several other benefit streams from watershed rehabilitation and PW investments, such as increased or more sustainable access to resources from communal lands, such as fodder or firewood. These are not part of the scope of the study, which instead focused particularly on water-related benefit streams.

2.2 Selection of study sites/watersheds

Several watersheds were selected for in-depth analysis using a stratified random sampling framework that considered size of the intervention, geographic diversity, and implementer diversity. The specific set of criteria used to select study watersheds for primary data collection include: (1) availability of secondary data from household surveys; (2) size of the watershed (with a minimum size of 7,000 ha); (3) availability of a development map, which was needed to support biophysical analysis; (4) size of land under irrigation through BHA investments (40 ha or more); and (5) implementation of multiple and overlapping watershed interventions.. Site selection also attempted to consider the inclusion of at least two sites from each of the implementers and representation from states where BHA operated.

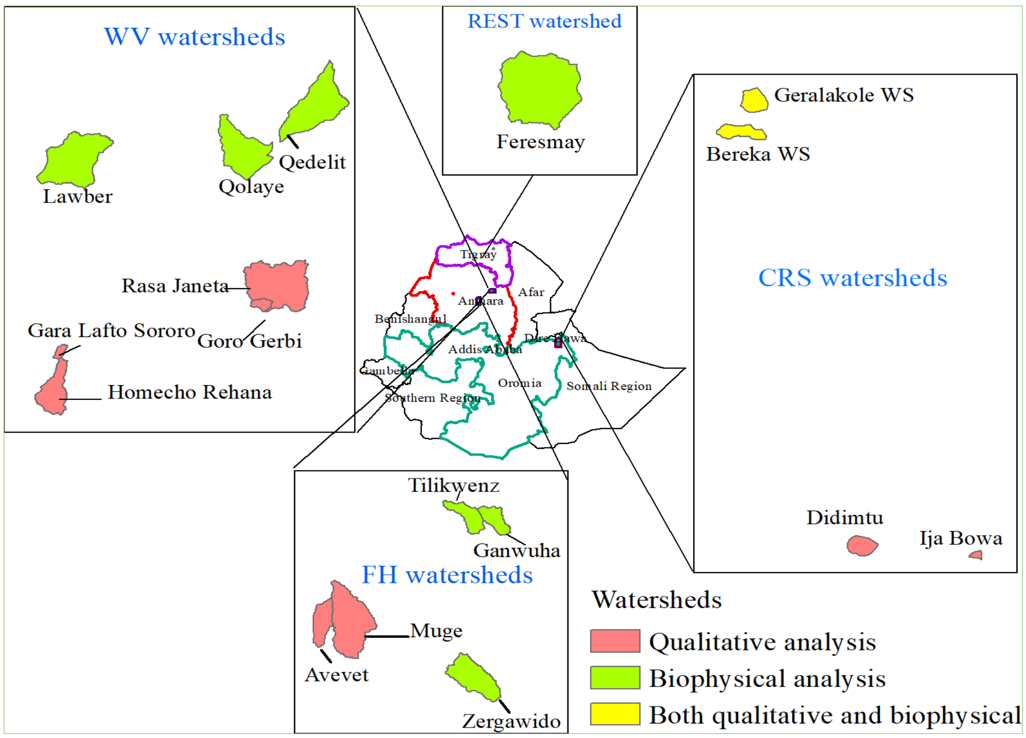

Figure 2. Map of selected watersheds for the study

The selection was based on the data and information provided by USAID BHA implementers, including Catholic Relief Services (CRS), Food for the Hungry (FH), World Vision (WV), and the Relief Society of Tigray (REST). Due to the breakout of armed civil conflict in November 2020 in the Tigray Region, these sites were not visited. Moreover, floods and other challenges led to additional deviations from the original random design. Primary qualitative data were collected in 10 of the selected study watersheds including Muge and Avevet (Amhara Region), Bereka and Garalakole (Dire Dawa), Ija Bowa, Didimtu, Goro Gerbi, Rasa Janeta, Homecho Rehana, and Lega Lafto Sororo (Oromia Region) (see also Figure 2).

All study sites have experienced severe land degradation including deforestation, soil erosion, and loss of soil fertility. PSNP-supported interventions have therefore focused on the rehabilitation of degraded lands through establishing area enclosures, and on implementing both physical and biological soil and water conservation measures. Moreover, communities at all sites depend on agriculture for their livelihoods and mostly implement mixed-crop livestock activities. Average farm sizes range from 0.5 ha in the highlands to 1 ha in the lowlands. Key crops include teff (*Eragrostis tef*), wheat, sorghum, and maize during the rainy season, and irrigated crops such as fruits and vegetables in the dry season.

2.3 Data collection

2.3.1 Qualitative data and methods

Key informant interviews (KIIs) and focus group discussions (FGDs) were used to better understand the knowledge, attitudes, priorities, preferences, and perceptions of target beneficiaries and other stakeholders. KIIs and FGDs were conducted using semi-structured interview guides and protocols that were approved by the International Food Policy Research Institute (IFPRI) ethics review board (see Annexes A1 and A2 for the FGDs and KIIs guides). Using the interview guides, we conducted national-level KIIs in June and July 2021 with 16 national stakeholders who were working on PSNP, including representatives from different government organizations, nongovernmental organizations (NGOs), private consultants, development partners, universities, and research institutes. KIIs at the local level were administered with program implementers, government staff, and facilitators. FDGs were used to collect local-level qualitative data from the PSNP beneficiaries. We implemented FGDs with beneficiaries of water-related investments, including those participating in PW/watershed activities, and those directly or indirectly benefiting from such structures.

KIIs and FGDs at local levels were conducted in August and September 2021 at 10 sites in the Amhara regional state, Dire Dawa City Administration, and Oromia regional state; these consisted of 10 group interviews with PSNP4 implementing partners and government partners, and 20 gender-disaggregated FGDs. Across the study sites, 32 key informants participated in 10 group interviews. Participants of FGDs were predominantly PSNP beneficiaries. Men and women participated in the FGDs, and each FGD comprised 8 to 10 participants (Table 1).

Table 1. Men and women participants of focus group discussions

Woreda	Women	Men	Total
Simada	25	22	47
Dire Dawa	19	20	39
Babile	17	18	35
Kurfa Chele	19	18	37
Gemechis	14	15	29
Total	94	93	187

2.3.2 Quantitative data

The quantitative part of the study makes use of three rounds of household-level panel data collected for the monitoring and evaluation of Phase 4 of PSNP conducted in 2016 (baseline), 2018, and 2021. Since the BHA interventions began in 2017, these data can show the dynamics and impacts of the program interventions over those years. The PSNP4 surveys covered rural households in six major regions of Ethiopia (Tigray, Amhara, Oromia, Somali, Afar, and Southern Nations, Nationalities, and Peoples Region) except for the PSNP4 endline (2021), which excluded the Tigray region due to the armed civil conflict.

Since the BHA interventions cover the Tigray, Amhara, and Oromia regions, our quantitative analysis uses data from these three regions.

Table 2 shows the matching of PSNP4 data and BHA *woredas*[4]. From the three regional states, a total of 66 *woredas* were covered by the PSNP4 survey; these included 21 BHA and 45 non-BHA *woredas*. Three *kebeles*[5] per *woreda* and 28 households per *kebele* were randomly selected from the PSNP4 data. We thus have information on 1,764 households from 63 BHA *kebeles* and 3,780 households from 135 non-BHA *kebeles* resulting in a total of 5,544 sample households used in the econometric analysis (Table 2).

Table 2. PSNP woredas and their match with BHA interventions

Region	Number of BHA *woredas*	Number of BHA *woredas* in PSNP data	Number of non-BHA *woredas* in PSNP data	Total *woredas* surveyed
Tigray	17	10	12	22
Amhara	20	4	18	22
Oromia	17	7	15	22
Total	54	21	45	66

The survey covered watershed rehabilitation activities that include soil and water conservation activities, water-harvesting practices (such as rainwater harvesting and small pond construction), and private irrigation practices. It also covered household characteristics, including food and non-food consumption expenditures, assets, access to basic services, food gaps, exposure to natural disasters such as droughts and flood shocks, and participation in PSNP, among others.

2.4 Empirical approach

Watershed rehabilitation activities provide short- and long-term benefits including reducing runoff and soil loss (Abera et al. 2020), improving soil fertility (Legesse, Bogale, Likisa 2018), increasing crop productivity (Gebrehaweria et al. 2016), and building resilience (Knippenberg and Hoddinott 2019). The quantitative analysis focuses on assessing the effects of PSNP/BHA-affiliated watershed rehabilitation and irrigation investments on food security, nutrition, and resilience building. The key evaluation assumptions and treatment assignments include (Fig. 3):

i. All PSNP *woredas* are comparable in terms of PSNP eligibility parameters.
ii. The sample of households from PSNP/BHA intervention *woredas* (n_1=1,764) and those from PSNP/Non-BHA *woredas* (n_2= 3,780) were randomly selected for the panel surveys.
iii. Evaluation samples (treatment and control):
    A. Treatment = BHA investments/interventions in PW on watershed rehabilitation and SSI
    B. Treated households = Sampled households in BHA *woredas*, received BHA intervention, and included in the PSNP survey, i.e., the dark, green-shaded area in Figure 3 (n_1=1,764).

[4] A '*woreda'* is an official government administrative unit in Ethiopia equivalent to the English word 'district'. It is the fourth level of administrative division in the country – Federal, States, Zonal, and *woreda*.
[5] A '*kebele'* is an official government administrative unit in Ethiopia equivalent to the English word 'county'. It is the fifth level of administrative division in the country – Federal, States, Zonal, *woreda*, and *kebele*.

C. Control households = Sampled households in PSNP *woredas*, that did not receive BHA interventions (n_2=3,780)

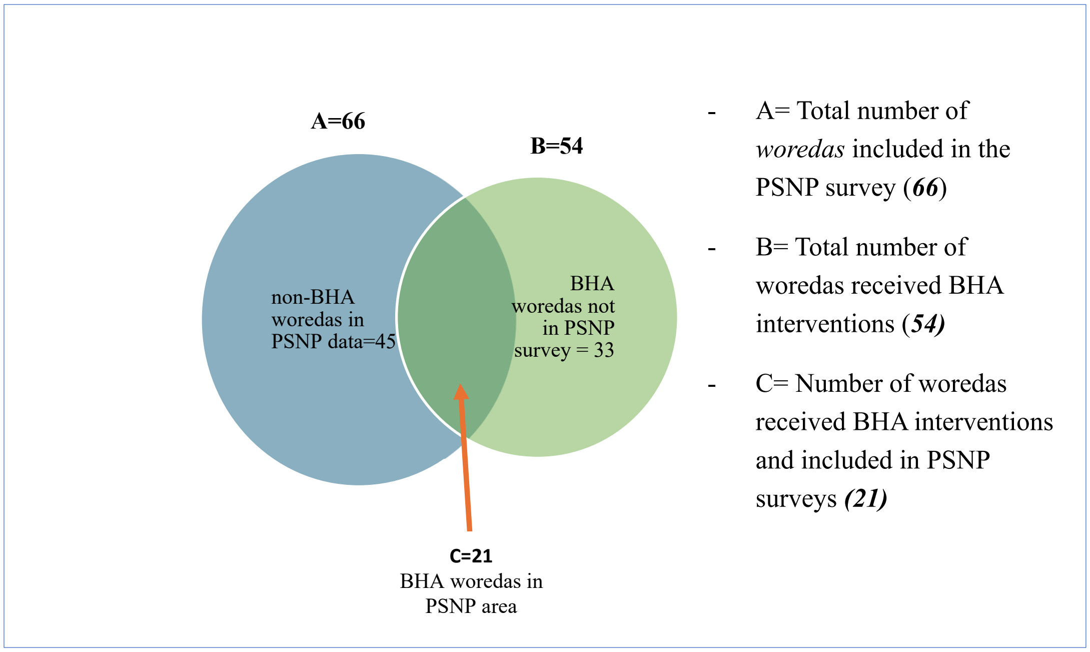

Figure 3. Quantitative evaluation design

In terms of the econometric models, first, we are interested in understanding how likely PSNP beneficiaries in BHA *woredas* are to participate in watershed rehabilitation and irrigation practices on own plots compared to their counterpart PSNP households in non-BHA *woredas*. Hence, adoption of soil and water conservation and irrigation practices on own plots are binary outcome variables that take 1 if the household participates in watershed rehabilitation and irrigation practices and 0 otherwise. BHA is our key variable of interest for controlling investments in rehabilitation and irrigation infrastructure. Other covariates such as household demographics and assets are included in the model to control the effects of these variables on the adoption decision of SWC and irrigation practices on own plots. A random effects probit model (equ. 1) represents a conditional probability of adoption and regression model (equ. 2) is used to fit the binary outcome of adoption of SWC and irrigation practices on own plot.

$$\Pr(y_{it} \neq 0 \mid X_{it},\ BHA_i, v_i) = \Phi(\beta X_{it} + \lambda\, BHA_{it} + v_i) \quad \text{----------------(1)}$$

$$y_{it} = \beta X_{it} + \lambda\, BHA_{it} + v_i + u_{it} \quad \text{---(2)}$$

y_{it} is the observed binary outcomes (0 or 1) indicating whether a household participates in SWC or irrigation practice, X_{it} is a set of control variable, BHA_{it} takes 1 if a household is in BHA *woreda* and 0 otherwise, λ and β are parameters to be estimated, v_i a time-invariant individual specific effect, u_{it} is an i.i.d. idiosyncratic standard normal error term with mean zero, Φ is the standard normal cumulative distribution function, and $\lambda, \beta,$ and σ_u^2 are jointly estimated using maximum likelihoods. Two versions of this model are considered for the panel data set using *xtpobit* command in Stata: random effects model and population-averaged probit model. The latter assumes equal correlation of the observations within the panel

(i^{th} individual) and estimated by adding the 'pa' option to the *xtpobit* command in Stata (Cameron and Trivedi, 2010).

Secondly, we are interested in assessing whether the soil and water conservation practices and irrigation are associated with food security as measured by the number of months (in the last 12 months) that households had trouble meeting their food need (the *food gap*) and with nutrition using the intermediate indicator of the household dietary diversity score (HDDS). A larger food gap indicates a greater degree of food insecurity, and a smaller food gap value suggests better food security conditions in the household. The food gap values range from 0 to 12, with zero indicating that households are fully food secure and 12 suggesting the worst food insecurity scenario, in which households reported difficulty meeting their food needs in all months. Since both the food security indictor (food gap) and the dietary diversity indicator (HDDS) are non-negative count dependent variables, we employ a random effects Poisson panel regression model (equ. 3) with the assumption of Poisson distribution.

$$\Pr(Y_{it} = y_{it} \mid X_{it},\ BHA_i) = F(y_{it},\ x_{it}\beta + \alpha\, BHA_{it} + v_i) \text{ ----------------(3)}$$

For $i = 1, \ldots, n$ panels, $t = 1, \ldots, n_i$, $F(.)$ is the cumulative distribution function, y_{it} is the observed discrete non-negative outcomes (values range from 0 to 12 for the food gap or HDDS score), x_{it} is a set of control variables; BHA_{it}, λ and β as defined in equation 2, and v_i a time-invariant individual specific effect assumed to be i.i.d. Equation 3 is estimated using the *xtpoisson* command in Stata.

Thirdly, we measure the resilience capacity of households using the FAO RIMA II approach. This approach defines resilience as a latent construct, the Resilience Capacity Index (RCI), with multiple predictors and multiple outcomes. The predictors of RCI are categorized into four pillars (see Annex Table A for the description and construction of these predictors). The resilience index constructed using multivariate analysis is the outcome variable with fractional values between zero and one, measuring the endurance capacity of the household. Generalized Estimating Equation (GEE) is the appropriate approach to model resilience capacity of households using the correlated RI as an outcome variable. GEE is an extended generalized linear model designed to model correlated measures of panel data (Liang and Zeger 1986; Agresti, 2002; Diggle et al., 2002). Thus, the model specification has a similar form with that of generalized linear model (equ. 4)

$$RI_{it} = \mu_i + \varepsilon_{it}, \qquad g(\mu_i) = \beta X_{it} + \psi\, BHA_{it} \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

where RI_{it} is resilience index of household i at time t, μ_i is the mean of the resilience index for the *ith* subject; BHA_{it} and X_{it} are as defined previously, β and ψ are parameters, and ε_{it} is the error term, while g stands for the probit link function that maps the RI to a linear function of covariates that leads to a computationally simple estimator in the presence of endogeneity (Papke and Wooldridge, 2008). Thus, we used the GEE model to estimate the resilience capacity of households in BHA and non-BHA *woredas* assuming a binomial distribution. Biophysical analyses that were also implemented are described elsewhere (Bayissa et al., 2023).

3. INSIGHTS FROM QUALITATIVE FINDINGS

In this section we present the key findings from the qualitive field works (KIIs and FGDs). KIIs were implemented at the national and at implementation area level and focused on quality of the activities and perceived benefit streams. The FGDs explored the livelihood strategies of PSNP beneficiary households (including livelihood assets, activities, and outcomes); changing dynamics in gender roles; and vulnerability to climate shocks and coping strategies households pursued to mitigate the impacts of shocks.

3.1. Quality of PW activities

One of the key areas the qualitative work focused on was understanding whether the program had met its target in terms of addressing the needs of vulnerable households such as food insecurity.

According to PSNP guidance, beneficiaries are identified through a participatory process whereby the poorest members of the community were selected by the *kebele* food security task force using criteria that included: (1) asset ownership (i.e., land and livestock), (2) crop productivity and income in the last three consecutive years, and (3) size of household. Key Informants from government and implementing partners noted possible inclusion and exclusion errors and emphasized the importance of correcting errors with retargeting processes. Participants of all FGDs stated that the targeting had been fair and had followed a transparent process. It was observed, however, that graduation from PSNP lacked clarity and only the Amhara sites reported graduation of beneficiaries; this was attributed to the frequent shocks and the time required to realize livelihood improvements at other sites. At the Amhara sites, concerns were raised over the transparency of livelihood assessments during graduation of PSNP beneficiaries; for instance, FGD participants indicated the existence of a bias among committee members in terms of overestimating the livelihood improvements of PSNP beneficiaries with whom they were not on good terms. A participant in one women's FGD in Avevet watershed stated:

> *"The graduation might be biased. For instance, if a PSNP beneficiary had disagreements with the committee, they will report that he/she has livelihood improvements and to give the chance to another poor person. This might happen regardless of the actual improvements in livelihoods*."

At a men's FGD in the same watershed, it was pointed out that:

> *"The decision-making process in identifying the graduates does not include the beneficiaries themselves. The office of agriculture and local administration made the decision. There is bias as they decide without knowing details of our livelihood improvements. People who have someone from the leadership would stay in the program, while others graduate. The enrolment is done in a public assembly and there is no bias. The problem is at the stage of graduating from the PSNP program."*

In terms of targeting women, the PSNP4 gender provisions were implemented; these included issuing direct transfers to women from the time they know they are pregnant until one year after giving birth. Women also benefited from flexible working hours, being allowed to come late, and leave early for PW. Women's burden was also reduced by assigning them less-demanding PW activities. Participants in FGDs and group interviews expressed their appreciation of the gender-responsiveness of PSNP4, emphasizing how the provisions helped women save time and energy. Assigning women to *kebele* watershed committees and task forces was also considered to be an important step toward women's empowerment by participants.

Participants of all 20 FGDs at the Amhara, Dire Dawa, and Oromia sites raised concerns over the inadequacy of compensation in PSNP4. They also noted that a maximum of five household members could be PSNP beneficiaries, but most families had more members.

Regarding the time spent, participants at the Dire Dawa and Oromia sites tended to consider participation in PSNP public works as employment and noted fewer time concerns. Participants in men's FGDs in the Amhara region, however, underlined the imbalance between the duration of PW activities and the amount of compensation. They also pointed out that the time spent on PW affected their engagement in more profitable income-generating activities. This difference could be attributed to the fact that PSNP beneficiaries at other sites contributed labor for 6 months, which was much lower than at the Amhara sites where public works were conducted for 10 to 12 months in a year. This suggests the need for a review of the length of time commitment of PW activities with more participation options that reflect the opportunity cost of different groups of participants.

Through FGDs and KIIs, the qualitative studies have further explored the views of stakeholders (beneficiaries, program implementers, and national experts) on potential factors that affect the sustainability and achievement of PSNP/BHA program goals. The key factors that make-or-break sustainability identified by these experts include appropriate site selection, appropriate design and interventions, quality assurance, strong institutions, and equity. The participants noted that for water-related PW investments to be sustainable and effective, the selected sites need to have large biophysical potential for rehabilitation and irrigation investments, which is not always the case. Participants also noted lack of sustainability associated with poor intervention design. For irrigation, water storage was sometimes inappropriately sized and earthen irrigation canals have led to wastage of water and irrigation serving only a few households in some sites. Implementation of PW activities on private lands

> *"Rehabilitation practices do not take into consideration climate, topography, and agroecology. As a result, most of the rehabilitation works do not function more than two years" (Key informant No 11).*

> *"Institutional capacity is far lower than the required level, particularly at a lower level. Context-specific training on how to select interventions, for what type of agroecology, soil, which species for which place and so on should be provided for local implementors. The role of top officials is mostly limited to administration, fundraising and decision making. Capacity gaps are huge at the grassroots level" (Key informant No. 2).*

> *"Most of the time, rehabilitation and irrigation do not exist in the same area. Conceptually, rehabilitation and irrigation are complementary to each other, but it is not true in practice. The order of implementation is not arranged in such a manner both spatially and institutionally" (Key informant No. 13).*

The avoidance of machinery to maximize the labor contribution has also, in some cases, contributed to poor sustainability because of poor construction quality or inappropriate sizing of infrastructure. Moreover, while there are clear procedures during construction, a lack of infrastructure maintenance affects its lifespan. Strong and enforceable local institutions or bylaws that guide the management and utilization of watershed resources have been identified as an important criterion for sustainability. Similarly, institutions that support benefit sharing and effective conflict resolution among common pool resource users were listed as an important sustainability criterion, such as effective and functional water users' associations (WUAs).

> *"The program has international pressure on irrigation investments. It is not allowed to build more than 10m height micro-dam size due to hydro politics. One can't transform the livelihood of the poor without promoting irrigation practice" (Key informant No. 16)*[6]
>
> *"Irrigation works are done using locally available materials by food-insecure farmers with a limited capital budget and resulting in lower technical quality, compared with other activities" (Key Informant No. 12)*
>
> *"Resource user group such as water user associations need to be established and get legal recognition as an institution to ensure sustainable functionality of built schemes. The introduction of a water use fee especially is important for irrigation schemes maintenance" (Key Informant No. 2).*
>
> *"There is a WUA for governing the irrigation scheme. The association is established to ensure sustainable management of the scheme as we cannot always have a project to support us. This could help us do maintenance where needed and sustain the irrigation investment. We established byelaws for ensuring fair water allocation, participation in maintenance works, and equitable benefit sharing. We have not received any training on maintenance of public work infrastructures." (mixed FGD, Lega Lafto Sororo watershed)*

3.2. Benefits streams from PW activities

The qualitative study also assessed the views of beneficiaries on the benefit streams from the PW activities. Benefits included increased water availability for irrigation, better access to drinking water, improved nutrition, and in some cases, increased women's agency.

In 6 out of the 10 study sites, increased water availability has led to investment in irrigation infrastructure. The majority of the communities did not have experience in irrigation practices prior to the PSNP IV. Investments in SSI included construction of river diversion schemes, lined canals, earthen canals, and water harvesting ponds (e.g., night storage pond, rainwater harvesting). Participants of most of the FGDs (nine out of 10) rated the quality of watershed management and irrigation infrastructures good. The irrigation investments benefited PSNP beneficiaries directly in Oromia sites, but mostly non-PSNP farmers in Muge and Avevet watersheds, because PSNP beneficiaries were landless farmers. They could still engage in irrigation by renting land, engaging in labor sharing arrangements, and by working as casual workers. However, the high cost of land rentals in irrigated areas might exclude PSNP beneficiaries from reaping the benefits of irrigation for improving their livelihoods.

Participants in all the FGDs at the Amhara, Dire Dawa, and Oromia sites confirmed that the work done in rehabilitating the watersheds had increased water discharge. They benefited from improved access to water

[6] In PSNP-5, the height can increase to 15 meters if the government covers a larger portion of the budget.

for drinking, domestic use, and agricultural purposes. Moreover, in 6 out of the 10 study sites, increased water availability has led to investment in irrigation infrastructure.

Participants of FGDs reported increased water availability and changing gender roles regarding the fetching of water. For instance, one FGD participant in the Avevet watershed in Amhara Region expressed that:

> *“The water availability in our community is highly linked with the watershed development work. We have access to water for drinking and domestic purposes without interruption. In the past, we used to use pond water and harvest rainwater for domestic use. We faced problems as cattle and children fetching water for domestic use competed for water sometimes leading to accidents. Now, we have tap water in our area in the rainy season and dry season. The water is treated once or twice a year with chlorine. Both men and women fetch water implying the changing role of women. It used to be a women’s responsibility.”*

There was a consensus among participants of group interviews and FGDs in Amhara, Dire Dawa, and Oromia sites on the positive effect of the watershed development works on building resilience through the restoration of forests and increased soil fertility, increased crop productivity, and enhanced access to livestock feed in the exclosures, among others.

> *"Stone bunds are built on degraded areas, to reduce soil erosion. Soil bunds are made on dry areas, and the soil is used to plant fodder trees. We have seen the impact on rehabilitating degraded land, improved nutrition, and increased agricultural production. We learned that the fodder trees are drought tolerant. We know the benefits, but we can't say we have seen the impacts fully." (men FGD, Muge watershed)*

> *"When shocks happen, we used to sell assets like cattle. The watershed development reduces the floods, and we do not have a shortage of feed. We also diversified our food habits. So, our resilience has improved in every aspect." (women FGD, Avevet watershed)*

Participants of FGD and group interviews in Amhara sites also underlined that the benefits in food security, nutrition, and resilience were more pronounced among farmers with irrigable plots compared to the PSNP beneficiaries who are often landless.

> *"The main beneficiaries are those with irrigable land. The better-off farmers benefit from feeding their family vegetables. The poor farmers benefit from the income from the sale of vegetables for improving their food security. The landless may not benefit much except for the indirect benefits from the low price of vegetables in the market. […] the irrigation development has helped us access nutritious food at low prices, and our diets have improved as a result." (women FGD, Muge watershed)*

> *"Our engagement in irrigation is an outcome of the hard work we have done in watershed development. Public work investments support our resilience through production of diverse crops, vegetables, and fruits; and diversified income sources through income generating activities such as in small trades and participating in credit and saving associations. So, this could improve our resilience capacity from drought and shocks. We also have good grass harvest for feeding our livestock. We can buy grass and feed their livestock during the dry season. This helps our engagement in animal fattening and milk production." (men FGD, Rasa Janeta watershed)*

4. DESCRIPTIVE RESULTS

Table 3 presents descriptive statistics of key variables considered in the econometric analysis. These include mean and standard deviations of the variables for the pooled sample, households in BHA and non-BHA *woredas*. The table also presents the mean differences of the variables for the two samples to compare (using a two-sample means t-test) households participating in PSNP programs in BHA and non-BHA *woredas*. Comparing the two groups of households in terms of the key outcomes, we found that BHA interventions increased participation of households in PSNP program, improved household resilience capacity and increased participation in irrigated farming. The difference means in all three outcome variables between the two groups are statistically significant at the 1-percent level. In terms of dietary diversity (HDDS) and daily per capita calorie intake, we do not find statistically significant differences between BHA and non-BHA households.

Compared with households in non-BHA *woredas*, BHA households are characterized by cultivating larger farm areas and applying more agricultural inputs (inorganic fertilizer and improved seeds) with differences statistically significant at 1-percent level. Comparing the gender composition of household heads, more households are headed by women in BHA *woredas* than in non-BHA *woredas* (significant at the 5-percent level). Similarly, the average household size in BHA *woredas* is statistically larger than their counterparts in non-BHA households (at the 1-percent level). This may indicate a better targeting approach of the BHA interventions in terms of gender and households with larger size that are often food insecure but with better diets when headed by women.

In terms of poverty status (measured either using the national poverty line or self-perceived poverty), statistically, there are no statistically significant differences between households in the two groups. In the pooled sample, about 69 percent of the households are below the national poverty line, indicating a high proportion of poor households. The incidence of poverty is slightly lower for households in BHA *woredas* (68.3 percent) compared with households in non-BHA *woredas* (69.4 percent)

While households in the non-BHA *woredas* have shown a better financial inclusion (having accounts in formal banks) compared to BHA households (though at the extensive margin of 10-percent level), non-BHA households demonstrate a well-established informal financial access (membership of '*equb*') compared to the non-BHA household, at 1-percent level significance. In terms of access to extension services and road infrastructure, we do not find significant differences between the two sample groups.

Furthermore, as the survey data shows, almost 50 percent of the households in both the BHA and non-BHA *woredas* reported to be affected by recurrent drought. Drought is the most frequently reported shock experienced by farm households. Similarly, the incidence of flood and erosion has affected both BHA and non-BHA households.

Table 3. Descriptive statistics of key characteristics of the study sample (pooled, BHA, and non-BHA households)

	Pooled sample	BHA *Woreda* sample		Non-BHA *Woreda* sample		t-test (nonBHA – BHA) (Two-sample mean diff.)	
Outcome variables	Mean	Mean	Std. dev	Mean	Std. dev.	Diff.	p-values
PSNP beneficiary *(yes=1)*	0.465	0.523	0.500	0.440	0.496	**-0.083*** **	0.000
Months HH food shortage *(#)*	1.981	1.753	2.178	2.078	2.468	**0.325*** **	0.000
HDDS (#)	4.259	4.236	1.841	4.269	1.849	0.033	0.328
Resilience capacity index (RCI)	0.421	.423	0.059	0.420	0.055	**-0.003*** **	0.007
Daily per capita calorie intake *(k. ca)*.	2498.12	2528.86	2239.561	2484.99	2257.89	-43.87	0.0292
SWC on own land *(yes=1)*	0.031	.032	0.176	0.031	0.173	-0.001	0.0755
Irrigated own plot *(yes=1)*	0.070	.095	0.293	0.059	0.235	**-0.036*** **	0.000
Control (independent variables							
HH head age *(years)*	47.424	47.045	15.286	47.59	15.92	0.541*	0.060
HH head sex *(female=1)*	0.273	0.287	0.452	0.268	0.443	-0.019**	0.019
Size of household (#)	4.791	4.876	2.212	4.755	2.191	-0.121***	0.003
No. working HH members *(#)*	2.249	2.213	1.195	2.264	1.217	0.051**	0.024
HH head marital *(married=1)*	0.751	0.761	0.426	0.747	0.435	-0.014*	0.078
HH head literate *(yes=1)*	0.339	0.327	0.469	0.343	0.475	0.016*	0.068
Poor HH (national poverty line)	0.69	0.683	0.466	0.694	0.461	0.011	0.190
HH perceived poor (absolute)	0.721	0.722	0.448	0.720	0.449	-0.002	0.813
HH perceived poor (relative)	0.642	0.638	0.481	0.643	0.479	0.005	0.551
HH involved in non-farm *(yes=1)*	0.125	0.124	0.330	0.126	0.332	0.002	0.840
HH received transfer *(yes=1)*	0.065	0.064	0.245	0.065	0.246	0.001	0.904
Member of '*iddir' (yes=)*	0.542	0.505	0.500	0.558	0.497	0.053***	0.000
Member of '*equb' (yes=1)*	0.040	0.055	0.229	0.034	0.181	-0.021***	0.000
HH owns bank account *(yes=1)*	0.095	0.088	0.283	0.098	0.297	0.009*	0.069
Own telephone *(yes=1)*	0.338	0.321	0.467	0.345	0.475	0.024***	0.007
HH owns radio or TV *(yes=1)*	0.171	0.163	0.369	0.175	0.380	0.012*	0.076
Comm. has periodic market *(yes=1)*	0.288	0.301	0.459	0.283	0.450	-0.018**	0.029
Received extension visit *(yes=1)*	0.166	0.158	0.365	0.170	0.375	0.011	0.103
HH access all weather road *(yes=1)*	0.398	0.395	0.489	0.400	0.490	0.005	0.635
Land area cropped *(ha)*	0.609	0.708	0.455	0.566	0.496	-0.142***	0.004
HH uses improved seeds (yes=1	0.681	0.719	0.871	0.665	0.759	-0.054***	0.000
HH uses inorganic fertilizer *(yes=1*	0.173	0.193	0.395	0.164	0.371	-0.028***	0.000
HH affected by drought *(yes=1)*	0.550	0.507	0.500	0.570	0.495	0.063***	0.000
HH affected by rain/flood *(yes=1)*	0.451	0.504	0.500	0.429	0.495	-0.075***	0.000
Crop damaged by pest *(yes=1)*	0.101	0.105	0.307	0.099	0.298	-0.006	0.244
Amhara Region *(=1)*	0.381	0.232	0.422	0.444	0.497	0.212***	0.000
Oromia Region (=1)	0.367	0.389	0.488	0.357	0.479	-0.032***	0.000

Source: Authors' computations for the survey data. **Note:** HH= Household. SWC= soil and water conservation.

5. ECONOMETRIC RESULTS

We report three sets of results (Tables 4, 5, and 6) obtained from a series of econometric models outlined in section 2.4. The key variable of interest in all the econometric models is the BHA interventions/investments in watershed rehabilitation and small-scale irrigation as part of Ethiopia's PSNP-4 program. Table 4 reports results from the random effects probit regression model that examines the effects of BHA interventions on adoption of SWC and irrigation practices on private or own land plots. Table 5 reports regression results from the random effects Poisson model on the effects of BHA interventions on indicators of household food security and dietary diversity. Finally, Table 6 reports the results on the association between BHA interventions and household resilience capacity.

5.1 Effects on watershed rehabilitation and irrigation adoption

The results in Table 4 suggest a positive and significant association between BHA *woredas* and PSNP participation and irrigation practices. Compared to non-BHA *woredas*, households in BHA *woredas* were more likely to participate in irrigation activities, and this is statistically significant at the 1-percent level. We also found that the rate of participation of households in PSNP is higher in BHA interventions areas than in the non-BHA *woredas*. Households in BHA *woredas* are about 17 percent more likely to participate in PSNP compared to households in non-BHA areas. Examining the gender differential of participation in the PSNP program, we find that women-headed households are 15.4 percent more likely to participate in the PSNP program than male-headed households. Commonly, women are more vulnerable to shocks as they have more limited access to resources. In terms of the association between PSNP program participation and poverty, sample households below the national poverty line are more likely to participate in the program compared to those above the national poverty level (at the 1-percent significance level). Furthermore, households headed by older individuals are more likely to participate in PSNP as part of its direct support program and are thus less likely to engage in SWC and water-harvesting practices in public areas. These practices require fairly heavy physical work and, therefore, are not suitable for elderly household heads (consistent with the argument by Teklewold and Köhlin (2011)). These results indicate achievement of the pro-poor and pro-women targeting of the PSNP and corroborates descriptive results (Table 3).

Moreover, older household heads are more likely to practice irrigation on their farmland, compared to younger household heads, maybe because of their experience in farming and the changing climate over years. Hired labor is not commonly used, and thus family members are the most important source of labor for own farm management and natural resource conservation practices. Our estimation revealed a positive and significant association between family size and irrigation practices on own land.

Land size is negatively associated with PSNP participation. This means the program primarily targets landless households and those with small farm sizes. Related to this, experiences of drought shock correlate positively with PSNP, PW SWC, and negatively with irrigation practices. The latter may indicate water shortages as the binding constraint for irrigation activities during severe drought shocks which may necessitate investments in agriculture water management such as on water storage facilities (see also Mekonnen et al., 2024). Access to extension services is highly correlated with public watershed rehabilitation indicators (SWC) but not with irrigation adoption.

Table 4. Results from random effects probit (effects of BHA investments on PNSP participation, SWC and SSI adoption on own plots)

	Dependent variables: participation in PSNP, SWC on own plot and SSI on own plot								
	PNSP participation (n=12738)			SWC own land (n=12,738)			Irrigated own plots (n=11,140)		
Independent variables	Coeff. (PSNP)	Std. err.	Marginal effects (dy/dx)	Coef. (SWC)	Std. err.	Marginal effects (dy/dx)	Coeff. (Irrigation)	Std. err.	Marginal effects (dy/dx)
HH in BHA_*woreda (yes=1)*	**0.173****	**0.087**	**0.027****	0.030	0.057	0.002	**0.188*****	**0.072**	**0.016*****
HH head age *(years)*	0.009***	0.002	0.001***	-0.006**	0.002	-0.001**	0.008***	0.002	0.001***
HH head sex *(female=1)*	0.998***	0.082	0.154****	0.044	0.065	0.003	-0.075	0.084	-0.006
Size of household (#)	0.057***	0.018	0.009***	0.016	0.017	0.001	0.033*	0.020	0.003*
No. working HH member *(#)*	-0.048*	0.027	-0.007*	0.019	0.027	0.001	0.056*	0.031	0.005*
HH head literate *(yes=1)*	-0.043	0.061	-0.007	0.047	0.059	0.003	0.142**	0.068	0.012**
Poor HH (national poverty line)	0.131***	0.049	0.020***	0.069	0.057	0.004	-0.231***	0.061	-0.019***
Member of '*iddir' (yes=)*	0.003	0.054	0.000	0.168***	0.061	0.011**	0.125*	0.068	0.011*
Member of '*equb' (yes=1)*	0.122	0.121	0.019	0.073	0.128	0.005	0.106	0.141	0.009
HH owns bank account *(yes=1)*	0.048	0.079	0.007	-0.090	0.085	-0.006	0.177*	0.090	0.015**
Owns telephone *(yes=1)*	-0.126**	0.055	-0.019**	-0.119**	0.059	-0.008*	0.262***	0.063	0.022***
HH owns radio or TV *(yes=1)*	-0.189***	0.064	-0.029***	0.089	0.069	0.006	0.092	0.071	0.008
Comm. has periodic market *(yes=1)*	0.057	0.055	0.009	0.011	0.055	0.001	-0.406***	0.073	-0.034***
Received extension visit *(yes=1)*	0.191***	0.058	0.029***	0.248***	0.061	0.016***	0.045	0.071	0.004
Land area cropped *(ha)*	-0.129***	0.033	-0.020***	-0.078**	0.036	-0.005**	-0.056	0.039	-0.005
HH affected by drought *(yes=1)*	0.080*	0.042	0.124*	0.117**	0.052	0.007**	-0.155***	0.055	-0.013***
HH affected by rain/flood *(yes=1)*	-0.052	0.069	-0.009	-0.038	0.078	-0.002	-0.024	0.087	-0.002
Amhara Region *(=1)*	-0.055	0.103	-0.009	0.027	0.085	0.002	-0.446***	0.098	-0.038***
Oromia Region *(=1)*	-0.312***	0.106	-0.048**	-0.230***	0.088	-0.014**	0.187**	0.092	0.016
Constant	-0.796***	0.167	-	-6.673	0.488	-	-2.826***	0.197	-
/lnsigma2	1.543			-2.151			0.321		
Sigma_u	2.274			0.341			1.174		
Rho	0.838			0.104			0.679		
Prob. Chi2	0.000			0.000			0.000		

Source: Results from the econometric models. **** $p<0.01$, ** $p<0.05$, * $p<0.1$*
PSNP status regression: LR test of rho=0: chibar2(01) = 3472.58 Prob >= chibar2 = 0.000
SWC own land regression: LR test of rho=0: chibar2(01) = 2.13 Prob >= chibar2 = 0.072
Irrigated own plot regression: LR test of rho=0: chibar2(01) = 372.43 Prob >= chibar2 = 0.000

5.2 Effects on food security and nutrition outcomes

This section presents findings from the econometric models (Table 5) on food security and dietary diversity of the watershed/irrigation related interventions.

Table 5. Effects of BHA watershed/irrigation investments on food security and nutrition indicators

	Food insecurity indicator: No. of months HH experienced food shortage (food gap)				Dietary diversity indictor (HDDS)			
	Randon effects ML regression[2, a]		Random effects Poisson model[3, b]		Randon effects ML regression [c]		Random effects Poisson model [d]	
BHA variables[1]	Coef.	Std. err	Coef.	Std. err.	Coef.	Std. err	Coef.	Std. err.
BHA *woreda (yes=1)*	-0.312***	0.047	-0.177***	0.028	-0.039	0.038	-0.013	0.010
SWC on own land *(yes=1)*	0.365***	0.114	0.152***	0.042	0.284***	0.091	0.055**	0.025
Irrigated own plot *(yes=1)*	-0.168**	0.081	-0.062*	0.037	0.314***	0.065	0.076***	0.017
Covariates (other controls)								
HH head age *(years)*	-0.290***	0.067	-0.121***	0.034	-0.024	0.054	-0.009	0.014
HH head sex *(female=1)*	0.250***	0.054	0.089***	0.028	0.187***	0.044	0.042***	0.011
Size of household (#)	0.081**	0.011	0.032***	0.005	0.043***	0.009	0.010***	0.002
HH received transfer *(yes=1)*	0.198**	0.084	0.105***	0.034	0.442***	0.068	0.100***	0.018
HH involved in non-farm *(yes=1)*	0.224***	0.064	0.101***	0.026	0.326***	0.052	0.077***	0.014
Member of '*iddir*' *(yes=)*	.085**	0.042	0.038**	0.019	0.347***	0.034	0.085***	0.009
Member of '*equb*' *(yes=1)*	-0.328***	0.107	-0.133***	0.049	0.428***	0.087	0.094***	0.022
HH owns bank account *(yes=1)*	-0.470***	0.071	-0.230***	0.033	0.603***	0.057	0.131***	0.015
Received extension visit *(yes=1)*	-0.012	0.053	0.019	0.022	0.233***	0.042	0.052***	0.011
HH access to all weather road *(yes=1)*	-0.373***	0.042	-0.207***	0.019	0.146***	0.034	0.037***	0.009
Land area cropped *(ha)*	-0.284***	0.026	-0.172***	0.014	0.034	0.021	0.008	0.006
HH uses inorganic fertilizer *(yes=1*	-.0557***	0.044	-0.193***	0.020	0.428***	0.035	0.103***	0.010
HH uses improved seeds (yes=1	0.032	0.055	0.021	0.024	0.132***	0.045	0.029**	0.012
Cons.	3.28***	0.262	1.234***	0.134	3.384***	0.212	1.252***	0.056

Source: Results from the econometric models.

Notes: HH= Household, HDDS= Household dietary diversity scores.

[1] The three BHA interventions/variables were measured in a binary scale (0/1): *BHA_Woreda*= survey households are in the BHA intervention areas *(0/1); SWC_own_land* = Household practiced SWC activities in his/her own/private land (*01/); plot_irrigated:* Household adopted/implemented irrigated production in his/her own/private plot (*01/).*

[2] *Randon effects ML estimator*: A linear panel random effects specification and estimated using a maximum likelihood estimator *(xtreg…mle)* in Stata.

[3] *Randon effects Poisson model Estimator*: A count data random effects model (*xtpoisson*) and estimated using random effects Poisson estimator (*xtpoisson…, re)* in Stata.

[a] LR test of sigma_u=0: chibar2(01) = 113.21; Prob >= chibar2 = 0.000; [c]LR test of sigma_u=0: chibar2(01) = 108.86; Prob >= chibar2 = 0.000

[a, c] An LR test of sigma_u=0: chibar2(01) = 30.16; Prob >= chibar2 = 0.000. An LR test of sigma tests the significance of panel-level variance. When sigma u is zero, this variance component is not important, and the panel estimator is no different from the pooled estimator. Based on this test sigma is significantly greater than zero, so a panel estimator is preferred.

[b, d] Likelihood-ratio test of alpha compares the panel estimator with the pooled (Poisson) estimator. The test shows that for the food gap model, the random-effects model is significantly different from the pooled model; but for the HDDS model the random-effects model and the pooled model are not different. [b]LR test of alpha=0: chibar2(01) = 4280.63; Prob >= chibar2 = 0.000; [d]LR test of alpha=0: chibar2(01) = 1.1e-03; Prob >= chibar2 = 0.487

The results in Table 5 show the effects of BHA investments in watershed rehabilitation and irrigation practices on the food security and dietary diversity status of surveyed households. Food (in)security was measured using a self-reported *food gap* (i.e., the number of months that households had trouble meeting their food needs over a 12-month period prior to the survey) and nutritional status was measured using the HDDS score. The food gap values range from 0 to 12, with zero indicating that households are fully food secure and 12 referring to the worst food insecurity scenario, in which households reported difficulty meeting their food needs in all months. Thus, negative coefficients of the BHA intervention variables signify a greater degree of food insecurity, and their positive coefficients are associated with a better food security condition in the household. On the other hand, the coefficients of watershed rehabilitation and irrigation indicator variables are directly associated with the HDDS scores. We employ a random effects panel Poisson regression model with the assumption of Poisson distribution to analyze these associations between BHA intervention variables, food security and nutrition, and other controls covariates.

Households in BHA *woredas* are found to have a smaller food gap, which implies better food security status. The association between participating in SWC practices and food security is statistically significant and negative (at the 1-percent level). Similarly, households that participated in irrigation practices on their own plots are found to have higher food security status than those without irrigation. This is attributed to the fact that water harvesting practices and irrigation can benefit households directly by boosting their agricultural production and incomes. Other key covariates with positive effects on household food security include membership in '*equb*' (an informal community-based saving and credit association), access to the formal financial system (bank account), access to road infrastructure, use of yield enhancing agricultural inputs (inorganic fertilizer), and size of farm area cultivated. These results are as per *a priori* expectations and are self-explanatory. On the other hand, women-headed households are associated with a high degree of food insecurity (positive and statistically significant coefficient at the 1-percent level). Similarly, a larger family size significantly and positively affects food insecurity. Gender-differentiated interventions and family planning may improve food security conditions in the long run.

Regarding the effect of the BHA program on nutritional outcomes, we found a positive association between the HDDS and watershed rehabilitation indicators of the PSNP program on own plots while controlling for key cofounding factors. However, looking at BHA households overall (not conditioned by SWC and irrigation practices on own plots), we find no statistically different results between BHA and non-BHA households. We differentiated between SWC conservation activities on communal land (i.e., SWC public works) and those practiced on a farmer's private land. While the association between participating in PW SWC and HDDS is statistically insignificant, practices on private land positively impacted household dietary diversity. This suggests that the BHA interventions on SWC activities in communal lands had no or little impact on the nutritional outcomes of the households during the study periods. This might well be due to the time it takes for communal exclosures to increase animal feed availability. Moreover, SWC and other activities on communal lands as part of watershed rehabilitation contributes to the development of irrigation activities on private land.

Irrigation on one's own plot appears to have a statistically significant relationship with household nutritional status. Moreover, financial access (informal, formal, remittances, or non-farm income); social capital ('*iddir*'); extension services; and use of modern agricultural inputs play important and positive roles for household nutritional outcomes. These associations may appear to be intuitive at first, but the empirical results confirm the critical role of financial inclusion, modern agricultural technologies, and access to extension services on improving the nutritional outcomes in small-holder farm households in low-income countries. This is consistent with other recent studies that show the positive relationship between financial access and use of agricultural inputs, productivity, and incomes (Aggarwal et al., 2020; Batista and Vicente, 2020).

5.3 Effects on household resilience

Enhancing the resilience capacities of households via PSNP PW investments is one of the main PSNP targets for long-term welfare improvement as these investments, particularly watershed rehabilitation and irrigation, primarily target community asset creation and resilience building.

Table 6. Effects of BHA watershed and SSI investments on household resilience capacities

	Population-averaged model (GEE)[1]		Linear panel model (MLE) [2]	
BHA variables	Coef.	Std. err	Coef.	Std. err.
BHA *woreda (yes=1)*	0.004***	0.001	0.004***	0.001
SWC on own land *(yes=1)*	0.009***	0.003	0.009***	0.003
Irrigated own plot *(yes=1)*	0.007***	0.002	0.007***	0.002
Other covariates (controls)				
HH head age *(years)*	0.010***	0.002	0.010***	0.002
HH head sex *(female=1)*	0.005***	0.001	0.005***	0.001
Size of household (#)	-0.001***	0.000	-0.008***	0.000
HH received transfer *(yes=1)*	0.008***	0.002	0.008***	0.002
HH involved in non-farm *(yes=1)*	0.001	0.001	0.001	0.001
Member of '*iddir*' *(yes=)*	0.002*	0.001	0.002*	0.001
Member of '*equb*' *(yes=1)*	0.009***	0.002	0.009***	0.002
HH owns bank account *(yes=1)*	0.011***	0.002	0.011***	0.002
Received extension visit *(yes=1)*	0.007***	0.001	0.007***	0.001
HH access to all weather road *(yes=1)*	0.005***	0.001	0.005***	0.001
Land area cropped *(ha)*	0.009***	0.001	0.009***	0.001
HH uses inorganic fertilizer *(yes=1*	0.010***	0.001	0.010***	0.001
HH uses improved seeds (yes=1	0.005***	0.001	0.005***	0.001
Const.	0.401***	0.006	0.401***	0.006

Source: Regression results based econometric model (4).
Notes: [1]GEE= Generalized estimating equation. With panel data the GEE *(xtgee)* fits population-averaged panel-data models (generalized linear models) and allows you to specify the within-group correlation structure for the panels.
[2] LR test of sigma_u=0: chibar2(01) = 30.16; Prob >= chibar2 = 0.000. An LR test of sigma tests the significance of panel-level variance. When sigma u is zero, this variance component is not important, and the panel estimator is no different from the pooled estimator. Based on this test sigma is significantly greater than zero, so a panel estimator is preferred

The econometric results in Table 6 suggest that BHA *woredas* are more resilient than non-BHA *woredas*. Like the results in Table 5, SWC and irrigation on own plots show a positive and significant impact (at the 1-percent level) on the resilience capacities of households. In particular, the resilience impacts of irrigation are higher—households that practice irrigation on their farm are much more resilient to shocks than their counterparts. While the evidence here focuses on investments on own farm, we note that these investments are facilitated by investments in watershed rehabilitation that support more regular water flows to downstream areas.

Examining the effects of other covariates in the model, we find most of them have positive and significant effects on households' resilience capacity. This may be partly due to the way the RCI index was constructed (see Appendix Table A2). So, these results should be considered with caveats because of potential reverse causality or multilinearity problems. Future research needs to further refine the construction and measurement of resilience capacities at the household level. We also note that household characteristics appear to play an influential role in determining resilience capacities. An interesting result to highlight is that female-headed households are found to be more resilient than male-headed households. This may imply that a relatively low investment in these households may lift their resilience capacities substantially, suggesting the potential higher effectiveness of gender-disaggregated interventions.

6. CONCLUSIONS

Using a mixed-methods approach—qualitative social science methods and quantitative econometric models—this paper assessed the effects on household food security, nutritional outcomes and resilience capacities of BHA investments in watershed rehabilitation and agricultural water management, including irrigation development. The qualitative studies involved a series of focus group discussions and key informant interviews with beneficiary households, program implementers, and experts. The econometric analysis used three rounds of household-level panel data collected for the monitoring and evaluation of Phase 4 of the PSNP. Panel data econometric models were used to estimate the effects of BHA interventions on the above outcomes.

We found that the BHA PW interventions were generally well implemented and that water availability for both productive and reproductive uses has substantially increased because of these interventions. Econometric results show that households in BHA woredas had smaller food gaps, and this association is statistically significant. Results also show that while the HDDS of households in BHA *woredas* in general is not statistically different from non-BHA households, households that adopted irrigation and other agricultural water management practices on their own plots have better diets. Measuring the resilience capacities of households using the FAO RIMA II methodology, constructing resilience as a latent construct using the Resilience Capacity Index (RCI) with multiple predictors and multiple outcomes, we find that, in general, the BHA *woredas* are more resilient than non-BHA *woredas*. Higher resilience capacity is associated with irrigation and SWC on own plots and not with participation in PNSP PW. This suggests that the outcomes of rehabilitation practices may take substantial time to materialize and that the econometric analysis does not pick up benefit streams from PSNP participation that accrue indirectly through better water access.

Furthermore, discussions with beneficiaries and interviews with program implementers confirm that the BHA-supported interventions strengthened institutional infrastructures and built up the technical and managerial capacity of communities, government experts, and local governments. However, there is considerable room for improvement in infrastructure design, quality, and maintenance and for institutions to secure sustainability of the PW investments. For PSNP investments in watershed rehabilitation and irrigation to increase impact, we propose the following recommendations:

- If nutrition and resilience to climate shocks are goals of PSNP investments, then intentional actions are needed to aid both goals, including strengthening interventions that support nutrition and resilience and reducing activities that adversely affect nutrition and resilience. Discussions with implementers, local governments, and PSNP beneficiaries suggest that there is currently no common understanding on PSNPs pathways to nutrition and resilience outcomes.
- Irrigation has been shown to support both resilience and nutrition, but current support to irrigation does not reach PSNP beneficiaries equally, particularly landless beneficiaries and those who own land outside rehabilitated areas or irrigation schemes. Direct support to individuals for groundwater irrigation could be one solution for beneficiaries with land holdings or those who can rent land.
- Further differentiation of optimal time for PW activities could improve outcomes for PSNP beneficiaries, for example, to invest in SWC on their own land. As an example, PSNP participants in Amhara sites report 10–12 months of PW engagement.
- Increased emphasis needs to be placed on the functionality and maintenance of constructed irrigation and watershed infrastructure, as the current focus is primarily on construction.
- Alternative and innovative public works should be identified that target area-specific problems along with approaches for contextual solutions. Alternative intensification approaches are particularly needed in land-scarce areas.
- Introduce periodic and targeted capacity-building for user associations (such as WUAs and forest user associations), community leaders, community facilitators, and other entities that can strengthen the sustainability of investments. Experience-sharing programs among *kebeles*, *woredas*, and implementing agencies can promote peer learning and help avoid common challenges.

The study faced several challenges linked to the COVID-19 pandemic as well as substantial armed civil conflict in the Tigray Region. Moreover, endline data collection linked to a separate BHA effort did not move forward, reducing the quality and quantity of data that the study team could access. Finally, the only additional quantitative dataset that became available to the team (PSNP4 2021 data) did not include information on Tigray. These limitations need to be considered when using the study results linked to the implementation quality of BHA investments as well as results focused on nutrition and resilience benefits of the investment.

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Annex Table A. Pillars of resilience capacity and proxy variables

Resilience Pillars	Indicator variables
Food security (FS)	-Monthly per capita food expenditure
	-No of months a household suffered from food shortages (food gap)
Access to Basic services (ABS)	=1 if there is access to electricity
	=1 if there is access to pied public water
	=1 if there is access to daily market
	=1 if there is access to primary school
	=1 if there is cellphone coverage
	=1 if there is access to roads in rainy times
Asset (A)	-Land size (ha) (per capita)
	-TLU (Per capita)
	-radio/tv ownership
	-table/chair ownership
Social Safety Nets (SSN)	-Total amount in birr for all in kind payments (log)
	-Total cash payment in birr (log)
	-Remittance from relatives (log)
	-Loan transfer (log)
Adaptive Capacity (AC)	=1 if household head has formal education (literate)
	Dependency ratio (inverse)
	No of crop produced
	=1 if household member is engaged in off-farm wage work or casual/irregular wage